(54) Title: A PHYSICAL ADSORPTION BASED REFRIGERATION SYSTEM

(57) Abstract: One aspect of the present invention relates to a physical adsorption based refrigeration system, which generally comprises (1) an adsorption bed substantially filled or packed with an activated carbon adsorbent adapted to adsorb a refrigerant, and (2) heat exchange means located within the adsorption bed and adapted to exchange heat between the adsorption bed and a waste heat fluid carried by the heat exchange means. The refrigeration system may include of a series of integrated adsorption beds and heat exchange means in a cascadelike configuration. Another aspect of the present invention relates to a method of charging a physical adsorption bed filled with an activated carbon adsorbent. The method generally comprises the steps of (1) evacuating a substantial amount of residual gas from the adsorption bed at a reduced pressure, (2) charging the adsorption bed with a refrigerant which adsorbs to the activated carbon adsorbent, and (3) providing a cooling fluid to the adsorption bed to maintain its temperature at a relatively low level.
A PHYSICAL ADSORPTION BASED REFRIGERATION SYSTEM

FIELD OF THE INVENTION

The present invention broadly relates to a physical adsorption based refrigeration system. The invention also generally relates to a method of charging and operating a physical adsorption based refrigeration system.

BACKGROUND OF THE INVENTION

The magnitude of heat rejected through the stack of thermal power plants is about the same as the power generated. For example, a 500 MW (megawatt) thermal power plant would release nearly 500 MW through the stack gas even after recovering most of it in economizers and air pre-heaters. The temperature of this stack gas is in excess of 150 °C. In some combined cycle plants using natural gas as primary energy source, it is even higher. Similarly, numerous process industries have the perennial problem recovering waste heat with more and more environmental laws being put in place in several countries.

Hitherto, the technology available for recovering the waste heat was quite limited. The possibilities are to use a LiBr-water or ammonia-water liquid absorption cooling systems. The former is bogged down with problems of operation under sub-atmospheric pressures and limited range of source of heat energy (typically no greater than 90 °C in single stage systems) due to reorystallization problems. The latter uses ammonia as a refrigerant and in association with water makes a highly corrosive mixture creating numerous maintenance and operational issues. In addition, these liquid sorption systems need solution pumps and heat exchangers, a separate adsorber and a desorber complicating the hardware inventory. Further, these systems are seldom scalable to large capacities of the order of several hundreds of kilowatts of cooling capacity. Silica-gel-water based solid sorption systems posed some challenge to liquid sorption cooling but it has the same problem of entire system operating well below atmospheric pressure and impossibility of using below sub-zero temperatures.

Prior art pertaining to adsorption cooling systems (see for example US patent no. 5,388,637 by Jones) has been directed to systems or methods to increase the heat conductivity to and from an adsorbent, for example by coating a relatively thin layer of the adsorbent onto a heat exchanger using a binder. The use of a binder, however, reduces the adsorption surface area of the adsorbent, thereby compromising the amount of refrigerant that can be adsorbed. Furthermore, the amount of heat that can be recovered by systems suggested in the prior art is limited, and not suited for heat recovery of more than hundreds of kilowatts.

SUMMARY OF THE INVENTION

According to one aspect of the present invention there is provided a physical adsorption based refrigeration system comprising:
an adsorption bed substantially filled or packed with an activated carbon adsorbent
adapted to adsorb a refrigerant; and
heat exchange means located within the adsorption bed and adapted to exchange heat
between the adsorption bed and a waste heat fluid carried by the heat exchange means.

Preferably the heat exchange means is located throughout the adsorption bed. More preferably the
heat exchange means includes one or more heat exchange conduits being adapted to carry the
waste heat fluid. Even more preferably said one or more conduits are in the form of concentric flow
passage ways. Alternately the conduits are each finned tubes wherein the fins are formed as a
helix or spiral.

Preferably the refrigeration system also comprises a heat valve and a cooling valve operatively
coupled to the heat exchange conduits and dedicated to the waste heat fluid and a cooling fluid,
respectively. More preferably, the heat valve and the cooling valve are individually controlled.

Preferably the adsorption bed includes an insulated and generally cylindrical-shaped adsorption
vessel. More preferably the adsorption vessel has approximately equal dimensions of length and
diameter to reduce heat loss.

