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(54) **METHOD AND APPARATUS FOR HARVESTING WATER AND LATENT ENERGY FROM A GASEOUS MIXTURE**

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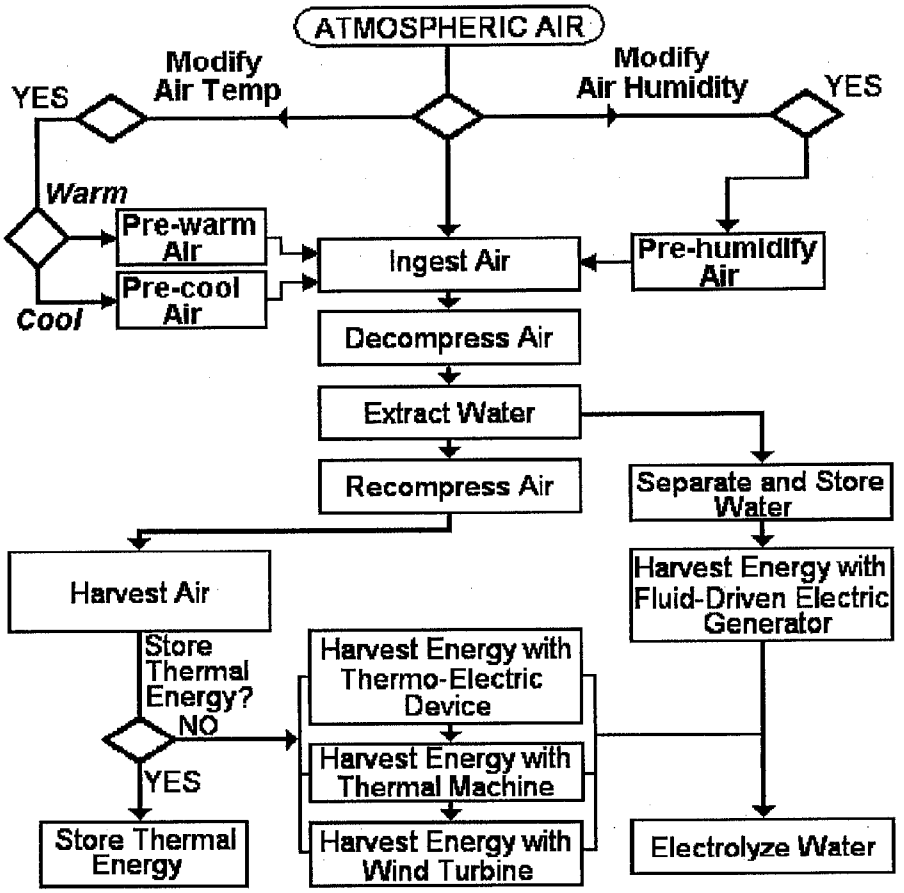
Publication Classification

(51) **Int. Cl.**
F25D 21/14 (2006.01)

(52) **U.S. Cl.** **62/93**; 62/273

(57) **ABSTRACT**

An apparatus harvests latent energy and water by adiabatically decompressing a controlled volume of atmospheric air to lower its pressure and temperature below the saturation point of included water vapor, thus causing the water vapor to change state to nonvaporous water and release to the decompressed air thermal energy associated with the change of state. The apparatus then extracts the nonvaporous water, leaving the released thermal energy in the decompressed air. The apparatus then recompresses the decompressed air, which will have a resulting temperature, and thus a thermal energy, greater than those of the initially ingested air, and harvests the recompressed air and its increased thermal energy. The apparatus can also humidify and warm atmospheric air before it is ingested to increase appreciably the amount of harvested thermal energy.



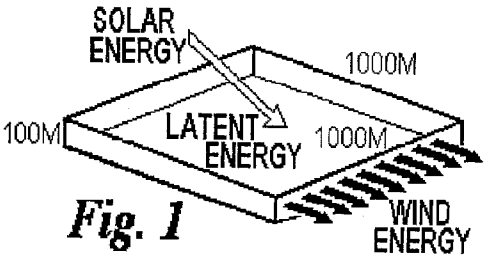


Fig. 1

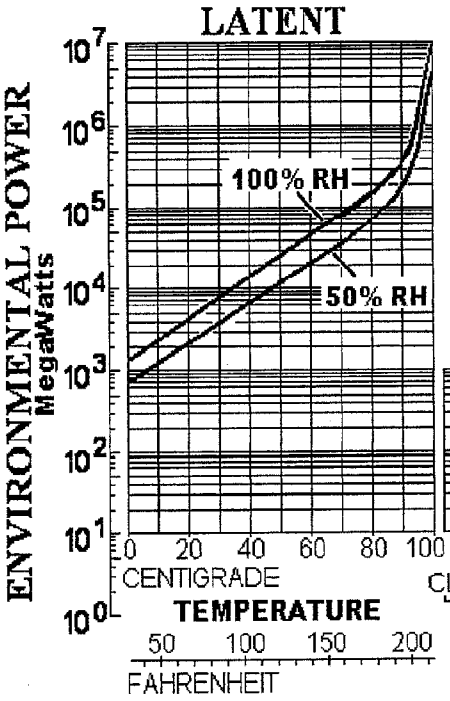


Fig. 2

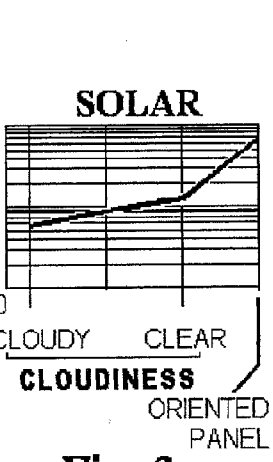


Fig. 3

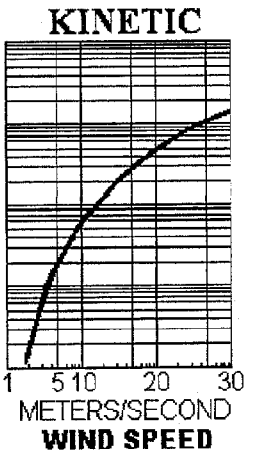


Fig. 4

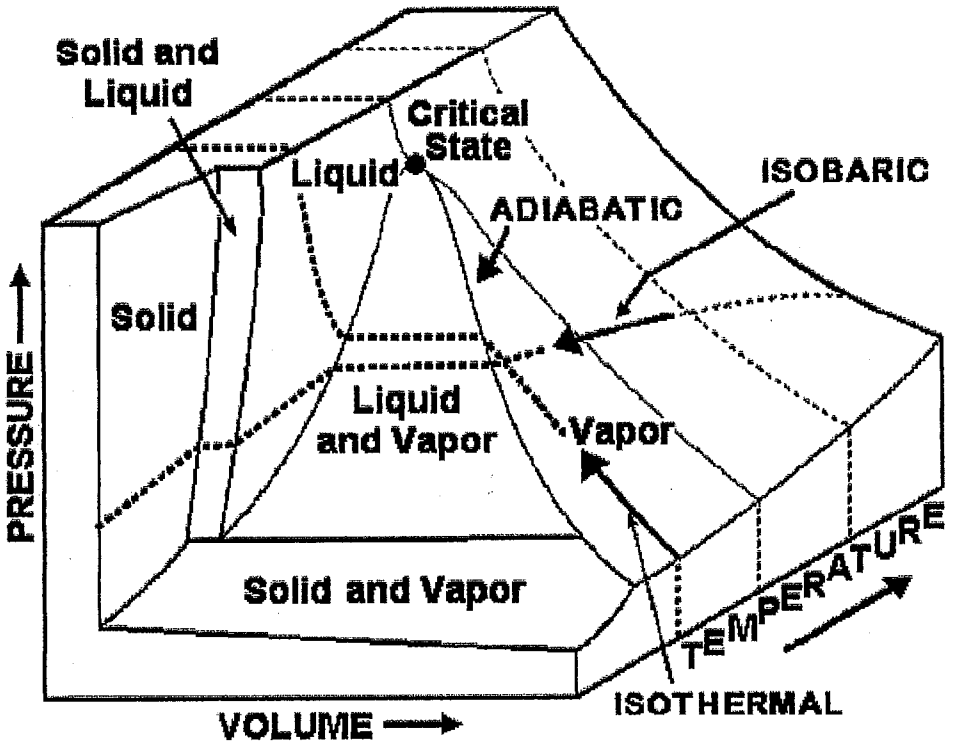

Solid and Liquid
Critical State
Liquid
ISOBARIC
ADIABATIC
Solid
Liquid and Vapor
Vapor
PRESSURE
Solid and Vapor
TEMPERATURE
ISOTHERMAL
VOLUME

Fig. 5

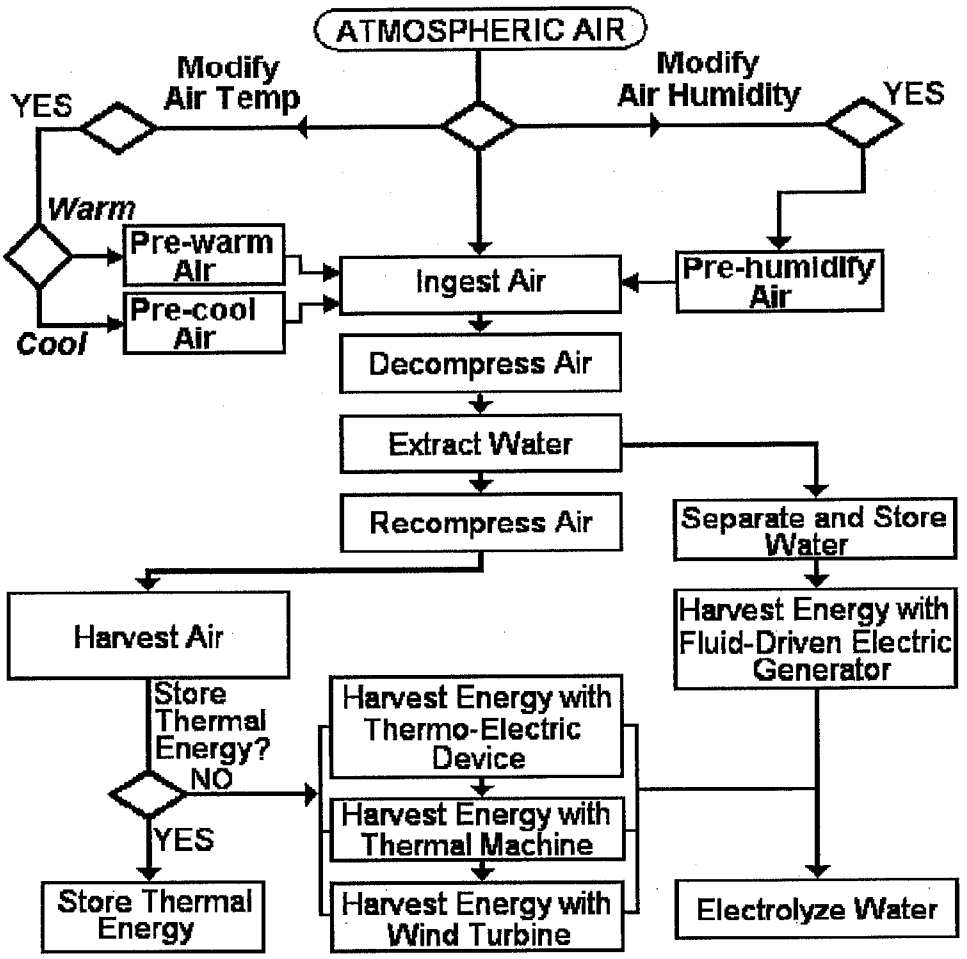
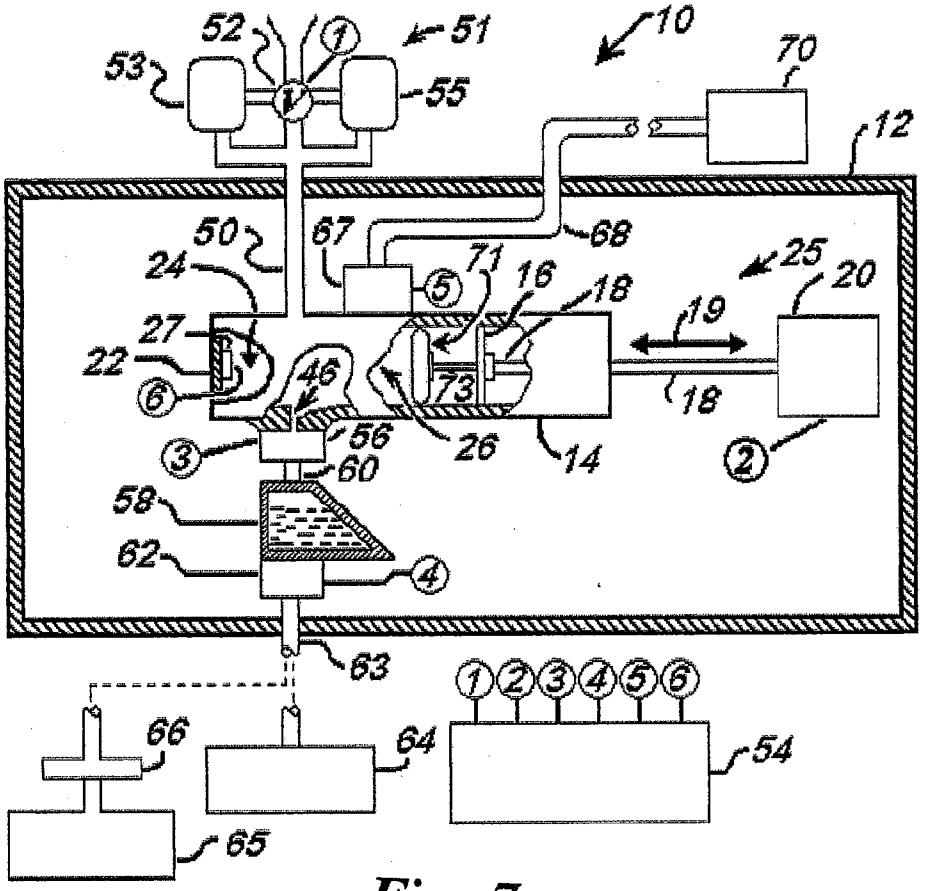

ATMOSPHERIC AIR
Modify Air Temp
YES
Modify Air Humidity
YES
Warm
Pre-warm Air
Cool
Pre-cool Air
Ingest Air
Pre-humidify Air
Decompress Air
Extract Water
Recompress Air
Separate and Store Water
Harvest Energy with Fluid-Driven Electric Generator
Harvest Air
Store Thermal Energy?
NO
YES
Store Thermal Energy
Harvest Energy with Thermo-Electric Device
Harvest Energy with Thermal Machine
Harvest Energy with Wind Turbine
Electrolyze Water

Fig. 6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6
46
73
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14
2
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1 2 3 4 5 6
66
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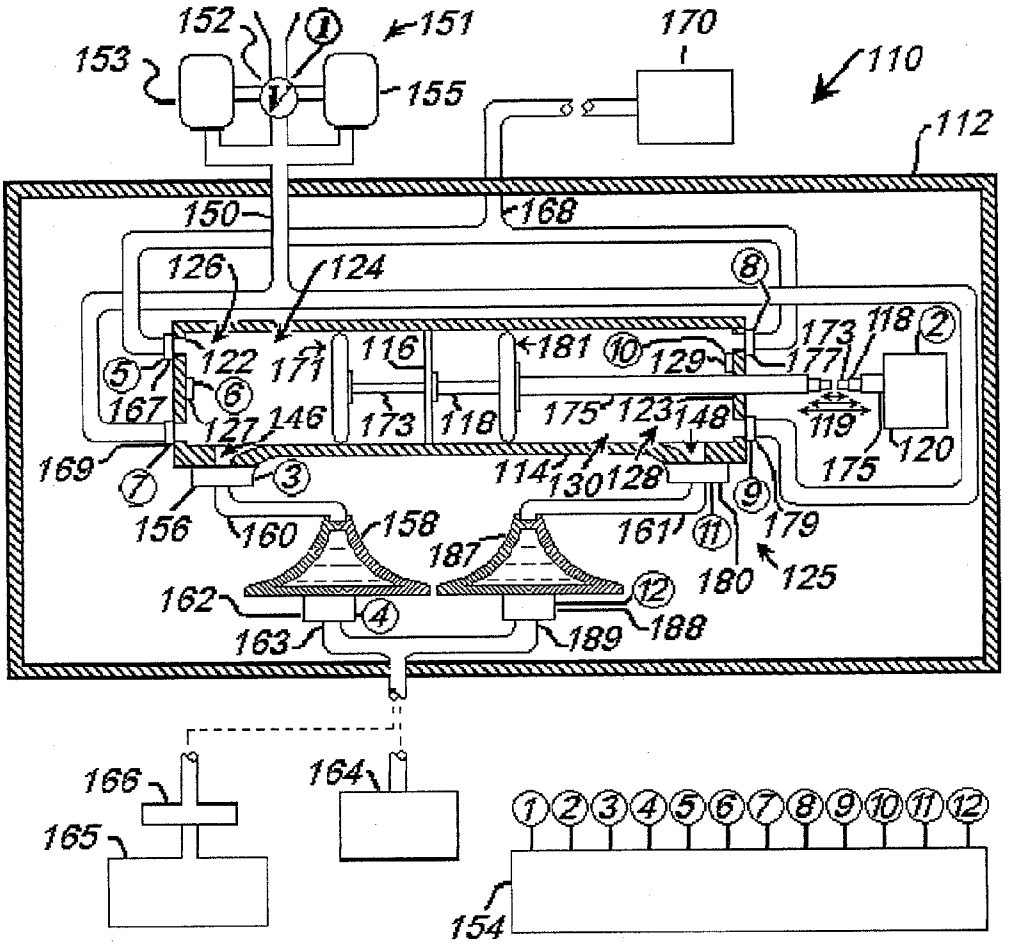
54
65

