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(54) Extracting water from air

(57) A method for abstracting water from air and apparatus for implementing the method, wherein in a first phase of a recurrent cycle a stream of cool humid air taken from the ambient atmosphere is used first to cool a first heat storage condenser and then to humidify a hygroscopic medium, wherein in a subsequent second phase of the cycle a stream of warm air heated by solar radiation is used to expel the moisture from the hygroscopic medium and carry it into the first heat storage condenser, where it precipitates while yielding heat of condensation and is then drained away. In a subsequent third phase of the cycle another stream of cool, humid air taken from the ambient atmosphere is used first to cool a second heat storage condenser and then to rehumidify the hygroscopic medium, and in a fourth and final phase of the cycle another stream of warm air heated by solar energy is used to expel the moisture from the hygroscopic medium and carry it to the second heat storage condenser where it precipitates and is then drained away, and where dependent on the intensity of solar radiation, the warm air stream of the second phase, is heated by means of the heat of condensation picked up by the second heat storage condenser in the fourth phase and/or the air stream of the fourth phase is heated by means of the heat of condensation picked up by the first heat storage condenser, in each case before the moisture is expelled, and/or the said streams are heated by solar radiation.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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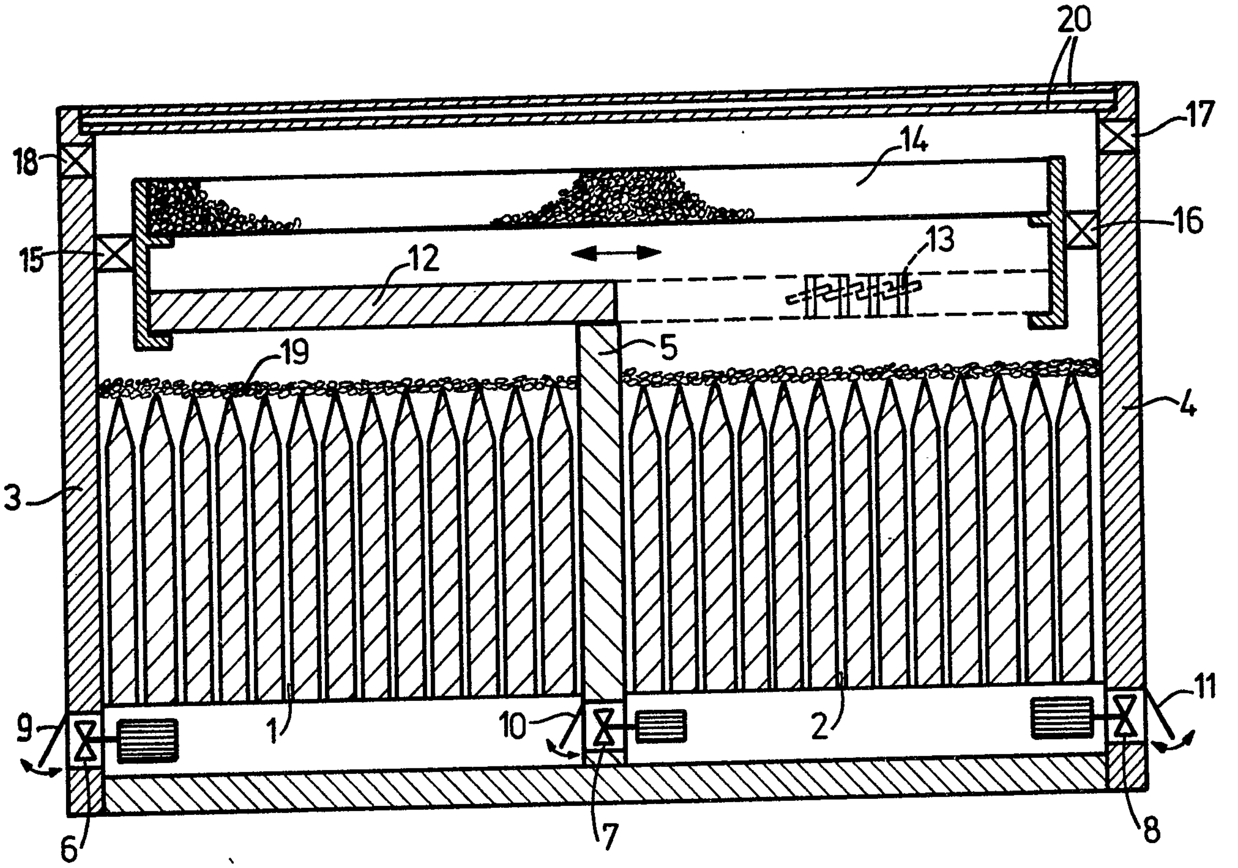