Preferably the activated carbon adsorbent is in a powder, granule or pellet form. More preferably
the activated carbon adsorbent has an adsorption surface area of no less than 2000 m$^2$/g. Even
more preferably the activated carbon adsorbent has a micropore volume of no less than 1 cc/g.

Preferably the adsorption bed further comprises filters connected to the adsorption vessel and
arranged to contain the activated carbon adsorbent within the adsorption bed. More preferably the
filters have a pore size that is less than or equal to 5 µm.

Preferably the bulk density of the activated carbon within the adsorption bed is 300 kg/m$^3$ or higher.

Preferably the physical adsorption based refrigeration system includes a series of integrated
adsorption beds and heat exchange means in a cascadeable configuration. More preferably the
refrigeration system includes an intercooler located between each of the series of the integrated
adsorption bed and heat exchange means.

According to another aspect of the invention there is provided a method of charging a physical
adsorption bed filled with an activated carbon adsorbent, said method comprising the steps of:
evacuating a substantial amount of residual gas from the adsorption bed at a reduced
pressure;
charging the adsorption bad with a refrigerant which adsorbs to the activated carbon
adsorbent; and
providing a cooling fluid to the adsorption bed to maintain its temperature at a relatively low
level.

Preferably the step of charging the adsorption bed includes the steps of:
at least partially charging the adsorption bed with the refrigerant and at least partially evacuating the refrigerant from the adsorption bed one or more times; and fully charging the adsorption bed with the refrigerant.

More preferably the step of at least partially evacuating the refrigerant from the adsorption bed includes providing a waste heat fluid to the adsorption bed to maintain its temperature at a relatively high level.

Preferably the reduced pressure is of the order of 0.01 mbar.

Preferably the step of charging the adsorption bed with a refrigerant is performed at a rate of no more than 1 kg of refrigerant per minute.

Preferably the step of charging the adsorption bed with a refrigerant is performed at a slower rate near the beginning and near the end of the charging process.

Preferably the step of evacuating residual gas from the adsorption bed includes a period of reduced pressure of at least a day.

**BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS**

**FIG. 1A** Side view of one embodiment of the adsorption thermal compressor.

**FIG. 1B** Top view of one embodiment of the adsorption thermal compressor.

**FIG. 2** An embodiment of the heat exchanger.

**FIG. 3** Schematic arrangement of a series of compressors sharing the same supplies of waste heat fluid and cooling fluid.

**FIG. 4** Schematic arrangement of a series of compressors sharing the same refrigeration circuit.

**FIG. 5A** Plan view of a top flange suitable for use with the embodiment of the thermal compressor shown in Figures 1A and 1B.

**FIG. 5B** Top view of a bridging component suitable for connecting between the top flange shown in Figure 5A and the refrigerant passage ways.

**FIG. 5C** Side view of a bridging component suitable for connecting between the top flange shown in Figure 5A and the refrigerant passage ways.

**FIG. 6A** A plot showing the compression cycle of an adsorption thermal compressor.

**FIG. 6B** A plot showing the compression cycle of an adsorption thermal compressor.

**FIG. 7** Schematic arrangement of two compressors cascaded into a two-stage system.
FIG. 8 Schematic arrangement of a physical adsorption based refrigeration system comprising two sub-systems with an external heat exchanger.

FIG. 9 Schematic arrangement of a physical adsorption based refrigeration system and a conventional mechanical vapour compression refrigeration system with an external heat exchanger.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

One aspect of the present invention in its preferred form is directed towards an adsorption thermal compressor that forms part of a physical adsorption based refrigeration system.

Figures 1A and 1B show the side view and the top view, respectively, of one embodiment of the adsorption thermal compressor 1. The compressor 1 generally includes an adsorption bed 2 and a heat exchanger 3 located within the adsorption bed 2. The adsorption bed 2 is substantially filled or packed with an activated carbon adsorbent 4 which may physically adsorb a refrigerant. A high filling factor of the activated carbon adsorbent in the adsorption bed enables high heat recovery capacities in a compact compressor. An example of a suitable refrigerant is R-507a.