Fig. 7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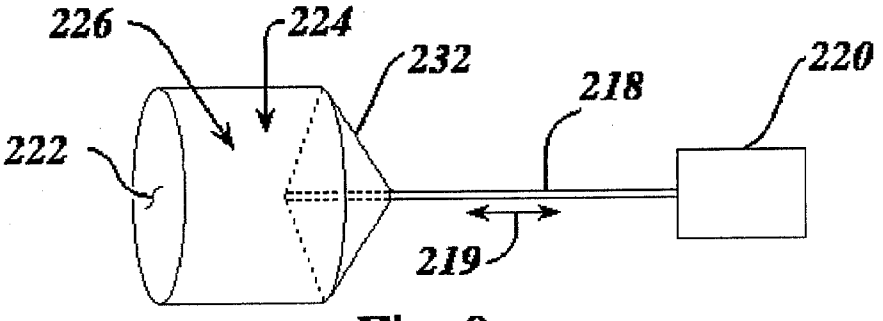
1
151
153
155
170
110
112
150
168
126
124
8
122
171
116
181
10
129
173
177
118
2
5
6
167
127
146
173
118
175
123
148
119
120
175
169
7
3
114
130
128
9
156
160
158
187
161
11
179
180
125
162
12
4
163
189
188
166
164
165
1 2 3 4 5 6 7 8 9 10 11 12
154

Fig. 8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232
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220
222
219

Fig. 9

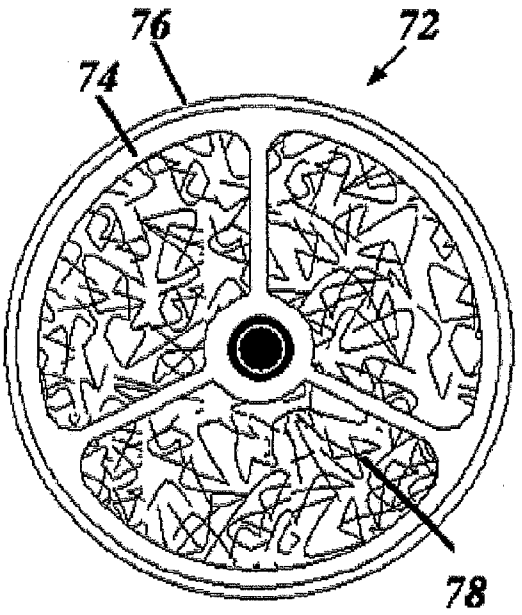


Fig. 10

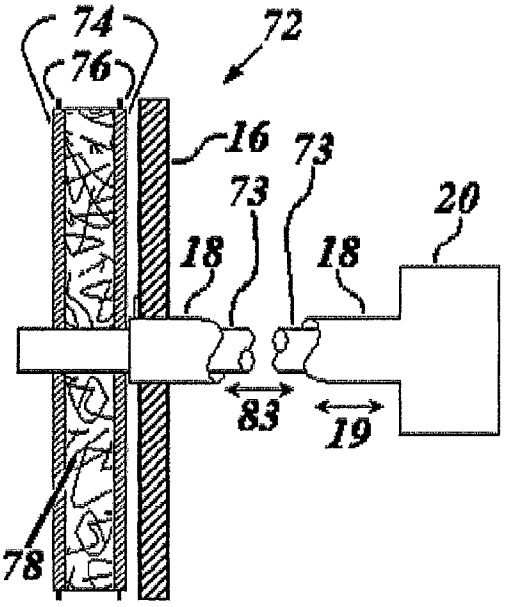


Fig. 11

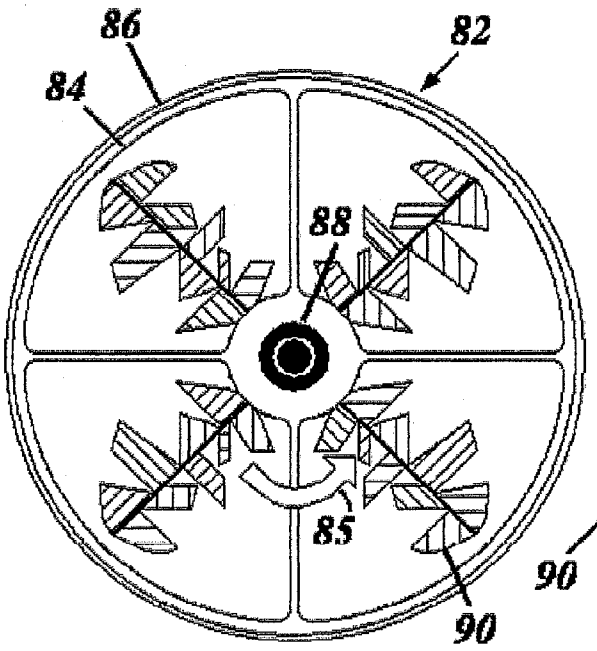


Fig. 12

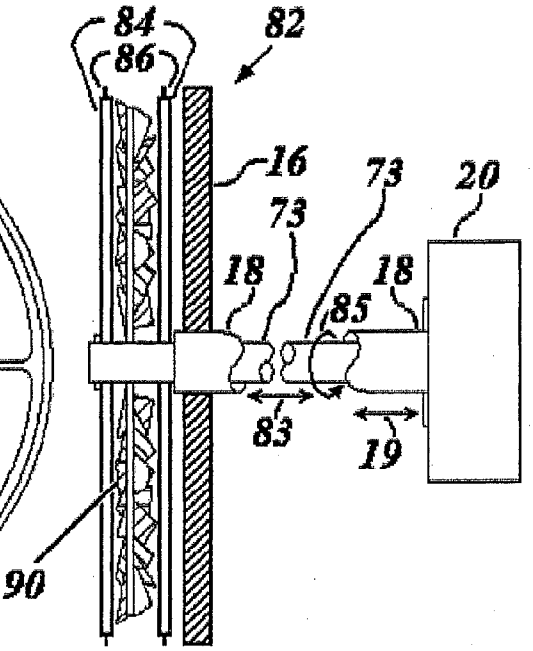


Fig. 13

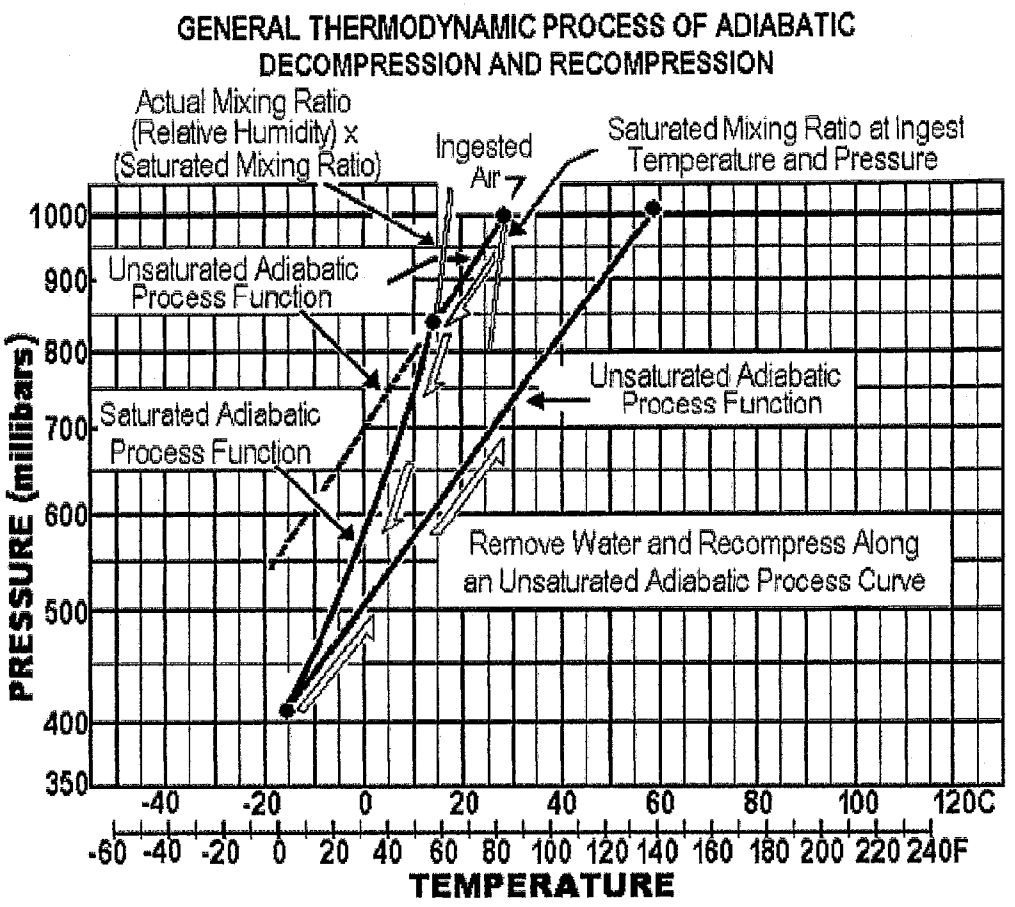

GENERAL THERMODYNAMIC PROCESS OF ADIABATIC DECOMPRESSION AND RECOMPRESSION
Actual Mixing Ratio (Relative Humidity) x (Saturated Mixing Ratio)
Ingested Air
Saturated Mixing Ratio at Ingest Temperature and Pressure
Unsaturated Adiabatic Process Function
Saturated Adiabatic Process Function
Unsaturated Adiabatic Process Function
Remove Water and Recompress Along an Unsaturated Adiabatic Process Curve
PRESSURE (millibars)
1000
900
800
700
600
500
400
350
-40 -20 0 20 40 60 80 100 120C
-60 -40 -20 0 20 40 60 80 100 120 140 160 180 200 220 240F
TEMPERATURE

Fig. 14

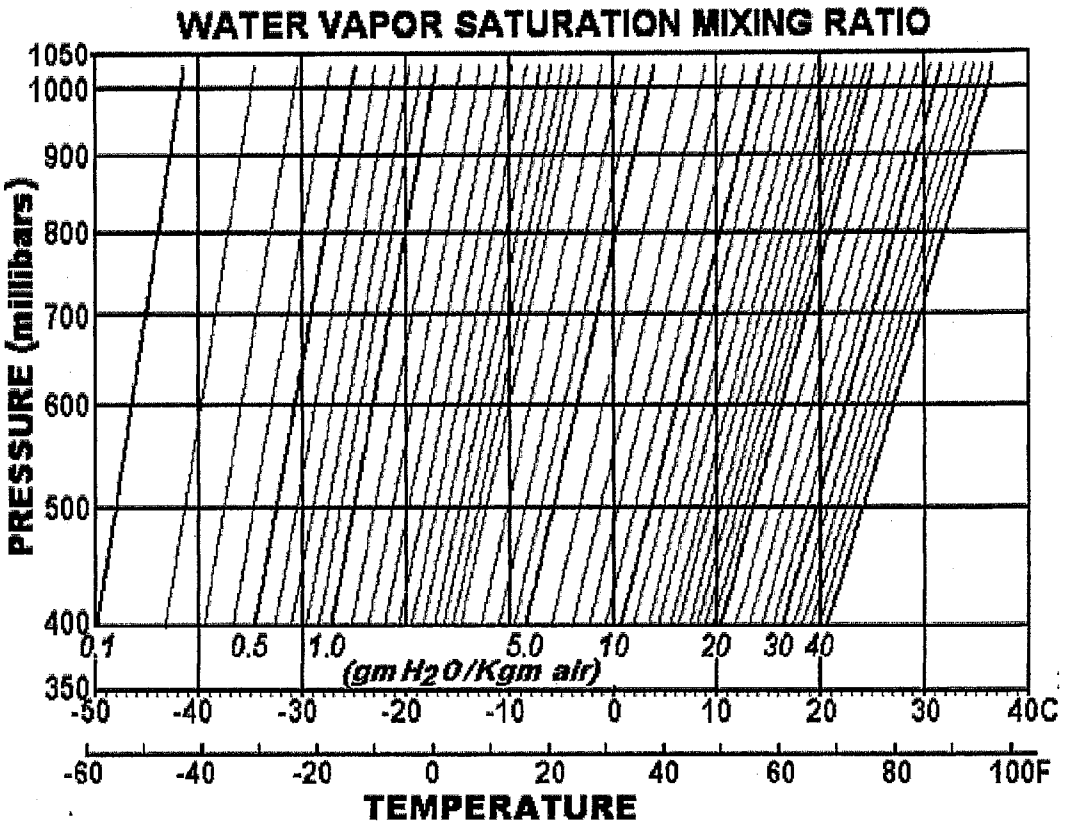

WATER VAPOR SATURATION MIXING RATIO
PRESSURE (millibars)
1050
1000
900
800
700
600
500
400
350
0.1
0.5
1.0
5.0
10
20
30
40
(gm H2O/Kgm air)
-50
-40
-30
-20
-10
0
10
20
30
40C
-60
-40
-20
0
20
40
60
80
100F
TEMPERATURE

Fig. 15

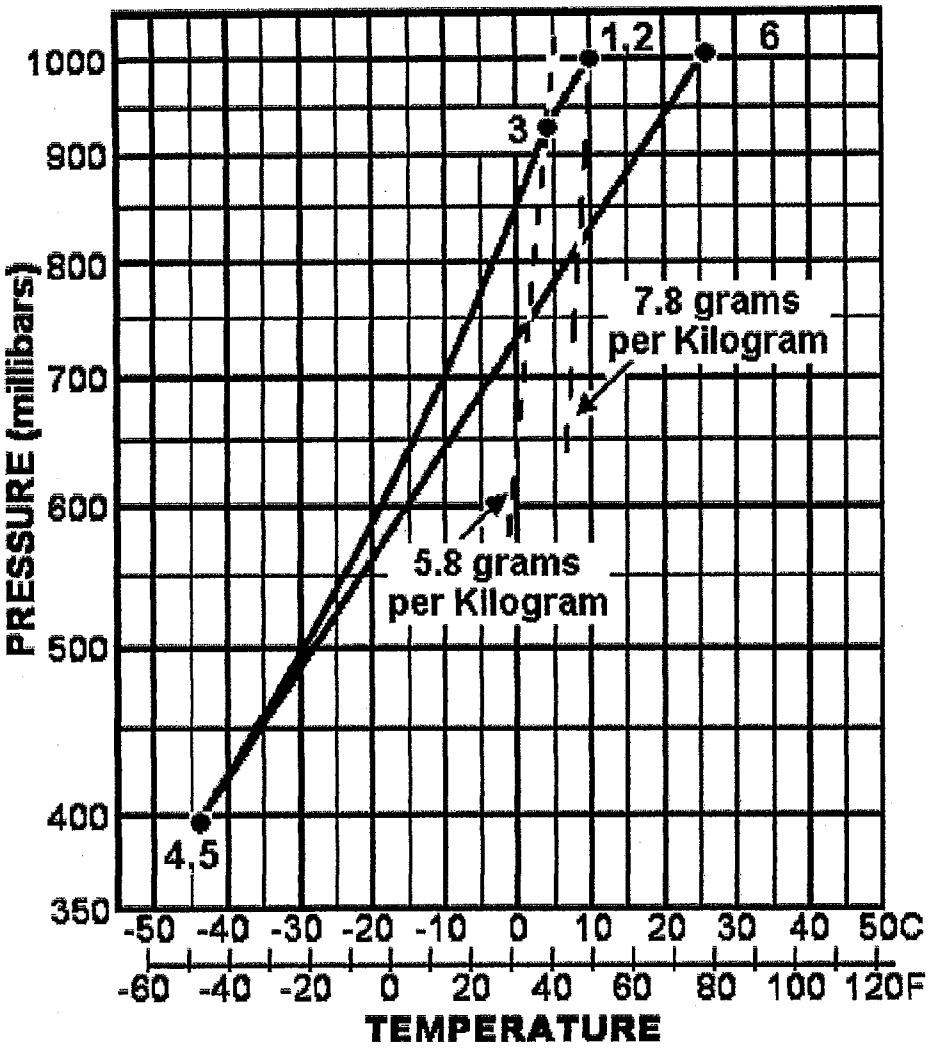

1,2
6
3
7.8 grams
per Kilogram
5.8 grams
per Kilogram
4,5
1000
900
800
700
600
500
400
350
PRESSURE (millibars)
-50 -40 -30 -20 -10 0 10 20 30 40 50C
-60 -40 -20 0 20 40 60 80 100 120F
TEMPERATURE

Fig. 16

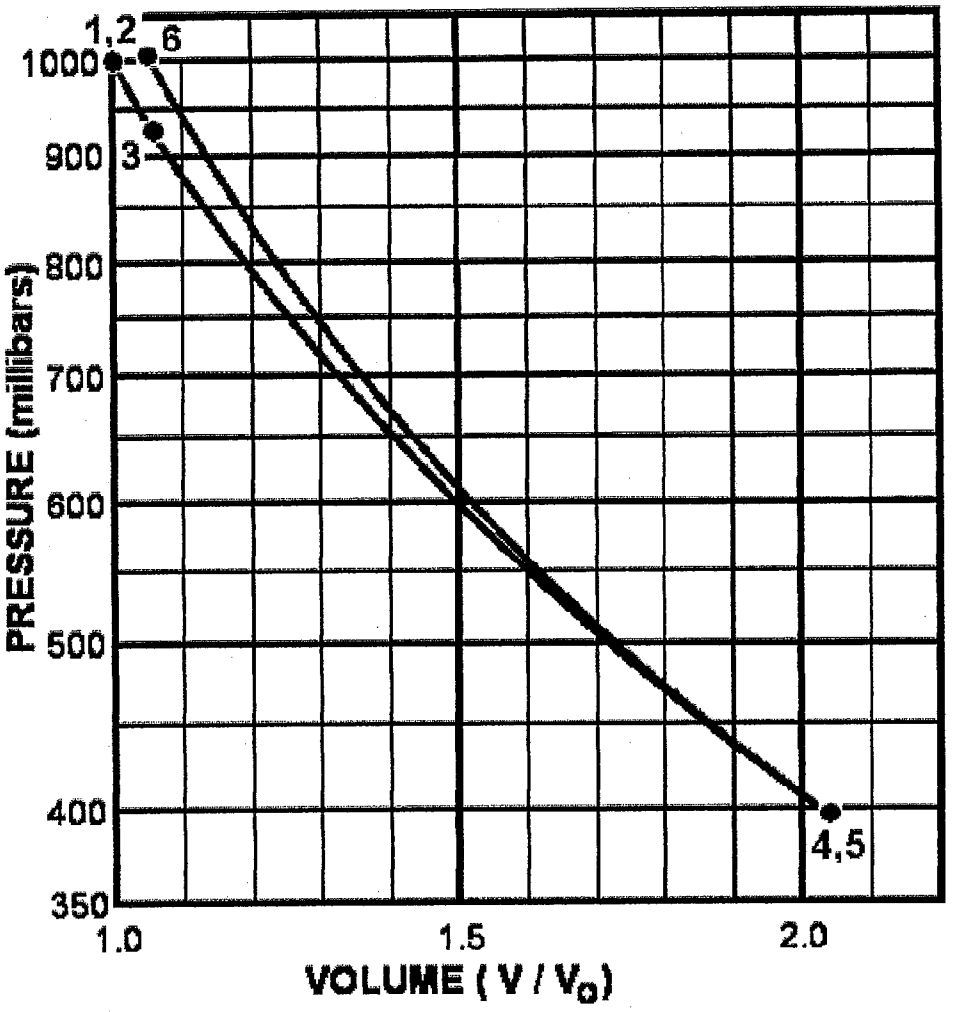

1,2
6
3
4,5
1000
900
800
700
600
500
400
350
PRESSURE (millibars)
1.0
1.5
2.0
VOLUME (V / V0)