Fig. 1

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Fig. 2

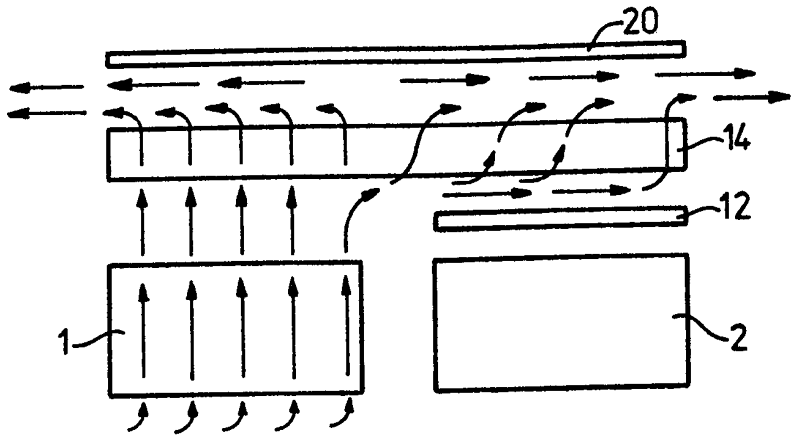


Fig. 3

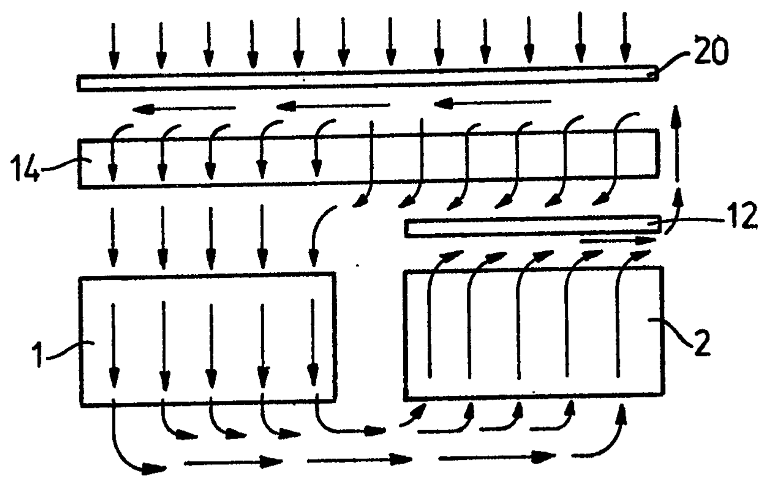


Fig. 4

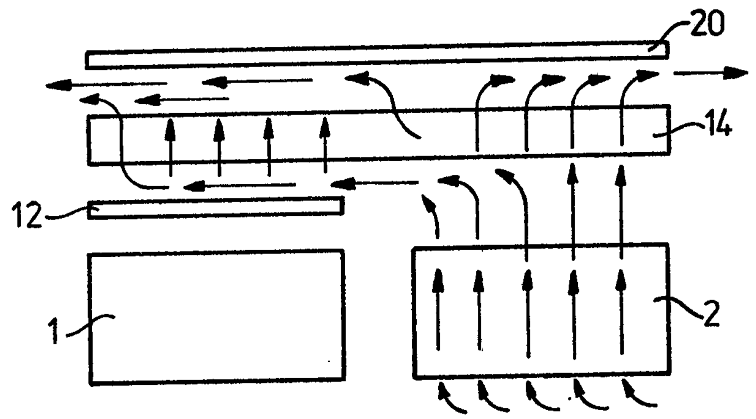
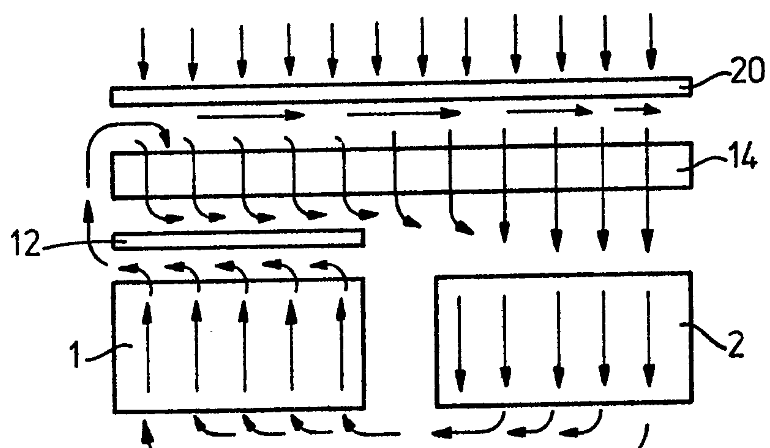


Fig. 5



SPECIFICATION

Method and apparatus for extracting water from air

This invention relates to a method of extracting water from air and more particularly, a method wherein in a first phase of a recurrent cycle a stream of cool, humid air from the surrounding atmosphere is used first to cool a heat storage condenser, then to humidify a hygroscopic medium, and where in a subsequent second phase of the cycle a stream of warm air reheated by solar radiation is used to again expel the moisture from the hygroscopic medium and to carry it into the heat storage condenser where while yielding heat of condensation it precipitates to be drained away.

This invention also relates to apparatus for implementing said method.

Such a method is disclosed in, e.g., printed German patent specification 266 00 68, but it is possible to extract sufficient water from the air for large-scale irrigation purposes and, further, utilizing a difference in height to enable generation by hydroelectric methods of sufficient energy to drive the system operating the water yield is nevertheless limited by the fact that the supply of heat required for the expulsion of moisture in every second phase of the process cycle cannot be improved beyond the limited amount of solar radiation available.

Broadly the present invention aims to improve the above described method of water extraction such that the yield is substantially raised with little or no change in the cost or complexity of the apparatus needed to put the method into effect.