The heat exchanger 3 is responsible for transferring heat to or from the adsorption bed 2, and is ideally located throughout the adsorption bed 2. In the embodiment shown in Figures 1A and 1B the heat exchanger 3 comprises heat exchange conduits in the form of concentric flow passage ways, for example, roll bond stainless steel sheets bent in a semi-circular fashion. In another embodiment, the heat exchange conduits may take the form of a tube 5 with helical or spiral fins 6, as shown in Figure 2.

In some embodiments, the heat provided by the heat exchanger 3 to the adsorption bed 2 may come from waste heat produced in thermal power plants or process industries, or utilisation of solar or geothermal energies. The heat exchanger 3 may also carry a cooling fluid for cooling the adsorption bed 2. The cooling fluid may be compressed air at the ambient temperature.

In the embodiment shown in Figure 1B both the waste heat fluid 7 and the cooling fluid 8 supplied to the heat exchanger 3 are carried by the same heat exchange conduits. The supply of the waste heat fluid 7 and the cooling fluid 8 may be controlled by a heating valve 9 and a cooling valve 10, respectively. These control valves allow the heating fluid 7 alone or the cooling fluid 8 alone (or a combination of both) to flow to the heat exchanger 3 thereby controlling the temperature of the adsorption bed 2. The fluid may then exit through exhaust passage way 11 to a stack.

In some embodiments, the adsorption bed 2 is insulated to minimise heat loss. The adsorption bed may also be of a generally cylindrical-shaped adsorption vessel. To further minimise heat loss, the adsorption vessel may have approximately equal dimensions of length and diameter.

The activated carbon adsorbent 4 may be in powder, granule or pellet form. It is recommended that the activated carbon used have an adsorption surface area (termed as BET surface area) of no
less than 2000 m³/g and a micropore volume of no less than 1 cc/g. AX-21 and Maxsorb are some commercial specimens that meet these targets.

One aspect of the invention applies to large cooling capacities of the order of several hundreds of kilowatts (kW) where heat recovery, for example, from thermal power plants is involved. In some embodiments, as shown in Figure 3, a series of compressors 1 each having their own adsorption bed may share the same supply of waste heat fluid 7 and cooling fluid 8 and the same exhaust passage way 11. In these embodiments, there may be a heating valve 9 and a cooling valve 10 dedicated to each compressor, as shown in Figure 3, whereby the temperature of each of the compressors may be controlled individually.

Similarly a series of compressors may also share the same refrigeration circuit. Figure 4 shows one embodiment of the invention where each of the four compressors is connected to refrigerant passage ways 12 and 13, which in turn are connected to a common refrigeration circuit. The refrigerant passage ways 12 and 13 may include a hot refrigerant valve 16 and a cold refrigerant valve 17, respectively, to control the flow of refrigerant in and out of each of the compressors 1.

The common refrigeration circuit may include a hot refrigerant line 14 connected to a condenser and a cold refrigerant line 15 connected to an evaporator. The external refrigeration circuit comprising the condenser, the evaporator and an expansion device is in line with what one would find in a conventional mechanical vapour compression refrigeration system.

Generally hot refrigerant leaves the compressor 1, enters the hot refrigerant line 14 through the hot refrigerant valve 16 and flows to the condenser. After passing through the expansion device and into the evaporator, the hot refrigerant is cooled. Cold refrigerant then flows from the evaporator, through the cold refrigerant line 15 and the cold refrigerant valve 17 back to the compressor 1.

Preferably one or more filters are inserted between the compressor 1 and the hot and cold refrigerant lines 14 and 15 to prevent the activated carbon from entering the external refrigeration circuit. The filters preferably have a pore size that is less than or equal to 5 µm and are preferably made from sintered stainless steel.

Figure 5A shows the plan view of a top flange 19 suitable for use with the embodiment of the compressor shown in Figures 1A and 1B to cover the adsorption bed 2. The top flange 19 includes heat exchange openings 20 through which the waste heat fluid 7 and the cooling fluid 8 may flow to the heat exchanger 3. The top flange 19 also includes refrigerant inlet/outlets 21 through which the refrigerant flows in and out of the adsorption bed 2. The top flange 19 may also include manholes 22 through which the activated carbon adsorbent 4 may be loaded into or unloaded from the adsorption bed 2. Figures 5B and 5C show the plan and side views of a bridging component 23 suitable for connecting between the top flange 19 and the refrigerant passage ways 12 and 13.