Fig. 17

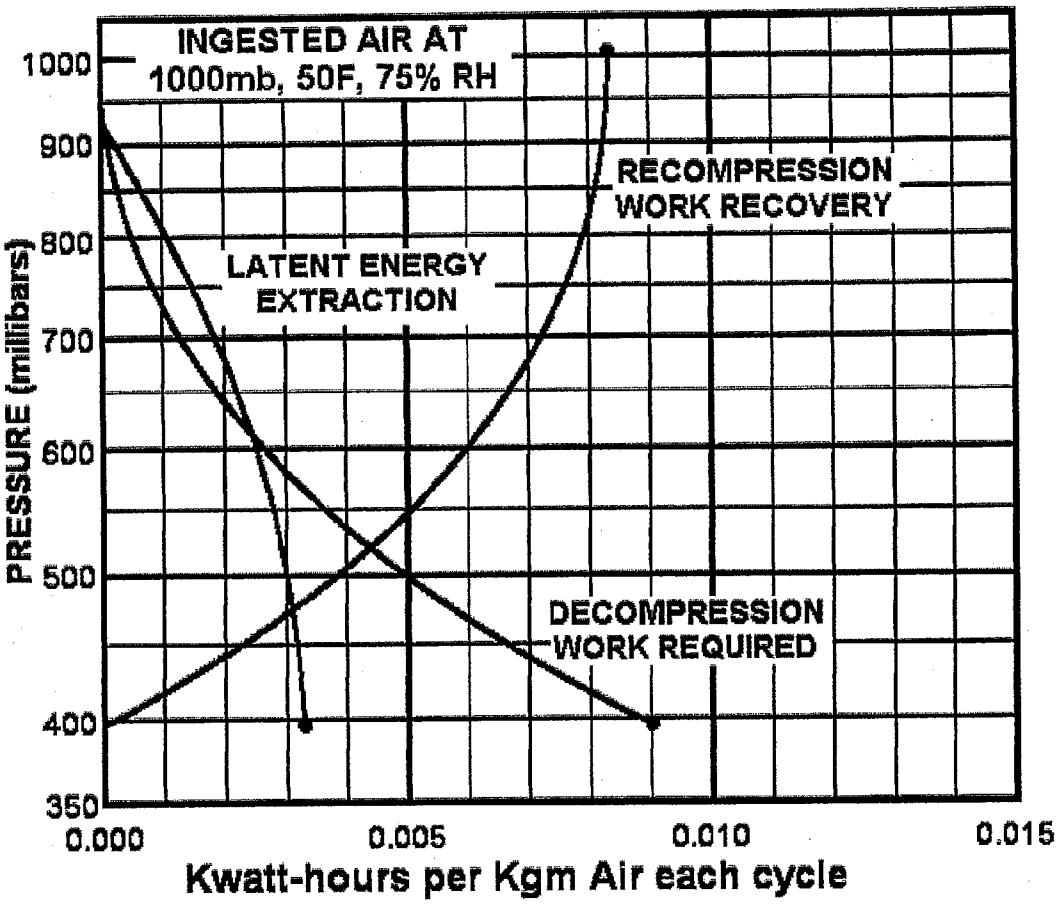

INGESTED AIR AT
1000mb, 50F, 75% RH
RECOMPRESSION
WORK RECOVERY
LATENT ENERGY
EXTRACTION
DECOMPRESSION
WORK REQUIRED
PRESSURE (millibars)
1000
900
800
700
600
500
400
350
0.000
0.005
0.010
0.015
Kwatt-hours per Kgm Air each cycle

Fig. 18

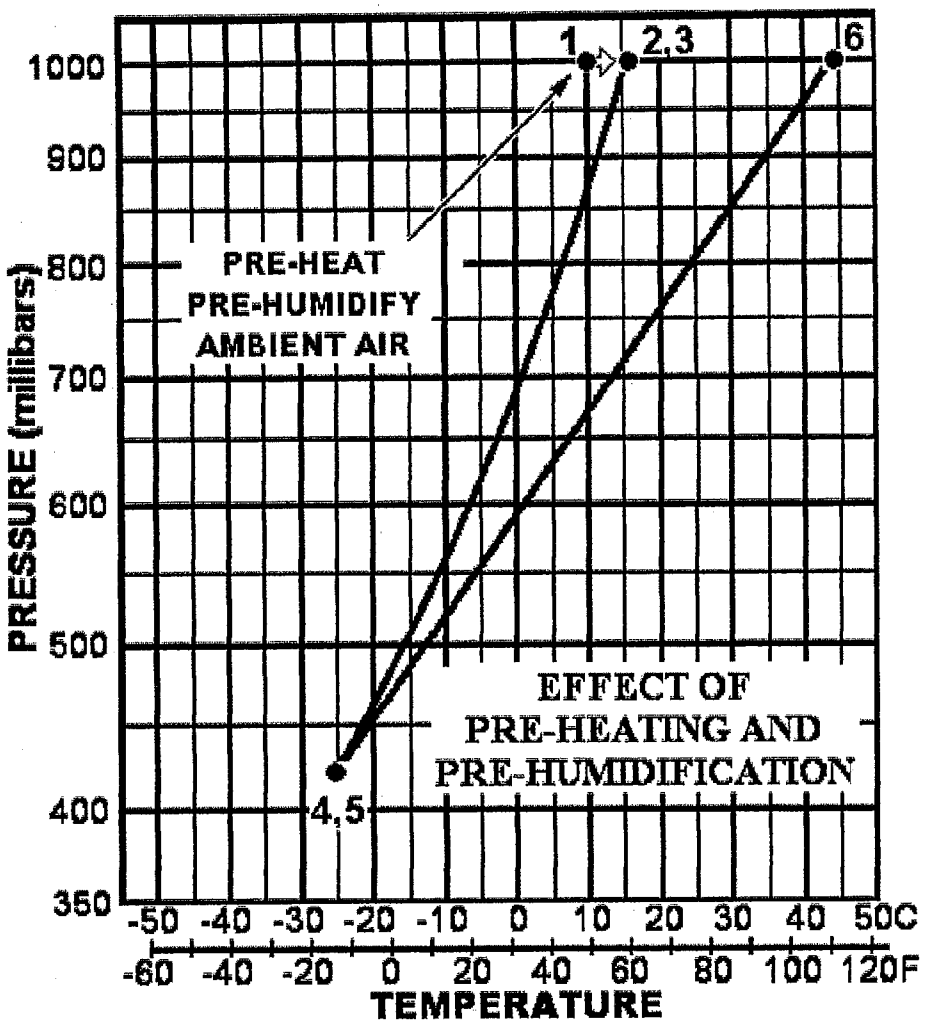

1
2,3
6
1000
900
800
700
600
500
400
350
PRESSURE (millibars)
PRE-HEAT
PRE-HUMIDIFY
AMBIENT AIR
EFFECT OF
PRE-HEATING AND
PRE-HUMIDIFICATION
4,5
-50 -40 -30 -20 -10 0 10 20 30 40 50C
-60 -40 -20 0 20 40 60 80 100 120F
TEMPERATURE

Fig. 19

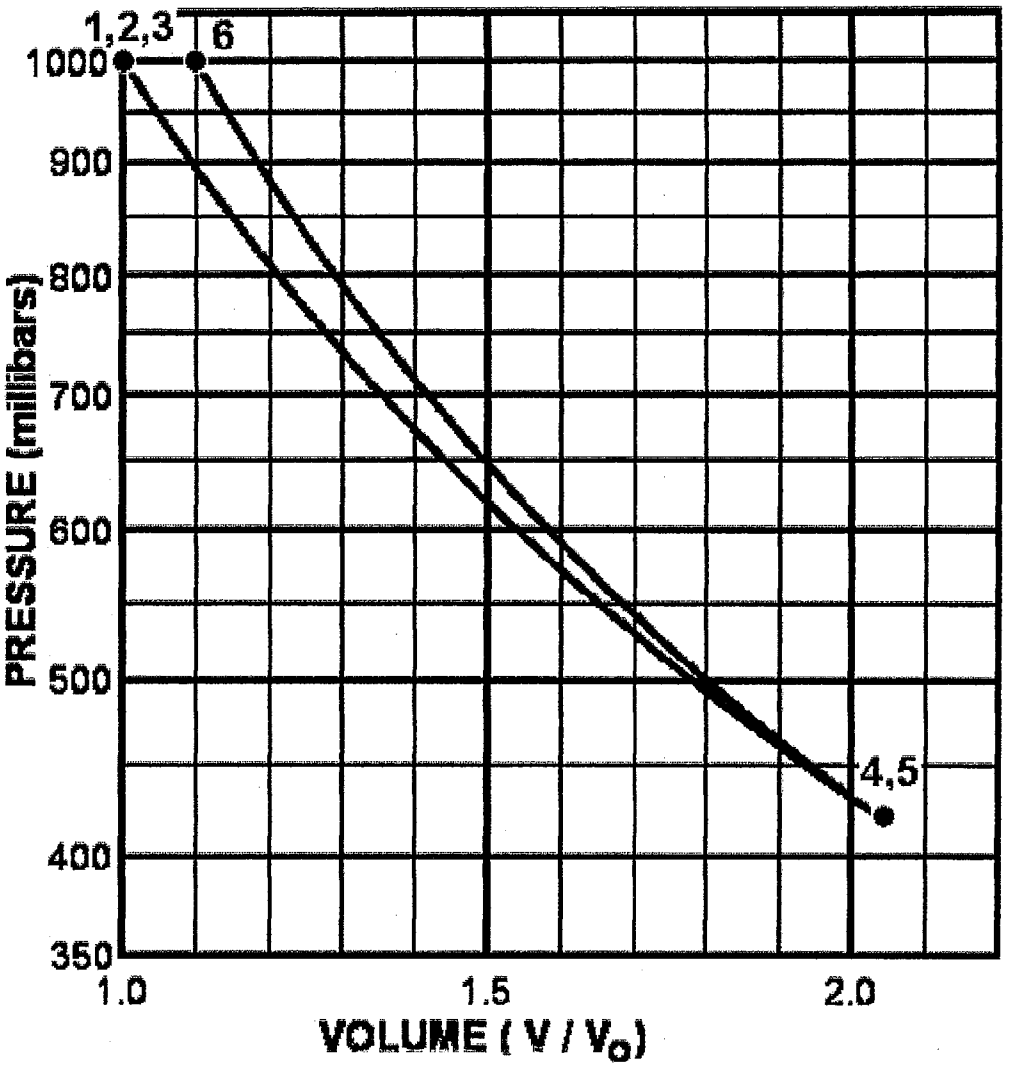

1,2,3
6
1000
900
800
700
600
500
400
350
PRESSURE (millibars)
4,5
1.0
1.5
2.0
VOLUME (V / Vo)

Fig. 20

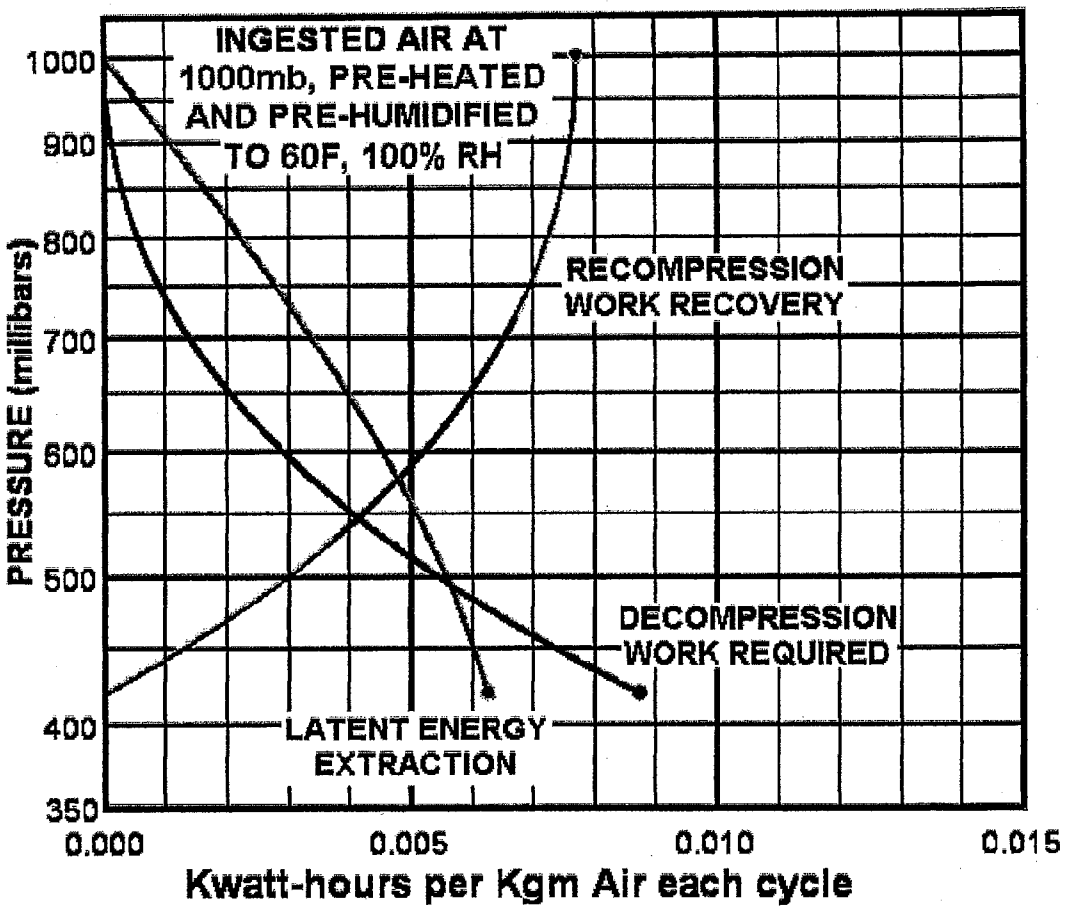
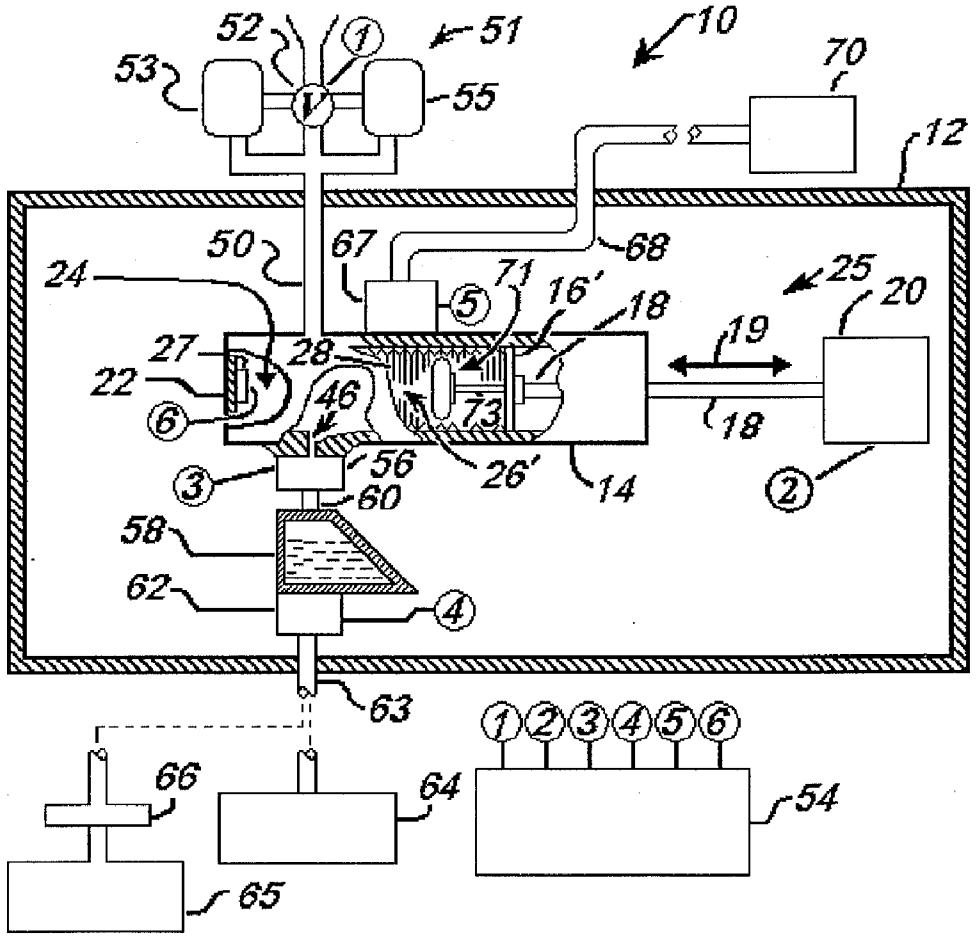

