

ADSORPTION CHILLER

Field of Invention

- 5 The present invention relates to an adsorption chiller and to a system comprising the adsorption chiller.

Background

- 10 Adsorption chillers are based on the use of a heat source to provide the energy to drive the cooling process. They are based on the evaporation of a liquid refrigerant (such as water) at low partial pressure, which provides evaporative cooling. This cooling can be used to cool an external fluid source, providing an output of chilled fluid.

- 15 After the refrigerant has evaporated, it is adsorbed onto an adsorbent (e.g. a desiccant). The refrigerant can be regenerated by applying a heat source to the adsorbent, causing the refrigerant to evaporate, after which it can be collected before the cycle is restarted.

- Adsorption chillers are described in US Patent 8,302,425 and Singapore patent 170810.
- 20 US8302425 describes an adsorption chiller having a spraying chamber for direct evaporating/condensing installed outside of vacuum housing chamber. A direct spraying chamber with one adsorption bed is used for both evaporating and condensing cycles. During the adsorption cycle, the spraying chamber works as an evaporator, while in the regeneration cycle it works as a condenser. This means that the chiller is only able to
- 25 perform either evaporation or regeneration at any one time, and so chilled water can only be produced about 50% of the time (with the other time spent on a regeneration cycle).

- SG170810 describes an adsorption chiller having a single evaporator and four adsorption beds. This means that the chiller is only able to produce a single temperature cold water at
- 30 any one time.

- There is a need for an adsorption chiller which is able to operate almost continuously, producing two chilled water outputs having different temperatures. This would be useful in a number of situations, for example continuously (or almost continuously) producing chilled
- 35 water for air conditioning and chilled drinking water at the same time in an office building.

Summary of Invention

The present invention provides an adsorption chiller which is able to operate almost continuously. The adsorption chiller comprises four adsorption beds, which means that two
5 adsorption beds can be operated in an adsorption cycle and the other two in a regeneration cycle. This means that, with the exception of a brief time period when the cycles are switched, the chiller can operate continuously. In addition, the use of two evaporator heat exchangers allows the present invention to provide two cold water outlets having different temperatures.

10

Thus, the present invention provides the following.

1. An adsorption chiller comprising:
 - a first and second liquid container;
 - 15 a first to fourth absorber bed device, where each absorber bed device comprises a vacuum chamber comprising an evaporative chamber, a condensing chamber and an adsorption bed chamber, where the adsorption bed chamber is situated between the evaporative and condensing chambers and is fluidly connected to said chambers;
 - the adsorption bed chamber comprises a desiccant and one or more means
 - 20 or apparatus to heat or cool the adsorption bed chamber;
 - the evaporative chamber comprises a nozzle and a liquid receiving portion, where both the nozzle and liquid receiving portion are in selective fluid connection with the first liquid chamber;
 - the condensing chamber comprises a nozzle and a liquid receiving portion,
 - 25 where both the nozzle and liquid receiving portion are in selective fluid connection with the second liquid chamber;
 - a first heat exchanger in selective fluid connection with the first liquid container and any one of the first to fourth absorber bed devices when so connected;
 - a second heat exchanger in selective fluid connection with the first liquid container
 - 30 and any one of the first to fourth absorber bed devices when so connected, provided that it is not connected to the absorber bed device that the first heat exchanger is coupled to; and
 - a third heat exchanger in selective fluid connection with the second liquid container and to any one or two of the first to fourth absorber bed devices when so connected, provided that it is not connected to the absorber bed devices that the first and second heat
 - 35 exchangers are coupled to.

2. The adsorption chilled according to Clause 1, which is configurable into the following modes (A), (B), and (C):

(A) a first adsorption/regeneration cycle configuration, where:

5 the evaporator chamber of the first adsorber bed device is in fluid connection with the first liquid container and the first heat exchanger;

the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;

10 the evaporator chamber of the third adsorber bed device is in fluid connection with the first liquid container and the second heat exchanger;

the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, wherein the configurations of the first and second absorber beds and third and fourth adsorber beds are reversible to provide a second adsorption/regeneration cycle configuration;

15

(B) a desalination configuration, where:

the evaporator chamber of the first adsorber bed device is in fluid connection with the first liquid container and the first or second heat exchanger and the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, and/or

20

the evaporator chamber of the third adsorber bed device is in fluid connection with the first liquid container and the first or second heat exchanger, and the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;

25

(C) a desalination configuration, where:

the evaporator chamber of the first adsorber bed device is in fluid connection with the first liquid container and the third heat exchanger, and the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, or

30

the evaporator chamber of the third adsorber bed device is in fluid connection with the first liquid container and the third heat exchanger, and the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger.

35

3. The adsorption chiller according to Clause 1, wherein the first liquid container comprises a first receiving tank and a second receiving tank, wherein:

the first receiving tank is in fluid connection with the first heat exchanger, and is in selective fluid connection with the nozzle and liquid receiving portion of the evaporative chambers in the third and fourth adsorber bed devices; and

the second receiving tank is in fluid connection with the second heat exchanger, and is in selective fluid connection with the nozzle and liquid receiving portion of the evaporative chambers in the first and second adsorber bed devices.

4. The adsorption chilled according to Clause 3, which is configurable into the following modes (A'), (B'), and (C'):

(A') a first adsorption/regeneration cycle configuration, where:

the evaporator chamber of the first adsorber bed device is in fluid connection with the first receiving tank and the first heat exchanger;

the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;

the evaporator chamber of the third adsorber bed device is in fluid connection with the second receiving tank and the second heat exchanger;

the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, wherein the configurations of the first and second absorber beds and third and fourth adsorber beds are reversible to provide a second adsorption/regeneration cycle configuration;

(B') a desalination configuration, where:

the evaporator chamber of the first adsorber bed device is in fluid connection with the first or second receiving tank and the first or second heat exchanger, and the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, and/or

the evaporator chamber of the third adsorber bed device is in fluid connection with the first or second receiving tank and the first or second heat exchanger, and the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;

(C') a desalination configuration, where:

the evaporator chamber of the first adsorber bed device is in fluid connection with the first or second receiving tank and the third heat exchanger, and the condensing

chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, or
the evaporator chamber of the third adsorber bed device is in fluid connection with the first or second receiving tank and the third heat exchanger, and the condensing chamber of
5 the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger.

5. The adsorption chiller according to Clause 1 which is configurable into mode (A) or (A'), as described in Clauses 2 and 4, respectively.
- 10 6. The adsorption chiller according to Clause 1 which is configurable into mode (B) or (B'), as described in Clauses 2 and 4, respectively.
7. The adsorption chiller according to Clause 1 which is configurable into mode (C) or (C'), as described in Clauses 2 and 4, respectively.
- 15 8. The adsorption chiller according to Clause 1 which is configurable into mode (D) or (D'), as described in Clauses 2 and 4, respectively.
- 20 9. The adsorption chiller according to any one of the preceding clauses, wherein the selective fluid connections are formed by one or more valves.
10. The adsorption chiller according to any one of the preceding clauses, wherein the means or apparatus to heat or cool the adsorption bed comprises one or more pipes suitable
25 for transporting variable temperature fluid.
11. The adsorption chiller according to any one of the preceding clauses, wherein the adsorption bed chamber comprises a plate fin heat exchanger, and at least a portion of the desiccant is coated onto the fins of the plate fin heat exchanger.
- 30 12. The adsorption chiller according to Clause 11, wherein the plate fin heat exchanger is a brazed plate fin heat exchanger, optionally wherein the brazed plate fins are made of aluminium or stainless steel.
- 35 13. The adsorption chiller according Clause 11 or 12, wherein the desiccant is selected from one or more of the group consisting of CaCl_2 impregnated silica-gel and a composite desiccant comprising a hygroscopic salt (such as lithium chloride) dispersed within the

polymeric matrix of a superabsorbent polymer (such as polyvinyl alcohol, sodium polyacrylate and potassium polyacrylate), optionally wherein the desiccant is coated to a thickness of from about 100 to about 300 microns, such as about 200 microns.

5 14. The adsorption chiller according to any one of the preceding clauses, wherein the first, second and third heat exchangers are shell and tube heat exchangers or plate heat exchangers.