Having described a preferred embodiment of the compressor, we now describe the operation of the compressor. Generally the operation cycles through the following four steps: (1) adsorption, (2)
heating and pressurisation, (3) desorption, and (4) cooling and depressurisation. Figures 6A and 6B show these four steps on the pressure-concentration-temperature plane (p-C-T plane).

(1) Adsorption

A refrigerant flowing along the cold refrigerant line 15 may be drawn into the compressor 1 by closing the hot refrigerant valve 16 and opening the cold refrigerant valve 17. The refrigerant is adsorbed by the activated carbon adsorbent 4 in the adsorption bed 2. Since adsorption is an exothermic process, the adsorption bed 2 may be kept cooled when adsorption takes place by opening the cooling valve 10 and closing the heating valve 9. Since the amount of adsorption decreases with an increase in the temperature, keeping the adsorption bed 2 cool also increases the amount of adsorbed refrigerant. This step is indicated by a-b in Figures 6A and 6B.

(2) Heating and pressurisation

When the adsorption bed 2 is at least partially saturated with the refrigerant, it may be isolated by closing both the hot refrigerant valve 16 and the cold refrigerant valve 17. The adsorption bed 2 may then be heated by opening the heating valve 9 and closing the cooling valve 10. The increase in temperature causes the pressure inside the compressor 1 to increase. This step is indicated by b-c in Figures 6A and 6B.

(3) Desorption

When the required pressure inside the compressor 1 is attained, the hot refrigerant valve 16 is opened and the refrigerant flows out of the compressor 1, and along the hot refrigerant line 14 to the condenser. This step is indicated by c-d in Figures 6A and 6B.

(4) Cooling and depressurisation

The adsorption bed 2 is isolated by closing both the hot refrigerant valve 16 and the cold refrigerant valve 17. The adsorption bed 2 may then be cooled by closing the heating valve 9 and opening the cooling valve 10. The decrease in temperature causes the pressure inside the compressor 1 to decrease. This step is indicated by d-a in Figures 6A and 6B. Ideally this step brings the adsorption bed 2 back to the start of step (1).

In some embodiments, the hot refrigerant valve 16 and the cold refrigerant valve 17 may be either check valves that open and close at preset pressure differentials or solenoid operated. In the latter case, a sequencing of opening and closing may be programmed. The valves may also be individually controlled.

The duration of the four steps described above is usually of the order to several minutes. To maintain a relatively continuous flow of refrigerant into the external refrigerant circuit, it may be preferable in some embodiments to operate two or more compressors with some of them
performing different steps of the operation cycle at any one time. Table 1 shows an example of operating four compressors, with each performing a different step of the operation cycle.

Table 1: Compressor Operating Phases

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<th>Compressor 1</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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<td>Desorption</td>
<td>Cooling and depressurisation</td>
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<td>Heating and pressurisation</td>
<td>Desorption</td>
<td>Cooling and depressurisation</td>
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<td>Compressor 4</td>
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<td>Heating and pressurisation</td>
<td>Desorption</td>
</tr>
</tbody>
</table>

We now describe the process of charging an adsorption bed with a refrigerant. When a compressor is first commissioned, it may be beneficial to remove all the residual gases in the adsorption bed 2 (and in the activated carbon adsorbent 4) before fully charging the adsorption bed 2 with the refrigerant. This may be done in the following steps:

(A) Gas is evacuated from the adsorption bed 2 at a reduced pressure. The evacuation and reduced pressure may be achieved by using a vacuum pump such as a turbomolecular pump backed by a rotary pump or a high vacuum oil diffusion pump backed by a rotary pump. Ideally the reduced pressure is of the order of 0.01 mbar and/or is retained for a few days. The vacuum pump may be connected to the hot and/or cold refrigerant lines 14 and 15 for evacuating the adsorption bed 2. Alternatively, especially when the amount of gas to be evacuated from the compressor is relatively large, it is preferred that the vacuum pump is connected as close to the compressor as possible. For example the vacuum pump may be connected to the end of either or both of the refrigerant passage ways 12 and 13, where they would otherwise be connected to the hot and cold refrigerant lines 14 and 15 as shown in Figure 4. After the evacuation, the hot and/or cold refrigerant valves 16 and 17 may be closed to isolate the adsorption bed 2 before connecting the refrigerant passage ways 12 and 13 to the hot and cold refrigerant lines 14 and 15, respectively. During this step it is also preferred that waste heat fluid 7 be supplied to the heat exchanger 3 by opening the heating valve 9 and closing the cooling valve 10 thereby heating the adsorption bed 2 to accelerate the evacuation process.