INGESTED AIR AT
1000mb, PRE-HEATED
AND PRE-HUMIDIFIED
TO 60F, 100% RH
RECOMPRESSION
WORK RECOVERY
DECOMPRESSION
WORK REQUIRED
LATENT ENERGY
EXTRACTION
PRESSURE (millibars)
1000
900
800
700
600
500
400
350
0.000
0.005
0.010
0.015
Kwatt-hours per Kgm Air each cycle

Fig. 21


52
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51
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67
68
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71
16'
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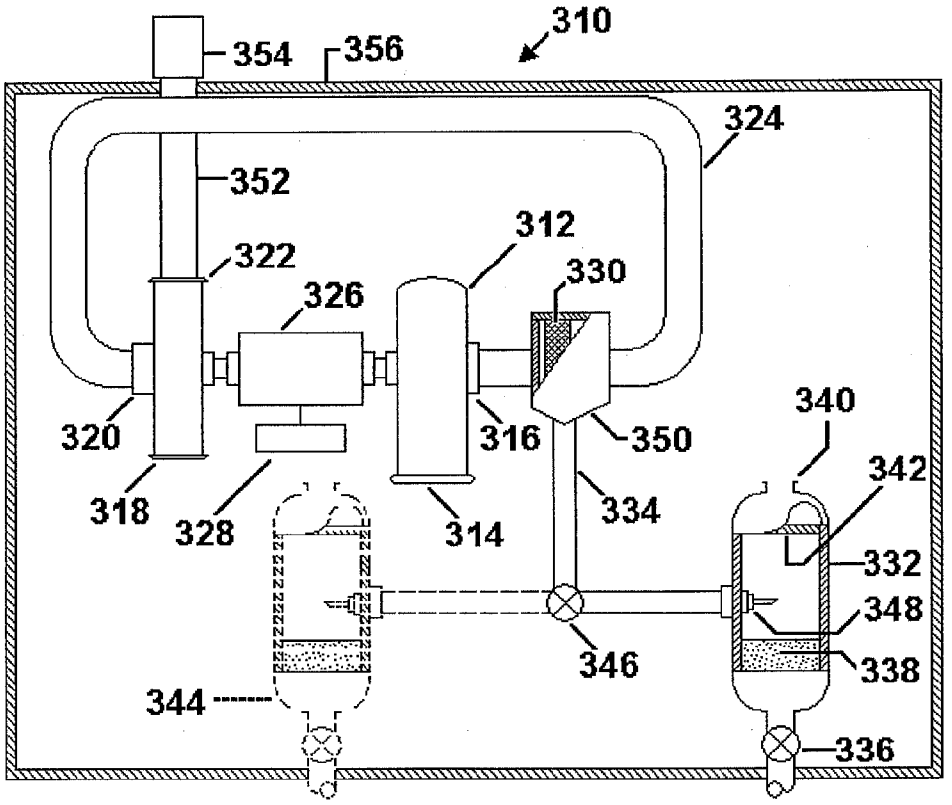
22
46
73
18
6
56
26'
14
3
60
2
58
62
4
63
1 2 3 4 5 6
66
64
54
65

Fig. 22


310
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324
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332
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346
338
344
336

Fig. 23

METHOD AND APPARATUS FOR HARVESTING WATER AND LATENT ENERGY FROM A GASEOUS MIXTURE

CROSS-REFERENCE TO A RELATED APPLICATION

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 11/627,216 filed Jan. 25, 2007 by Christopher E. Thompson rt al. and incorporates the disclosure thereof in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates to a method for harvesting latent energy and nonvaporous water from atmospheric air.

[0004] 2. Background Art

[0005] There has been an increasing interest in environmental energy harvesting. The most well-developed methodologies focus on wind energy, solar energy, and the energy of water flowing under the influence of gravity. A number of strategies have also been developed for harvesting latent energy from atmospheric air. Some of these strategies depend on added water vapor and vertically decreasing atmospheric pressure to stimulate an upward movement of air. Such air within an enclosed, vertical conduit is forced by a pressure differential to rise through a wind turbine driving an electric generator to extract energy. In another strategy, air at the conduit base is warmed; and warm water vapor is added. The vapor is assumed to condense as air rises within the enclosed conduit, warming the air and enhancing upward motion. The condensed water is removed in an upper region of the conduit. Other strategies seek similar results but depend on evaporating liquid water into air, thus cooling the air and stimulating the air to move downwardly rather than upwardly. This process finds useful application, for example, in cleaning pollution from industrial stacks, where there is no interest in energy harvesting. Another strategy has liquid water pumped to a high elevation and sprayed into environmental air at that level to cool the air by evaporation. The evaporative air cooling is performed within a conduit that extends from a high to a low altitude, and kinetic energy of the resulting downdraft of air is extracted by a wind turbine driving an electric generator.

[0006] Still other strategies do not depend on pressure-altitude differences but disclose machine means for harvesting energy from water vapor provided by a boiler. At least one other strategy uses a flash evaporator to produce steam and a steam-driven turbogenerator to produce energy, and another depends on elaborate machine means to harvest energy by liquefying air itself rather than merely liquefying water vapor.

[0007] A number of strategies disclose the removal of condensed liquid water from an air-water mixture contained within a closed volume. One discloses means to control the formation of condensate into liquid droplets using a condensing surface of inverted circular cones attached to a metal plate.

Another discloses means for collecting water blown off a cooling coil by high velocity air, improving such collection by coils used in low-fluid-velocity water collection systems. Yet another discloses the use of charged aerosol sources powered directly by the wind. The means comprise a large area electrode screen, which emits charged water droplets into a wind stream as a wind-electric power transducer. Still another discloses means for harvesting water from air that involve an isothermal compression to a saturated state that requires means to remove energy from the process to maintain the isothermal compression. In contrast, the process of the present invention adiabatically decompresses, with no exchange of energy with an external environment, a controlled volume of atmospheric air to a pressure at which resident water vapor reaches a saturated state.

SUMMARY OF THE INVENTION

[0008] An object of the present invention is to provide a process for harvesting latent energy and nonvaporous water, that is, liquid or solid water, from water vapor in atmospheric air. In carrying out the foregoing object, the process for harvesting latent energy includes decompressing a controlled volume of the atmospheric air so that the temperature of the air is decreased to a point where the water vapor reaches saturation; and the water vapor changes state by condensation, and possibly by deposition, and releases latent heat. Nonvaporous water resulting from the state change of the water vapor is then extracted to an internal water reservoir that is separated from, but at the same pressure as, the controlled volume of air, thus rendering the process of latent heat harvesting nearly irreversible. The decompressed air is then recompressed so that, as a result of having absorbed the latent heat released by the water vapor, the recompressed air has a much higher temperature than it had prior to being decompressed. The latent energy of the recompressed air and the nonvaporous water are then harvested.

[0009] Another object of the present invention is to provide an apparatus that functions according to the process described by the foregoing paragraph. The apparatus includes a thermally insulated chamber defining therewithin a controllable volume of air to be processed; per unit time; and it further includes a controllable inlet, or air ingestion valve, for admitting atmospheric air into the chamber. A thermally insulated decompressing mechanism for adiabatically increasing the controllable volume of air in the chamber is provided to lower the temperature of the humid air within the chamber so that the water vapor in the humid air reaches a point of saturation, changes state and releases latent heat. A nonvaporous water extracting valve is provided to extract nonvaporous water resulting from the state change of the water vapor within the chamber. The extracted water is retained within an internal water reservoir for harvesting after the controlled volume of air has been recompressed to a desired state of release. A recompressing mechanism is provided for decreasing the controllable volume of air in the chamber to increase the temperature of the air; and an air harvesting valve is provided to release the recompressed air so that thermal energy, associated with latent heat absorption and the resulting increase in its temperature, can be harvested. A nonvaporous water harvesting valve is also provided to harvest the nonvaporous water retained in the internal water reservoir.

[0010] In the process and apparatus of the present invention described by the foregoing paragraphs, decompression and recompression are performed adiabatically. Those skilled in the art to which the present invention pertains will appreciate that, in practical applications, the term "adiabatic" is taken to mean nearly adiabatic.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a perspective view of a model representing exemplary dimensions of a particular volume of atmospheric air;

[0012] FIG. **2** is a graph illustrating the power potentially realizable by harvesting latent energy from the particular volume of atmospheric air of FIG. **1**;

[0013] FIG. **3** is a graph illustrating the comparative power potentially realizable by harvesting energy converted from solar energy impinging on the same volume of atmospheric air as illustrated by FIG. **1**.

[0014] FIG. **4** is a graph illustrating the comparative power potentially realizable by harvesting kinetic energy from the same volume of atmospheric air of FIG. **1** moving at various velocities;

[0015] FIG. **5** is a perspective view of a three-dimensional representation illustrating solid, liquid and vapor states of substances as a function of thermodynamic state variables;

[0016] FIG. **6** is a logic flow diagram of a process to harvest latent energy and nonvaporous water from a gaseous mixture;

[0017] FIG. **7** is a side view, partially broken away, and partially in section, of an exemplary cylinder-piston mechanism for decompressing and recompressing a gas;

[0018] FIG. **8** is a side view, partially broken away, and partially in section, of an apparatus similar to that of FIG. **7** but providing a dual-phase process;

[0019] FIG. **9** is a transparent, perspective view of an exemplary closed chamber having a flexible diaphragm for decompressing and recompressing a gas;

[0020] FIG. **10** is a front view of a water droplet removal filter;

[0021] FIG. **11** is a side view of the water droplet removal filter of FIG. **10**;

[0022] FIG. **12** is a front view of a water droplet removal fan;

[0023] FIG. **13** is a side view of the water droplet removal fan of FIG. **12**;

[0024] FIG. **14** is a graph illustrating the relationship of temperature and pressure during an adiabatic decompression of atmospheric air, a removal of nonvaporous water, and a subsequent adiabatic recompression of the air, which then contains latent heat of condensation;

[0025] FIG. **15** is a graph illustrating mixing ratios of saturated air as functions of temperature and pressure;

[0026] FIG. **16** is a graph illustrating the thermodynamic relationship of temperature to pressure during humid air adiabatic processing, including ingestion, decompression, condensation, water extraction, recompression and harvesting;

[0027] FIG. **17** is a graph illustrating the thermodynamic relationship of volume to pressure during the adiabatic processing illustrated by FIG. **16**;

[0028] FIG. **18** is a graph illustrating the amount of latent energy harvesting, required decompression work and recoverable recompression work using atmospheric air in the processes illustrated by FIGS. **16** and **17**;

[0029] FIG. **19** is a graph illustrating the effects of preparing and prehumidifying ingested air of the process illustrated by FIG. **16**;

[0030] FIG. **20** is a graph illustrating the thermodynamic relationship of initial and final volume to pressure during the processing illustrated by FIG. **19**;

[0031] FIG. **21** is a graph similar to FIG. **18** and illustrates the amount of latent energy harvesting, required decompression work and recoverable recompression work using atmospheric air in the processes illustrated by FIGS. **19** and **20**;

[0032] FIG. **22** is a side view, partially broken away, and partially in section, of another exemplary mechanism for decompressing and recompressing a gas;

[0033] FIG. **23** is a side view, partially broken away and partially in section, of yet another exemplary mechanism for decompressing and recompressing a gas.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] The present invention provides a method and an apparatus for harvesting latent energy and nonvaporous, that is, liquid and/or solid, water produced by state changes of water vapor present in atmospheric air. It is to be noted that, in the present specification, the term "atmospheric air" is intended to mean natural, atmospheric air that contains water vapor as one of its constituents. It is also to be noted that the term "extraction" refers to removing nonvaporous water to an internal water reservoir following a decompression process within an inventive apparatus and that the term "harvesting" refers to the removal and disposition of extracted nonvaporous water, air and energy when being separated from the apparatus. As used in this document, the term "thermal energy" refers to potential and kinetic energies of random motions of atoms and molecules of a substance. "Thermodynamic free energy" denotes the total amount of energy in a physical system that can be converted to do work.

[0035] Latent heat of vaporization of water varies between 540 calories per gram at 100 degrees Celsius and 600 calories per gram at 0 degrees Celsius. It is absorbed by liquid water during its vaporization and released by water vapor during its condensation. Latent heat of sublimation varies between 600 calories per gram of water at 100 degrees Celsius and 680 calories per gram of water at 0 degrees Celsius. It is absorbed by ice when ice changes directly to water vapor (sublimates) and is released by water vapor when water vapor changes directly to ice (deposition).

[0036] An exemplary air mass 1000 meters in length, 1000 meters in width and 100 meters in depth exposes to the Sun an area of 1,000,000 square meters and a total volume of 100,000,000 cubic meters. FIG. **1** shows a model representing exemplary dimensions of such an air mass. In the language of physics, the term power specifically means energy transferred per unit time. The term is used in this document in this sense. For example, the latent energy harvested (transferred) from humid air per unit time can be appropriately referred to as latent power. FIG. **2** is a graph illustrating the latent power potentially realizable by harvesting latent energy from water vapor in a particular volume of atmospheric air having these dimensions. This potential power (energy transferred per unit time) has been computed for the condensation of all water vapor within the particular volume of air, illustrated by FIG. **1**, at atmospheric air pressure and for the ranges of temperature and relative humidity shown. The latent power associated with the condensation of water vapor at relative humidity of 50 percent and of 100 percent is shown to vary from approximately 1000 megawatts toward a value approaching 10 million megawatts over the nominal range of temperatures shown.

[0037] FIG. **3** is a graph illustrating the comparative power potentially realizable by harvesting energy converted from solar energy (radiant energy from the Sun) impinging on the same volume of atmospheric air as illustrated by FIG. **1**. As shown, under optimum atmospheric conditions and orientation, the power contributed can be nearly 1000 megawatts. Solar power is shown to vary from approximately 70 megawatts, under cloudy conditions, to more than 100 megawatts for horizontal surfaces. Were collection devices covering this

total area oriented to face solar radiation directly, even more solar power could be extracted; however, the lowest values of latent power shown by FIG. **2** are comparable to the optimum solar power generated by collectors, all of which being oriented perpendicular to the sun's rays at ground level.

[0038] FIG. **4** is a graph illustrating the comparative power potentially realizable by harvesting kinetic energy from the same volume of atmospheric air moving at various velocities. As shown, the power contributed can be greater than 1000 megawatts. Values of latent power are shown for a wind speed of just 1 meter per second (2.24 mph), which corresponds to the lowest speed in the kinetic power graph of FIG. **4**. As indicated, the latent power of a humid air mass is as much as 100 to 1000 times greater than its potential kinetic power.

[0039] In a comparison of the three types of environmental energy, FIGS. **2**, **3** and **4** make evident the substantial amount of power potentially realizable by harvesting latent energy from water vapor in atmospheric air. The latent energy of water vapor at freezing temperature and only 50 percent relative humidity exceeds the average, climatological availability of solar radiation energy; and it is even competitive with solar energy harvested at optimum solar harvesting conditions. The latent energy of the water vapor in this cold, 50-percent-relative-humidity condition also exceeds the kinetic energy of wind over the range of wind speeds utilized by modern wind energy harvesting technology. At locations around the world having much higher atmospheric temperatures and relative humidity, the latent energy potentially available from water vapor is far greater than that available from solar and kinetic energy sources.

[0040] FIG. **5**, which is similar to figures in many physics textbooks, is a three-dimensional model illustrating solid, liquid and vapor states of substances as a function of thermodynamic state variables, namely, temperature, pressure and volume. Frequently used methods for condensing a vapor and solidifying a liquid in an apparatus are isobaric cooling and isothermal compression; and these are indicated by specific process arrows. In these latter processes, desired state-changed materials are obtained, but energy released by molecules as they change state does not remain within a controlled volume of air and must be removed and discarded in a systematic manner for the controlled volume of air to follow the specified isobaric or isothermal process. In contrast, the process of the present invention decompresses a controlled volume of humid air until included water vapor reaches a saturated state. This is done with no exchange of energy with the external environment and is described as being an adiabatic decompression. As stated in the Summary of the Invention, those skilled in the art to which the present invention pertains will appreciate that, in practical applications, the term "adiabatic" is taken to mean nearly adiabatic.

[0041] The present process is represented in FIG. **5** as "adiabatic" decompression in contrast to the "isobaric" cooling and "isothermal" compression pathways to condensation shown in that figure. The process of the present invention specifies an adiabatic decompression process, wherein the energy released by water vapor as it changes state is not removed and discarded but remains within the controlled volume of the decompressed air. Both the state-changed water and the energy released by the state change are subsequently harvested following a recompression process as products of the present inventive process. Preferred processes for harvesting latent energy and nonvaporous water are illustrated by the logic flow diagram of FIG. **6** in conjunction with FIGS. **7**, **8**, **9**, **22** and **23**; and the processes will be detailed following a description of the five preferred embodiments illustrated by FIGS. **7**, **8**, **9**, **22** and **23** and a description of process-supporting elements illustrated by FIGS. **10** through **13**. FIG. **6** of the present continuation-in-part differs from the original FIG. **6** of the parent application. Whereas, in the parent application, the temperature of pre-ingested atmospheric air is shown to be pre-warmed, in the present continuation-in-part, it is shown to be pre-warmed or pre-cooled.

[0042] FIG. **7** is a schematic drawing, not drawn to scale, symbolically representative of elements of a preferred embodiment of an apparatus of the present invention, generally indicated by reference numeral **10**. The apparatus **10** is a thermodynamically closed system that includes an insulated structure **12** to prevent the escape of thermal energy. It is to be understood that, in the interest of simplicity, the insulated structure **12** is shown schematically surrounding a space including a combination of apparatus components. As will be appreciated by those skilled in the art to which this invention pertains, insulation could alternatively be effectively disposed about individual components of the apparatus **10** that require insulation.

