Sept. 24, 1929. E. B. MILLER 1,729,081

REFRIGERATION

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FIG. 1.

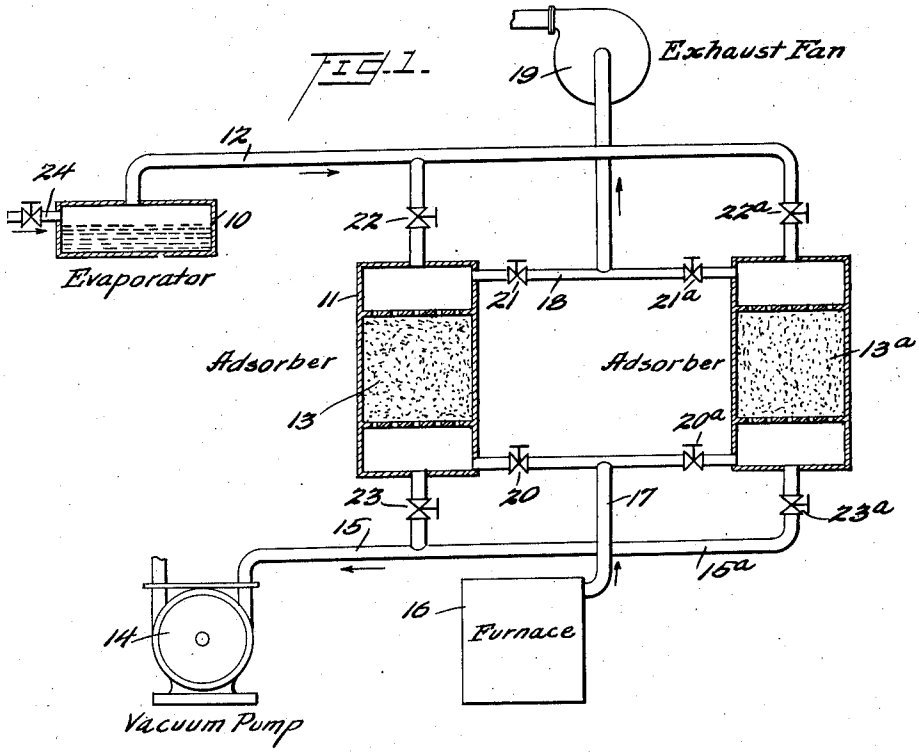
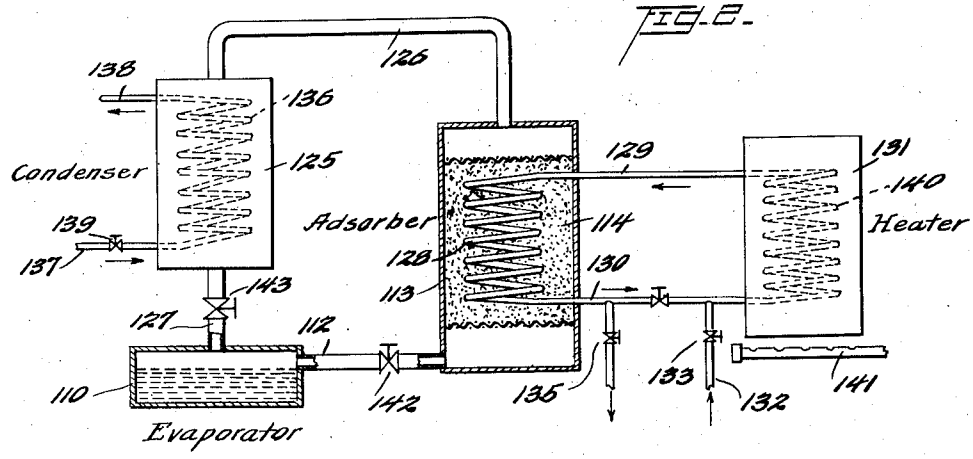


FIG. 2.