(B) The adsorption bed 2 is then partially or fully charged with a refrigerant which adsorbs to the activated carbon adsorbent 4. This is done by opening the cold refrigerant valve 17 while the cold
refrigerant line 15 is connected to an external refrigerant source. During the charging process, the adsorption bed 2 may be kept cool by opening the cooling valve 10 in order to increase the adsorption of refrigerant by the activated carbon adsorbent 4.

(C) Ideally the adsorption bed is then evacuated following similar procedures in step (A). During this discharging process, the adsorption bed may also be heated by opening the heating valve 9 in order to reduce the adsorption of refrigerant by the activated carbon adsorbent 4.

The charging (step (B)) and discharging (step (C)) processes may be repeated several times before fully charging the adsorption bed 2 with the refrigerant. Alternatively, the adsorption bed 2 may be charged following only steps (A) and (B) once, without following step (C).

The rate of charging is ideally no more than 1 kg of refrigerant per minute. Generally the rate of charging is slower near the beginning and near the end of the charging process.

In another aspect of the invention two or more compressors may also be cascaded to form a multi-stage thermal compression system. Figure 7 shows such an embodiment with two compressors 1. The left compressor, hereinafter termed as low stage compressor, partially compresses a refrigerant to an intermediate pressure before the refrigerant is received and further compressed by the right compressor, hereinafter termed as high stage compressor. An intercooler 18 may be located between the two compressors 1 to reduce the temperature of the refrigerant released from the low stage compressor to near ambient conditions before it is adsorbed in the high stage compressor. This embodiment can be used for generating lower refrigeration temperatures than those envisaged under the first aspect of invention. This may be suited for, for example, the production of ice using Waste heat. Further, this embodiment can be even more useful when waste heat is available at two different temperatures because the low and high stage compressors may rely on different heat sources.

In another aspect of the invention, the physical adsorption based refrigeration system may comprise a number of sub-systems. In this embodiment, the sub-systems may operate with different refrigerants, and therefore operate at different refrigeration temperatures. The sub-systems may also include any number of compressors. The embodiment shown in Figure 8 comprises two sub-systems 24 (each having two compressors 1) which exchange heat at an external heat exchanger 25. The refrigerant flowing out of the compressor in the left subsystem 24 is first cooled by the desuperheater 30 where the refrigerant temperature drops to nearly the ambient temperature. The sub-system 24 on the right then provides further cooling of the refrigerant to below the ambient temperature at the external heat exchanger 25, before the refrigerant expands in the evaporator 31. The external heat exchanger 25 acts as both the condenser in the refrigeration circuit of the sub-system operating at a lower temperature and the evaporator in the refrigeration circuit of the sub-system operating at a higher temperature. For example, carbon dioxide may be used as the refrigerant for the sub-system operating at the lower temperature, while HFC 134a may be used as the refrigerant for the sub-system operating at the
higher temperature. In this embodiment, the different sub-systems may also operate with the same or different waste heat sources. This embodiment may be suited for the process industries where a large quantity of waste heat is available. For example one may wish to generate sub zero temperatures using waste heat entirely with a physical adsorption technique. Although the two stage system described in Fig. 7 allows this, often one may find it convenient to use two different refrigerants for each stage.