[0043] In view of the basic functional similarities of the embodiments shown by FIGS. **7**, **8** and **9**, the most detailed description will be of the embodiment shown by FIG. **7**. The apparatus **10** includes a hollow cylinder **14** within which is slidably disposed a piston **16** connected by a piston rod **18** to a driver **20**, which translates the piston rod **18** and the piston **16** in opposite, rightward and leftward directions as indicated by a double-ended arrow **19**. The driver **20** can include any of an applicable number of well-known devices (not shown) driven by hydraulic, pneumatic, cam, rack and pinion, ball screw, belt or chain mechanisms or by linear or rotary motors. The driver **20** also includes position sensors (not shown) for indicating driven element positions. The cylinder **14** has a closed end **22**. A chamber, generally indicated by reference numeral **24**, is defined as being within the cylinder **14** and between the closed end **22** and the piston **16**. The chamber **24**, piston **16**, piston rod **18** and driver **20** comprise a decompression-recompression mechanism, generally indicated by reference numeral **25**. A controllable volume, generally indicated by reference numeral **26**, is defined, as is the chamber **24**, as being within the cylinder **14** and between the closed end **22** and the piston **16**. This volume is controlled by positioning the piston **16**. It is to be understood that the hollow cylinder **14** is not necessarily limited to having a circular or, in some applications, even a symmetrical cross-section.

[0044] The chamber **24** is connected to atmospheric air via a thermally insulated air ingestion conduit **50**; and air flow through the conduit **50** and into the chamber **24** is controlled by a controllable inlet, such as an air ingestion device, or valve, **52**. Those skilled in the art to which the invention pertains will appreciate that, by definition, a valve is a device that controls the flow of a fluid. Valves include lids, plugs, and covers applied to openings so that, by their movements, such as by swinging, lifting and falling, sliding, turning, or the like, they open and close the openings to permit or prevent passage by such as fluids. Modern valves can control not only the flow but also the pressure, rate, volume, and direction of liquids, gases, slurries and even dry materials through a pipeline, flume, chute or similar passageway. They can turn on and off, regulate, modulate and isolate; can range in size from a fraction of an inch to some 30 feet in diameter; and can vary considerably in complexity.

[0045] FIG. **7** shows a symbolic representation of an air pretreatment system, generally indicated by reference numeral **51**, which includes the air ingestion valve **52**, an air temperature modifying device **53**, and an air prehumidifying device **55**. The air ingestion valve **52** is shown as one multifunctional valve capable of routing incoming, atmospheric air directly into the chamber **24**. Alternatively, it is also capable of routing incoming, atmospheric air through the air preparing device **53**, through the air prehumidifying device **55**, or through both devices, **53** and **55**, before routing atmospheric air into the chamber **24**. Those skilled in the art to which the invention pertains will appreciate that separate valves (not shown) can also be used for thus routing atmospheric air into the chamber **24**. Each of the three alternatives result in available external energy being added to latent energy of the atmospheric air before ingestion. Examples of available external energy sources include solar radiation, a hot engine manifold, hot flue gases passing through an industrial plant, steam exhausting from a power plant, and the like.

[0046] An apparatus controller **54** is shown by FIG. **7** as having symbolic terminals, represented by circled numerals **1** through **6**, that communicate with like-identified terminals of the apparatus **10**. As shown, the air ingestion valve **52** is connected to and controlled by the apparatus controller **54** via connections between terminals that are each represented by a circled numeral **1**. The driver **20** positions the piston **16** under control of the apparatus controller **54** via connections between terminals that are each represented by a circled numeral **2**.

[0047] A nonvaporous water extracting valve **56** extracts nonvaporous water from the chamber **24** under control of the apparatus controller **54** via connections between terminals that are each represented by a circled numeral **3**. An insulated, internal water reservoir **58** receives, via a thermally insulated conduit **60**, and retains the nonvaporous water within the apparatus **10** prior to the water being harvested for external use. It is important to note that extracting the water and necessitating that it be held in the internal reservoir **58**, separated from but at the same pressure as the controlled volume of air **26** in the chamber **24**, renders the process of latent heat release nearly irreversible.

[0048] As shown by FIG. **7**, to minimize evaporation, the internal water reservoir **58** is slopingly configured so that the upper surface area of retained water is much smaller than the summative surface area of all water droplets within the controlled volume of air. Rather than being linearly sloped as shown by FIG. **7**, the internal water reservoir **58** can also be concavely configured, as shown by FIG. **8**, for the same reason. The dimensions of the conduit **60** between the chamber **24** and the internal reservoir **58** are also kept as small as possible to minimize the volume of air located outside the chamber **24** and to minimize evaporation. Also, the operation of the nonvaporous water extracting valve **56** is coordinated with that of the external air ingestion valve **52** for the same reason. Additionally, the nonvaporous water extracting valve **56** is controlled to maintain nonvaporous water within the internal water reservoir **58** and the conduit **60** at maximum possible levels to minimize the amount of air contained therewithin and not within the chamber **24**, where nonvaporous water is subject to removal by a water removal device, a generic representation of which is generally indicated by reference numeral **71**. It is the possibility of there being a minimal amount of water, remaining in a conduit or valve, that could be evaporated during subsequent decompression processes that encourages the use of the word "nearly" in the foregoing term "nearly irreversible."

[0049] The chamber **24** of the cylinder **14** has a drain channel, generally indicated by reference numeral **46**, which is shown in exaggerated scale, to receive and direct nonvaporous water within the chamber **24** to the nonvaporous water extracting valve **56**. The piston rod **18** has a configuration of an elongate, hollow tube. A water droplet removal device driver rod **73** coaxially and slidably extends through the piston rod **18** and is operatively connected between the water droplet removal device **71** and the driver **20**. The driver **20** translates the water droplet removal device rod **73** and the water droplet removal device **71** in rightward and leftward directions, independently of the piston rod **18** and of the piston **16**, to transfer water condensed and coalesced on the water droplet removal device **71** and on the interior surface of the chamber **24** toward the drain channel **46** for subsequent extraction.

[0050] A nonvaporous water harvesting valve **62** harvests the nonvaporous water from the internal water reservoir **58**, via a thermally insulated conduit **63**, to an external water reservoir **64** of the apparatus **10**. The nonvaporous water harvesting valve **62** is under control of the apparatus controller **54** via connections between terminals that are each represented by a circled numeral **4**. If the apparatus **10** is located in suitable terrain, an extra, or alternate, low-level, external water reservoir **65** can be located at an elevation lower than that of the internal water reservoir **58**. An energy-harvesting device, such as a water-turbine-driven electric generator **66**, can then be positioned proximate the low-level, external water reservoir **65** to harvest energy derived from water flowing, under the influence of gravity, from the internal reservoir **58** to the low-level, external water reservoir **65**. This alternate arrangement is also illustrated by FIG. **7**, the alternate paths of water flow being indicated by dashed lines.

[0051] An air harvesting valve **67** harvests warmed, recompressed air from the chamber **24**, via a thermally insulated conduit **68**, to a thermal energy harvesting device **70** external to the thermally isolated apparatus **10**. The air harvesting valve **67** is under control of the apparatus controller **54** via connections between terminals that are each represented by a circled numeral **5**. A pressure sensor **27** is mounted within the chamber **24** to measure pressure within the chamber **24** and to send a signal representative of the pressure to the apparatus controller **54** via connections between terminals that are each represented by a circled numeral **6**. It is to be noted that chamber pressure can be estimated from data indicating the location at which the driver **20** positions the piston **16**.

[0052] FIG. **8** is a schematic drawing, not drawn to scale, symbolically representative of an apparatus, generally indicated by reference numeral **110**, of another preferred embodiment of the present invention. Like the apparatus **10** shown by FIG. **7**, the apparatus **110** is a closed system that includes an insulated structure **112** to prevent the escape of thermal energy. As in FIG. **7**, and for the same reason, the insulated structure **12** is shown schematically surrounding a space including a combination of apparatus components.

[0053] The apparatus **110** is similar to the cylinder-piston apparatus **10** shown by FIG. **7** but includes, in a common cylinder **114**, a first chamber, generally indicated by reference numeral **124**, and a second chamber, generally indicated by reference numeral **128**. The first and second chambers **124** and **128** have longitudinal axes that are collinear. The cylinder **114** has a first closed end **122** and a second closed end **123**.

The two chambers are operated in an oppositely phased manner by a common piston **116** that is slidably disposed within the cylinder **114**. The first chamber **124** is defined as being within the cylinder **114** and between the first closed end **122** and the piston **116**, and the second chamber **128** is defined as being between the second closed end **123** and the piston **116**. The piston **116** is connected by a piston rod **118** to a driver **120**, which translates the piston rod **118** and the piston **116** in rightward and leftward directions as indicated by a mid-length one of three double-ended arrows **119**. As mentioned in the description of FIG. **7**, the driver **120** can include any of an applicable number of well-known devices (not shown) driven by hydraulic, pneumatic, cam, rack and pinion, ball screw, belt or chain mechanisms or the like or by linear or rotary motors. It also includes position sensors (not shown) for indicating driven element positions.

[0054] As similarly illustrated by FIG. **7**, FIG. **8** shows a symbolic representation of an air pretreatment system, generally indicated by reference numeral **151**, which includes an air ingestion device, or valve, **152**, an air preparing device **153**, and an air prehumidifying device **155**. The air ingestion valve **152**, which controls the admission of atmospheric air through a thermally insulated air ingestion conduit **150**, is shown as one multifunctional valve capable of routing incoming, atmospheric air directly into the chambers **124** and **128**. Alternatively, it is also capable of routing incoming, atmospheric air through an air preparing device **153**, through an air prehumidifying device **155**, or through both devices, **153** and **155**, before routing atmospheric air into the chamber **124** and **128**. Also, as previously mentioned in the description of FIG. **7**, those skilled in the art to which the invention pertains will appreciate that separate valves (not shown) can also be used for thus routing atmospheric air into the chambers **124** and **128**. Again, each of the three alternatives result in available external energy being added to latent energy of the atmospheric air before ingestion.

[0055] An apparatus controller **154** is shown by FIG. **8** as having symbolic terminals, generally indicated by circled numerals **1** through **12**, that communicate with like-identified terminals of the apparatus **110**. As shown, the air ingestion valve **152** is connected to and controlled by the apparatus controller **154** via connections between terminals that are each represented by a circled numeral **1**. The driver **120** positions the piston **116** under control of the apparatus controller **154** via connections between terminals that are each represented by a circled numeral **2**.

[0056] The chambers **124** and **128**, piston **116**, piston rod **118** and driver **120** comprise a decompression-recompression mechanism, generally indicated by reference numeral **125**. Controllable volumes, generally indicated by reference numerals **126** and **130**, are defined within the chamber **124** as being within the cylinder **114** and between the closed end **122** and the piston **116** and within the chamber **128** as being within the cylinder **114** and between the closed end **123** and the piston **116**, respectively. The controllable volumes **126** and **130** are controlled by positioning the piston **116**. The decompression and recompression cycles within the two chambers, **124** and **128**, respectively, are 180 degrees out of phase. As air in one chamber is being decompressed, air in the other is being recompressed. As is the case with the apparatus shown by FIG. **7**, it is to be understood that the hollow cylinder **114** is not necessarily limited to having a circular or, in some applications, even a symmetrical cross-section.

[0057] First and second internal air ingestion valves **169** and **179** control the ingestion of air, from the thermally insulated conduit **150** to the first and second chambers **124** and **128**, under control of the apparatus controller **154** via connections between terminals that are represented by circled numerals **7** and **9**, respectively. First and second nonvaporous water extracting valves **156** and **180** extract nonvaporous water from the first and second chambers **124** and **128**, via thermally insulated conduits **160** and **161**, to internal water reservoirs **158** and **187** under control of the apparatus controller **154**, via connections between terminals that are represented by circled numerals **3** and **11**, respectively.

[0058] As shown by FIG. **8**, to minimize evaporation, the internal water reservoirs **158** and **187** are concavely configured so that the upper surface area of retained water exposed to air is much smaller than the summative surface area of all water droplets within the controlled air. The internal water reservoirs **158** and **187** could also be slopingly configured, as shown by FIG. **7**, for the same reason. The dimensions of the conduits **160** and **161** between the chambers **124** and **128**, respectively, and the internal reservoirs **158** and **187** are also kept as small as possible to minimize evaporation; and the operations of the nonvaporous water extracting valves **156** and **180** are coordinated with that of the external air ingestion valve **152** for the same reason. Additionally, the first and second nonvaporous water extracting valves **156** and **180**, respectively, are controlled to maintain nonvaporous water within the internal water reservoirs **158** and **187** and the conduits **160** and **161** at maximum possible levels. This minimizes the amount of air contained therewithin and not within the first and second chambers **124** and **128**, respectively, where nonvaporous water is subject to removal by first and second water removal devices, generally indicated by reference numerals **171** and **181**, respectively.

[0059] The first and second chambers **124** and **128** of the cylinder **114** have first and second drain channels, generally indicated by reference numerals **146** and **148**, respectively, which are shown in exaggerated scale, to receive and direct nonvaporous water from the first and second chambers **124** and **128**, respectively, to the first and second nonvaporous water extracting valves **156** and **180**, respectively. The piston rod **118** has a configuration of an elongate, hollow tube. A first water droplet removal device driver rod **173** coaxially and slidably extends through the piston rod **118** and is operatively connected between the first water droplet removal device **171** and the driver **120**. A second water droplet removal device driver rod **175** also has a configuration of an elongate, hollow tube. The piston rod **118** coaxially and slidably extends through the hollow second water droplet removal device driver rod **175** and is operatively connected between the second water droplet removal device **181** and the driver **120**. The driver **120** translates the first and second water droplet removal device rods **173** and **175**, and therefore the first and second water droplet removal devices **171** and **181**, respectively, in opposite, rightward and leftward directions, as indicated by the shortest and longest ones, respectively, of the three double-ended arrows **119**. The first and second water droplet removal devices **171** and **181**, respectively, move independently of the piston **116** and of each other to transfer water condensed and coalesced on the water droplet removal device **71** and on the interior surfaces of the first and second chambers **124** and **128** toward the first and second drain channels **146** and **148** for subsequent extraction.

[0060] Nonvaporous water harvesting valves **162** and **168** harvest nonvaporous water, from the internal water reservoirs **158** and **187** via thermally insulated conduits **163** and **189** to an external water reservoir **164**, under control of the apparatus controller **154** via connections between terminals each represented by circled numbers 4 and 12. If the apparatus **110** is located in suitable terrain, an extra or alternate, low-level, external water reservoir **165** can be located at an elevation lower than that of the internal water reservoir **158**. An energy-harvesting device, such as a water-turbine-driven electric generator **166**, can then be positioned proximate the low-level, external water reservoir **165** to harvest energy derived from water flowing, under the influence of gravity, from the first and second internal reservoirs **158** and **187** to the low-level, external water reservoir **165**. This alternate arrangement is also illustrated by FIG. **8**, the alternate paths of water flow being indicated by dashed lines.

[0061] First and second air harvesting valves **167** and **177** harvest air, from the first and second chambers **124** and **128** via a thermally insulated conduit **168** to a thermal energy harvesting device **170**, under control of the apparatus controller **154** via connections between terminals that are represented by circled numerals **5** and **8**, respectively. First and second pressure gauges **127** and **129** send signals representative of pressures in the chambers **124** and **128** to the apparatus controller **154** via connections between terminals that are represented by circled numbers 6 and 10, respectively. It is to be noted that chamber pressures can be estimated from data indicating the locations at which the driver **120** positions the piston **116**.

[0062] Decompression and recompression can be accomplished by using a number of apparatuses and methods. For example, as an alternative preferred embodiment to that of the cylinder-piston mechanism shown by FIG. **7**, FIG. **9**, not drawn to scale, shows a transparent, perspective view of a closed chamber, generally indicated by reference numeral **224**, having a closed end **222** and a flexible diaphragm **232** at opposite ends of the chamber **224**. A controllable volume, generally indicated by reference numeral **226**, is defined as being within the chamber **224** and between the closed end **222** and the flexible diaphragm **232**. The controllable volume **226** is controlled by the position of the flexible diaphragm **232**, which is connected to a driver **220** by a diaphragm rod **218**, which is driven in rightward and leftward directions as indicated by a double-ended arrow **219**. Although the chamber **224** is shown having a circular cylindrical shape, it could have almost any fixed configuration. Although not shown in the representative FIG. **9**, as with the chamber **24** shown by FIG. **7**, the chamber **224** would also have an air pretreatment system, an air harvesting valve, a water extracting valve and a water removal device. The flexible diaphragm **232** would basically perform the same function as the piston **16** shown by FIG. **7**. The operation of the valves and water removal devices would also be as previously described for the similar elements shown by FIG. **7**.

[0063] As in the case of the apparatus **110** shown by FIG. **8**, where a common piston **116** and a pair of oppositely disposed and operated chambers **124** and **128** are used to perform a pair of decompression and recompression operations that are 180 degrees out of phase with each other, an alternative preferred embodiment (not shown) to that shown by FIG. **8** could use the flexible diaphragm **232** in common with a pair of oppositely disposed and operated chambers **224**, shown by FIG. **9**, to perform similar decompression and recompression operations that are 180 degrees out of phase with each other. Although not shown, as with the second chamber **128** shown by FIG. **8**, the additional chamber would also have an air ingestion valve, an air harvesting valve, a water extracting valve and a water removal device. The common flexible diaphragm **232** would basically perform the same function as the common piston **116** shown by FIG. **8**. The operation of the valves and water removal devices would also be as previously described for the similar elements shown by FIG. **8**.

[0064] It is to be noted that other alternative embodiments could be substituted for those shown by FIGS. **7** through **9**. An example (not shown) would combine a plurality of thermally insulated chambers and operationally supporting elements similar to those shown by FIGS. **7** and **8**. Separate longitudinal axes, each passing through at least one chamber, would extend radially from a common, central driver.

[0065] As shown by FIGS. **10** and **11**, one species of the generic water droplet removal device **71** shown by FIG. **7** (and devices **171** and **181** as shown by FIG. **8**), namely, a water droplet removal filter, generally indicated by reference numeral **72**, is disposed within the chamber **24** (or within the chambers **124** and **128** as shown by FIG. **8**) such that there is relative motion between the filter **72** and the controlled air. An analogy to water extraction using filter fibers is the familiar experience of water vapor from exhaled air condensing upon fibers of a ski mask or scarf as exhaled air passes between them. In the present device, water droplets collect and coalesce upon fibers **78** of the filter **72**. Resulting liquid water descends and runs downwardly under the influence of gravity, pools in the lower portion of the chamber **24** (or the chambers **124** and **128** as shown by FIG. **8**), and is extracted via the water extracting valve **56** (or the water extracting valves **156** and **180** as shown by FIG. **8**) under control of the apparatus controller **54**. Although the filter **72** is shown and described as having fibers **78**, it is to be understood that it could also have any of a number of other filter elements capable of condensing and coalescing water droplets upon their surfaces.