Inventor

Ernest B. Miller

By Watson, Cole, Morse & Grindle

Attorney

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UNITED STATES PATENT OFFICE

ERNEST B. MILLER, OF BALTIMORE, MARYLAND, ASSIGNOR TO THE SILICA GEL CORPORATION, OF BALTIMORE, MARYLAND, A CORPORATION OF MARYLAND

REFRIGERATION

Continuation of applications Serial No. 675,929, filed November 20, 1923, Serial No. 688,020, filed January 23, 1924, and Serial No. 236,322, filed November 28, 1927, and in Great Britain and Irish Free State October 25, 1924. This application filed August 3, 1929. Serial No. 383,319.

The present invention relates to refrigeration and more particularly to the type wherein the cooling effect is obtained by the evaporation of a liquid such as brine or water.

One of the objects of the invention is to provide an improved method of refrigeration employing apparatus as nearly fool-proof and reliable as possible.

Another object of the invention is to provide apparatus which requires a minimum of attention.

Another object is to provide a method and apparatus of the type mentioned wherein the refrigerating effect is obtained without any chemical action.

Another object is to provide an apparatus so simple that it can be manufactured to sell at a price that is within the reach of the majority of the people.

Briefly stated, the invention consists in adsorbing, in a porous material, vapor from a liquid, the adsorption taking place substantially in the absence of permanent gases. The evaporation of the liquid gives the refrigerating effect. The porous material adsorbs the vapor in its pores and thereafter the material is treated to liberate the adsorbed vapor, so that the material may be used for another adsorbing cycle.

A second form of the invention aims to provide a method and apparatus of the type described above but more particularly adapted for embodiment in small units, such as used with the usual household refrigerator.

The principal feature of this second form of the invention resides in the elimination of all pumps and machinery, the only requirements for operating the apparatus being a supply of water and heat.

An apparatus for carrying out the method of the second form of the invention comprises an evaporator, an adsorber charged with a porous material, said adsorber being in communication with the evaporator, both said parts being substantially free from permanent gases, whereby vapor evaporating from liquid in the evaporator is adsorbed by the material, giving a refrigerating effect. In order to use the vapor over again, a condenser, also substantially free of permanent gases, has communication with the evaporator and the adsorber. Means is provided to liberate the vapor from the porous material causing it to pass to the condenser where it is liquefied and then returned to the evaporator.

The adsorbing material should have very fine pores in order to adsorb the vapor at low pressures. More specifically stated the materials should have pores of such size that they will adsorb water vapor under static conditions to such an extent as to contain not less than substantially 10% of their own weight of water when in equilibrium with water vapor at 30° C. and 22 mm. of mercury.

Other objects and features of novelty will be apparent from the description taken in connection with the drawings in which:

Figure 1 is a diagrammatic illustration of a refrigerating apparatus constructed in accordance with one form of the present invention; and

Figure 2 is a diagrammatic illustration of a refrigerating apparatus adapted for carrying out the method of the second form of the invention.

Referring to Figure 1 of the drawings which illustrates one form of the invention, a closed vessel forming an evaporating chamber 10 is in communication with an adsorber 11 by means of a conduit 12. The evaporator 10 contains a liquid such as brine or water which is evaporated to obtain the refrigerating effect. The adsorber 11 is of any suitable form and is charged with a porous material 13 preferably in granular form, adapted to adsorb the vapor from the liquid in its pores.

