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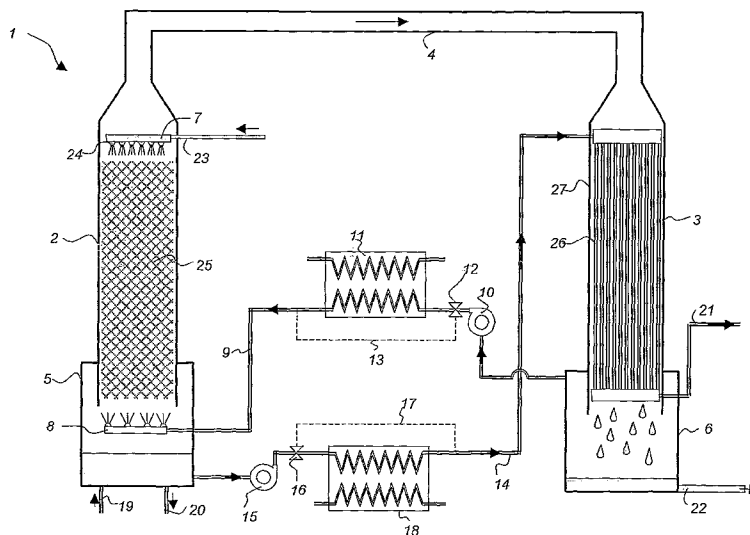
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(54) Title: DESALINATION METHOD AND APPARATUS



(57) Abstract: A humidification-dehumidification desalination apparatus (1), including a humidifier (2) for mixing a water-based solution with a substantial non air based carrier gas. The carrier gas evaporates water from the solution, thereby humidifying the carrier gas. A dehumidifier (3) condenses the moisture laden carrier gas thereby extracting desalinated water, which is collected in a sump (6). A substantially closed loop circulation system including a blower (10) circulates the carrier gas between the humidifier and the dehumidifier. The preferred carrier gas is hydrogen, helium, or ammonia. Also claimed it is a method for selecting a suitable carrier gas by determining different parameters and comparing gases.

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TITLE: DESALINATION METHOD AND APPARATUS**FIELD OF THE INVENTION**

The present invention relates generally to a method and apparatus for the
5 desalination of salt water.

The invention has been developed primarily for use in humidification-
dehumidification (HDH) desalination, and will be described with reference to this
application.

10 BACKGROUND OF THE INVENTION

The worldwide demand for fresh water is escalating due to the population
growth and ever-increasing industrialisation of our society. According to the latest
data from the Australian Bureau of Statistics (ABS), the demand for fresh water in
Australia over the five year period between 1996 to 2001 steadily rose reaching a
15 usage rate of 24,909 GL per year in 2001, almost 8% greater than the annual usage
rate in 1996. The worldwide effect of such demand rises, combined with the
substantial decline of natural resources is currently affecting 25% of the world's
population across 50 countries where the water shortage has already reached a critical
stage. The shortage of fresh water affects poor and rich countries alike primarily
20 because the arid and semi-arid regions spread across the globe not only in the third
world countries but in rich countries, such as USA, UK and Australia.

The following discussion of the prior art is provided as technical background,
to enable the features and benefits of the invention to be fully appreciated in an
appropriate technical context. However, any reference to the prior art should not be
25 taken as an express or implied admission that such art is widely known or forms part
of common general knowledge in the field.

It is known in the art to use desalination to extract freshwater from a variety of
brine sources, such as sea water, salt water from surface resources like lakes and
ponds, and brackish (i.e. salty) water found in deep geothermal reservoirs and
30 aquifers. The terms "brine" as used herein is intended to be construed sufficiently
broadly to encompass not only any type of water/mineral solution such as brines, salt

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water or brackish water whether naturally occurring or artificially produced, but also other water and suspensions and mixtures.

The conventional desalination processes can be classified into three main groups:

- 5 1. Thermal processes, such as multi-stage flash distillation (MSF), multi-effect distillation (MED), thermal vapour compression (TVC), mechanical vapour compression (MVC), and air-based HDH.
2. Membrane processes, such as reverse osmosis (RO), and electrodialysis (ED).
3. Electrolysis processes (EL).