[0066] As shown by FIG. **7**, and as previously described, the piston rod **18** of the apparatus **10** is centrally connected to the piston **16**; and both are translatable by the driver **20** in rightward and leftward directions, as indicated by the double-ended arrow **19**, to decompress and recompress, respectively, controlled air within the chamber **24** (or within the chambers **124** and **128** as shown by FIG. **8**). FIGS. **10** and **11**, respectively, show front and side views of the water droplet removal filter **72**, which includes a filter holder **74** that supports the filter fibers **78**. The water droplet removal device driver rod **73** is centrally connected to the filter holder **74**, and both are translatable by the driver **20** in rightward and leftward directions as indicated by a double-ended arrow **83**. The filter holder **74** can be translated independently of the piston **16**, provided the position of the piston **16** allows sufficient space for the filter holder **74** to do so, to produce relative motion between the water droplet removal filter **72** and the controlled air.

[0067] The filter holder **74** is configured to fit slidably within the chamber **24**, and a resilient ring **76** is mounted peripherally around the filter holder **74**. The water droplet removal filter **72** transfers water condensed and coalesced on the filter **72**, and the resilient ring **76** wipes water condensed and coalesced on the interior surface of the chamber **24**, toward the drain channel of the cylinder **14** for subsequent extraction. Since the filter holder **74** can be moved independently of the piston **16**, the latter can be held motionless until

a desired percentage of water droplets has been removed by the water droplet removal filter **72** from the controlled air and transferred to the closed end **22** of the cylinder **14**. A specification of a desired percentage of water droplet removal would be based on an optimization of overall productivity of energy and water extraction per unit time in relation to the time spent for each machine cycle and the work performed during decompression and water removal. This means that the desired percentage is a variable based on the desired operating parameters and existing weather conditions.

[0068] FIGS. **12** and **13** respectively illustrate another species of the generic water droplet removal device **71** shown by FIG. **7** (and devices **171** and **181** as shown by FIG. **8**), namely, a water droplet removal fan, generally indicated by reference numeral **82**. FIGS. **12** and **13** respectively show front and side views of the water droplet removal fan **82**, which includes a fan holder **84**. A hub **88** is centrally and rotatably supported by the fan holder **84**, and at least one fan blade **90**, four being shown by FIG. **12**, radially extends from the hub **88**. The water droplet removal device rod **73** is centrally connected to the hub **88**. Both are axially moved by the driver **20** in rightward and leftward directions as indicated by the double-ended arrow **83**, and the water droplet removal device rod **73** can also be rotated by the driver **20** as indicated by a circular arrow **85**. The hub **88** can be rotated and axially moved independently of the piston **16** provided the position of the piston **16** allows sufficient space for the hub **88** to do so.

[0069] The fan **82** creates a turbulence in the air that impels water droplets to collide with each other and to condense, impact and coalesce, and perhaps impel some water vapor to deposit, upon the inner surface of the chamber **24** (or the chambers **124** and **128** as shown by FIG. **8**). The pitch of a conventional propeller blade generally decreases smoothly with distance from the blade's axis of revolution, and such blades would produce a relatively smooth flow of air and water droplets. Note, however, that the pitch of the blades **90** of the fan **82** undergoes numerous, abrupt transitions to create brutally forceful turbulence that causes water droplets to collide with the blades **90**, with each other, and with the inner surface of the chamber **24** (or the chambers **124** and **128** as shown by FIG. **8**) and to coalesce and descend to the lower, inner surface of the chamber **24** (or the chambers **124** and **128** as shown by FIG. **8**).

[0070] The fan holder **84** is configured to fit slidably within the chamber **24** (or the chambers **124** and **128** as shown by FIG. **8**), and a resilient ring **86** is mounted peripherally around the fan holder **84**. The fan holder **84** transfers water condensed and coalesced on the fan **82**, and the resilient ring **86** wipes water condensed and coalesced on the interior surface of the chamber **24** (or chambers **124** and **128** as shown by FIG. **8**) toward the drain channel **46** (or the drain channels **146** and **148** as shown by FIG. **8**) of the cylinder **14** (or the cylinder **114** as shown by FIG. **8**) for subsequent extraction. As with the filter **72**, since the fan hub **88** can be moved independently of the piston **16** (or **116** as shown by FIG. **8**), the latter can be held motionless until a desired percentage of water droplets has been removed by the water droplet removal fan **82** from the controlled air and transferred to the drain channel **46** (or the drain channels **146** and **148** as shown by FIG. **8**) of the cylinder **14** (or the cylinder **114** as shown by FIG. **8**) for subsequent extraction. Although the water droplet removal filter **72**, shown by FIGS. **10** and **11**, and fan **82**, shown by FIGS. **12** and **13**, have been described as they would be used with the apparatuses shown by FIGS. **7** and **8**, it is to be understood that they could also be similarly used in the apparatuses shown by FIG. **9**.

[0071] As previously mentioned, the logic flow diagram of FIG. **6** illustrates a preferred process of the present invention for harvesting latent energy and nonvaporous water from a gaseous mixture. In the interest of brevity, except as otherwise indicated, the process steps will primarily be described with respect to the mechanism shown by FIG. **7**, which is functionally representative of the other embodiments. As shown, in a first process step, a particular amount of atmospheric air is ingested into the controllable volume **26** of the apparatus **10**. This is initiated by the opening of the air ingestion valve **52** and of the rightward movement of the piston **16** within the cylinder **14** under urging of the driver **20**. Both actions are controlled by the apparatus controller **54**, which also closes the air ingestion valve **52** when a particular volume of air has been ingested into the chamber **24**.

[0072] In a first of three previously described alternatives, pre-ingested, atmospheric air is warmed using available energy collected externally to the apparatus **10**, for example, as illustrated by FIG. **1** to increase the ingested thermal energy of the thermodynamic process. In a second of the three alternatives, water vaporized using available energy collected externally to the apparatus **10** is introduced into pre-ingested, atmospheric air. In a third of the three alternatives, pre-ingested, atmospheric air is warmed; and vaporized water is also introduced into it.

[0073] In a second process step, following its ingestion into the controllable volume **26** within the apparatus **10**, the ingested air is controllably decompressed so that it has a greater volume and thus a lower density. The decompression is performed such that little or no energy is exchanged between the decompressing air and the external environment; that is, the decompression is performed nearly adiabatically. As the adiabatic decompression progresses, the partial pressure of the water vapor decreases toward a saturation vapor pressure, where the water vapor condenses to a liquid state, a portion of the water vapor possibly also depositing to a solid state. The decompressing air thus includes, as constituents, a mixture of water vapor, liquid water and, possibly, solid water. The change of state of water is attended by a release of latent energy that is added to the overall internal energy of the decompressed air. FIG. **14** is a graphic representation of the relationship of temperature and pressure during an adiabatic decompression of atmospheric air, a removal of nonvaporous water, and a subsequent adiabatic recompression of the air, which then contains latent heat of condensation. FIG. **15** is a graphic representation of mixing ratios of saturated air as functions of temperature and pressure.

[0074] In a third process step, during decompression and/or at the point of maximum decompression, a fraction greater than zero and less than one of nonvaporous water in the decompressed air is extracted. At this point in the process, the fractional portions of the liquid and any solid water are retained in a separate, internal water reservoir **58** within the apparatus **10**, as shown by FIG. **7**, prior to being harvested for external use. Since the internal energy of the nonvaporous water is extracted from the system as the water is extracted, the process is slightly nonadiabatic, but the internal energy of removed nonvaporous water is small in comparison to the internal energy of the air being processed. This process involves no significant change in pressure or temperature and is therefore represented as occurring at coincident points **4**

and **5** (indicating the lowest pressure to which the controlled air is decompressed and indicating the condition of controlled air after all nonvaporous water has been removed, respectively, in FIGS. **16** and **19**).

[0075] In a fourth process step, after the fractional portions of the nonvaporous water have been extracted and placed in the internal reservoir, the remaining decompressed air is recompressed adiabatically toward the pressure it had when initially ingested. Recompression can be terminated when the pressure of the recompressing air reaches that of the initial controlled volume of air. Recompression can also be terminated when the volume of the recompressing air reaches that of the initial controlled volume of air. In the latter case, for thermodynamic reasons, the final pressure will be higher than the initial ingestion pressure. Additionally, recompression can be terminated when the pressure and the volume of the recompressing air are at any state along an unsaturated adiabat between a point where the pressure of the recompressing air reaches that of the initial controlled volume of air and a point where the volume of the recompressing air reaches that of the initial controlled volume of air. Actually, as a practical matter, recompression can be terminated when pressure and volume of the recompressing air are at any state along an unsaturated, recompression adiabat by opening the air harvesting valve **67**.

[0076] In a fifth process step, with the final thermodynamic conditions being as described, the recompressed air is harvested from the chamber **24** containing the controllable volume **26** of FIG. **7**. The recompressed air is then conducted through the conduit **68** to the external thermal energy harvesting device **70** to harvest the increased internal energy of the recompressed air. The final condition of the recompressed air has temperature, and possibly pressure, exceeding that of the initial, atmospheric air. As desired and appropriate, the thermal energy of the harvested air can be retained for use at a later time. For example, the thermodynamic free energy can be used to change the state of a working material, the stored energy being released when the working material is allowed to change back to its initial state. A working material commonly used in this process is paraffin wax.

[0077] Alternately, the thermal energy of the harvested air can be immediately harvested by one or more methods that operate on differences between harvested air temperature and pressure and atmospheric air temperature and pressure. Harvesting increased internal energy, and energy derived from the pressure difference, can be accomplished by any of several means. Thermal energy and pressure differences between harvested air and atmospheric air can be used to drive thermodynamic pumps and engines. Temperature differences between the harvested air and external, atmospheric air can be used to convert thermal energy to electric energy by using thermoelectric generators such as thermocouples, thermoelectric thin films on silicon, and the like. The temperature differences can also be used to convert thermal energy to mechanical energy by using a thermal engine such as a Stirling engine. Temperature and pressure differences between harvested air and atmospheric air can also be used to convert thermal energy to electric energy by using a convection device such as a vertically oriented, wind-turbine-driven electric generator **66**.

[0078] In a sixth process step, which can be performed before, after, or simultaneously with, the fifth process step, the nonvaporous water harvesting valve **62**, shown by FIG. **7**, is opened, releasing nonvaporous water that was extracted from initially ingested, atmospheric air and retained in the internal water reservoir **58** of the apparatus **10**. The released nonvaporous water passes through the conduit **63** and into the external water reservoir **64** at environmental conditions and at or near the altitude of the internal water reservoir **58**. Alternatively, and as desired and appropriate, the nonvaporous water can be released into a flume or conduit that, under the influence of gravity, conducts the water to a lower altitude to facilitate harvesting potential energy possessed by virtue of the relatively elevated initial position of the nonvaporous water. As indicated by FIG. **7**, the potential energy can be harvested as descending water is conducted through the turbogenerator **66** before reaching the external, low-level water reservoir **65**. The harvested potential energy can be added to the energy gained by harvesting latent energy. It is noteworthy that the third process step, which performs a required extraction of nonvaporous water from the decompressed air, also provides potable water by harvesting the water from atmospheric air by taking advantage of a latent change of state rather than a chemical process.

[0079] As a result of the nonvaporous water extraction, the total remaining mass of nonvaporous water within the air is substantially less than the total mass of water vapor that was condensed and possibly deposited during the decompression process. The portion of the increased internal energy involved in returning the remaining nonvaporous water to water vapor is, therefore, likewise substantially less than the total internal energy that was increased during the decompression process. The internal energy of the recompressed air is thus significantly higher than was the internal energy of the initially ingested air. Depending on operational specifications of conditions at which the recompression is to be terminated, the pressure of the recompressed air could also be significantly higher than was the pressure of the initially ingested air.

[0080] The physical process, and its options, described by the foregoing may be categorized as harvesting latent energy of humid air by forced condensation or crystallization, thereby adding a portion of the energy released by water vapor molecules, as they condense and possibly deposit, to the internal thermal energy in the controlled air. According to the first law of thermodynamics, energy added to a gaseous system is accounted for by the sum of the increase in the internal energy of the system and the work done by the system. It is convenient to describe this in terms of energy and work per unit mass of the gaseous system. The change in internal energy of the gaseous system per unit mass can be specified in two parts: the change in energy per unit mass of the portion of the gas that does not change state (that is, does not condense or deposit); and the change in energy per unit mass of the portion of the gas that does change state by condensing to a liquid state and possibly depositing to a solid state.

[0081] The first of these two contributions to changes of internal energy can be conveniently expressed as the product of the mass-specific heat capacity of air at constant volume multiplied by the change in temperature of the gas mixture as it undergoes the thermodynamic process. The second contribution to change in internal energy can be expressed as the product of the latent heat of condensation, or sublimation, if appropriate, for the gaseous constituent that condenses multiplied by the mass of that constituent that is condensed per unit mass of the gaseous system. The work per unit mass done by the gaseous system is expressed as being the product of the pressure of the gas mixture and the change in volume per unit

mass. All these quantities refer to a process underway. In differential-equation form, the process can be expressed in terms of the first law of thermodynamics as:

$$dq=cdT+Ldm+pda,$$

where dq is the energy added to the system per unit mass of air, c is the mass-specific heat capacity of air at constant volume, dT is the temperature change, L is the latent heat of condensation, as appropriate (energy per unit-mass of vapor condensed and possibly deposited), dm is the change in mass of water vapor that changes state per unit mass of air, p is the pressure of the gas, and da is the change in air volume per unit mass of air. The mass of water vapor per unit mass of dry air is commonly known as the mixing ratio, and the volume per unit mass of dry air is often called specific volume, which is the reciprocal of air density.

[0082] The differential changes in all terms of the equation representing the first law of thermodynamics refer to a specified process. The process specified by the foregoing is an adiabatic process. By definition, for a perfectly adiabatic process, dq=0. FIG. **14** illustrates the process for a perfectly adiabatic process. The temperature scale of FIG. **14** is spaced uniformly. The pressure scale is spaced nonuniformly, and it is calibrated such that an unsaturated adiabatic process that does not involve state change of the water vapor component is a sloping straight line. Ingested air is represented by a dot at a pressure of 1000 millibars, a temperature of 85 degrees Fahrenheit, and a relative humidity of 75 percent. The actual amount of water vapor in the ingested air is 75 percent of the amount required for saturation. The maximum water vapor concentration is identified in FIG. **15** as the saturation mixing ratio, which, as previously mentioned, is defined as the ratio of the maximum mass of water vapor that can be contained per unit mass of all remaining constituents of dry air. The ratio of the actual mixing ratio of an air parcel to the saturation mixing ratio of air at the same temperature and pressure (times 100 percent) is known as relative humidity. The saturation mixing ratio is a known function of air temperature and pressure. The water vapor lines in FIG. **15** show a collection of selected values of this saturation mixing ratio function.

[0083] The first stage of the decompression process specifies unsaturated adiabatic decompression. This is shown in FIG. **14** by the straight-line path extending from ingested air state toward lower pressure and cooler temperature. As this unsaturated adiabatic process proceeds, there is no condensation, hence dm=0. The maximum amount of water vapor maintained in a vapor state is limited, however, by the saturated mixing ratio value and is therefore specified by pressure and temperature. The lines, or adiabats, relating temperature and pressure and representing unsaturated adiabatic processes in FIG. **14** have a less positive, that is, less steep, slope than do the lines representing the water vapor saturation mixing ratio in FIG. **15**. As air is decompressed adiabatically, the lines representing unsaturated adiabatic processes cross the saturation mixing ratio lines, as illustrated by FIG. **16**, as they each extend toward lower values of temperature and pressure. This illustrates that the amount of water that can remain in a vapor state is rapidly decreased during the decompression process, as the unsaturated adiabatic decompression reduces both pressure and temperature, until it has been reduced to the precise amount of water vapor contained. That is, the actual mixing ratio becomes equal to the diminishing value of the saturation mixing ratio, at which point, the relative humidity reaches 100 percent. As the decompression process continues past the saturation point, the water vapor condenses to liquid water at a rate that essentially maintains the actual mixing ratio of air being decompressed at the diminishing value of the saturation mixing ratio. Dust, smoke particles, and so forth in ambient air, that act as eater vapor condensation nuclei do not allow the relative humidity of ambient air to significantly exceed a 100 percent value.

[0084] The latent energy of condensation is designated, in the equation representing the first law of thermodynamics, by the term L dm. In terms of FIG. **14**, which specifically tracks pressure and temperature during adiabatic decompression, the latent energy of state change remains within the adiabatically changing system and adds to the internal energy of the processed air mixture, thereby appreciably modifying the temperature-pressure relationship. The substantial amount of latent energy released during the decompression process, as water vapor condenses to liquid water, adds to the internal energy of the controlled air mixture. In terms of the equation of the adiabatic first law of thermodynamics, this latent energy addition, L dm, slightly lowers the term c dT. This addition of latent heat is illustrated by FIG. **14** as a substantial departure of the decompressional change in temperature producing a smaller rate of temperature cooling with respect to pressure. To minimize the possibility of misunderstanding, adiabatic decompression after saturation will hereafter be referred to as a saturated adiabatic process to distinguish it from the initial unsaturated adiabatic process. The saturated adiabatic decompression continues to a specified endpoint indicated in FIG. **14** by a point on the process curve representing minimum pressure. At the endpoint, the represented controlled volume of air is a gaseous mixture including liquid water droplets and, possibly, ice crystals.