The pores of the adsorbing material required in the present method are ultramicroscopic, so that it is a very difficult matter to accurately determine and define their size. One satisfactory method of comparing the size of the pores in two bodies and also the total volume of these pores consists in determining the amount of water that one gram of each body will adsorb when exposed to water vapor under definite condition of temperature and partial pressure. The amount of water vapor adsorbed by a porous body at a given temperature and partial pressure depends both upon the size of the

pores and upon the total interior volume of said pores. Thus, two materials may have pores such that the internal volume of the pores in a gram of one material is the same as in a gram of the other, and yet the pores in one may be smaller than in the other. The one having the smaller pores will adsorb vapor at lower partial pressures than the other. In other words very small pores are required in order to adsorb vapors at low partial pressures. To illustrate, assume that a building brick has the same internal volume as an equal weight of silica gel. The brick, however, will adsorb substantially no water vapor at pressures below atmospheric, whereas the silica gel will adsorb large amounts at very low pressures. This is explained as follows. A liquid that wets a capillary tube will rise in the tube above the level of the surface of the liquid surrounding the same, the extent of the rise varying with the diameter of the tube. The vapor pressure of the liquid inside the tube is smaller than the vapor pressure at the level surface of the liquid outside the tube. This lowering of the vapor pressure by the liquid within the capillary tube is not appreciable until the diameter of the tube is extremely small, and the smaller the bore of the tube, the greater the decrease in vapor pressure. Consequently the vapor pressure within the pores of a body having small pores is less than in a body having large pores, with the result that the body having the smaller pores will adsorb vapors and gases at lower partial pressures.

Thus, by determining the amount of a given material, water for example, which may be adsorbed by each of two porous bodies under the same condition of temperature and partial pressure, I have a means of comparing the size and volume of the pores in the two adsorbents. For example, a sufficient percentage of the total internal volume in silica gel is made up of such small pores that the gel will adsorb water to such an extent that it will contain, at 30° C. about 21% of its own weight of water when in equilibrium with water vapor at a partial pressure of substantially 22 mm. of mercury.

Materials suitable for the present invention should have pores of such size that the material will adsorb water vapor to such an extent as to contain not less than about 10% of its own weight of water when in equilibrium with water vapor at 30° C. and a partial pressure of substantially 22 mm. of mercury.

Preferably silica gel is employed as the porous material. As stated this material has pores of such size that it will adsorb water vapor to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at 30° C. and a partial pressure of substantially 22 mm. of mercury. But other adsorbents might be used provided they have a sufficient percentage of their internal volumes made up of small pores. Other gels might be used, also, provided they are made with pores of the size required for this invention i. e. gels of oxide of tin, aluminum, tungsten, titanium, iron, combinations of two or more of these oxides, and gels consisting of silica oxide with one or more of the foregoing and other oxides. At the present time, however, I have found silica gel to be the most satisfactory adsorbent for vapor from the liquid in the evaporator. In stating that the adsorbents for the present invention should adsorb not less than 10% of their weight of water vapor, I do not mean this is an exact line of demarcation between satisfactory and unsatisfactory adsorbents. The limit of 10% is intended to indicate in general about the maximum size pores that can be employed with some degree of success. Of course, for best results materials having smaller pores should be used.

The adsorbing action is a purely physical phenomenon, and involves no chemical action. Any body or material having pores of the size and quantity defined herein will act as stated and is suitable for use as an adsorbent in the present apparatus.

A porous adsorbent may adsorb a vapor or gas either "statically" or "dynamically". In dynamic adsorption there is relative movement of the adsorbent and the vapor. For example, the vapor may be adsorbed from a stream of gases passing through a bed of the adsorbent.

In "static" adsorption there is no relative movement of the vapor and adsorbent. For example, the adsorbent is disposed in a closed vessel containing the vapor to be adsorbed. Thus, when a dish containing the adsorbent is placed in a closed jar having sulphuric acid therein, the adsorbent will take up water vapor until it is in equilibrium with the water vapor in the jar.

Van Bemelen and others have studied the adsorption of water vapor by silica gel statically and found that it required a long time for silica gel to come into equilibrium with the vapor around the gel. In most cases it took weeks, and sometimes months.

Later, as disclosed in Patent No. 1,335,348 it was discovered that silica gel would adsorb a vapor, dynamically, almost instantaneously.