10 Depending on the type of application and location, conventional desalination processes can be driven by fossil fuel or renewable energy sources (e.g. solar, wind, geothermal). The majority of common desalination processes are expensive and energy intensive since in such processes either the brine has to be heated up to temperatures well above the ambient temperature using multi-effect heat transfer units
15 (e.g. MSF, MED, TVC, MVC), or high levels of electrical power are required for the process (e.g. RO, ED and EL). As a result, desalination technologies, such as MSF, MED, TVC, MVC, RO, ED and EL are mostly suitable for large-scale production of freshwater from seawater in densely populated locations where sizable power plants are available.

20 Contrary to the case of densely populated regions, there are circumstances where the desalination needs are relatively small and do not exceed 30 m³/day. For example, on average the potable water usage in most remote rural communities in Australia with populations below 150 is about 10 m³/day. This seemingly small demand creates a whole range of logistical problems for communities living in arid to
25 semi-arid regions in terms of transportation and delivery of freshwater. Technically, all conventional desalination technologies can be applied to small-scale operations particularly if they are driven by renewable energy sources. However, arguably, the desalination technology that is most suited to low capacity freshwater production is the so-called humidification-dehumidification process commonly referred to as HDH
30 process.

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As described before, in the HDH process a stream of air is first humidified to its saturation state by evaporating water from an incoming source of brine and then distilled water is recovered in a condenser. The thermal energy for evaporation can be fed to the system by either heating-up the air or alternatively the brine stream. The principle innovation in the HDH process is that heat recoveries equivalent to multi-effect systems are achieved by maintaining a continuous flow of humid air between the evaporator and condenser, and by partially recycling the brine. This minimises the sensible heat losses and allows the desalination process to be carried out at relatively low temperatures (60-90°C) in a low energy intensive manner.

Desalination of salt water by the HDH process has been the subject of many investigations in the past mainly with the intention of decreasing construction and running costs whilst increasing efficiency. Particular attention has been paid to the use of renewable energy sources for powering the process, especially solar and geothermal energies. In addition, studies have been made on the feasibility of using coolant sea water, ejected at a temperature of about 55°C from a power plant.

Other research has been made of carefully managing the gas flows such as incorporating a closed loop arrangement for air in the solar assisted HDH process by recycling air between the dehumidifier and humidifier units.

However, studies have revealed that even in geothermal assisted HDH processes where the evaporation is efficiently carried out using hot / warm brine, the major shortcoming is that large amounts of air are needed to achieve a given throughput. This is due to the fact that the quantity of water vapour contained in saturated air is relatively low. Thus, the cost of air circulation, not to mention construction and maintenance costs, becomes prohibitively high making conventional HDH systems only marginally viable from an economic standpoint.

It has been proposed to use carrier gases other than air to overcome this weakness. In one modelling study, it was proposed that if CO₂ is circulated through a HDH system by natural convection, not only reasonable gains in heat and mass transfer coefficients can be achieved but the pumping cost of the carrier gas can be also significantly reduced. The use of gases lighter than water vapour (e.g. H₂, He, etc) was dismissed because the mixture densities of these gases and water vapour

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increase with an increase in the water vapour content of the mixture, in turn, slowing down the natural convection process.

However, the use of CO₂ has problems because under the same set of temperatures and pressures, saturated CO₂ contains even less water than saturated air.

5 In addition, the solubility of CO₂ in water is quite high. As a result, great quantities of the CO₂ gas dissolve in water in a HDH process requiring an additional and costly unit operation to separate dissolved carbon dioxide from water.

It is an object of the present invention to overcome or substantially ameliorate one or more of the limitations of the prior art, or at least to provide a useful
10 alternative.

DISCLOSURE OF THE INVENTION

Accordingly, in a first aspect, the invention provides a humidification-dehumidification desalination apparatus including:

15 a humidifier for mixing a water based solution with a substantially non-air based carrier gas to evaporate water from the solution thereby humidifying the carrier gas;

a dehumidifier for condensing water vapour from the carrier gas and thereby dehumidifying the carrier gas; and

20 a substantially closed loop circulation system including a blower, to circulate the carrier gas between the humidifier and dehumidifier.

The term "air" refers to the mixture of gases comprising the earth's atmosphere. This is understood to include approximately 78% Nitrogen, and approximately 21% Oxygen with small amounts of Argon, Carbon Dioxide and other
25 gases.

The term "non-air" refers to any gas which is substantially dissimilar to the composition of "air" with regard to the constituent components and/or the relative proportions thereof.

The term "water based solution" includes any liquid solution, suspension,
30 mixture or combination thereof including water as a constituent component.