[0085] The maximum amount of water vapor included in atmospheric air is a small percentage, generally less than 3 or 4 percent. This statement is supported by data represented in FIG. **15**, which shows saturation water vapor mixing ratios in terms of the maximum water vapor mass per unit mass of noncondensing constituents of air. The data shown in FIG. **15** represent air pressures ranging within a domain extending from 400 millibars to more than 1000 millibars, the latter being a value representative of atmospheric air at Earth's surface. As the graph illustrates, variations in the water vapor capacity are strongly related to air temperature and pressure. For a given value of pressure, the greater the temperature, the greater the water vapor capacity. For example, at a pressure of 1000 mb, increasing the temperature from 30 to 90 degrees Fahrenheit increases the water vapor capacity by a factor of approximately 10. The largest value of saturation mixing ratio shown in FIG. **15** is 40 grams of water vapor per kilogram of dry air. For an atmospheric air density of the order of 1 kilogram per cubic meter, this maximum amount of water vapor mass represents only approximately 4 percent of the air mass. The amount of internal energy of the liquid water droplets that remain within the system is also quite small in comparison with the internal energy of the same mass of water in the vapor state. Thus, in the third process step, where removal of most or all liquid water droplets thereby removes the internal energy of those water droplets, the water removal is a nonadiabatic process step. Because the internal energy of the condensed water droplets is very small compared to the internal energy of the gaseous air mixture, however, water removal from the air mixture may be considered as being nearly adiabatic in terms of the overall mixture of gases and liquid droplets. This means that the true value of the energy

added to the system per unit mass of air (dq) for loss of internal energy of small amounts of liquid water is negligibly small in comparison with the energy terms on the right side of the equation of the first law of thermodynamics previously stated.

[0086] The extraction of water can be accomplished by any of a number of methods. One method is simply to allow water that has condensed on the inner surface of the chamber **24**, as shown by FIG. **7**, during decompression to run downwardly under the influence of gravity, pool in the lower portion of the chamber **24**, and be extracted via the water extracting valve **56** under control of the apparatus controller **54**. A more efficient method includes the use of a water droplet removal device **71** (or 171 and 181 as shown by FIG. **8**) as previously described.

[0087] After all, or most, liquid water droplets have been extracted from the decompressed air, the air is adiabatically recompressed toward its initial pressure and temperature. FIG. **14** illustrates this recompression from the lowest pressure point near 400 millibars upward and rightward toward the process endpoint near 1000 millibars. This recompression process illustrates a case when all liquid and solid water has been removed. In this case, the adiabatic recompression follows an unsaturated adiabatic process curve, for the water vapor content of the air becomes immediately unsaturated the instant recompression begins. This is because the actual water vapor content of air has been substantially reduced by condensation, and the recompression increases the temperature and pressure of the controlled air such that the maximum water vapor content, measured by the saturation mixing ratio, systematically exceeds the actual mixing ratio during recompression. The relative humidity is therefore systematically less than 100 percent, and recompression is unsaturated adiabatic. The recompression process remains unsaturated and adiabatic until the end of recompression. FIG. **14** shows that the decompression, nonvaporous water removal, and recompression processes bring the recompressed air to a final temperature significantly higher than was the temperature of the initially ingested air. In terms of the first law of thermodynamics, all the latent energy of condensation has been retained within the system and converted to internal energy of the recompressed air, which is manifest by virtue of the air temperature increase. As previously stated, if any liquid water droplets remain in the thermodynamic system, the initiation of adiabatic recompression would cause an evaporation of the droplets. This would involve a conversion of some internal energy of the recompressing air to latent energy of evaporation. In terms of FIG. **14**, this early stage of the recompression process would follow backwardly along the same saturated adiabatic process that specified the decompression but only until all liquid water droplets or ice crystals are evaporated. After that, the process would proceed as an unsaturated adiabatic recompression. In this case, the unsaturated adiabatic process curve would be slightly to the left of the one actually shown in FIG. **14**. This would lead to a slightly cooler final temperature than in the previous case, but it would still be much warmer than ingestion temperature. Note that this process option is not explicitly shown by FIG. **14**.

[0088] The adiabatic process described can be served by thermally insulating any of the embodiments of the present invention from the external environment. Nonadiabatic heat exchange, dq, between the gaseous mixture contained within the apparatus **10** and the external environment of the apparatus **10** would be generally proportional to the difference between internal and external temperatures. Unlike the temperature differences attending combustion engines and similar apparatuses, as FIG. **14** indicates, such temperature differences attending the present invention would be a few tens of degrees Kelvin rather than hundreds or thousands of degrees Kelvin. Thus, thermal insulation to maintain adiabatic, thermodynamic processing can be provided using existing thermal insulation technology.

[0089] FIG. **16** quantitatively illustrates the thermodynamic relationship of temperature to pressure during humid air processing, including ingestion, decompression, condensation, water extraction, recompression and harvesting. Atmospheric air having a temperature of 50 degrees Fahrenheit, a pressure of 1000 millibars, and a relative humidity of 75 percent is ingested. At this initial temperature and pressure, the saturation mixing ratio, as shown by FIGS. **15** and **16**, is roughly 7.8 grams of water per kilogram of dry air. The actual mixing ratio would therefore be (0.75)(7.8)=5.85 grams of water per kilogram of dry air. Since the air is not initially saturated, the decompression follows an unsaturated adiabat until the air reaches a temperature and pressure at which the saturated mixing ratio equals this actual mixing ratio value. Following a saturated adiabatic process, decompression continues until a pressure of 400 millibars is reached. Water droplets are then extracted, and a subsequent unsaturated adiabatic recompression to 1000 millibars pressure brings the air to a final temperature of approximately 77 degrees Fahrenheit.

[0090] FIG. **17** is a graph illustrating the thermodynamic relationship of volume to pressure during the processing illustrated by FIG. **16**. The horizontal axis of the graph shown by FIG. **17** represents the ratio of the actual, instantaneous volume V of air being processed to the volume Vo of the initially ingested air. This initial volume Vo equals the cross-sectional area of the chamber **24** as shown by FIG. **7** times the distance between piston **16** and the closed end **22** of the cylinder **14** at the instant the air ingestion valve **52** was closed. Points **1** and **2** of the graphs of FIGS. **16** and **17** represent an air ingesting portion of the process. The portion involves no changes in temperature or pressure. At these coincident points, V and Vo are equal; and the volume ratio is therefore 1.0. Decompression begins at these coincident points, and the ratio increases until decompression ends at coincident points **4** and **5**, where the volume ratio is just above 2.0. Point **3** represents a point during decompression at which included water vapor begins to undergo condensation and, possibly, deposition. It is to be noted that, since the air ingestion valve **52** is controllable, the amount of initially ingested air Vo can be set to any desired fraction of the maximum volume of the chamber **24** of the embodiment represented by FIG. **7**.

[0091] As decompression proceeds, that is, as the piston **16** is moved farther away from the closed end **22**, the instantaneous air volume V increases through values larger than the initial volume Vo. The variable of each of the horizontal scales shown by FIGS. **17** and **20** represents the ratio of expanding or contracting air volume to the initial volume Vo. The graphs therefore show the V/Vo ratio proceeding upwardly from a value of 1.0 to some maximum value determined by embodiment design. With the embodiments represented by FIGS. **7**, **8** and **9**, there is a limit to how much the air can be expanded. That limit for the embodiment represented by FIG. **7** is specified by the length of the piston stroke. The limit for the embodiment represented by FIG. **9** is the maximum volume that can be created by a rightward movement of the flexible diaphragm **232**. The process represented by FIGS. **16** and **17**

is designed to have final, decompressed volumes V, slightly more than twice the initially ingested air volume Vo.

[0092] FIG. **19** is a graph illustrating the effect of preparing and prehumidifying ingested air of the process shown by FIG. **16**, and FIG. **20** is a graph illustrating the thermodynamic relationship of volume to pressure during the processing illustrated by FIG. **19**. The horizontal axis of FIG. **20** is identical to that of FIG. **17**, and the process is similarly designed to decompress the controlled air to a final decompression volume slightly more than twice the ingestion volume. An effect of the three alternatives to the first process step in using available external energy is to increase the water vapor mixing ratio prior to air ingestion. The effect of this preparing and/or prehumidification of pre-ingested, atmospheric air is illustrated by FIG. **19**, in which the temperature of the pre-ingested, atmospheric air shown by FIG. **16** is increased by just 10 Fahrenheit degrees and the water vapor content is brought to saturation at that warmer temperature. The value of the mixing ratio at a temperature of 60 degrees Fahrenheit, a pressure of 1000 millibars and a humidity of 100 percent, as shown by FIG. **15**, is slightly greater than 11 grams of water per kilogram of dry air, an increase of some 3.2 grams of water per kilogram of dry air over the 7.8 grams of water per kilogram of dry air of the previous example at 50 degrees Fahrenheit.

[0093] In the third process step, as illustrated by FIG. **16**, the unsaturated adiabatic decompression specified in the description of the second process step proceeds from representative points **2** to **3** as the piston **16**, shown by FIG. **7**, is moved rightwardly within the cylinder **14** under urging of the driver **20**. As represented by point **3** of FIG. **16**, the pressure and temperature of the humid air mixture attain values such that included water vapor reaches a point of saturation, begins to condense into a liquid, and possibly also to deposit to form a solid.

[0094] As decompression continues, condensation continues; and the latent heat of condensation continues to be added to the internal energy of the air mixture. As shown by FIG. **16**, the increase in the internal energy decreases the rate at which the temperature of the air decreases during the nearly adiabatic expansion and decompression. The rate of change of air temperature with pressure decompression represented by FIG. **16** as being between points **2** and **3** is therefore significantly different from the rate of change represented as being between points **3** and **4**.

[0095] As previously discussed in regard to the three alternatives to the first process step, if available energy is used to prewarm and/or prehumidify atmospheric air, the ingested air will have very different thermodynamic properties. In the example introduced and represented by FIG. **19**, the ingested air has a temperature of 60 degrees Fahrenheit rather than the 50 degrees Fahrenheit. Moreover, the prehumidification is assumed to increase the relative humidity of the ingested air to 100 percent. These modified values are represented by point **1** (indicating the pre-ingestion, atmospheric conditions when the air ingestion valve **52** is opened) and point **2** (indicating the conditions of ingested air when the air ingestion valve is closed) for the prewarmed and prehumidified ingested air of FIGS. **19** and **20**.

[0096] Whereas it is generally possible that some other gaseous component of atmospheric air might also come to saturation during the decompression process, as specified in the third process step, the actual values of pressure decompression from 1000 millibars to just 400 millibars in FIG. **16** essentially limits the number of common, atmospheric air constituents that come to saturation to just one, namely, water vapor.

[0097] By the end of the decompression process, specified by the arrival of the piston **16**, shown by FIG. **7**, at the extreme of its rightmost travel, a fraction of the initial water vapor of atmospheric air has been condensed into liquid water. Since the temperature represented by point **4** in FIG. **16** is below the freezing temperature of water, a fraction of the condensed water might have frozen into some crystalline state of ice, thereby releasing additional latent energy of solidification, which is added to the internal energy of the decompressed air.

[0098] Importantly, the prehumidification means that the air ingested is saturated so that point **2**, representing an ingestion condition, and point **3**, representing saturation, coincide in FIGS. **19** and **20**. This is significantly different in comparison with the example of atmospheric air ingested as represented by FIG. **16**, where the air follows an unsaturated adiabatic decompression from point **2** to point **3** and thereafter follows a saturated adiabat from point **3** to point **4**. The temperature represented by point **4** of FIG. **16** is approximately −47 degrees Fahrenheit, whereas the temperature represented by point **4** for prewarmed and prehumidified air represented by FIG. **19** is only approximately −15 degrees Fahrenheit. The difference between these temperatures at full decompression illustrates the additional latent energy realized as a result of prewarming and prehumidifying ingested air by available external energy as illustrated by FIG. **19**. In the cylinder-piston mechanism shown by FIG. **7**, the decompression process is executed by a specified change in volume of ingested air as the piston **16** moves from its position at the moment of closure of the air ingestion valve **52** to its most extreme position under control of the apparatus controller **54**. This volumetric change is identical for the examples shown by FIGS. **17** and **20**, and a consequence is the resulting difference in minimum pressures represented by the position of point **4** in FIGS. **16** and **19**.

[0099] Adiabatic recompression of the controlled quantity of air proceeds, as represented in FIGS. **16**, **17**, **19** and **20**, from points **5** to points **6** (the latter indicating the final state of controlled air after being recompressed to a pressure of the atmospheric air), respectively. The recompression is accomplished by moving the piston **16**, shown by FIG. **7**, leftwardly toward the closed end **22** of the cylinder **14** under urging of the driver **20**. During the recompression process, a small portion of internal energy of the controlled air might be used to melt any ice crystals and to re-evaporate any water droplets that were not effectively removed from the air during the third process step. If that is the case, a first portion of adiabatic recompression would be represented as a reversed movement between points **4** and **3** of FIGS. **16**, **17**, **19** and **20**, respectively, until remaining ice crystals and water droplets are fully converted to water vapor. After that, adiabatic recompression would be represented as following a straight-line path nearly parallel to the process path from points **5** toward points **6**.

[0100] As shown by FIGS. **16**, **17**, **19** and **20**, the removal of a substantial fraction of water droplets and ice crystals from the decompressed air provides an adiabatic recompression process that returns the air to its initial pressure with a substantially higher temperature than it had upon its ingestion. The substantial temperature difference is due to the latent energies of condensation and solidification that have been added to the internal energy of the recompressed air.

[0101] Note that the location of points **6** along the adiabatic recompression curves is a function of the position of the piston **16** within the cylinder **14** of FIG. **7** when the air harvesting valve **67** is opened. For example, point **6**, which represents the volume in the chamber **24** following the recompression process in FIG. **17**, is not at the same location as is point **1**, which represents the volume of initially ingested air. Rather, point **6** is located at a position indicating a slightly larger volume. If opening the air harvesting valve **67** is delayed until the recompression process returns the recompressed air to its initial volume, the final temperature and pressure will both be higher than represented by point **6** in FIG. **16**. This would represent an even greater thermal difference and a positive pressure difference relative to those of the environment. The recompression process illustrated by FIGS. **19** and **20** is specified to finish when the recompressed air arrives at the air ingestion pressure and the apparatus controller **54** opens the air harvesting valve **67**. With conditions as represented by the points **6** of FIGS. **19** and **20**, and in anticipation of a subsequent air decompression-recompression processing cycle, the recompressed air is harvested by opening the air harvesting valve **67**. The thermal energy of the harvested air can then be retained for use at a later time by, for example, changing the state of another material, or it can be used immediately by converting it to electric energy and/or mechanical energy using such devices as previously described.

[0102] The final thermodynamic conditions (point **6**) of recompressed air in the examples in FIG. **16** (untreated atmospheric air) and FIG. **19** (atmospheric air prewarmed and prehumidified by available external energy sources) are each significantly different from the ingestion conditions. Moreover, as previously mentioned, the final thermodynamic conditions of the example in FIG. **19** are significantly different from the corresponding endpoint in FIG. **16**. The final air temperature at point **6** of FIG. **16** is approximately 77 degrees Fahrenheit whereas the final air temperature at point **6** of the atmospheric air that has been prewarmed and prehumidified by available external energy in FIG. **19** is approximately 114 degrees Fahrenheit. This final process temperature is 64 Fahrenheit degrees warmer than the initial, atmospheric temperature of the air, and approximately 37 Fahrenheit degrees warmer than the final recompressed air represented by FIG. **16** using no prewarming or prehumidification. As a result of prehumidification, even with salinated or otherwise impure water, and of prewarming, the amount of potable water harvested, as well as the amount of latent energy harvested, is increased substantially. As previously mentioned, the harvested water is increased from 5.8 grams to 11 grams of water per kilogram of dry air.

[0103] An analysis based on the thermodynamic definition of the internal energy of the exemplary processed air shows that, at process conclusion, the air of each example has a greater amount of thermodynamic free energy than it had upon its ingestion. Such an analysis also clearly demonstrates that the preliminary use of available external energy can significantly enhance the final recompressed air temperature produced by the process described. To put the integration of available external energy into perspective, latent energy extraction, decompression work required, and recompression work recovery have been computed for the examples shown by FIGS. **16**, **17**, **19** and **20**. The values are easily interpreted for the exemplary embodiments in FIGS. **7**, **8** and **9** where the decompression work required is to pull the pistons **16** or **116** or pull the flexible diaphragm **232** away from their respective closed ends, **22**, **122** or **222**, respectively. The recompression work is recoverable work on the piston or diaphragm supplied by the difference between the pressure of the decompressed air and the higher pressure of atmospheric air.

[0104] FIG. **18** illustrates the process results for air ingested at 1000 mb, 50 degrees Fahrenheit and 75 percent relative humidity. FIG. **21** illustrates the process results for a similar volume of air ingested at 1000 mb, prewarmed to a higher temperature of 60 degrees Fahrenheit and prehumidified to a higher relative humidity of 100 percent using available external energy and humidity sources. The process curves trace the details of the process, and the final results are represented by endpoints. Separate curves are shown in FIGS. **18** and **21** for latent energy harvesting from the processed air, work required to force the decompression process, and recoverable work as recompression occurs while returning to an air harvest position. The curves trace the accumulated values of these quantities, and the endpoints on each curve show the final values. In both figures, it can be seen that latent energy harvesting becomes more and more difficult as the decompression process progresses. FIG. **18** shows that the latent energy harvested falls significantly short of the level of energy required to perform the decompression work required. When the air is prewarmed and prehumidified, however, even by a relatively small amount as shown by FIG. **21**, the latent energy is considerably increased and the decompression work required is reduced somewhat, thus significantly increasing the ratio of latent energy extraction to net work supplied.

[0105] These results should not be interpreted as a violation of the laws of thermodynamics, and they should not be viewed as support for any sort of "perpetual motion" apparatus. No additional energy is "created." Latent energy, the internal energy associated with the state of a system, is already present in water vapor and is merely converted to thermodynamic free energy, the energy in a physical system that can be converted to do work, by changing the state of the water.

[0106] Harvesting latent energy by this process can be considered as being analogous to sailing a sailboat. The energy a sailboat extracts from atmospheric wind clearly exceeds the work required by the sailor to operate the tiller. The latent energy extracted from natural, environmentally energetic, humid air exceeds the difference between work that must be supplied for decompression and work recovered during recompression. The net energy harvested is provided by nature and not by the operator of this energy process apparatus **10**.