In the present invention, the adsorber is in communication with the evaporator, and so the vapor from the evaporator is adsorbed statically by the silica gel. From what was known, prior to my invention, I reasoned that this adsorption would be so slow that it would be impractical. I have discovered, however, that the adsorption is rapid provided there are substantially no permanent gases present. In order to carry on the adsorption in the

absence of permanent gases I provide a vacuum pump 14 in communication with the adsorber by means of a conduit 15.

After the adsorbing material has adsorbed vapor from the liquid in the evaporator, it may be freed of this adsorbed vapor and again used as an adsorbent. One method of thus freeing the adsorbent of its vapor, or as it is termed "activating" the material, is shown in the drawings. Hot gases from a furnace or other source 16 are conducted by means of a conduit 17 to the adsorber and these gases heating the adsorbent material drive off the vapor that may be present in its pores, a discharge conduit 18 being provided, this conduit being connected to an exhaust fan 19.

In operation the valves 20 and 21 controlling the activation of the adsorbing material are closed and valves 22 and 23 opened. The vacuum pump substantially removes the permanent gases from within the adsorber and evaporator, whereupon the liquid boils and the vapor given off is adsorbed by the porous material. This evaporation of the liquid within the evaporator of course produces a refrigerating effect. After the adsorbing material has taken up vapor from the liquid in the evaporator, the valves 22 and 23 are closed and valves 20 and 21 opened. The exhaust fan 19 will then effect a flow of the hot gases through the bed of adsorbing material and liberate the vapor adsorbed thereby so that the adsorbing material is "activated". After this has been done the valves 20 and 21 will be closed and valves 22 and 23 opened whereupon the adsorbing material will again become active to take up vapor and produce a refrigerating effect. Liquid to make up for that lost in activating the adsorbing material may be supplied to the evaporator through a conduit 24.

If it is desired to carry on the refrigerating effect without any interruption, then two adsorbers may be employed, one being used to adsorb the vapor while the adsorbing material in the other is being activated. Thus, as shown, a second adsorber 13^a at its upper end has a conduit 12^a in communication with the conduit 12 leading to the evaporator and this conduit 12^a has a valve 22^a for controlling the flow therein. At its lower end the second adsorber 13^a by means of a conduit 15^a is in communication with the conduit 15 leading to the vacuum pump, valve 23^a being provided to control this conduit. This second adsorber is also in communication with the conduit 17 leading to the furnace and with the conduit 18 leading to the exhaust fan 19, valves 20^a and 21^a being provided to control flow to or from said furnace and fan, respectively.

The operation of this second adsorber is exactly like the one already described. When one adsorber is in communication with the evaporator, the other is cut off therefrom and is having its adsorbing material activated.

The second form of the invention is shown in Figure 2 wherein a closed vessel forming an evaporating chamber 110 is in communication with an adsorber 113 by means of a conduit 112. The evaporator 110 contains a liquid such as brine or water which is evaporated to obtain the refrigerating effect. The adsorber 113 is of any suitable form and is charged with a porous material 114 preferably in granular form, adapted to adsorb in its pores, the vapor from the liquid.

Suitable means, hereinafter described, is provided to liberate the vapor from the porous material, and this liberated vapor is condensed and returned to the evaporator. For this purpose a condenser 125 is provided, being in communication with the adsorber through a conduit 126 and with the evaporator through a conduit 127. The condenser as well as the conduits 126 and 127 are free of permanent gases. In other words the evaporator, adsorber, and condenser which form a closed path for the vapor are substantially free of permanent gases.

The permanent gases are exhausted from the parts just described in any suitable manner. According to one method, this can be effected by means of a vacuum pump, the opening through which the apparatus has communication with the pump being sealed after the permanent gases have been removed. For this purpose, the valve 142 in conduit 112 might be a three-way valve, the third opening in the valve being adapted to be connected with a pump. After the permanent gases have been exhausted, the valve will be turned to close the said third opening and then this third opening might be sealed to prevent the admission of any gases. Of course, the evaporator is supplied with the necessary liquid, such as brine or water before the opening is sealed. According to another method of exhausting the permanent gases, the evaporator may be supplied with its liquid and then heated to convert some of the liquid into vapor, thereby driving out the permanent gases from the apparatus through a vent. After all the permanent gases have been driven out in this way, the vent which may be the third opening of valve 142 mentioned above is sealed. In order that no permanent gases may leak into the apparatus, or the vacuum be destroyed in any way, the conduit connections to the evaporator, condenser and adsorber are all welded to these parts respectively.