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Preferably, the carrier gas is selected such that the ratio of the gas constant of the carrier gas, to the gas constant of the water vapour, (R_g/R_v) is greater than the ratio of the gas constant of the air, to the gas constant of the water vapour, (R_a/R_v).

Preferably, the carrier gas is selected such that the ratio of the specific heat of the carrier gas, to the specific heat of the water vapour, (c_{pg}/c_{pv}) is greater than the ratio of the specific heat of the air, to the specific heat of the water vapour, (c_{pa}/c_{pv}).

Preferably, the carrier gas is selected such that the ratio of the thermal conductivity of the carrier gas, to the thermal conductivity of the water vapour, (k_g/k_v) is greater than the ratio of the thermal conductivity of the air, to the thermal conductivity of the water vapour, (k_a/k_v). Preferably, the carrier gas includes H_2 , He and/or NH_3 gas. More preferably, the carrier gas is composed substantially entirely of one or more gases selected from the group consisting of H_2 , He, and NH_3 .

Advantageously, the closed loop circulation system both recycles the carrier gas and minimises contact between the outside air and the carrier gases.

The dismissal of lighter gasses such as H_2 , He or NH_3 gas, is a major oversight of the prior art. Thermodynamically gases like H_2 and He can accommodate larger quantities of water vapour while exhibiting much better heat and mass transfer rates than air. Advantageously, the issues associated with the density difference between the water vapour and low molecular weight carrier gases can be easily resolved if the mixture is circulated by forced convection. The increase in the pumping power associated with forced convection will be negligible because much smaller volumes of the carrier gas are needed. Advantageously, the invention, at least in a preferred form proposes an HDH based process which integrates the non-air carrier gas and forced convection principles into a unified platform for increasing the production rate of freshwater per unit volume of the brine fed to the system, thereby, substantially reducing the construction, operation and maintenance costs per unit volume of freshwater produced.

Preferably, the humidifier is a packed tower evaporator and the dehumidifier is a shell and tube heat exchanger.

Preferably, the humidifier and dehumidifier are fluidly connected at respective upper ends by means of an insulated duct.

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Preferably, a water solution catchment sump is located at a lower end of the humidifier and a water catchment sump is located at a lower end of the dehumidifier.

Preferably, the closed loop circulation system includes a heat exchanger.

In a second aspect the invention provides a method of selecting a suitable
5 carrier gas for use in a humidification-dehumidification desalination apparatus, said method including the steps of:

determining an initial series of candidate gases;

for each member of the series of candidate gases, determining a series of relative candidate parameters including:

10 an absorption parameter, indicative of the capability of the gas to absorb water vapour relative to air;

a transport parameter, indicative of the heat and mass transfer capability of the gas relative to air; and

15 a heat exchanger parameter, indicative of the heat exchanger size required to operate as an evaporator under equivalent conditions, relative to air;

selecting one or more suitable carrier gas from the series of candidate gases which provide superior performance to that of air based on the combined influence of said parameters.

Preferably, said relative candidate parameters include at least any one of:

20 a cost parameter, indicative of the cost of the gas;

an availability parameter, indicative of the availability of the gas;

a flammability parameter, indicative of the potential flammability risks of the gas;

a toxicity parameter, indicative of the toxicity of the gas; and

25 a solubility parameter, indicative of the solubility of the gas in water.

In another aspect, the invention provides a method of desalinating water in a humidification-dehumidification desalination process, said method including the steps of:

30 humidifying a substantially non-air based carrier gas in a humidifier by means of mixing a water based solution with the carrier gas to evaporate water from the solution;

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dehumidifying the carrier gas in a dehumidifier to extract water; and
forcibly recirculating the carrier gas between the humidifier and dehumidifier
in a closed loop circulation system.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will now be described, by way of
example only, with reference to the accompanying drawings in which:-

Fig. 1 is a flow diagram displaying the algorithm used to determine the
suitability of various carrier gasses;

10 Fig. 2 is a schematic representation of a Humidification-Dehumidification
plant in accordance with the invention;

Fig. 3A is a schematic cross section of a shell and tube heat exchanger with an
in-line tube bundle configuration; and

15 Fig. 3B is a schematic cross section of a shell and tube heat exchanger with a
staggered tube bundle configuration.

PREFERRED EMBODIMENT OF THE INVENTION

Referring to Fig. 1, the desalination apparatus 1 includes a pair of heat
exchangers in the form of a humidifier 2, and dehumidifier 3, which respectively
20 evaporate a brine water source to water vapour and subsequently condense the water
vapour to pure water.