10 15. The adsorption chiller according to any one of the preceding clauses, wherein the first liquid container, or where present at least one of the first receiving tank and second receiving tank, comprises an inlet for providing water to the system, and the second liquid container comprises an outlet for supplying distilled water.

15 16. The adsorption chiller according to any one of the preceding clauses, further comprising a power supply, optionally wherein the power supply comprises a photovoltaic thermal hybrid solar collector.

20 17. The adsorption chiller according to any one of the preceding clauses, wherein the chiller further comprises an overflow connection from the second liquid container to the first liquid container, where the overflow connection is configured to allow the flow of fluid from the second liquid container to the first liquid container, but which does not allow fluid to flow from the first liquid container to the second liquid container, optionally wherein the overflow connection comprises a U-bend connector.

25 18. The adsorption chiller according to any one of the preceding clauses, wherein the adsorption chiller further comprises a cooling tower, which cooling tower comprises a first and optionally a second water source, where the first water source is configured to selectively supply water to the third heat exchanger and, when present, the second water source is configured to selectively supply water to one or two of the first to fourth adsorber
30 bed devices.

19. The adsorption chiller according to any one of the preceding clauses, wherein the first heat exchanger, when used in operation, is configured to reduce the temperature of the first heat exchanging water and, the second heat exchanger, when used in operation, is
35 configured to reduce the temperature of the second heat exchanging water.

20. The adsorption chiller according to Clause 19, wherein the first heat exchanger is configured in operation to cool the first heat exchanging water to a temperature of from 7-12°C, such as 9-10°C and, when the second heat exchanging water is present, the second heat exchanger, when used in operation, is configured to cool the second heat exchanging
5 water to a temperature of from 15-18°C, such as 16-17°C.

21. The adsorption chiller according to any one of the preceding clauses, further comprising a dirty water source configured to supply dirty water to the first liquid container.

10 **Brief Description of the Figures**

Figure 1 shows a four-bed 2-evaporator adsorption chiller.

Figure 2 shows an example layout of a two 2-bed adsorption chiller.
15

Figure 3 shows a plate fin heat exchanger of the type that may be coated in desiccant and used in an adsorption bed.

Figures 4a and 4b show a configuration of a two 2-bed adsorption chiller of the present
20 invention, which is configured for adsorption of dirty water and regeneration of distilled water, as well as producing two temperatures of chilled water.

Figures 5a and 5b show an alternative, complimentary, configuration to Figures 4a and 4b in which each adsorber bed performs the opposite function to in Figures 4a and 4b.
25

Figure 6 shows a desalination configuration of two of the beds of the adsorption chiller.

Figure 7 shows an alternative desalination configuration two of the beds of the adsorption
30 chiller.

Detailed Description

The present invention provides an adsorption chiller comprising:
a first 405 and second 406 liquid container;

a first to fourth absorber bed device 401, 402, 403, 404 where each absorber bed device comprises a vacuum chamber 401a, 402a, 403a, 404a comprising an evaporative chamber 401b, 402b, 403b, 404b, a condensing chamber 401c, 402c, 403c, 404c and an adsorption bed chamber 401d, 402d, 403d, 404d, where the
5 adsorption bed chamber is situated between the evaporative and condensing chambers and is fluidly connected to said chambers;

the adsorption bed chamber comprises a desiccant 401e, 402e, 403d, 404e and one or more means or apparatus to heat or cool the adsorption bed chamber 401f, 402f, 403f, 404f;

10 the evaporative chamber comprises a nozzle 401g, 402g, 403g, 404g and a liquid receiving portion 401h, 402h, 403h, 404h, where both the nozzle and liquid receiving portion are in selective fluid connection with the first liquid chamber;

the condensing chamber comprises a nozzle 401i, 402i, 403i, 404i and a
15 liquid receiving portion 401j, 402j, 403j, 404j, where both the nozzle and liquid receiving portion are in selective fluid connection with the second liquid chamber;

a first heat exchanger 407 in selective fluid connection with the first liquid container 405 and any one of the first to fourth absorber bed devices 401, 402, 403, 404 when so
20 connected;

a second heat exchanger 408 in selective fluid connection with the first liquid container 405 and any one of the first to fourth absorber bed devices 401, 402, 403, 404 when so connected, provided that it is not connected to the absorber bed device that the first heat exchanger is coupled to; and

25 a third heat exchanger 409 in selective fluid connection with the second liquid container 406 and to any one or two of the first to fourth absorber bed devices 401, 402, 403, 404 when so connected, provided that it is not connected to the absorber bed devices that the first and second heat exchangers are coupled to.

30 As used herein, the word "comprising" may be interpreted as requiring the features mentioned, but not limiting the presence of other features. Alternatively, the word "comprising" may also relate to the situation where only the components/features listed are intended to be present (e.g. the word "comprising" may be replaced by the phrases "consists of" or "consists essentially of"). It is explicitly contemplated that both the broader and
35 narrower interpretations can be applied to all aspects and embodiments of the present invention. In other words, the word "comprising" and synonyms thereof may be replaced by

the phrase “consisting of” or the phrase “consists essentially of” or synonyms thereof and *vice versa*.

5 The chillers of the present invention comprise a first liquid container 405 and a second liquid container 406. The first liquid container may comprise a first liquid tank 425 and a second liquid tank 426, which may be fluidly isolated from each other (i.e. the first receiving tank is connected to one adsorber bed and heat exchanger, and the second receiving tank is connected to a different adsorber bed and a different heat exchanger). Each liquid container/receiving tank is in selective fluid connection with a number of components as
10 described hereinbelow.

The adsorber bed devices 401, 402, 403, 404 in the chiller of the present invention comprise a vacuum chamber 401a, 402a, 403a, 404a housing the evaporative chamber 401b, 402b, 403b, 404b, condensing chamber 401c, 402c, 403c, 404c and adsorption bed chamber 401d,
15 402d, 403d, 404d. As noted above, the adsorption bed chamber is positioned between the evaporative chamber and condensing chamber. This arrangement minimises the possibility of any contaminants present in the liquid (e.g. water) supplied to the evaporative chamber passing to the condensing chamber. The generation of a vacuum promotes the evaporation of liquid (e.g. water) to form a gas (e.g. water vapour), for example when a liquid (e.g. water)
20 is sprayed from a nozzle to be adsorbed by the desiccant, and when the wet desiccant is heated. The pressure in the vacuum chambers will correspond to the saturation vapour pressure of the liquid (e.g. water) at the temperature of the vacuum chamber and the applied vacuum.

25 While the first 405 and second 406 liquid containers, as well as the first 407, second 408 and third 409 heat exchangers are located outside of the vacuum chamber, they are connected to the components within the vacuum chamber, and to each other, by air-tight connections which maintain the vacuum within the liquid containers and heat exchangers.

30 Typically, the fluid/liquid which is transported through the components of the chiller is water, but any other suitable liquid could be used instead, such as ethanol. Although embodiments of the invention are described below in the context of a chiller that uses water as the fluid, this is not to be construed as restricting the chillers of the invention to chillers that use water.

35 When the liquid is water, it may be clean, potable water (e.g. distilled water, deionised water, or otherwise treated water such as municipal drinking water), or the water may be dirty water. As used herein, “dirty water” means water which is not potable. Sources of dirty water

include sea water, brackish water, and water from a river, lake or other body of water. Dirty water may be converted into distilled water by the chiller of the invention. As used herein, "distilled water" means water which is obtained from the condensation of water vapour.