After the adsorbing material has adsorbed vapor from the liquid in the evaporator, it may be freed of this adsorbed vapor and can again be used as an adsorbent. One method of thus freeing the adsorbent of its vapor, or as it is termed "activating" the material, is shown in the drawings. One or more coils

128 are disposed in the porous material in the adsorber, these coils, at one end through a conduit 129, and at the other end through a conduit 130, being in communication with a heater 131. The heater may be of any suitable type. As shown it comprises a coil 140 having communication at its ends with the conduits 129 and 130 respectively. A burner or any other source of heat 141 is disposed beneath the coil 140. A liquid such as water is supplied through the pipe 132, a valve 133 being provided to control the flow. Preferably this pipe 132 is connected with the water supply in the house. The water in the coil 140 is thus heated and flows through pipe 129 to the coils 128 within the adsorber and thence returns by conduit 130 to the heating coil 140. The hot water passing through the coils within the adsorber heats the adsorbing material thereby liberating the vapor adsorbed within its pores. The water within the heater may be heated above the boiling point so that the vapor will be rapidly driven off from the adsorbing material. After the porous material has been activated in this manner, the valve 133 is opened thereby admitting cold water from the water mains of the house, and valve 134 is closed and valve 135 opened permitting discharge of the cooling water. Thus the coils 128 within the adsorber now become cooling coils and reduce the temperature of the porous material so that it will adsorb more efficiently.

The vapor liberated from the porous material pases through the conduit 126 to the condenser 125. Suitable means such as a valve 142 in conduit 112 may be provided so that the vapors will not return to the evaporator through pipe 112. If desired, this condenser may be cooled in any suitable manner, as by means of a coil 136 supplied with cooling water from the water mains of the house through pipe 137, this cooling water being carried off through a pipe 138. A valve 139 in pipe 137 may be provided to control the flow of the cooling water. Suitable means such as a valve 143 may be provided in the conduit 127 so that communication between the evaporator and the condenser may be cut off when the vapor is being adsorbed by the porous material.

To start the apparatus, valve 142 is opened and valve 143 closed whereupon vapor from the evaporator is adsorbed by the porous material in the adsorber. If desired, cooling water for the adsorber may be admitted through pipe 132, the flow being controlled by valves 133 and 135. After the porous material has been adsorbing the vapor for a sufficient time, valves 142, 133 and 135 are closed. Then the heater 131 is put into operation so that the water within the coils is heated thereby activating the porous material. The vapor driven off from the porous material passes through conduit 126 to the condenser 125, cooling water being admitted to coil 136 through valve 139. After the porous material has been activated, valves 143, 133 and 135 are opened and valves 134 and 139 closed. The setting of valves 135 will control the circulation of cooling water through the coil 128. The vapor condensed in the condenser will then flow through conduit 127 into the evaporator. To start another cycle of operations, the valve 143 is closed and valve 142 opened.

It will be observed that no vacuum pump or compressor is employed in this form of the apparatus. The only manipulation required is to start and stop the heater 131 and operate certain valves 142, 143. Although not shown, of course automatic means may be provided to operate these parts, the automatic means being thermostatically controlled or not as desired.

While the invention has been disclosed using a refrigerant which is normally a liquid it can be practiced equally as well by using a gas. As a specific instance sulphur dioxide (SO_2) may be mentioned. If this gas is pumped into the system to completely fill the same and to exclude air and other permanent gases and is put under sufficient pressure, a portion of it will liquefy. The process will then operate as before described using however a positive pressure. Other suitable refrigerants either liquid or gaseous may also be used.