According to one aspect of this invention we propose a method of the kind referred to wherein, in a third phase following the second phase of the cycle another stream of cool, humid air from the surrounding atmosphere is used first to cool a further heat storage condenser, then to humidify, again, the hygroscopic medium, wherein in a fourth and last phase of the cycle another stream of warm air equally reheated with solar energy is used to expel the moisture from the hygroscopic medium and to carry it into the other heat storage condenser, in which while yielding heat of condensation it precipitates to be drained away, and wherein as a measure of the intensity of solar radiation, the warm stream of air of the second phase, using the heat of condensation picked up by the other heat storage condenser in the fourth phase, and/or the warm stream of air of the fourth phase using the heat of condensation picked up by the one heat storage condenser in the second phase, is pre-heated before the moisture is expelled and/or is reheated using solar radiation.

This method makes it possible, with the same amount of solar radiation, to improve the water yield by a multiple of its original amount by utilizing the heat of condensation stored alternately in the one and the other heat storage condenser to pre-heat the stream of air destined for the expulsion of moisture, so that utilizing a suitable difference in elevations the water yield will generate much more hydroelectric energy than is required to drive the apparatus. Further, the amounts of water gained are sufficient for large-scale economical generation of useful energy via the production of biological substance. The recovery of condensation heat makes for economical use of solar energy such that the extraction of water from air becomes economically feasible also in countries where the amount of solar radiation available is less than in strictly desert regions, for example, in Mediterranean countries.