5 The evaporative chamber 401b, 402b, 403b, 404b is utilised when the desiccant 401e, 402e, 403e, 404e in the absorber bed device is dry. The evaporative chamber comprises a nozzle 401g, 402g, 403g, 404g and a liquid receiving portion 401h 402h, 403h, 404h. When water enters the evaporative chamber (which is at reduced pressure) through the nozzle of the evaporative chamber, a portion of the liquid is turned into water vapour, which in turn results
10 in the remaining liquid being cooled. As the water vapour is in gaseous form, it may travel from the evaporative chamber into the adsorption bed chamber 401d, 402d, 403d, 404d (for example by diffusion), where it is adsorbed by the desiccant. To assist in this adsorption, a cooling means or apparatus 401f, 402f, 403f 404f is applied to the adsorber bed. In contrast, the cooled liquid water left in the evaporative chamber falls to the bottom of said chamber,
15 which is described hereinabove as the liquid receiving portion of the evaporative chamber. When a liquid (e.g. water) is supplied to the evaporative chamber, the receiving portion of the evaporative chamber is in fluid communication with the first liquid container 405, thereby allowing the collecting liquid to be siphoned off from the evaporative chamber at a speed that ensures that the evaporative chamber does not overflow with liquid. Typically, this is
20 achieved by gravity, with the receiving portion of the evaporative chamber at a higher location than the first liquid container, such that liquid can flow into the first liquid container. This fluid connection may be governed by a valve 417 that is only opened when the evaporative chamber is supplied with water. Typically, the connection between the liquid receiving portion and the first liquid chamber is such that any suspended particles in the dirty
25 water pass back into the first liquid chamber and do not accumulate in the evaporative chamber.

The condensing chamber 401c, 402c, 403c, 404c is utilised when the desiccant 401e, 402e, 403e, 404e in the absorber bed device is saturated, or almost saturated, with liquid (i.e.
30 water). When this occurs, heat is applied to the adsorber bed from the heating means 401f, 402f, 403f, 404f to vaporise the water trapped within the desiccant and clean, chilled water is supplied to the nozzle 401i, 402i, 403i, 404j of the condensing chamber. The clean water is sprayed into the condensing chamber. Water vapour produced by evaporation of water from the desiccant is able to enter the condensing chamber, which is a vapour rich environment.
35 This means that there is minimal evaporation of the sprayed water. The water vapour entering the condensing chamber is condensed by the reduced temperature of the condensing chamber, relative to that in the other chambers of the adsorber bed apparatus,

and condenses on the chilled water spray. The sprayed water is in the form of fine water droplets having a large surface area. This results in a high degree of contact between the sprayed water and water vapour, resulting in high heat transfer and condensation from the vapour to the water spray. This direct contact between the water vapour and cold spray
5 enhances the transfer of heat and increases the rate of condensation. The mixture of chilled water spray and condensate collects in the liquid receiving portion 401j, 402j, 403j, 404j of the condensing chamber. When a liquid (e.g. water) is supplied to the condensing chamber, the receiving portion of the condensing chamber is in fluid communication with the second liquid container 406, thereby allowing the collecting liquid to be siphoned off from the
10 condensing chamber at a speed that ensures that the condensing chamber does not overflow with liquid. As for the evaporative chamber, this is typically achieved by gravitational flow of liquid from the condensing chamber to the second liquid container. This fluid connection may be governed by a valve 417 that is only opened when the condensing chamber is supplied with water.

15 Each adsorption bed chamber described herein comprises a desiccant 401e, 402e, 403e, 404e and one or more means for selectively heating or cooling the desiccant 401f, 402f, 403f, 404f. The desiccant is provided in any suitable form within the adsorption bed chamber. The desiccant may be in the form of a conventional desiccant bed, or more typically may be
20 coated onto a surface as a layer, allowing for a higher surface-area to volume ratio. Typically, the coating will have a thickness of from about 100 to about 300 microns, such as about 200 microns.

As used herein, a "desiccant" is a composition which is able to absorb liquid vapour (e.g. water) from the surrounding air, thereby reducing the level of vapour in the surrounding air.
25 After absorbing water, the desiccant will be wet and can be dried by heating. A reference to a desiccant herein includes a reference to the dry (e.g. anhydrous) desiccant, and a reference to the wet (e.g. saturated) desiccant, as well as to a partially wet desiccant. Typically, desiccants used in the present invention will be solid desiccants, as they are
30 easier to coat onto surfaces having a high surface area. The desiccant will also typically be a desiccant that can be dried at temperatures of 70°C or less, as this allows for a more energy efficient chiller that can run on waste thermal energy, or solar power (such as a photovoltaic cell and/or a photovoltaic thermal hybrid solar collector). Desiccant compositions that can be dried at this temperature and are therefore suitable for use in the present invention include
35 CaCl_2 impregnated silica-gel, and superabsorbent polymers such as PVA or polyacrylate with hygroscopic salts dispersed throughout the polymer matrix. For example, crosslinked PVA or crosslinked sodium polyacrylate with LiCl dispersed throughout the polymer matrix.

Such desiccants can be prepared by dissolving appropriate amounts (e.g. 30-50 wt%) of lithium chloride in water, then adding an appropriate amount (e.g. 50-70 wt%) of superabsorbent polymer followed by stirring until a homogenous gel solution is formed. Preparation of such desiccants is described in PCT application no. PCT/SG2019/050449,
5 which is incorporated herein by reference.

The means or apparatus for heating or cooling the desiccant 401f, 402f, 403f, 404f can be any appropriate means. For example, pipes configured to supply a hot or cold fluid (e.g. air or, typically, water) to the vicinity of the desiccant, but without allowing the fluid to contact the
10 desiccant, may be used. When such a pipe is used, the heating/cooling fluid will be contained within the pipe, and the desiccant may be provided on the outside of the pipe, such that heat energy is transferred through the wall of the pipe. This configuration is that of a basic heat exchanger. As will be appreciated, the means or apparatus for heating or cooling the desiccant may extend outside of the vacuum chamber 401a, 402a, 403a, 404a,
15 such that only a part of the means or apparatus is housed within the vacuum chamber and the adsorption bed chamber 401d, 402d, 403d, 404d. Thus, when the means or apparatus is a pipe which can carry hot or cold fluid, part of the pipe will be inside the vacuum chamber, and part of the pipe will be outside the vacuum chamber and connected to a hot or cold fluid source.

20 Typically, the adsorption bed chamber 401d, 402d, 403d, 404d comprises a heat exchanger onto which the desiccant 401e, 402e, 403e, 404e is coated. For example, a plate fin heat exchanger (such as a brazed plate fin heat exchanger) where the desiccant is coated onto the fins of the heat exchanger, may be used. The heat exchanging elements of the heat exchanger (e.g. the fins or brazed fins) may be made of a metal, such as aluminium, copper or stainless steel, for example aluminium or stainless steel. Such heat exchangers are well known to a person skilled in the art who would readily be able to include an appropriate heat exchanger having a desiccant coating in the adsorption bed chamber. When a heat exchanger is used, the means for heating or cooling the desiccant 401f, 402f, 403f, 404f can
25 be a fluid such as water which is pumped through the portion of the heat exchanger which does not contain the desiccant. When a part of a heat exchanger is coated with desiccant, it is typically coated with desiccant to a thickness of from about 100 to about 300 microns, such as about 200 microns.

35 When the desiccant 401e, 402e, 403e, 404e is dry, and the evaporative chamber 401b, 402b, 403b, 404b is in use (forming water vapour), the desiccant will adsorb water vapour which passes from the evaporative chamber to the adsorption bed chamber. During

- adsorption, the desiccant is cooled so that the heat produced by adsorption does not lead to evaporation. Alternatively, when the desiccant is wet and the condensation chamber 401c, 402c, 403c, 404c is in use, the desiccant is heated to evaporate the previously adsorbed water, forming water vapour. This water vapour is able to pass from the adsorption bed chamber 401d, 402d, 403d, 404d to the condensing chamber 401c, 402c, 403c, 404c. As mentioned hereinabove, the adsorption bed chamber is situated between the evaporative and condensing chambers which facilitates the passage of water vapour between the adsorption bed chamber and the evaporative or condensing chamber.
- 10 The adsorption bed chamber 401d, 402d, 403d, 404d is fluidly connected to the evaporative chamber 401b, 402b, 403b, 404b and condensing chamber 401c, 402c, 403c, 404c. This is to enable to passage of gas, such as water vapour, between the three chambers. The adsorber bed device 401, 402, 403, 404 (along with its constituent components the adsorption bed chamber, evaporative chamber and condensing chamber) is configured to prevent the passage of dirty water from the evaporative chamber to the condensing chamber, and also to prevent the passage of any desiccant to the condensing chamber. This ensures that all water in the condensing chamber is distilled water which can be extracted and used as potable water. As such, as used in this context the term "fluidly connected" means that the adsorption bed chamber, evaporative chamber and condensing chamber are connected in a way which allows the passage of gas (e.g. water vapour) but does not allow the passage of liquid (e.g. dirty water), and does not allow the passage of aerosolised liquid (e.g. aerosolised dirty water). This can be achieved by using a wall within the vacuum chamber which is positioned between the nozzle and desiccant, where the nozzle is located below the top of the wall, such that the liquid sprayed from the nozzle cannot pass over the wall. In addition, a demister can be used to prevent liquid entering the rest of the vacuum chamber (e.g. in the form of aerosols). Thus, in an embodiment, the vacuum chamber comprises one or more demisters configured to prevent the passage of liquid between a nozzle and the desiccant.
- 30 During operation, fluid (e.g. water such as dirty water) will be added to the chiller and received in a liquid container, e.g. the first liquid container 405. When dirty water is used, it is important to prevent contamination of the parts of the chiller which handle distilled water. Therefore, during the course of normal operation, the liquid container which receives dirty water ("dirty liquid container"), e.g. the first liquid container 405, will only ever be in fluid connection with the evaporative chambers 401b, 402b, 403b, 404b of each adsorber bed 401, 402, 403, 404. In this case, the second liquid container 406 will be clean and will contain distilled water. Thus, during the course of normal operation the second liquid