In general terms, the invention utilises a closed loop re-circulation system
wherein the carrier gas and carrier gas-water vapour mixture are circulated under
forced convection. Furthermore, the invention replaces air, which ordinarily acts as a
25 carrier gas, by another gas (or a mixture of gases) which is selected to have overall
superior carrier gas characteristics than air. Those characteristics include at least one
of, but are not limited to having a greater gas constant (R_g), specific heat (c_{pg}) and
thermal conductivity (k_g) than those of air and water vapour (i.e. R_v , c_{pv} , and k_v).

Advantageously, this configuration allows comparatively larger quantities of
30 water vapour to be mixed with the carrier gas in a mixture for which the ratios of ($R_g /$

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R_v), (c_{pg} / c_{pv}) , and (k_g / k_v) , are greater than those of air-water vapour. This ultimately enhances the efficiency and productivity of the plant.

From a thermodynamic perspective, the amount of water vapour that can be absorbed by air under a given set of temperature and pressure is expressed by the absolute or specific humidity denoted by ω :

$$\omega = \frac{m_v}{m_g} = \frac{P_v V / (R_v T)}{P_g V / (R_g T)} = \left(\frac{R_g}{R_v} \right) \left(\frac{P_v}{P - P_v} \right) \quad (\text{kg water vapour / kg dry air}) \quad (1)$$

where m_v is the mass of the water vapour, m_g the mass of dry air, P_v the partial pressure of water vapour, P_g the partial pressure of dry air, V volume, and P the total pressure. What thermodynamically differentiates the moisture content of air from another gas under identical set of temperature and pressure is the ratio of R_g / R_v . This ratio for air is about 0.622 which is fairly small. If one uses a gas with a higher gas constant, then the moisture content of the mixture will be significantly higher than that of the air-water vapour mixture.

However, the water vapour carrying capacity of a carrier gas is underpinned not only by its equilibrium (i.e. thermodynamic) characteristics but also by its heat and mass transfer rates in the heat exchange unit operations. In a flow situation where the forced convection is prevailing, the convective heat (h) and mass transfer (J) coefficients of a gas-vapour mixture can be estimated from:

$$h = (L \times k \times Nu), \quad J = h / (c_p \times Le) \quad (2)$$

where L is a characteristic length, k the mixture thermal conductivity, Nu the Nusselt number (a function of Reynolds and Prandtl numbers), and Le the Lewis number (a function of Prandtl and Schmidt numbers). Preliminary calculations for a simple counter-current flat-plate evaporator, with a characteristic length of 1 m operating under laminar flow conditions at an average temperature of 50°C (ΔT) and atmospheric pressure, has provided the results presented in the table below. The number of plates (N), their total surface area (A), and dimensions (L & W) were determined using the following relationships for the number of transfer units of heat (NTU_h) and mass (NTU_m). Note that, assuming a vertical plate arrangement, J is expressed per unit length of the plate.

$$NTU_h = UA / C_{min} = (hA + JLH_v / \Delta T) / (\dot{m}c_p)_{min} \quad NTU_m = \dot{m}_v / (JD), \quad N = NTU_m + 1, \quad W = A / (ND) \quad (3)$$

where U and \dot{m}_v are the overall heat transfer coefficient and the mass flow rate of water vapour, respectively, and C_{min} is the minimum value of $\dot{m}c_p$ corresponding to either heat or cold flow streams.