[0107] FIG. **22** illustrates an apparatus similar to that shown by FIG. **7**. It differs primarily in that, wherein, in FIG. **7**, the chamber **26** that is formed within the cylinder **14** between the end **22** of the cylinder **14** and the piston **16** has been replaced by a bellows **28**, the volume within the bellows being identified by the reference numeral **26'**. A first end of the bellows **28** is secured to the closed end **22** of the cylinder **14**, and chamber inlets **50** and outlets **67** have been relocated to the end **22** of the cylinder **14**. The piston **16** has been replaced by a pressure plate **16'**. The present combination operates on the same basic principle of the decompression-recompression mechanism illustrated by FIG. **7** and described previously. The bellows **28** and pressure plate **16'**, having less mass than the piston **16**, requires less energy to operate. Being made of materials having a low thermal energy

conductivity, the bellows **28** and pressure plate **16'** will reduce thermal energy losses. Also, since the bellows **28** does not require, as does the piston **16**, constant lubrication, maintenance expenses and down time will be reduced.

[0108] FIG. **23** is a schematic drawing, not drawn to scale, symbolically representative of a preferred embodiment of an apparatus, generally indicated by the reference numeral **310**, of the present invention, The apparatus **310** includes a decompression, or expander, turbine **312** that has an atmospheric air inlet **314** and a decompressed air outlet **316**. The apparatus **310** also includes a recompression, or compressor, turbine **318** that has a decompressed air inlet **320** and a compressed air outlet **322**. A first air conduit **324** extends between the decompressed air outlet **316** and the decompressed air inlet **320** to conduct decompressed air from the decompression turbine **312** to the recompression turbine **318**. A drive motor **326**, or an equivalent mechanism, drives both the decompression turbine **312** and the recompression turbine **318**. The drive motor **326** is controlled by a drive motor controller **328**, and controlling the drive motor speed controls the volume of air passing through various stations of the apparatus **310** during any specific period.

[0109] The diametric dimensions of the portion within the decompression turbine **312** proximate the atmospheric air inlet **314** is smaller than is the diametric dimensions of the portion within the decompression turbine **312** proximate the decompressed air outlet **316**. The diametric differences create a pressure and temperature decrease due to the differences in respective air pressures and temperatures within the different portions. Both pressure and temperature are lowered in the turbine portion that is larger. This causes vaporous water present in the air to change state and condense. It is to be understood that chambers (not shown) having similar dimension ratios can be disposed external to the actual turbines to supplement the previously described, turbine portions.

[0110] As indicated by FIG. **23**, a condensing filter **330** resides within a condenser filter housing **350** that is connected within the first air conduit **324**. The condenser filter **330** facilitates the condensing and coalescing of water vapor in the decompressed air, and the condenser filter housing **350** directs the condensed and coalesced water into a water conduit **334** that is connected to a water reservoir **332**, It is to be understood that the illustrated disposition of the condenser filter **330** and the condenser filter housing **350** are intended to be representative of a number of possible configurations that could accomplish the functions of filtering water from the decompressed air and/or channeling the water to the reservoir **332**. It is also to be understood that, in the interest of simplicity, the insulated structure **356** is shown schematically surrounding a space including a combination of apparatus components. As will be appreciated by those skilled in the art to which this invention pertains, insulation could alternatively be effectively disposed about individual components of the apparatus **310** that require insulation.

[0111] In the interest of simplicity, a symbolic representation of an air pretreatment system **51** shown in FIG. **7**, including an air ingestion valve **52**, an air temperature modifying device **53** and an air pre-humidifying device **55**, have not been included in FIG. **23**. Reference to the air pretreatment system **51** can be found in FIG. **7**.

[0112] The water reservoir **332** has a diffuser **348** to distribute entering water, a liquid level control valve **336** to release water **338** accumulated within the water reservoir **332**, a vapor vent **340** to release vapors, and a de-entrainment mesh pad **342** to retain water still entrained within the vapor being released. Water released through the liquid level control valve **336** can be captured and stored in a water reservoir (not shown) outside the insulated structure **356**. As shown by phantom lines, an additional water vapor reservoir **344** can be incorporated to act as an alternate water reservoir when water from the water reservoir **332** is being harvested. A directional valve **346** directs water to one or the other water reservoir.

[0113] The diametric dimensions of the portion within the recompression turbine **318** proximate the decompressed air inlet **320** larger than is the diametric dimensions of the portion within the recompression turbine **318** proximate the compressed air outlet **322**. The diametric differences create a pressure and temperature increase due to the differences in respective air pressures and temperatures within the different portions. Both pressure and temperature are increased in the turbine portion that is smaller. It is to be understood that chambers (not shown) having similar dimension ratios can be disposed external to the actual turbines to supplement the previously described, turbine portions.

[0114] Warm, dry, recompressed air exits the compressed air outlet **322** of the decompression turbine **318** and is carried by a second air conduit **352** to a thermal energy harvesting device **354**. Such a device can be any of a number of energy harvesting devices such as a thermal engine, a thermoelectric generator for directly producing electric energy proportional to the difference between the temperature of the harvested air and the temperature of the atmospheric air, a thermal energy reservoir containing a working material that changes state in response to thermal energy transferred to the working material, such as paraffin wax, from the harvested air.

[0115] While the best mode for carrying out the invention has been illustrated and described in detail, it is not intended that all possible forms of the invention have been illustrated and described. Rather, the words used in the specification are words of description and not of limitation; and it is to be understood by those familiar with the art to which this invention pertains that various changes may be made without departing from the spirit and scope of the invention as defined by the following claims.

What is claimed is:

1. A method of operating a mechanically and thermodynamically closed system for harvesting latent energy and water from atmospheric air, one of a desired number of cycles of the method comprising the steps of:

(a) ingesting a mechanically controlled volume of atmospheric air per unit time into a thermally insulated decompression mechanism;

(b) adiabatically decompressing the controlled volume of atmospheric air to decrease the pressure and temperature of the air to a point where (1) the pressure equals the saturation vapor pressure of the water vapor of the decompressing atmospheric air, (2) the water vapor commences to change state to a nonvaporous water, (3) the adiabatic decompression continues to decrease pressure, temperature and saturation vapor pressure, producing a continuation of water vapor phase change to nonvaporous water, and (4) the water vapor changes of phase continues to release latent energy into the decompressing air;

(c) extracting from the thermally insulated decompression mechanism nonvaporous water that results from the state change and retaining it in a separate, insulated reservoir at the same pressure as that of the decom-

pressed air within the thermally insulated decompression mechanism to render the process of latent energy release nearly irreversible;

(d) adiabatically recompressing, in a thermally insulated recompression mechanism, the previously decompressed air, which now has a much higher temperature, and a greater amount of thermal energy, than had the ingested air before being decompressed; and

(e) extracting the recompressed air from the thermally insulated recompression mechanism, conducting the recompressed air to an external thermal energy harvesting device, and harvesting the greater amount of thermal energy from the recompressed air.

2. The method as defined by claim **1**, wherein recompressing the decompressed air during step (d) is terminated when amounts of the pressure and of the volume of the recompressing air are at a state represented at a point along an unsaturated adiabat between a point where the amount of pressure of the recompressing air reaches that of the initial controlled volume of air and a point where the amount of volume of the recompressing air reaches that of the initial controlled volume of air.

3. The method defined by claim **1**, wherein:

in step (b), adiabatically decompressing the controlled volume of atmospheric air further comprises introducing turbulence into the controlled volume of atmospheric air and directing the controlled volume of atmospheric air through a decompression turbine; and

in step (d), adiabatically recompressing the previously decompressed air further comprises directing the decompressed air through a recompression turbine.

4. A latent energy and water harvesting apparatus, comprising:

a thermally insulated decompression-recompression mechanism comprising a decompression element and a recompression element, for respectively decreasing the pressure and temperature of atmospheric air within the decompression element and increasing the pressure and temperature of the decompressed air within the recompression element of the thermally insulated decompression-recompression mechanism;

a thermally insulated water reservoir separated from, but in communication with, the decompression element of the thermally insulated decompression-recompression mechanism, for at least temporarily retaining, at the same pressure as the pressure within the decompressing element, nonvaporous water resulting from a state change of water vapor during a decompression of the air within the decompression element; and

an energy harvesting device for harvesting, from recompressed air, thermal energy resulting from the change of state of the water.

5. The apparatus as defined by claim **4**, wherein the decompressing-recompressing mechanism comprises:

a decompression turbine having an air inlet and an air outlet and configured to draw in air at an atmospheric pressure and temperature, decompressing and lowering the temperature of the atmospheric air in the process and causing water vapor present in the atmospheric air to condense;

a reservoir for collecting and isolating the condensed water from the decompressed air;

a recompression turbine having an air inlet and an air outlet and configured to draw in the decompressed air from the decompression turbine, compressing and raising the temperature of the decompressed air in the process;

a conduit extending between the air outlet of the decompression turbine to the air inlet of the recompression turbine to conduct decompressed air from the decompression turbine to the recompression turbine;

a controlled driving device to rotate the decompression and recompression turbines; and

an energy harvesting device for harvesting, from the recompressed air, thermal energy remaining in the recompressed air resulting from the change of state of water from vaporous to nonvaporous.

6. The apparatus as defined by claim **4**, wherein the decompression-recompression mechanism comprises:

a cylinder having a closed end;

a piston slidably disposed within the cylinder, the closed end of the cylinder and the piston defining therebetween a chamber containing air the volume of which is controlled by the position of the piston;

a piston rod connected to the piston; and

a driver for translating the piston rod and piston away from and toward the closed end of the cylinder to decompress and recompress, respectively, air within the chamber.

7. The apparatus as defined by claim **4**, wherein the decompression-recompression mechanism comprises:

a cylinder having a closed end;

a flexible diaphragm disposed at the opposite end from the closed end, the diaphragm and the closed end of the cylinder defining therebetween a chamber containing air, the volume of which is controlled by the position of the diaphragm;

a diaphragm rod connected to the diaphragm; and

a driver for translating the diaphragm rod and diaphragm away from and toward the closed end of the chamber to decompress and recompress, respectively, air within the chamber.

8. The apparatus as defined by claim **4**, wherein the decompression-recompression mechanism comprises:

a cylinder having a closed end;

a cylindrical bellows slidably disposed within the cylinder and having a first end and a second end, the first end being sealingly secured to the closed end of the cylinder;

a pressure plate sealingly secured to the second end of the cylindrical bellows;

a pressure plate rod connected to the second end of the cylindrical bellows; and

a driver for translating the bellows rod and the pressure plate away from and toward the closed end of the cylinder to decompress and recompress, respectively, air within the cylindrical bellows.

9. The apparatus as defined by claim **6**, further comprising:

an external air ingestion device for admitting a controlled volume of atmospheric air containing water vapor into the at least one chamber;

at least one thermally insulated nonvaporous water extracting valve for extracting, from the at least one chamber, the nonvaporous water resulting from the state change of water vapor during decompression;

a nonvaporous water harvesting valve for harvesting nonvaporous water retained in the internal water reservoir;

an external water reservoir to receive and retain nonvaporous water harvested from the internal water reservoir;

at least one thermally insulated air harvesting valve for terminating recompression in, and harvesting recompressed air from, the at least one chamber; and

an apparatus controller for controlling the operation of the air ingestion device, the driver, the at least one nonvaporous water extracting valve, the nonvaporous water harvesting valve, and the at least one air harvesting valve.

10. The apparatus as defined by claim **9**, further comprising a pressure sensor for sending signals representative of pressure within the at least one chamber to the apparatus controller.

11. The apparatus of claim **9**, wherein the external water reservoir is disposed at an elevation lower than that of the internal water reservoir, and wherein the apparatus further comprises a fluid-turbine-driven electric generator disposed proximate the external water reservoir to harvest energy associated with water flowing, under the influence of gravity, from the internal water reservoir to the external water reservoir.

12. The apparatus of claim **9**, wherein the external air ingestion device is an external air ingestion valve, and wherein the apparatus further comprises temperature modifying devices including an air prewarming device, a precooling device and an air prehumidifying device, the external air ingestion valve having the capability of directing air being ingested along one of four routes to the at least one chamber, a first route being directly into the at least one chamber, a second route being through the prewarming or precooling device and then into the at least one chamber, a third route being through the prehumidifying device and then into the at least one chamber, and a fourth route being through both the temperature modifying devices and the prehumidifying device and then into the at least one chamber.

13. The apparatus of claim **6**, wherein the piston rod is hollow and the apparatus further comprises:

a water droplet removal filter comprising a filter holder supporting at least one filter element, the filter being slidably disposed within the at least one chamber to allow relative motion between the filter and air within the at least one chamber to promote the collection and coalescence of water droplets within the at least one chamber upon the filter element; and

a water droplet removal device rod having first and second ends, the first end being connected to the driver and the second end being connected to the filter holder, the water droplet removal device rod coaxially and slidably extending through the hollow piston rod, the driver axially moving the water droplet removal device rod, and thus axially moving the filter holder within the at least one chamber, the motion of the filter holder being independent of the motion of the piston.

14. The apparatus of claim **6**, wherein the piston rod is hollow and the apparatus further comprises:

a water droplet removal fan comprising a fan holder centrally and rotatably supporting a hub about a rotational axis, the fan being slidably disposed within the at least one chamber along the rotational axis;

at least one fan blade radially extending from the hub, the hub being rotatable to revolve the at least one fan blade about the rotational axis of the hub to collect and coalesce water droplets and to create air turbulence that promotes water droplet motion and attending droplet collisions with each other and with the interior surface of the at least one chamber; and

a water droplet removal device rod having first and second ends, the first end being connected to the driver and the second end being connected to the hub, the water droplet removal device rod coaxially, slidably and rotatably extending through the hollow piston rod, the driver axially moving and rotating the water droplet removal device rod, and thus axially moving the fan holder within the at least one chamber and rotating the hub, the motion of the fan holder and of the hub being independent of the motion of the piston.

15. The apparatus of claim **14**, wherein the at least one fan blade comprises a radially extending series of blade segments, each blade segment having a pitch that abruptly differs from the pitch of neighboring blade segments, for creating forceful air turbulence within the at least one chamber.

16. The apparatus of claim **5**, wherein the energy harvesting device comprises a wind turbine driving an electric generator.

17. The apparatus of claim **5**, wherein the energy harvesting device comprises a thermal engine.

18. The apparatus of claim **5**, wherein the energy harvesting device comprises a thermoelectric generator for directly producing electric energy proportional to the difference between the temperature of the harvested air and the temperature of the atmospheric air.

19. The apparatus of claim **8**, wherein the energy harvesting device comprises a thermal energy reservoir containing a working material that changes state in response to thermal energy transferred to the working material from the harvested air.

20. A latent energy and water harvesting apparatus, comprising:

a first, thermally insulated chamber containing a first controllable volume and having a longitudinal axis;

a second, thermally insulated chamber containing a second controlled volume and having a longitudinal axis collinearly disposed with respect to the longitudinal axis of the first chamber;

an external air ingestion valve for ingesting atmospheric air containing water vapor for subsequent admission to the first and second chambers;

a first, thermally insulated, internal air ingestion valve for admitting a controllable volume of ingested atmospheric air into the first chamber;

a decompression-recompression mechanism for increasing the controlled volume within the first chamber to lower the pressure and temperature of the humid air within the first chamber so that included water vapor reaches a point of saturation, commences to change state, and commences to release latent heat, the decompression-recompression mechanism then continuing to lower the pressure and temperature and saturation mixing ratio thereby continuing the change of state of water vapor to nonvaporous water, the decompression-recompression mechanism subsequently decreasing the controlled volume within the first chamber to raise the pressure and temperature of the recompressing air within the first chamber;

a first, thermally insulated, nonvaporous water extracting valve for extracting, from the first chamber, nonvaporous water resulting from the state change of water within the first chamber during decompression to render the process of latent energy release nearly irreversible;

a first thermally insulated water reservoir for temporarily retaining, within the apparatus and at the same pressure as that of the decompressed air in the first chamber, the nonvaporous water extracted from the first chamber;

a first, thermally insulated, air harvesting valve for terminating recompression and harvesting recompressed air from the first chamber;

a second, thermally insulated, internal air ingestion valve for admitting a controllable volume of ingested atmospheric air into the second chamber, the decompression-recompression mechanism increasing the controlled volume within the second chamber to lower the pressure and temperature of the humid air within the second chamber so that included water vapor reaches a point of saturation, commences to change state, and commences to release latent heat, the decompression-recompression mechanism then continuing to lower the pressure and temperature and saturation mixing ratio, thereby continuing the change of state of water vapor to nonvaporous water, the decompression-recompression mechanism subsequently decreasing the controlled volume within the second chamber to raise the pressure and temperature of the recompressing air within the second chamber while the controllable volume within the first chamber is being increased to lower the pressure and temperature of the humid air within the second chamber so that included water vapor reaches a point of saturation, changes state, and releases latent heat;

a second, thermally insulated, nonvaporous water extracting valve for extracting, from the second chamber, nonvaporous water resulting from the state change of water within the second chamber during decompression to render the process of latent energy release nearly irreversible;

a second, thermally insulated water reservoir for temporarily retaining, within the apparatus and at the same pressure as that of the decompressed air in the second chamber, the nonvaporous water extracted from the second chamber;

a second, thermally insulated, air harvesting valve for terminating recompression and harvesting recompressed air from the second chamber;

an energy harvesting device for harvesting thermal energy from air harvested from the first and second chambers;

a first, thermally insulated, nonvaporous water harvesting valve for harvesting water retained in the first water reservoir;

a second, thermally insulated, nonvaporous water harvesting valve for harvesting water retained in the second water reservoir; and

an apparatus controller for controlling the operations of the air ingestion device, the first and second internal air ingestion valves, the decompression-recompression mechanism, the first and second nonvaporous water extracting valves, the first and second air harvesting valves, and the first and second water harvesting valves so that the decompression of the first chamber coincides with the recompression of the second chamber and the recompression of the first chamber coincides with the decompression of the second chamber.

21. The apparatus of claim **20**, wherein the first and second chambers comprise a hollow cylinder, closed at each end, within which is slidably disposed a piston that divides the cylinder into the first and second chambers, a controllable volume being defined within each chamber between each closed end and the piston, and wherein the decompression-recompression mechanism comprises the first and second chambers, the piston, a driver and a piston rod connected between the piston and the driver for translating the piston in alternately opposite directions to decompress air within the first chamber while compressing air within the second chamber and then recompressing air within the first chamber while decompressing air within the second chamber.

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