container will only ever be in fluid connection with the condensing chambers 401c, 402c, 403c, 404c of each adsorber bed. This prevents contamination of the distilled water by dirty water.

- 5 The evaporative 401b, 402b, 403b, 404b and condensing 401c, 402c, 403c, 404c chambers both comprise a nozzle and a liquid receiving portion. As used herein, "nozzle" refers to a device or part which is able to turn a liquid stream into a spray. The "liquid receiving portion" refers to a portion of the evaporative and condensing chambers where, when a spray is directed into a suitable direction, the sprayed water can collect before passing back to the
- 10 first or second liquid container. Typically, the evaporative and condensing chambers will be oriented such that, when in use, the liquid receiving portions are at the bottom of the evaporative and condensing chambers, such that liquid collects in the liquid receiving portions due to gravity.
- 15 The chiller comprises a first 407, second 408 and third 409 heat exchanger. The purpose of the heat exchangers is to exchange heat from one liquid to another. Thus, water in the first 405 and second 406 liquid containers passes through a heat exchanger before being sprayed by the nozzle of an evaporating or condensing chamber. This serves two functions. First, the temperature of the water can be increased or decreased depending on whether
- 20 warmer water is required for an evaporation chamber or colder water is required for a condensing chamber. In addition, cold water from a liquid container (e.g. cold water received from an evaporating chamber) can be used to cool an external water source, thereby providing chilled water. By using two heat exchangers for this purpose, the cooler of the present invention is able to produce chilled water having two different temperatures.
- 25 Typically, the first 407, second 408 and third 409 heat exchangers are shell and tube heat exchangers (e.g. shell and copper tube heat exchangers) or plate heat exchangers (e.g. brazed plate heat exchangers or gasketed plate-and-frame heat exchangers).
- 30 The nozzle and liquid receiving portions of the evaporative 401b, 402b, 403b, 404b and condensing chambers 401c, 402c, 403c, 404c in each of the first to fourth adsorber bed devices are in selective fluid connection with the first 405 or second 406 liquid container, respectively. As used herein, "selective fluid connection" means that the chiller may be configured both such that the respective parts are in fluid connection, and such that the
- 35 respective parts are fluidly isolated from each other. Typically, this is achieved through the use of one or more valves 417, which may be opened to allow fluid connection, and closed to provide fluid isolation. This allows each liquid container 405, 406 to be selectively

connected to the evaporative or condensing chambers of any of the first to fourth adsorber bed devices 401, 402, 403, 404. Thus, an adsorber bed may be used for evaporation of dirty water to be collected by the desiccant 401e, 402e, 403e, 404e, with the evaporative chamber of the adsorber bed device connected to the first (dirty) liquid container 405. The connections may then be switched by opening and closing appropriate valves, such that the adsorber bed device is connected to the second (clean) liquid container 406, through the condensing chamber. The use of selective connections in this manner also avoids having distilled water flow through a pipe or connection which has contacted dirty water, preventing contamination of the distilled water.

10

The changing of selective fluid connections may be done manually, e.g. by manually opening and closing the necessary valves. However, typically the chiller will comprise one or more computers running programs which are able to electronically change fluid connections, such as by electronically opening and closing valves. Thus, in an embodiment of the invention the chiller comprises one or more computers configured to control the selective connections, optionally wherein the one or more computers are configured to control the opening and closing of one or more valves. The one or more computers may be operated by a human, or may be fully automated with the use of an appropriate computer program.

15

To assist with automation, the chiller may comprise one or more sensors to detect the water levels in the first and second liquid containers, as well as in the liquid receiving portions of each condensing and evaporative chamber. Sensors could also be used to detect the humidity levels/vapour saturation in the adsorption bed chamber, and/or the respective fluid flow rates into and out of an evaporative chamber and a condensing chamber. This will allow an operator or computer program to determine the rates of adsorption and condensation, such that it can determine when to switch the cycle from adsorption to regeneration. The sensors can also help optimise of the length of each cycle in order to maximise the distilled water output per unit time.

20

The pressure in each liquid container is the liquid (e.g. water) vapour saturation pressure for the temperature of the container and the pressure of the vacuum applied to the vacuum chamber connected to the container. The clean (i.e. the second) liquid container 406, which is at a higher temperature than the first liquid container 405, will be at a higher pressure. When the liquid is water, it can be regenerated from the desiccant at temperatures of around 70°C. Cooling water sprayed in the condensing chamber 401c, 402c, 403c, 404c can have a temperature of around 30°C, and the second container will be at around 30°C. In this case, the second container may be at a pressure of about 4.25 kPa. When the first liquid container

25

30

comprises a first receiving tank 425 and a second receiving tank 426, the two receiving tanks will be connected to different heat exchangers and be at different temperatures. For example, the first receiving tank may be at around 9°C and have a pressure of between about 1.15 kPa and about 1.23 kPa, and the second receiving tank may be at around 17°C and have a pressure of between about 1.94 kPa and about 2.06 kPa. When the first liquid container is connected to both the first and second heat exchanger (i.e. it does not comprise two receiving tanks at different temperatures), it may be at a temperature and pressure between those mentioned above.

10 The chiller may comprise an overflow connection 420 between the first 405 and second 406 liquid containers. The overflow connection is typically configured to allow the flow of fluid from one of the liquid containers to the other liquid container, but not in the reverse direction. Given that one of the liquid containers will be at a higher pressure than the other(s), the controlled flow direction may be achieved by using a pressure-sensitive overflow connection, such as a pressure release valve or a liquid-containing U-bend. For example, the overflow connection may allow the flow of fluid from the second liquid container 406 to the first liquid container 405, but not from the first liquid container to the second liquid container. The overflow connection can be used to transfer water from the “clean” side of the chiller (which accumulates water during a cycle) to the “dirty” side (which loses water during a cycle), but prevents transfer of dirty water to the clean side of the chiller.

An overflow connection is especially useful if no distilled water output is required (i.e. only a chilled water output is desired). As the cycle progresses, the water level in the dirty liquid container will become depleted (as water is adsorbed onto the desiccant 401e, 402e, 403e, 404e), and distilled water (obtained by evaporation from desiccant 401e, 402e, 403e, 404e and then condensation) will collect in the clean liquid container. The dirty liquid container can be topped up with distilled water from the clean liquid container.

As mentioned above, suitable pressure-sensitive overflow connections include a pressure release valve or a liquid-containing U-bend, which relies on gravity. A U-bend overflow could comprise a pipe attached to the clean liquid container below the water level of distilled water, and attached to the dirty liquid container above the water level of dirty water and above the connection to the clean liquid container, with a U-bend between the two containers as shown in Figures 4a to 7. Water will only flow into the dirty liquid container when the pressure difference between the two liquid containers produces a force high enough to overcome gravity and move water up to the dirty liquid container. The connector is attached to the dirty

liquid container above the water level, preventing dirty water from flowing into the clean liquid container.