5 Results for a production rate of 1 m³/day using mixtures of various gases and water vapour (W.V.).

Parameter or Variable	H ₂	He	NH ₃	CO ₂	Air	W.V.
Molecular weight (kg/kmol)	2.02	4.00	17.03	44.01	28.97	18.00
R_g / R_v (R for W.V. is 0.46 kJ/kg.K)	8.94	4.50	1.06	0.41	0.63	1.00
k_g / k_v (k for W.V. is 0.02 W/m.K)	9.63	7.88	1.37	1.04	1.4	1.00
C_{pg} / C_{pv} (k for W.V. is 2039 J/kg.K)	7.05	2.55	1.14	0.43	0.49	1.00
$\Delta\omega$ (% increase in ω of the mixture with respect to that of air/W.V.)	1320.7	617.24	68.97	-34.48	0.00	
Δh (% increase in h of the mixture with respect to that of air/W.V.)*	215.00	203.50	4.19	-20.69	0.00	
ΔJ (% increase in J of the mixture with respect to that of air/W.V.)**	-55.80	10.13	-58.91	-26.88	0.00	
NTU_m (m) assuming a characteristic length (L) of 1	4.73	1.90	5.08	2.86	2.09	
N (number of heat exchanger plates)	6	3	6	4	3	
A (m ²) total heat transfer area assuming a NTU_h of 1	1.48	1.53	4.47	5.87	4.66	
W (m) plate width	0.25	0.51	0.75	1.47	1.55	
A/A_{air} the ratio of total heat transfer area to that of air/W.V.	0.32	0.33	0.96	1.26	1.00	
ΔA (% reduction in A with respect to that of air/W.V.)	68.22	67.06	3.92	-26.15	0.00	

* h_{airWV} is 5.06 W/m².K,

** J_{airWV} is 5.54×10^{-3} kg/m.s

Referring to the table, for a given freshwater production rate of 1 m³/day, much smaller unit sizes are required when carrier gases, such as H₂, He and NH₃ with (R_g / R_v), (c_{pg} / c_{pv}), and (k_g / k_v) ratios greater than those of a conventional air / water vapour mixture, are employed. This confirms that much higher quantities of water vapour can be carried when gases like H₂, He and NH₃ are used. Conversely, in the case of CO₂ for which (R_g / R_v), (c_{pg} / c_{pv}), and (k_g / k_v) ratios are smaller than corresponding values for an air-water vapour mixture, a larger (26% larger than an air-based evaporator) heat transfer surface area is required. This is to compensate for the drop in the water vapour carrying capacity of CO₂ as indicated by the negative values of $\Delta\omega$, Δh , and ΔJ . The calculation indicates that contrary to the suggestions of the prior art, CO₂ is not a suitable carrier gas for HDH applications.

The solubility of H₂, He and NH₃ in water are also much smaller than those of CO₂ and air. For example, the mole fraction solubility of H₂ and He in water at 298.15 K and 101.325 kPa partial pressure of gas are 1.41×10^{-5} and 0.71×10^{-5} , respectively, while the solubility of CO₂ under similar conditions is 61.48×10^{-5} . This

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implies that compared with air or CO₂, less H₂ or He will dissolve in water.

Consequently, it may well be unnecessary to provide additional equipment to separate dissolved gas from freshwater in the dehumidifier.

It should be also highlighted that the values of $\Delta\omega$, Δh , and ΔJ do not have to be positive to be considered a suitable carrier gas, since the overall gain in the water carrying capacity is underscored by a balance among these parameters rather than their individual effects. For example, one can get almost the same gain (i.e. indicated by ΔA or A/A_{air}) if one uses either He or H₂ despite the fact that hydrogen shows a decrease of almost 55.8% in mass transfer coefficient (J) whereas helium exhibits a 10.13% increase. This is because the negative effect of the drop in J in the case of hydrogen is offset by its 13.207 (i.e. almost an order of magnitude) and 2.15 folds increase in ω and h , respectively (see Table 1). For helium, however, the rise in ω and h are only 6.1724 and 2.035 folds, respectively. Ammonia exhibits smaller gains (only about 3.92% in ΔA) because the 58.91% fall in J is only marginally offset by the increases of 68.97% in ω and 4.19% in h .

Referring to Fig 1, the algorithm described above and used to select suitable carrier gasses is shown in flow chart form. While the gases analysed above are limited to H₂, He, NH₃ and CO₂, it will be appreciated that other substantially pure gases, as well as other mixtures of gases might be considered in a similar manner. For instance some other gases which may be considered include, organic fluids such as propane and iso-butane, HFC based refrigerants, such as difluoromethane (R-32), pentafluoroethane (R-125), 1,1,1-trifluoroethane (R-143a) and 1,1,1,2-tetrafluoroethane (R-134a), as well as mixtures of such gases, for example H₂ and He or He and NH₃ or R-125 and R32, or any other combination of two, three or more gases.

In addition, other parameters should be considered when selecting suitable carrier gases. One such parameter is the prior mentioned absorption of the gas in water. Some gases dissolve more readily and to a greater degree than others in water. This parameter is of little concern when using air as a carrier gas however, in a closed system, it is generally preferable that the carrier gas is not lost via dissolution as it can add to expense, be harmful to the environment or flavour the water. The requirement

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to install and run additional apparatus to remove dissolved gas from the output water should be considered.