Either a part or all of the air streams of the second and fourth phases, depending upon the intensity of solar radiation, are circulated in counterflow through the two heat storage condensers and the hygroscopic medium, and when only some of the air flows are circulated, a portion of the respective air flow is yielded to the environment each time around, and is replaced by admixing air from the atmosphere. This makes the method very flexible. If the sky is lightly clouded, e.g., and the external temperature is not particularly high, part of a stream can be diverted, each time around, from the air stream circulating in the second and fourth phases and replaced with a corresponding air from the environment. If on the other hand the sky is extremely clouded, it will be possible to circulate all of the air streams of the second and fourth phases in isolation from the ambient air, so that moderate solar radiation will still be sufficient to offset heat losses which may result from radiation, convection or thermal conduction. Should the weather so require in the course of the second or fourth phase, conversion can naturally be made from the completely closed-loop circuit to the half-open circuit with ambient air being admixed, or even to a fully open circuit of the air streams or vice versa.

Preferably, the respective heat storage condenser is cooled in the first and third phases of the cycle such that the temperatures at its air inlet and outlet ends are approximately the same low level, while in the second and fourth phases of the cycle the respective heat storage condenser is heated such that a temperature gradient is produced between its air inlet and outlet ends of which the upper value is, at the end of condensation, approximately equal to the temperature of the warm air stream at the air outlet end of the hygroscopic medium, the air stream being humidified in the hygroscopic medium, and of which the lower value, at the end of condensation, remain approximately equal to the temperature prevailing at the end of the cooling process at the air outlet end of the respective heat storage condenser, and that the temperature gradient produced in the respective heat storage condenser is preserved until the second or fourth phase of the subsequent cycle for pre-heating the air stream going to the hygroscopic medium for the purpose of expelling moisture.

In a process of said sequence the optimum temperatures to work on would be these:

Depending on the intensity of solar radiation the temperature of the respective heat storage condenser after cooling in the first or third phase will be in the approximate range of 0° to 30°, and the upper and lower values of the temperatures gradient produced in the respective heat storage condenser by absorption of condensation heat will run in the approximate range of 50° to 70°C. Reheating of the preheated air stream by solar radiation in the second and fourth phases will give a temperature in the approximate range of 60° to 90°C.

It is possible to commence the process immediately with the cooling of the one heat storage condenser, while the other heat storage condenser does not have the temperature distribution needed to preheat the second and fourth phase air streams for the purpose of expelling moisture. It is nevertheless helpful, when prior to initial start of the cycle or after extended interruption between two phases, the respective heat storage condenser used for preheating the air stream in the second and fourth phase, respectively, is preheated with air from the ambient atmosphere until its temperature distribution is approximately equal to the temperature gradient that is subsequently formed at the time of condensation.

According to another aspect of this invention, we propose apparatus for implementing the method according to the said one aspect of this invention comprising a heat storage condenser arranged in a housing with a transparent roof and, above it, with an adsorber accommodating the hygroscopic medium, adjacent to the one heat storage condenser, another heat storage condenser of substantially the same size the adsorber extending over both heat storage condensers and comprising air handling means, such as fans, and air shut-off means, such as flap and slide valves, for adjusting the air requirements in each phase of the cycle, the housing being thermally insulated from the outside and the heat storage condensers being thermally insulated from each other to prevent thermal losses to the outside and heat transfer from the alternately condensation heat absorbing heat storage condensers.

Above the heat storage condensers, a slide valve covering the upper cross-sectional area of one heat storage condenser may be provided together with means for shifting it from one heat storage condenser to the other. This slide valve serves, on the one hand, for routing the air as required, and on the other hand it covers the top of that heat storage condenser which in the first and third phases of the cycle is not wetted with air, protecting it from heat losses. Instead of the slide valve a flap mechanism may be used covering both heat storage condensers and having provisions for alternately moving the flaps over the one heat storage condenser and the flaps over the other heat storage condenser to open and closed positions, respectively.

In order to be able to readily raise the air temperature in the second and fourth phases of the cycle to 80° or 90°C before it enters the adsorber, the adsorber is preferably formed as a flat solar collector with a hygroscopic medium that is dyed black and with a heat conducting and absorbing vessel for the hygroscopic medium. The transparent roof of the housing is preferably made of natural glass, polyacryl glass or polyester material. The roof may comprise transparent plates arranged one above the other and with an insulating layer of air between adjacent plates.