As explained above, one (i.e. the first 405) liquid container (or, when present, the first 425
5 and second 426 receiving tank) is in selective fluid connection with the evaporative
chambers 401b, 402b, 403b, 404b of each adsorber bed. When the first liquid container 405
comprises a first 425 and second 426 receiving tank, they may be in selective fluid
connection with different adsorber bed devices. For example, the first receiving tank may be
in selective fluid connection with the evaporative chambers 401b, 402b of the first 401 and
10 second 402 adsorber bed devices, and the second receiving tank may be in selective fluid
connection with the evaporative chambers 403b, 404b of the third 403 and fourth 404
adsorber bed devices. The other (i.e. the second 406) liquid container will only be in
selective fluid connection with the condensing chambers 401c, 402c, 403c, 404c of each
adsorber bed.

15 Given that each liquid container 405, 406 is connected to a specific heat exchanger 407, 408,
409, each heat exchanger will be in selective fluid connection with either the evaporative
401b, 402b, 403b, 404b or condensing 401c, 402c, 403c, 404c chambers of an adsorber
bed (depending on the liquid container to which they are connected). Thus, where the first
20 liquid container 405 is the dirty liquid container (i.e. receives dirty water input), it is in
selective fluid connection with the evaporative chambers. The first and second heat
exchangers 407, 408 (which are in fluid connection with the first liquid container) will also be
in selective fluid connection with the evaporative chambers. In this case, the second liquid
container 406 is the clean liquid container which is in selective fluid connection with the
25 condensing chambers, and the third heat exchanger 409 will be in selective fluid connection
with the condensing chambers. This provides different fluid flow paths through each heat
exchanger:

- 30 1. A first dirty fluid flow path flows from the liquid receiving portion of the
evaporative chamber of a first adsorber bed, to the first liquid container, to the first
heat exchanger, to the nozzle of the evaporative chamber of the first adsorber bed,
from which fluid can be sprayed to the liquid receiving portion, completing the circuit.
- 35 2. A second dirty fluid flow path flows from the liquid receiving portion of the
evaporative chamber of a second adsorber bed, to the first liquid container, to the
second heat exchanger, to the nozzle of the evaporative chamber of the second

adsorber bed, where it can be sprayed to the liquid receiving portion, completing the circuit.

5 3. A clean fluid flow path flows from the liquid receiving portion of the condensing chamber of a third and fourth adsorber bed, to the second liquid container, to the second heat exchanger, to the nozzle of the condensing chamber of the third and fourth adsorber bed, where it can be sprayed to the liquid receiving portion, completing the circuit. This clean fluid flow path through the third heat exchanger could be considered two separate fluid flow paths (one through each of
10 the third and fourth condensing chambers), which separate fluid flow paths converge at the second liquid container and third heat exchanger, before diverging on their way to each condensing chamber.

15 It will be apparent that the adsorber beds referred to in each of the above fluid flow paths are arbitrary, and each fluid flow path could run through a different adsorber bed to that mentioned.

20 The dirty fluid flow paths are fluidly isolated from the clean fluid flow path(s), subject to the pressure-sensitive overflow connection discussed herein. This prevents contamination of the distilled water, ensuring that the chiller is able to produce potable water. In addition, in the above examples, two dirty fluid flow paths run through the first liquid container, resulting in mixing of dirty water from each circuit.

25 If it is desired to isolate the two possible dirty water circuits (1 and 2) from each other, the first liquid container may be split into a first receiving tank 425 and a second receiving tank 426, where the first and second receiving tanks are fluidly isolated from each other. In embodiments comprising a first and second receiving tank, the first and second receiving tank, together with the components to which they are fluidly connected, may be connected to separate vacuum chambers (i.e. to separate adsorber bed devices). For example, the first
30 receiving tank, first heat exchanger and first adsorber bed may form one fluid flow path, and the second receiving tank, second heat exchanger and third adsorber bed may form another fluid flow path. This arrangement is advantageous because it allows for the liquid in each receiving tank and fluid flow path to be at a different temperature and pressure. When present, the first receiving tank 425 will be fluidly connected to a first heat exchanger 407,
35 and the second receiving tank 426 to a second heat exchanger 408 different from the first heat exchanger. Each of the first and second receiving tanks 425, 426 will be in selective fluid connection with evaporating chambers 401b, 402b, 403b, 404b of the first to fourth

adsorption bed devices 401, 402, 403, 404. While it is possible for the first and second receiving tanks to each be in selective fluid connection with all four of the evaporating chambers, they could each be in selective fluid connection with two different evaporating chambers. For example, in an embodiment, the first receiving tank 425 is in selective fluid
5 connection with the first 401b and second 402b evaporating chambers, and the second receiving tank 426 is in selective fluid connection with the third 403c and fourth 404c evaporating chambers. In an alternative embodiment, the first receiving tank 425 is in selective fluid connection with the third 403b and fourth 404b evaporating chambers, and the second receiving tank 426 is in selective fluid connection with the first 401c and second 402c
10 evaporating chambers.

As mentioned hereinbefore, when a desiccant which can be dried at a temperature of below about 70°C is used, this heat can be provided by waste thermal energy or solar power, such as by a photovoltaic cell and/or a photovoltaic thermal hybrid solar collector. Thus, in an
15 embodiment of the invention, the chiller comprises a power supply, which power supply may comprise a photovoltaic cell and/or a photovoltaic thermal hybrid solar collector.

The chiller may also comprise a cooling tower, which is configured to provide cooling water to the elements of the chiller which require it (e.g. to one or more of the heat exchangers, and to the adsorption bed chamber when it is necessary to cool the desiccant). The cooling
20 tower may comprise a first, and optionally a second water source. The first water source may be configured to supply water of one temperature to the third heat exchanger to cool the water which is used for condensation in the condensing chambers, and the second water source may be configured to selectively supply water of a different temperature to two of the
25 four adsorption beds, to cool the desiccant during the adsorption process.

The first 407 and second 408 heat exchangers are typically configured such that they cool the water supplied to them (e.g. supplied by a cooling appliance such as an air handling unit). As a result, the water which is heading to an evaporative chamber absorbs heat from the
30 water from the cooling appliance, which it in turn chilled. This chilled water can be returned to the cooling appliance. It is possible to supply cooling water having different temperatures to the first and second heat exchangers, allowing the chiller to output chilled water having two different temperatures. In an embodiment, the first output chilled water has a temperature of from 7-12°C (e.g. 9-10°C) and the second output chilled water has a
35 temperature of from 15-18°C (e.g. 15-16°C).

A 4-bed 2-evaporator adsorption chiller will now be described with reference to Figure 1. The chiller comprises a first 101, second 102, third 103 and fourth 104 adsorption beds. The first and second adsorption beds 101, 102 are in selective fluid connection with a low temperature evaporator receiver 105, and a condenser receiver 107. The third 103 and fourth 104 adsorption beds are in selective fluid connection with a high temperature evaporator receiver 106 and the condenser receiver 107. The selective fluid connections are controlled by a number of valves 108.

The low 105 and high 106 temperature evaporator receivers are in fluid connection with a low temperature evaporator 109 and high temperature evaporator 110, respectively. The condenser receiver 107 is in fluid connection with a condenser 111. A cooling water source 112 is connected to the condenser 111. A low temperature chilled water source 113 is connected to the low temperature evaporator 109, and a high temperature chilled water source 114 to the high temperature evaporator 110. Each of these components is housed in a vacuum chamber (not shown).

In operation, water from the low and high temperature evaporator receivers 105 and 106 passes into the respective evaporators 109 and 110, where it chills the incoming water sources 113 and 114 to produce chilled water 115 and 116. The temperature of chilled water 115 and 116 is dependent on the temperature of the input water sources 113 and 114. The water loses heat by evaporation in the evaporators and vapour from evaporation is adsorbed by an adsorption bed (e.g. the first 101 and third 103 adsorption beds) which is cooled by cooling water 112. Thus, the water is transferred to a desiccant composition, with any unevaporated water returning to the receivers 105 and 106.

Simultaneously, water from the condenser receiver 107 passes to the condenser 111, where it is cooled by the cooling water 112. The cooled water passes into the other two adsorption beds (e.g. the second 102 and fourth 104 adsorption beds). Here, water evaporates from the desiccant which is heated by hot water 115, and condenses on the cooled water as it passes through the adsorption bed. This water then passes back into the condenser receiver 107, having picked up distilled water from the desiccant in the adsorption beds 102 and 104. Distilled water 116 may be collected from the condenser receiver 107.