Another parameter is whether the gas is hazardous due to toxicity, flammability or for other reasons. Use of a such gases at best will require the use of special operating procedures and/or filtering of the output water and at worst render
5 the output unusable for consumption or other purposes.

A further parameter is that of the cost and availability of the gas. Alternative carrier gasses are unlikely to be both free and as readily available as air. Cost and logistically issues of rare gases may render them as unsuitable.

10 A further parameter is the degree of pumping required to force convection of the gas through the apparatus. Extreme, pumping energy costs may render a gas as unsuitable as a carrier gas relative to other gases.

Turning to more fully describe the specific embodiment of an HDH apparatus shown in Fig. 2, it can be seen that the humidifier 2 and dehumidifier 3 are connected
15 by a duct 4 at respective top ends. In this embodiment the humidifier 2 is a packed tower type and the dehumidifier 3 is a shell and tube type.

The lower ends of the heat exchangers 2 and 3 are effectively sealed from the surrounding atmosphere by brine and water catchment sumps respectively, 5 and 6.

A hot brine manifold 7 is located at the top end of the humidifier 2 and a
20 carrier gas manifold 8 is located at the lower end of the humidifier 2. The carrier gas manifold 8 is connected, by a dry gas return line 9, to the water catchment sump 6 under the dehumidifier 3. The return line 9 also includes a blower 10, a gas heat exchanger 11, a flow control valve 12 and a gas heat exchanger by-pass line 13.

A cold brine circulation loop 14 fluidly connects the brine sump 5 to the
25 dehumidifier 3 and includes a pump 15, a flow control valve 16, a by-pass line 17 and a brine heat exchanger 18. The brine sump 5 includes makeup and discharge ports 19 and 20.

An outlet port 21 is provided for draining brine from the dehumidifier and a water extraction port 22 for extracting fresh water collected in the water sump 6.

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The apparatus includes a control system comprising temperature, flow rate, velocity and moisture probes, solenoid valves, an A/D data converter, and a CPU mother board.

The desalination process involves the following steps:

5 Hot brine is fed to the manifold 7 through an inlet port 23. The hot brine can be from a variety of sources, for example, hot brackish water from a geothermal reservoir, hot/warm waste water from an industrial process (e.g. sea water heated up by the waste heat from a coal fired power station, or reject hot geothermal fluid from a geothermal power plant) or cold brine heated up by the exhaust gases of a diesel
10 engine.

The manifold 7 includes an array of nozzles 24 which spray the brine over the top of packing material 25 within the humidifier 2. The hot brine trickles through the packing material under the influence of gravity. Concurrently, relatively dry carrier gas is blown into the lower end of the humidifier through the gas manifold 8. The gas
15 rises through the packing material and is exposed to the hot brine. During this stage water vapour and heat are given up from the brine to the counter-current dry gas stream. As a result, the temperature of the brine drops leaving the tower almost at the ambient temperature.

Depending on the production rate of fresh water and design parameters, one
20 packed tower humidifier or several in series may be used. The choice of packed towers over other types of heat exchangers is to provide a greater contact surface area between the gas and brine, hence, maximise the efficiency of the process. Nevertheless, other forms of heat exchangers may be employed depending on the specific design requirements.

25 The cooled brine is collected in the sump 5 at the bottom of the humidifier 2. To prevent the build-up of salts in the sump 5, a portion of the concentrated brine is discharged via the discharge port 20 as blowdown while make-up brine is added via the make-up port 19 on a continuous basis to maintain the level of the cold brine in the sump 5. The make-up brine is supplied from a separate tank (not shown) and is
30 obtained by bleeding a portion of the hot brine and letting it cool under atmospheric conditions.

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Meanwhile, the moist, humidified carrier gas stream leaves the top of the humidifier 2 and passes through the connecting duct 4 to the dehumidifier 3. The connecting duct is completely insulated to ensure that the humid gas maintains temperature and does not lose enthalpy.