The hygroscopic medium, is preferably a special silica gel having an adsorption temperature in the 0° to 30°C range and of a desorption temperature in the 70° to 90°C range. A gel of this kind gives a water expulsion from the gel of 80 to 95%, and a water absorption of 30 to 65% of its own weight.

The heat storage condenser preferably comprises rock, concrete or similar slabs spaced side by side and preferably arranged vertically to define an air passage typically 4 to 10 mm wide for slabs of 1.50 to 2.50 m long and 40 to 120 mm thick. Owing to the poor conductivity of the slabs, the temperature distribution prevailing at the time of condensation will be from 70° to 10°C, going down. This makes it possible for them to yield heat to the air in the desorption phases while still operating in their cold region as condensers to abstract water.

For economy of energy in the air routing arrangement, diffusors can be formed between the upper ends of adjacent slabs by chamfering their upper edges.

Heat storage and recovery as it is practiced with the slab-type heat storage condenser can be achieved, when using water or latent heat storage condensers, by embedding the horizontal thermal insulating means in the heat storage condensers in stratiform arrangement.

To keep the apparatus clean, a layer of a filter substance, as perhaps of stratified pebbles, can be arranged over the heat storage condensers. This layer will clean itself in the desorption phases as a result of the water carried in the air and concurrently serves as thermal insulation for the heat storage condensers.

An embodiment of apparatus for putting into effect the method according to this invention will now be described by way of example with reference to the drawings of which:

FIG. 1 is a schematic drawing of the apparatus; and

FIGS. 2 to 5 illustrate the air routes during the various phases of the process cycle.

The heat storage condensers 1, and 2 are arranged at a distance above the floor of a housing or building having the outer walls 3, 4 in which and in partition 5 are fans 6, 7, 8 with associated flaps 9, 10, 11 for air handling. Arranged above the heat storage condensers 1, 2 is a gate valve 12 which, depending on the phase of the cycle, is moved into position over the one or the other heat storage condenser by means of conventional hydraulic or electric actuating means (not shown).

Instead of the gate valve 12, a flap mechanism 13 can be used which extends over both heat storage condensers 1 and 2, with the flaps over the one and the other heat storage condenser being alternately moveable into an open or closed position, depending on the phase of the cycle. Arranged at a distance above the gate valve 12 is an adsorber 14 consisting of an aluminium vessel which contains the hygroscopic medium, in this case, silica gel which is dyed black. The building is covered by two spaced transparent natural glass, polyacryl glass or polyester sheets 20. Valves 15 to 18 are provided in the upper area of the building for control of the air flow. Each heat storage condenser 1 or 2 has plurality of vertical stone slabs spaced apart to form air passages there between and are chamfered at their upper ends such that any two adjacent slabs will form a diffusor at their upper ends. A filter fabric 19 is deposited on the tips of the slabs of heat storage condensers 1 and 2.

After the air has been circulated for perhaps several days by the fan 8 through the heat storage condenser 2 with the slide valve 12 positioned over the heat storage condenser 1, and with the valves 11, 16 and 17 open to preheat the heat storage condenser 2, the process begins with its first phase where cool, humid outside air is forced by the fan 6, with the slide valve 12 moved to the right-hand side and the valves 7, 11 and 16 closed, through the heat storage condenser 1 and through the adsorber 14, which picks up water, and then to the open air through valves 17 and 18. This first phase preferably takes place at night-time for a duration of maximally 10 hours.

In the second phase of the process cycle, which preferably takes place at day-time, the air is circulated through the two heat storage condensers 1 and 2 and the adsorber 14 in a closed-loop circuit, in a semi-open circuit with outside air being admixed, or in a completely open circuit, where the valve 12 is invariably positioned over the heat storage condenser 2. In the closed-loop circuit, with the valves 10, 15 and 16 open, the air is circulated by fan 7 upwards through the heat storage condenser 2, then downwards through the adsorber 14, and finally downwards through the heat storage condenser 1, where the circulating air stream is preheated in the heat storage condenser 2, then reheated by the sun rays entering the building, humidified in the adsorber and cooled in the heat storage condenser 1 for condensation of the moisture. The water precipitated in the heat storage condenser 1 runs to the bottom where is is collected and drained away.