Figure 2 shows a possible layout of the adsorption chiller in accordance with an embodiment of the invention. Four adsorption bed devices 201, 202, 203 and 204 are present. Nozzles 205 are configured to spray water in the evaporating and condensing chambers, towards

receiving portions 206. A heat exchanger 207 is coated in desiccant for adsorbing water vapour, and a spray pump 208 is provided to assist the spraying of water.

Figure 3 shows an example layout of a plate fin heat exchanger as used in an embodiment of the invention. A module 300 comprises perforated corrugated fins 301 coated with adsorbent on one side. Channels 303 are formed between the fins, and hot or cold water can flow through the channels on the side of the fins which is not coated with desiccant. A number (e.g. 16) of modules 300 are placed together to form a unit 302.

10 An embodiment of the chiller of the invention will now be described with reference to Figures 4a and 4b. Figures 4a and 4b show four adsorption beds 401, 402, 403, 404. Each adsorption bed comprises a vacuum chamber 401a, 402a, 403a, 404a housing an evaporative chamber 401b, 402b, 403b, 404b, a condensing chamber 401c, 402c, 403c, 404c and an adsorption bed chamber 401d, 402d, 403d, 404d situated between the
15 evaporative and condensing chambers.

Each adsorption bed chamber comprises a desiccant 401e, 402e, 403e, 404e and means for heating or cooling the desiccant 401f, 402f, 403f, 404f. In this embodiment, the means for heating or cooling the desiccant extends out of the vacuum chamber.

20

Each evaporative chamber comprises a nozzle 401g, 402g, 403g, 404g and a liquid receiving portion 401h, 402h, 403h, 404h. Each nozzle is configured to spray liquid towards the liquid receiving portion of the evaporative chamber.

25 Each condensing chamber comprises a nozzle 401i, 402i, 403i, 404i and a liquid receiving portion 401j, 402j, 403j, 404j. As for the evaporative chamber, each nozzle in the condensing chambers is configured to spray liquid towards the liquid receiving portion of the condensing chamber.

30 A first liquid container 405 is in selective fluid connection with a first heat exchanger 407 (Figure 4a), the first evaporative nozzle 401g, and first evaporative liquid receiving portion 401h. The first liquid container 405 is also in selective fluid connection with a second heat exchanger 408 (Figure 4b), the third evaporative nozzle 403g, and third evaporative liquid receiving portion 403h.

35

A second liquid container 406 is in selective fluid connection with a third heat exchanger 409, second condensing nozzle 402i, and second condensing liquid receiving portion 402j, and

also in selective fluid connection with the fourth condensing nozzle 404i and fourth condensing liquid receiving portion 404j.

5 In operation, dirty water 410 may be provided into the first liquid container 405. It then passes to the first 407 and second 408 heat exchangers, where it gains heat from a first 411 and second 412 heat exchanging water (which are typically at different temperatures), thereby chilling the first 411 and second 412 heat exchanging water and producing a chilled water output 413, 414. When the first 411 and second 412 heat exchanging water have different temperatures, the chilled water output 413, 414 will have different temperatures.

10

The dirty water then passes to the nozzles 401g, 403g of the first 401b and third 403b evaporative chambers, where it is sprayed under reduced pressure in the vacuum chamber 401a, 403a and evaporates to form water vapour. This water vapour is able to pass to the adsorption bed chambers 401d, 403d where it is captured by the desiccant 401e, 403e. The
15 desiccant is cooled by cooling means 401f, 403f so that the heat of adsorption does not lead to evaporation of the water. The cooling means 401f, 403f may be cold water supplied from a cooling tower. Any dirty water that does not evaporate passes back to the first liquid container 405.

20 Simultaneously, water from the second liquid container 406 passes to the third heat exchanger 409 where it is cooled by a cooling fluid source 415 (for example cold water from a cooling tower). The cooled water then passes to the second and fourth condensing nozzle 402i, 404i, where it is sprayed to form cold water droplets. At the same time, wet desiccant 402e, 404e in the second and fourth adsorption bed chambers 402d, 404d is heated by the
25 heating means 402f, 404f (for example hot water heated by a waste heat source or solar power) under reduced pressure to form water vapour in the vacuum chamber 402a, 404a. This water vapour passes into the second and fourth condensing chambers 402c, 404c and condenses on the aforementioned cold water droplets produced by the nozzles 402i, 404i. The sprayed water collects in the second and fourth condensing liquid receiving
30 portions 402j, 404j and passes back to the second liquid container 406. The returning liquid has collected distilled water from the second and fourth adsorption bed chambers 402d, 404d, and this distilled water 416 may be collected from an outlet in the second liquid container.

35 Rather than having a single first liquid container 405 for supplying liquid to both the first 407 and second 408 heat exchangers, the chiller may comprise a first receiving tank 425 in fluid connection with the first heat exchanger 407, and a second receiving tank 426 in fluid

connection with the second heat exchanger 408. The respective connections for each of the first 425 and second 426 receiving tanks are shown in Figures 4a and 4b, respectively.

The chiller may comprise a number of valves 417 for implementing the selective fluid
5 connections. The selective fluid connections are necessary so that once a cycle has finished (e.g. the desiccant in the second and fourth adsorption bed chambers 402d, 404d has become fully, or almost fully, dry), the operation of the chiller may be switched over, so that dirty water is evaporated in the second and fourth adsorption beds 402, 404 to be captured by the now dry desiccant 402e, 404e. The water previously captured on the desiccant 401e,
10 403e in the first and third adsorption beds 401, 403 can be released by heating from heating means 401f, 403f. This reverse configuration is shown in Figures 5a and 5b, where it can be seen that in contrast to Figures 4a and 4b, the first 401c and third 403c condensing chambers are utilised, as well as the second 402b and fourth 404b evaporating chambers.

15 A desalination mode will now be described with reference to Figure 6. Figure 6 shows the first 401 and second 402 adsorber beds, and the first heat exchanger 407, but this desalination mode could be performed using the third 403 and fourth 404 adsorber beds and the second heat exchanger 408 (e.g. at the same time as using the first and second adsorber beds, or instead of the first and second adsorber beds). The water flow in Figure 6
20 corresponds to that in Figure 4a described above, except that there is no external cooling water supplied to the first and third heat exchangers. Instead, the warmed output from the third heat exchanger 409 is fed into the first heat exchanger 407 as the first heat exchanging water 411, to warm the water heading towards the first evaporative chamber 401b. Instead of collecting the chilled water from the first heat exchanger 407, the chilled water is cycled
25 back to the third heat exchanger 409 where it is used to cool water heading towards the second condensing chamber 402c. This desalination mode does not require the external water sources (i.e. first 411 and second 412 heat exchanging water and cooling water 415), but only produces distilled water 416, and does not produce a chilled water output (however, while this desalination mode is running, the other two adsorber bed devices may be
30 configured to produce a chilled water output). Once the cycle has finished (i.e. the desiccant 402e is dry), the connections may be switched in a way analogous to the configuration shown in Figure 5a.

Another desalination mode will now be described with reference to Figure 7. This mode
35 corresponds to that in Figure 6, except that instead of utilising two heat exchangers 407 and 409 and cycling the heat exchanging fluid between them, this mode utilises a single heat exchanger 409. This allows direct exchange of heat between fluid running to the evaporative

chamber of an adsorber bed 401, and fluid running to the condensing chamber of another adsorber bed 402. As for Figure 6, Figure 7 shows the first 401 and second 402 adsorber beds, but this mode could be performed using the third 403 and fourth 404 adsorber beds instead of, or at the same time as, the first 401 and second 402 adsorber beds. As for Figure 6, once the cycle has finished, the connections may be switched in a way analogous to the configuration shown in Figure 5a.

As will be appreciated, the chiller of the invention can be configured into a large number of configurations. Particular configurations which are useful in the production of two temperatures of chilled water and/or distilled water include the following modes (A), (B) and (C). Modes (A), (B) and (C) will now be described with reference to Figures 4a-5b, Figure 6 and Figure 7, respectively.