5 In this embodiment the dehumidifier is a shell-and-tube heat exchanger whereby the temperature of the humidified air is reduced to cause water formation by condensation. As seen in Fig 2, the moist gas is passed between an array of fluid cooled, cooling tubes 26 within the shell 27. Depending on the design requirements one or several dehumidifiers may be employed. The cooling fluid for the
10 dehumidifier is the cold brine collected in the sump 5 under the humidifier. The cold brine is pumped through the circulation loop 14 by pump 15. The temperature of the brine may be adjusted by directing it either through the brine heat exchanger 18 or by-pass line 17 as required. The heat exchanger may be air or water-cooled.

15 In operation, the humid carrier gas moves down through the shell of the dehumidifier, between the cooling tubes. Water vapour carried by the relatively warm carrier gas condenses on the external walls of cooling tubes effectively extracting water from the carrier gas. In addition this results in latent heat restitution of the brine circulating inside the tubes.

20 The condensing water eventually drips down through the dehumidifier and is collected in the sump 6 at the bottom of the dehumidifier where it is extracted through port 22. Similarly, the now mildly warm brine solution is discharged via outlet port 21.

25 It must be highlighted that a horizontal-tube falling film type shell-and-tube heat exchanger is used to enhance the heat exchange process and maximise the yield of fresh water. Both in-line or staggered tube bundle configurations as shown in Fig. 3A and 3B may be used. External surfaces of the tubes may be also fitted with fins so that the liquid film thickness on a given tube wall does not rise to undesirable levels. This is essential as the presence of a thick liquid film creates a barrier between the water vapour and cold tube walls thus slowing down the condensation process.

30 The gas leaving the condenser is almost devoid of moisture and at the ambient temperature. It should be highlighted that the entire carrier gas loop is closed to the

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external atmosphere. This not only allows the carrier gasses to be used repeatedly in a cyclic manner without any contact with air, but also minimises safety concerns if using a flammable or otherwise hazardous carrier gas.

As such, the dry carrier gas is forced out of the closed sump 5 using a small blower 10. In other embodiments the blower may be located in a different location or replaced by other means for forcing convection of the carrier gas. The gas is returned to the humidifier 2 via dry gas return line 9. If required, the dry gas may be passed through the gas heat exchanger 11 to adjust its temperature otherwise, the flow control valve 12 directs the gas to by-pass the heat exchanger. As with the brine heat exchanger, the gas heat exchanger 11 may be water or air-cooled.

The flow rates of the gas and brine as well as the temperature of the various components of the plant are controlled by a computerised system comprising several thermocouples, rotameters, hygrometers (moisture meters), solenoid valves, a fast analogue to digital (A/D) data converter, and a central processing unit (CPU) mother board.

It will be appreciated that the invention proposes an improved efficiency method and apparatus for the desalination of water by HDH. It achieves an advantage over existing HDH methods by use of a carefully selected non-air carrier gas which provides superior water vapor absorption characteristics and heat and mass transfer rates. The non-air gas is reused and recirculated between the humidifier and dehumidifier in a closed loop forced convection system. In these and other respects, the invention represents a practical and commercially significant improvement over the prior art.

Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:-

1. A humidification-dehumidification desalination apparatus including:
 - a humidifier for mixing a water based solution with a substantially non-air based carrier gas to evaporate water from the solution thereby humidifying the carrier gas;
 - a dehumidifier for condensing water vapour from the carrier gas and thereby dehumidifying the carrier gas; and
 - a substantially closed loop circulation system including a blower, to circulate the carrier gas between the humidifier and dehumidifier.
2. An apparatus according to claim 1 wherein, the carrier gas is selected such that the ratio of the gas constant of the carrier gas, to the gas constant of the water vapour, (R_g/R_v) is greater than the ratio of the gas constant of the air, to the gas constant of the water vapour, (R_a/R_v).
3. An apparatus according to claim 1 or 2 wherein, the carrier gas is selected such that the ratio of the specific heat of the carrier gas, to the specific heat of the water vapour, (c_{pg}/c_{pv}) is greater than the ratio of the specific heat of the air, to the specific heat of the water vapour, (c_{pa}/c_{pv}).
4. An apparatus according to any one of the preceding claims wherein, the carrier gas is selected such that the ratio of the thermal conductivity of the carrier gas, to the thermal conductivity of the water vapour, (k_g/k_v) is greater than the ratio of the thermal conductivity of the air, to the thermal conductivity of the water vapour, (k_a/k_v).
5. An apparatus according to claim 1 wherein, the carrier gas includes H_2 gas.
6. An apparatus according to claim 1 wherein, the carrier gas includes He gas.
7. An apparatus according to claim 1 wherein, the carrier gas includes NH_3 gas.
8. An apparatus according to claim 1 wherein, the carrier gas is composed substantially entirely of one or more gases selected from the group consisting of H_2 , He, and NH_3 .
9. An apparatus according to any one of the preceding claims wherein, the closed loop circulation system recycles the carrier gas and minimises contact between the outside air and the carrier gasses.