In yet another aspect of the invention a physical adsorption based refrigeration system may assist the operation of a conventional mechanical vapour compression refrigeration system. In this embodiment, as shown in Figure 9, a liquid refrigerant emerging from a condenser 26 connected to a conventional mechanical vapour compressor 27 may be further cooled by a physical adsorption based refrigeration system 28 at a subcooler 29. Such an embodiment may permit maintaining a constant liquid refrigerant temperature for feeding to an evaporator served by the mechanical compressor. This arrangement has the benefit of uninterrupted operation even on days/locations where the ambient temperature raises above the normal operating conditions. The fundamental benefit lies in the fact that, when the ambient temperature is high the only means of reducing the liquid refrigerant temperature below the ambient temperature is use refrigeration means. Most mechanical compressors manufacturers do not recommend operation at suction temperatures higher than about 15 °C for a refrigeration temperature for liquid subcooling of about 20-30 °C. A physical adsorption based refrigeration system together with a mechanical compressor may meet the needs.

Now that several preferred embodiments of the present invention have been described it will be apparent to those skilled in the art that the adsorption thermal compressor has the following advantages:

- Physical adsorption relies on surface phenomena driven by intermolecular attractive forces (Van der Waals forces) rather than formation of chemical bond as in liquid sorption or solid sorption with silica gel and zeolites. As a result, the adsorption - desorption cycles may be infinitely reversible which translates to the commercial benefit that the adsorption thermal compressor may not have be refilled periodically.

- The compressor in conjunction with a suitable refrigerant, such as halocarbon refrigerants, may operate under pressure close to but above atmospheric pressure (at approximately 2 to 13 bar), obviating leakage of air into the compressor and problems associated with the presence of non-condensable gases in the refrigeration circuit. In comparison, the prior art only teaches operating an adsorption system at near-vacuum conditions, or discloses systems that require the use of a corrosive refrigerant, such as ammonia, in order to maintain a desired operating pressure.

- Activated carbon is a natural product, which causes minimal harm to the environment when disposed of eventually.
There is no need for any lubricant for the cooling of the adsorption thermal compressor. This removes the problems created by oil separation, circulation and the drop in evaporator heat transfer.

The operation of the adsorption thermal compressor is relatively insensitive to changes in temperature of the waste heat fluid, unlike a LiBr-water system which fails if the operating temperature exceeds a certain limit.

When another better refrigerant becomes available or if the refrigerant currently used in the adsorption thermal compressor is phased out, no major changes to the cooling system are required. The adsorption bed only needs to be evacuated to remove all the unwanted refrigerant and replace with the new refrigerant.

If required, a physical adsorption based refrigeration system may assist a conventional mechanical vapour compression system, which may supplement high grade energy with low grade thermal energy to achieve the process of compression.

Depending on the requirements of the application, a variable number of adsorption thermal compressors may be used. A system involving the use of adsorption thermal compressors therefore provides scalable cooling capacity ranging from a few watts to, typically, several hundreds of kilowatts.

Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. For example, the refrigerant may be R-1 34a, R-404a, CO₂ or any other refrigerant that may be physically adsorbed to the activated carbon adsorbent. The number of compressors sharing the refrigerant circuit and sharing the supply of waste heat and cooling fluids may vary depending on factors such as the required cooling capacity. A cascadable system such as the one shown in Figure 7 may also comprise any number of compressors with the appropriate number of intercoolers.

All such variations and modifications are to be considered within the ambit of the present invention the nature of which is to be determined from the foregoing description. It is to be understood that any acknowledgement of prior art in this specification is not to be taken as an admission that this acknowledged prior art forms part of the common general knowledge in Australia or elsewhere.
CLAIMS

1. A physical adsorption based refrigeration system comprising:
   an adsorption bed substantially filled or packed with an activated carbon adsorbent
   adapted to adsorb a refrigerant; and
   heat exchange means located within the adsorption bed and adapted to exchange
   heat between the adsorption bed and a waste heat fluid carried by the heat exchange
   means.

2. A refrigeration system as claimed in claim 1 wherein the heat exchange means is located
   throughout the adsorption bed.

3. A refrigeration system as claimed in either of claims 1 or 2 wherein the heat exchange
   means includes one or more heat exchange conduits being adapted to carry the waste
   heat fluid.

4. A refrigeration system as claimed in claim 3 wherein said one or more conduits are in the
   form of concentric flow passage ways.

5. A refrigeration system as claimed in claim 3 wherein said one or more conduits are each
   finned tubes wherein the fins are formed as a helix or spiral.