(A) A first desalination and two temperature chilled water production configuration, where:

the evaporative chamber 401b of the first adsorber bed device 401 is in fluid connection with the first liquid container 405 and the first heat exchanger 407;

the condensing chamber 402c of the second adsorber bed device 402 is in fluid connection with the second liquid container 406 and the third heat exchanger 409;

the evaporative chamber 403b of the third adsorber bed device 403 is in fluid connection with the first liquid container 405 and the second heat exchanger 408;

the condensing chamber 404c of the fourth adsorber bed device 404 is in fluid connection with the second liquid container 406 and the third heat exchanger 409, wherein the configurations of the first 401 and second 402 adsorber beds and third 403 and fourth 404 adsorber beds are reversible to provide a second adsorption/regeneration cycle configuration (as shown in Figures 5a and 5b).

(B) A desalination configuration using two connected heat exchangers, where:

the evaporator chamber 401b of the first adsorber bed device 401 is in fluid connection with the first liquid container 405 and the first 407 or second 408 heat exchanger and the condensing chamber 402c of the second adsorber bed device 402 is in fluid connection with the second liquid container 406 and the third heat exchanger 409, or

the evaporator chamber 403b of the third adsorber bed device 403 is in fluid connection with the first liquid container 405 and the first 407 or second 408 heat exchanger, and the condensing chamber 404c of the fourth adsorber bed device 404 is in fluid connection with the second liquid container 406 and the third heat exchanger 409.

In mode (B), the warmed output from the third heat exchanger 409 is fed into the first 407 and/or second 408 heat exchangers as the heat exchanging water 411/412. Once the cycle has finished (i.e. the desiccant 402e/404e is dry), the connections
5 may be switched in a way analogous to the configuration shown in Figures 4b and 5b.

(C) A desalination configuration using a single heat exchanger, where:
the evaporator chamber 401b of the first adsorber bed device 401 is in fluid
connection with the first liquid container 405 and the third heat exchanger 409, and
10 the condensing chamber 402c of the second adsorber bed device 402 is in fluid
connection with the second liquid container 406 and the third heat exchanger 409, or
the evaporator chamber 403b of the third adsorber bed device 403 is in fluid
connection with the first liquid container 405 and the third heat exchanger 409, and
the condensing chamber 404c of the fourth adsorber bed device 404 is in fluid
15 connection with the second liquid container 406 and the third heat exchanger 409.

In mode (C), instead of utilising two heat exchangers 407 and 409 and cycling the
heat exchanging fluid between them, the chiller can be operated using a single heat
exchanger 409. This allows direct exchange of heat between fluid running to the
20 evaporative chamber of an adsorber bed, and fluid running to the condensing
chamber of another adsorber bed. Once the cycle has finished (i.e. the desiccant
402e/404e is dry), the connections may be switched in a way analogous to the
configuration shown in Figures 4b and 5b.

25 As will be appreciated, modes (B) and (C) only require the use of two of the adsorber beds.
The other two adsorber beds can either be used to produce a chilled water (whether low or
high temperature) as described in relation to a pair of the adsorber beds in mode (A), or they
may be used to produce desalinated water as described in mode (B) or (C).

30 Mode (A) corresponds to the configuration shown in Figures 4a, 4b, 5a and 5b.

Mode (B) corresponds to the configuration shown in Figure 6.

Mode (C) corresponds to the configuration shown in Figure 7.

35

When the first liquid container comprises a first receiving tank and a second receiving tank,
the chiller may be configured into one of the related modes (A'), (B') and (C'), which define

the connections for the first and second receiving tanks. Modes (A'), (B') and (C') will now be described with reference to Figures 4a-5b, Figure 6 and Figure 7, respectively.

5 (A') A first desalination and two temperature chilled water production configuration, where:
the evaporator chamber 401b of the first adsorber bed device 401 is in fluid connection with the first receiving tank 425 and the first heat exchanger 407;
the condensing chamber 402c of the second adsorber bed device 402 is in fluid connection with the second liquid container 406 and the third heat exchanger 409;
10 the evaporator chamber 403b of the third adsorber bed device 403 is in fluid connection with the second receiving tank 426 and the second heat exchanger 408;
the condensing chamber 404c of the fourth adsorber bed device 404 is in fluid connection with the second liquid container 406 and the third heat exchanger 409, wherein the configurations of the first 401 and second 402 adsorber beds and third
15 403 and fourth 404 adsorber beds are reversible to provide a second adsorption/regeneration cycle configuration (as shown in Figures 5a and 5b).

(B') A desalination configuration using two connected heat exchangers, where:
the evaporator chamber 401b of the first adsorber bed device 401 is in fluid
20 connection with the first 426 or second 426 receiving tank and the first 407 or second 408 heat exchanger, and the condensing chamber 402c of the second adsorber bed device 402 is in fluid connection with the second liquid container 406 and the third heat exchanger 409, and/or
the evaporator chamber 403b of the third adsorber bed device 403 is in fluid
25 connection with the first 425 or second 426 receiving tank and the first 407 or second 408 heat exchanger, and the condensing chamber 404c of the fourth adsorber bed device 404 is in fluid connection with the second liquid container 406 and the third heat exchanger 409.

30 In mode (B'), the warmed output from the third heat exchanger 409 is fed into the first 407 and/or second 408 heat exchangers as the heat exchanging water 411/412. Once the cycle has finished (i.e. the desiccant 402e/404e is dry), the connections may be switched in a way analogous to the configuration shown in Figures 4b and 5b.

35 (C') A desalination configuration using a single heat exchanger, where:
the evaporator chamber 401b of the first adsorber bed device 401 is in fluid connection with the first 425 or second 426 receiving tank and the third heat

exchanger 409, and the condensing chamber 402c of the second adsorber bed device 402 is in fluid connection with the second liquid container 406 and the third heat exchanger 409, or

5 the evaporator chamber 403b of the third adsorber bed device 403 is in fluid connection with the first 425 or second 426 receiving tank and the third heat exchanger 409, and the condensing chamber 404c of the fourth adsorber bed device 404 is in fluid connection with the second liquid container 406 and the third heat exchanger 409.

10 In mode (C'), instead of utilising two heat exchangers 407 and 409 and cycling the heat exchanging fluid between them, the chiller can be operated using a single heat exchanger 409. This allows direct exchange of heat between fluid running to the evaporative chamber of an adsorber bed, and fluid running to the condensing chamber of another adsorber bed. Once the cycle has finished (i.e. the desiccant
15 402e/404e is dry), the connections may be switched in a way analogous to the configuration shown in Figures 4b and 5b.

As will be appreciated, modes (B') and (C') only require the use of two of the adsorber beds. The other two adsorber beds can either be used to produce a chilled water (whether low or
20 high temperature) as described in relation to a pair of the adsorber beds in mode (A'), or they may be used to produce desalinated water as described in mode (B') or (C').

Mode (A') corresponds to the configuration shown in Figures 4a, 4b, 5a and 5b, in which the first liquid container comprises a first receiving tank 425 and a second receiving tank 426.
25

Mode (B') corresponds to the configuration shown in Figure 6, in which the first liquid container comprises a first receiving tank 425 and a second receiving tank 426.

Mode (C') corresponds to the configuration shown in Figure 7, in which the first liquid
30 container comprises a first receiving tank 425 and a second receiving tank 426.

Thus, in an embodiment of the invention, the chiller is configurable into each of modes (A), (B) and (C). In other embodiments, the chiller is configurable into one of modes (A), (B) and (C). In a further embodiment, the chiller is configurable into each of modes (A'), (B') and (C').
35 In yet further embodiments, the chiller is configurable into one of modes (A'), (B') and (C').

Advantages of the present invention

The adsorption chiller of the present invention is able to simultaneously produce chilled water of two different temperatures, as well as distilled water. The chilled is flexible, and can
5 be configured to provide just chilled water, or just distilled water, as required.

The use of direct spraying evaporators and condensers in the adsorption bed devices results in enhanced heat transfer and a higher coefficient of performance.

10 When a brazed plate fin heat exchanger is used in the adsorption bed chamber, a lower amount of desiccant is needed when compared to traditional desiccant beds. This is due to the large surface area of the plate fin heat exchanger allowing for improved adsorption/desorption rates.