In the semi-open circuit a portion of the circulating air stream is diverted into the open air, with the fan 6 operating and the valve 9 being open. The escaped portion of the circulating air stream is replaced by a corresponding partial air stream entering through the open valve 11 under pressure from fan 8.

In the open circuit, outside air enters the building through the open flap 11 under pressure from the fan 8, flows upwards through the heat storage condenser 2, then downwards through the adsorber 14, and downwards through the heat storage condenser 1 and finally into the open air through the open flap 9 under pressure from the fan 6.

In the third phase of the process cycle the valve 12 is positioned over the heat storage condenser 1, and cool, humid air enters the building through the open valve 11, the valves 7 and 9 being closed, after which it flows upwards through the heat storage condenser 2, then upwards through the adsorber 14 before it escapes from the building through the open valves 17 and 18. As does the first phase, the third phase preferably takes place at night-time.

In the subsequent, fourth and last phase the air is transported as in the second phase, except that directions are now reversed, with the valve 12 positioned over the heat storage condenser 1. The water now condenses in the heat storage condenser 2, and the circulating air is preheated in the heat storage condenser 1.

Of interest still relative to the water abstraction apparatus as described above are the following figures and technical particulars:

The slabs are 1.50 to 2.50 m high and 80 to 120 mm thick, with a distance of 4 to 10 mm between slabs for passageways. The thermal conductivity of the slabs is 0.8 to 1.6. If use is made of water or latent heat storage units, insulating layers are provided in the storage units, spaced some 50 to 150 mm apart to preclude the transfer of heat vertically. For reasons of weight the latter storage units would be a preferred solution for mobile apparatuses. The diffusors exhibit an angle of 15°. Compared with the known water abstraction means of the initially given description the apparatus of the present invention will save 80 to 90% of the solar energy, which spells a safe yield of 30 to 80 ltr of water per sqm adsorber area over 24 hours. A 400-m difference in elevation would be sufficient to generate enough energy to make the apparatus self-contained. The mass of the slabs should be some 5 200 kg, which would store 40 000 to 60 000 kcal. Depending on climate and temperature the volume of the desorption air will be 80 to 200 cbm per 1 l/sqm; and the water vapor/air mixture flowing into the heat storage condenser should have a velocity of 0.4 to 2 m/sec. Depending on night temperatures and relative humidity the adsorption air has a volume of 600 to 1500 cbm per sqm/h. The energy expended will be 1 to 1.5 kwh per cbm water, depending on conditions.

CLAIMS

1. A method of extracting water from air, wherein, in a first phase of a recurrent cycle, a stream of cool, humid air from the surrounding atmosphere is used first to cool a heat storage condenser, then to humidify a hygroscopic medium, wherein, in a subsequent second phase of the cycle, a stream of warm air reheated by

solar radiation is used to again expel the moisture from the hygroscopic medium and to carry it into the heat storage condenser where it precipitates while yielding heat of condensation, wherein, in a subsequent third phase of the cycle another stream of cool, humid air from the surrounding atmosphere is used to first cool a further heat storage condenser, then to humidify, again, the hygroscopic medium, wherein, in a fourth phase of the cycle, another stream of warm air equally reheated with solar energy is used to expel the moisture from the hygroscopic medium and to carry it into the other heat storage condenser, in which while yielding heat of condensation it precipitates to be drained away, and wherein, as a measure of the intensity of the solar radiation, the warm stream of air of the second phase, using the heat of condensation picked up by the other heat storage condenser in the fourth phase, and/or the warm stream of air of the fourth phase, using the heat of condensation picked up by the one heat storage condenser in the second phase, is preheated before the moisture is expelled and/or reheated using solar radiation.