In the claims, the words "in the total absence of permanent gases" are intended to signify that the permanent gases are removed to as great an extent as is practicable with present day methods and apparatus.

This application is a continuation of the following applications:

675,929, Ernest B. Miller, refrigeration, Nov. 20, 1923; 688,020, Ernest B. Miller and Axel Benzon, refrigeration, Jan. 23, 1924; 236,322, Ernest B. Miller, refrigeration, Nov. 28, 1927.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor in the substantial absence of permanent gases, in a porous material having pores of such size that it will absorb water vapor under static conditions to such an extent as to contain not less than about 10% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

2. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor in the substantial absence of permanent gases, in a porous material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water

when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

3. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor in the substantial absence of permanent gases, in silica gel having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

4. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor in the substantial absence of permanent gases, in silica gel having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury and thereafter freeing the material of the adsorbed vapor so that it may again adsorb.

5. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor in the substantial absence of permanent gases, in silica gel having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury and thereafter heating the gel to liberate the adsorbed vapor so that the gel may again adsorb.

6. In apparatus of the character described, in combination, an evaporator adapted to contain a liquid to be evaporated, an adsorber in communication therewith and charged with a porous material capable of adsorbing rapidly vapor from the liquid only in the absence of permanent gases, said material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain not less than about 10% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

7. In apparatus of the character described, in combination, an evaporator adapted to contain a liquid to be evaporated, an adsorber in communication therewith, and charged with a porous material capable of adsorbing rapidly vapor from the liquid only in the absence of permanent gases, said material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

8. In apparatus of the character described, in combination, an evaporator adapted to contain a liquid to be evaporated, an adsorber in communication therewith and charged with silica gel having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

9. A method of refrigeration consisting in evaporating a salt solution and adsorbing the water vapor in the substantial absence of permanent gases, in a hard porous gel having a pore structure like that of silica gel.

10. A method of refrigeration consisting in evaporating a salt solution and adsorbing the water vapor in the substantial absence of permanent gases, in a hard porous silica gel.

11. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor in the substantial absence of permanent gases, in an inorganic material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain not less than about 10% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

12. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor in the substantial absence of permanent gases, in an artificial porous material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

13. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor, in the total absence of permanent gases, in a porous material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain not less than about 10% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury, with such rapidity as to cause cooling of the liquid from which the vapor is evaporated, liberating the vapor thus adsorbed and returning the same for re-use.

14. The method according to claim 13 wherein the adsorbing material is a gel having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury.

15. Apparatus of the character described

including in combination, an evaporator, an adsorber charged with a porous material capable of adsorbing rapidly vapor from a liquid only in the total absence of permanent gases, and a condenser, said parts being in communication and sealed against the entrance of any air, said parts also being totally free from permanent gases, the evaporator being charged with a liquid capable of being evaporated at the temperatures desired and the porous material in the adsorber having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain not less than about 10% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury with such rapidity as to cause cooling of the liquid from which the vapor is evaporated.

16. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor, in the total absence of permanent gases, in an artificial porous material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain not less than about 10% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury, with such rapidity as to cause cooling of the liquid from which the vapor is evaporated, liberating the vapor thus adsorbed and returning the same for re-use.

17. A method of refrigeration consisting in evaporating a liquid and adsorbing the vapor, in the total absence of permanent gases, in an inorganic porous material having pores of such size that it will adsorb water vapor under static conditions to such an extent as to contain at least 21% of its own weight of water when in equilibrium with water vapor at substantially 30° C. and a partial pressure of substantially 22 mm. of mercury, with such rapidity as to cause cooling of the liquid from which the vapor is evaporated, liberating the vapor thus adsorbed and returning the same for re-use.

In testimony whereof I hereunto affix my signature.

ERNEST B. MILLER.