6. A refrigeration system as claimed in any one of claims 3 to 5 also comprising a heat valve
   and a cooling valve operatively coupled to the heat exchange conduits and dedicated to
   the waste heat fluid and a cooling fluid, respectively.

7. A refrigeration system as claimed in claim 6 wherein the heat valve and the cooling valve
   are individually controlled.

8. A refrigeration system as claimed in any one of the preceding claims wherein the
   adsorption bed includes an insulated and generally cylindrical-shaped adsorption vessel.

9. A refrigeration system as claimed in claim 8 wherein the adsorption vessel has
   approximately equal dimensions of length and diameter to reduce heat loss.

10. A refrigeration system as claimed in either of claims 8 or 9 wherein the adsorption bed
    further comprises filters connected to the adsorption vessel and arranged to contain the
    activated carbon adsorbent within the adsorption bed.

11. A refrigeration system as claimed in claim 10 wherein the filters have a pore size that is
    less than or equal to 5 μm.

12. A refrigeration system as claimed in any one of the preceding claims wherein the bulk
    density of the activated carbon within the adsorption bed is 300 kg/m³ or higher.
13. A refrigeration system as claimed in any one of the preceding claims wherein the activated carbon adsorbent is in a powder, granule or pellet form.

14. A refrigeration system as claimed in any one of the preceding claims wherein the activated carbon adsorbent has an adsorption surface area of no less than 2000 m²/g.

15. A refrigeration system as claimed in any one of the preceding claims wherein the activated carbon adsorbent has a micropore volume of no less than 1 cc/g.

16. A refrigeration system as claimed in any one of the preceding claims further including a series of integrated adsorption beds and heat exchange means in a cascadable configuration.

17. A refrigeration system as claimed in claim 16 further including an intercooler located between each of the series of the integrated adsorption bed and heat exchange means.

18. A method of charging a physical adsorption bed filled with an activated carbon adsorbent, said method comprising the steps of:
   - evacuating a substantial amount of residual gas from the adsorption bed at a reduced pressure;
   - charging the adsorption bed with a refrigerant which adsorbs to the activated carbon adsorbent; and
   - providing a cooling fluid to the adsorption bed to maintain its temperature at a relatively low level.

19. A method as claimed in claim 18 wherein the step of charging the adsorption bed includes the steps of:
   - at least partially charging the adsorption bed with the refrigerant and at least partially evacuating the refrigerant from the adsorption bed one or more times; and
   - fully charging the adsorption bed with the refrigerant.

20. A method as claimed in claim 19 wherein the step of at least partially evacuating the refrigerant from the adsorption bed includes providing a waste heat fluid to the adsorption bed to maintain its temperature at a relatively high level.

21. A method as claimed in any one of claims 18 to 20 wherein the reduced pressure is of the order of 0.01 mbar.

22. A method as claimed in any one of claims 18 to 21 wherein the step of charging the adsorption bed with a refrigerant is performed at a rate of no more than 1 kg of refrigerant per minute.
23. A method as claimed in any one of claims 18 to 22 wherein the step of charging the adsorption bed with a refrigerant is performed at a slower rate near the beginning and near the end of the charging process.

24. A method as claimed in any one of claims 18 to 23 wherein the step of evacuating residual gas from the adsorption bed includes a period of reduced pressure of at least a day.
FIG. 4
FIG. 6A

FIG. 6B
**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/AU2009/0001

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

**F2SB 17/08** (2006.01)  **F2SB 45/00** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

b. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPOCOC, WPI, IPC F2SB 17/08, 25/02, 27/02, 30/04, 30/06, 45/00 and keywords ADSOR, ACTIV, CARBON, CHARCOAL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>WO 1996/009504 A1 (UNIVERSITY OF WARWICK) 28 March 1996</td>
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[X] Further documents are listed in the continuation of Box C  [X] See patent family annex

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Date of the actual completion of the international search

20 March 2009

Date of mailing of the international search report

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Name and mailing address of the ISA/AU

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<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>GB 2076523 A (EXXON RESEARCH AND ENGINEERING COMPANY) 2 December 1981</td>
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<td>A</td>
<td>US 1729083 A (MILLER, ERNEST B et al) 24 September 1929</td>
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<td>See page 1, lines 55-56; page 1, line 71 - page 2, line 44</td>
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