15 The chiller can be adapted to make use of waste thermal energy sources and/or solar energy sources. In particular, when CaCl_2 impregnated silica-gel or a superabsorbent polymer (e.g. PVA or sodium polyacrylate) having LiCl dispersed within the polymeric matrix is used as the desiccant, the desiccant can be dried using temperatures of 70°C or below. Other desiccant compositions can also be used as described herein.

20

The chiller of the present invention does not require large vapour valves, and does not require all components to be housed in a vacuum chamber.

Claims

1. An adsorption chiller comprising:
 - a first and second liquid container;
 - a first to fourth absorber bed device, where each absorber bed device comprises a vacuum chamber comprising an evaporative chamber, a condensing chamber and an adsorption bed chamber, where the adsorption bed chamber is situated between the evaporative and condensing chambers and is fluidly connected to said chambers;
 - the adsorption bed chamber comprises a desiccant and one or more means or apparatus to heat or cool the adsorption bed chamber;
 - the evaporative chamber comprises a nozzle and a liquid receiving portion, where both the nozzle and liquid receiving portion are in selective fluid connection with the first liquid chamber;
 - the condensing chamber comprises a nozzle and a liquid receiving portion, where both the nozzle and liquid receiving portion are in selective fluid connection with the second liquid chamber;
 - a first heat exchanger in selective fluid connection with the first liquid container and any one of the first to fourth absorber bed devices when so connected;
 - a second heat exchanger in selective fluid connection with the first liquid container and any one of the first to fourth absorber bed devices when so connected, provided that it is not connected to the absorber bed device that the first heat exchanger is coupled to; and
 - a third heat exchanger in selective fluid connection with the second liquid container and to any one or two of the first to fourth absorber bed devices when so connected, provided that it is not connected to the absorber bed devices that the first and second heat exchangers are coupled to.
2. The adsorption chilled according to Claim 1, which is configurable into the following modes (A), (B), and (C):
 - (A) a first adsorption/regeneration cycle configuration, where:
 - the evaporator chamber of the first adsorber bed device is in fluid connection with the first liquid container and the first heat exchanger;
 - the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;
 - the evaporator chamber of the third adsorber bed device is in fluid connection with the first liquid container and the second heat exchanger;

the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, wherein the configurations of the first and second adsorber beds and third and fourth adsorber beds are reversible to provide a second adsorption/regeneration cycle configuration;

(B) a desalination configuration, where:

the evaporator chamber of the first adsorber bed device is in fluid connection with the first liquid container and the first or second heat exchanger and the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, and/or

the evaporator chamber of the third adsorber bed device is in fluid connection with the first liquid container and the first or second heat exchanger, and the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;

(C) a desalination configuration, where:

the evaporator chamber of the first adsorber bed device is in fluid connection with the first liquid container and the third heat exchanger, and the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, or

the evaporator chamber of the third adsorber bed device is in fluid connection with the first liquid container and the third heat exchanger, and the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger.

3. The adsorption chiller according to Claim 1, wherein the first liquid container comprises a first receiving tank and a second receiving tank, wherein:

the first receiving tank is in fluid connection with the first heat exchanger, and is in selective fluid connection with the nozzle and liquid receiving portion of the evaporative chambers in the third and fourth adsorber bed devices; and

the second receiving tank is in fluid connection with the second heat exchanger, and is in selective fluid connection with the nozzle and liquid receiving portion of the evaporative chambers in the first and second adsorber bed devices.

4. The adsorption chilled according to Claim 3, which is configurable into the following modes (A'), (B'), and (C'):

- (A') a first adsorption/regeneration cycle configuration, where:
the evaporator chamber of the first adsorber bed device is in fluid connection with the first receiving tank and the first heat exchanger;
the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;
the evaporator chamber of the third adsorber bed device is in fluid connection with the second receiving tank and the second heat exchanger;
the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, wherein the configurations of the first and second adsorber beds and third and fourth adsorber beds are reversible to provide a second adsorption/regeneration cycle configuration;
- (B') a desalination configuration, where:
the evaporator chamber of the first adsorber bed device is in fluid connection with the first or second receiving tank and the first or second heat exchanger, and the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, and/or
the evaporator chamber of the third adsorber bed device is in fluid connection with the first or second receiving tank and the first or second heat exchanger, and the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger;
- (C') a desalination configuration, where:
the evaporator chamber of the first adsorber bed device is in fluid connection with the first or second receiving tank and the third heat exchanger, and the condensing chamber of the second adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger, or
the evaporator chamber of the third adsorber bed device is in fluid connection with the first or second receiving tank and the third heat exchanger, and the condensing chamber of the fourth adsorber bed device is in fluid connection with the second liquid container and the third heat exchanger.

5. The adsorption chiller according to Claim 1 which is configurable into mode (A) or (A'), as described in Claims 2 and 4, respectively.

6. The adsorption chiller according to Claim 1 which is configurable into mode (B) or (B'), as described in Claims 2 and 4, respectively.
7. The adsorption chiller according to Claim 1 which is configurable into mode (C) or (C'), as described in Claims 2 and 4, respectively.
8. The adsorption chiller according to Claim 1 which is configurable into mode (D) or (D'), as described in Claims 2 and 4, respectively.
9. The adsorption chiller according to any one of the preceding claims, wherein the selective fluid connections are formed by one or more valves.
10. The adsorption chiller according to any one of the preceding claims, wherein the means or apparatus to heat or cool the adsorption bed comprises one or more pipes suitable for transporting variable temperature fluid.
11. The adsorption chiller according to any one of the preceding claims, wherein the adsorption bed chamber comprises a plate fin heat exchanger, and at least a portion of the desiccant is coated onto the fins of the plate fin heat exchanger.
12. The adsorption chiller according to Claim 11, wherein the plate fin heat exchanger is a brazed plate fin heat exchanger, optionally wherein the brazed plate fins are made of aluminium or stainless steel.
13. The adsorption chiller according Claim 11 or 12, wherein the desiccant is selected from one or more of the group consisting of CaCl_2 impregnated silica-gel and a composite desiccant comprising a hygroscopic salt (such as lithium chloride) dispersed within the polymeric matrix of a superabsorbent polymer (such as polyvinyl alcohol, sodium polyacrylate and potassium polyacrylate), optionally wherein the desiccant is coated to a thickness of from about 100 to about 300 microns, such as about 200 microns.
14. The adsorption chiller according to any one of the preceding claims, wherein the first, second and third heat exchangers are shell and tube heat exchangers or plate heat exchangers.

15. The adsorption chiller according to any one of the preceding claims, wherein the first liquid container, or where present at least one of the first receiving tank and second receiving tank, comprises an inlet for providing water to the system, and the second liquid container comprises an outlet for supplying distilled water.

16. The adsorption chiller according to any one of the preceding claims, further comprising a power supply, optionally wherein the power supply comprises a photovoltaic thermal hybrid solar collector.

17. The adsorption chiller according to any one of the preceding claims, wherein the chiller further comprises an overflow connection from the second liquid container to the first liquid container, where the overflow connection is configured to allow the flow of fluid from the second liquid container to the first liquid container, but which does not allow fluid to flow from the first liquid container to the second liquid container, optionally wherein the overflow connection comprises a U-bend connector.

18. The adsorption chiller according to any one of the preceding claims, wherein the adsorption chiller further comprises a cooling tower, which cooling tower comprises a first and optionally a second water source, where the first water source is configured to selectively supply water to the third heat exchanger and, when present, the second water source is configured to selectively supply water to one or two of the first to fourth adsorber bed devices.

19. The adsorption chiller according to any one of the preceding claims, wherein the first heat exchanger, when used in operation, is configured to reduce the temperature of the first heat exchanging water and, the second heat exchanger, when used in operation, is configured to reduce the temperature of the second heat exchanging water.

20. The adsorption chiller according to Claim 19, wherein the first heat exchanger is configured in operation to cool the first heat exchanging water to a temperature of from 7-12°C, such as 9-10°C and, when the second heat exchanging water is present, the second heat exchanger, when used in operation, is configured to cool the second heat exchanging water to a temperature of from 15-18°C, such as 16-17°C.

21. The adsorption chiller according to any one of the preceding claims, further comprising a dirty water source configured to supply dirty water to the first liquid container.