2. A method according to Claim 1, wherein, as a measure of the intensity of solar radiation, a part or all of the air streams of the second and fourth phases are circulated in opposite directions through the two heat storage condensers and the hygroscopic medium, and wherein when only a part of the air streams are circulated, some of the respective air stream is exhausted, each time around, to the surrounding atmosphere and is replaced by admixing air from the surrounding atmosphere.

3. A method according to Claim 1 or Claim 2, wherein in the first and third phases of the cycle the respective heat storage condensater is cooled such that the temperatures prevailing an air inlet and outlet ends thereof are approximately the same low level, while in the second and fourth phases of the cycle the respective heat storage condenser is heated by absorption of the heat of condensation heat such that a temperature gradient is produced between the air inlet and outlet ends the upper value of which is, at the end of condensation, approximately equal to the temperature of the warm stream of air at the air outlet end of the hygroscopic medium, the air having picked up moisture in the hygroscopic medium, and the lower value of which remains after condensation, approximately equal to the temperature prevailing at the after cooling, at the air outlet end of the respective heat storage condenser and wherein the temperature gradient produced in the respective heat storage condenser is maintained until the second and fourth phase, respectively, of the subsequent cycle for preheating the respective stream of air that is carried to the hygroscopic medium for the purpose of expelling moisture.

4. A method according to Claim 3, wherein, as a measure of the intensity of solar radiation, the temperature of the respective heat storage condenser after cooling in the first and fourth phase, respectively, is in the approximate range of 0° to 30°C, wherein the upper and lower values of the temperature gradient produced in the respective heat storage condenser by the absorption of condensation heat is in the approximate range of 50° to 70°C, and wherein reheating of the preheated air stream by means of solar radiation in the second and fourth phases produces a temperature in the approximate range of 60° to 90°C.

5. A method according to Claim 3 or Claim 4, wherein prior to the initial start of the cycle or following an extended interruption between two phases, the respective heat storage condenser used to preheat the stream of air in the second and fourth phases, respectively, is preheated with a stream of warm air taken from the surrounding atmosphere until its temperature distribution approximately equals the temperature gradient subsequently produced at the time of condensation.

6. Apparatus for implementing the method of the preceding Claims, comprising a heat storage condenser arranged in a housing with a transparent roof and, above it, an adsorber accommodating the hygroscopic medium, adjacent to the one heat storage condenser another heat storage condenser substantially the same size the adsorber extending over both heat storage condensers, and comprising air handling means, and air shut-off means for adjusting the air requirements for each phase of the cycle, the housing being thermally insulated from the outside and the heat storage condensers being thermally insulated from each other.

7. Apparatus according to Claim 6, wherein the air shut-off comprises a slide valve covering the upper cross-sectional area of a heat storage condenser and means for shifting it from one heat storage condenser to the other.

8. Apparatus according to Claim 6, wherein the air shut-off comprises a valve flap mechanism covering the upper cross-sectional area of both heat storage condensers, and means for alternately operating the flaps arranged over the respective one heat storage condenser and over the other heat storage condenser.

9. Apparatus according to any one of the Claims 6 to 8, wherein the adsorber comprises a flat solar collector consisting of a thermally conductive and absorbent vessel holding the hygroscopic medium, which is dyed black.

10. Apparatus according to any one of the Claims 6 to 9, wherein the hygroscopic medium, comprises silica gel having an adsorption temperature in the range of 0° to 30° and a desorption temperature in the range of 70° to 90°C.

11. Apparatus according to any one of the Claims 6 to 10, wherein the storage substance and condensation area in the heat storage condenser comprises slabs of rock, concrete or the like which are arranged side by side and spaced from the other.

12. Apparatus according to Claim 11, wherein

diffusors are formed at the upper end of adjacent slabs by chamfering their upper edges.

13. Apparatus according to any one of the Claims 6 to 12, wherein the heat storage condensers comprise water or latent heat reservoirs having thermal insulating means deposited in horizontal, stratiform arrangement.

14. Apparatus according to any of the Claims 6 to 13, wherein a layer of a filter substance, such as of stratified rock, is arranged over each heat storage condenser.

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