10. An apparatus according to any one of the preceding claims wherein, the humidifier is a packed tower evaporator.
11. An apparatus according to any one of the preceding claims wherein, the dehumidifier is a shell and tube heat exchanger.
- 5 12. An apparatus according to any one of the preceding claims wherein, the humidifier and dehumidifier are fluidly connected at respective upper ends by means of an insulated duct.
13. An apparatus according to any one of the preceding claims wherein, a water solution catchment sump is located at a lower end of the humidifier.
- 10 14. An apparatus according to any one of the preceding claims wherein, a water catchment sump is located at a lower end of the dehumidifier.
- An apparatus according to any one of the preceding claims wherein, the closed loop circulation system includes a heat exchanger.
15. A method of desalinating water in a humidification-dehumidification desalination
15 process, said method including the steps of:
- humidifying a substantially non-air based carrier gas in a humidifier by means of mixing a water based solution with the carrier gas to evaporate water from the solution; dehumidifying the carrier gas in a dehumidifier to extract water; and
- forcibly recirculating the carrier gas between the humidifier and dehumidifier in
20 a closed loop circulation system.
16. A method according to claim 15 wherein, the carrier gas is selected such that the ratio of the gas constant of the carrier gas, to the gas constant of the water vapour, (R_g/R_v) is greater than the ratio of the gas constant of the air, to the gas constant of the water vapour, (R_a/R_v).
- 25 17. A method according to claim 15 or 16 wherein, the carrier gas is selected such that the ratio of the specific heat of the carrier gas, to the specific heat of the water vapour, (c_{pg}/c_{pv}) is greater than the ratio of the specific heat of the air, to the specific heat of the water vapour, (c_{pa}/c_{pv}).
18. A method according to any one of claims 15 to 17 wherein, the carrier gas is
30 selected such that the ratio of the thermal conductivity of the carrier gas, to the thermal

conductivity of the water vapour, (k_g/k_v) is greater than the ratio of the thermal conductivity of the air, to the thermal conductivity of the water vapour, (k_a/k_v).

19. A method according to claim 15 wherein, the carrier gas includes H₂ gas.
20. A method according to claim 15 wherein, the carrier gas includes He gas.
- 5 21. A method according to claim 15 wherein, the carrier gas includes NH₃ gas.
22. A method according to claim 15 wherein, the carrier gas is composed substantially entirely of one or more gases selected from the group consisting of H₂, He, and NH₃.
23. A method according to any one of claims 15 to 22 wherein, the closed loop circulation system recycles the carrier gas and minimises contact between the outside air
10 and the carrier gasses.
24. A method of desalinating water in a humidification-dehumidification desalination process, said method utilising the apparatus according to any one of claims 1 to 15.
25. A method of selecting a suitable carrier gas for use in a humidification-dehumidification desalination apparatus, said method including the steps of:
- 15 determining an initial series of candidate gases;
 for each member of the series of candidate gases, determining a series of relative candidate parameters including:
- an absorption parameter, indicative of the capability of the gas to absorb water vapour relative to air;
- 20 a transport parameter, indicative of the heat and mass transfer capability of the gas relative to air; and
- a heat exchanger parameter, indicative of the heat exchanger size required to operate as an evaporator under equivalent conditions, relative to air;
- selecting one or more suitable carrier gas from the series of candidate gases
25 which provide superior performance to that of air based on the combined influence of said parameters.
26. A method according to claim 25 wherein, said relative candidate parameters include at least any one of:
- a cost parameter, indicative of the cost of the gas;
- 30 an availability parameter, indicative of the availability of the gas;

a flammability parameter, indicative of the potential flammability risks of the gas;

a toxicity parameter, indicative of the toxicity of the gas; and

a solubility parameter, indicative of the solubility of the gas in water.

- 5 27. A method according to claim 25 or 26, wherein said candidate gases include substantially pure gases.
28. A method according to any one of claims 25 to 27, wherein said candidate gases include gases which are a mixture of gases.

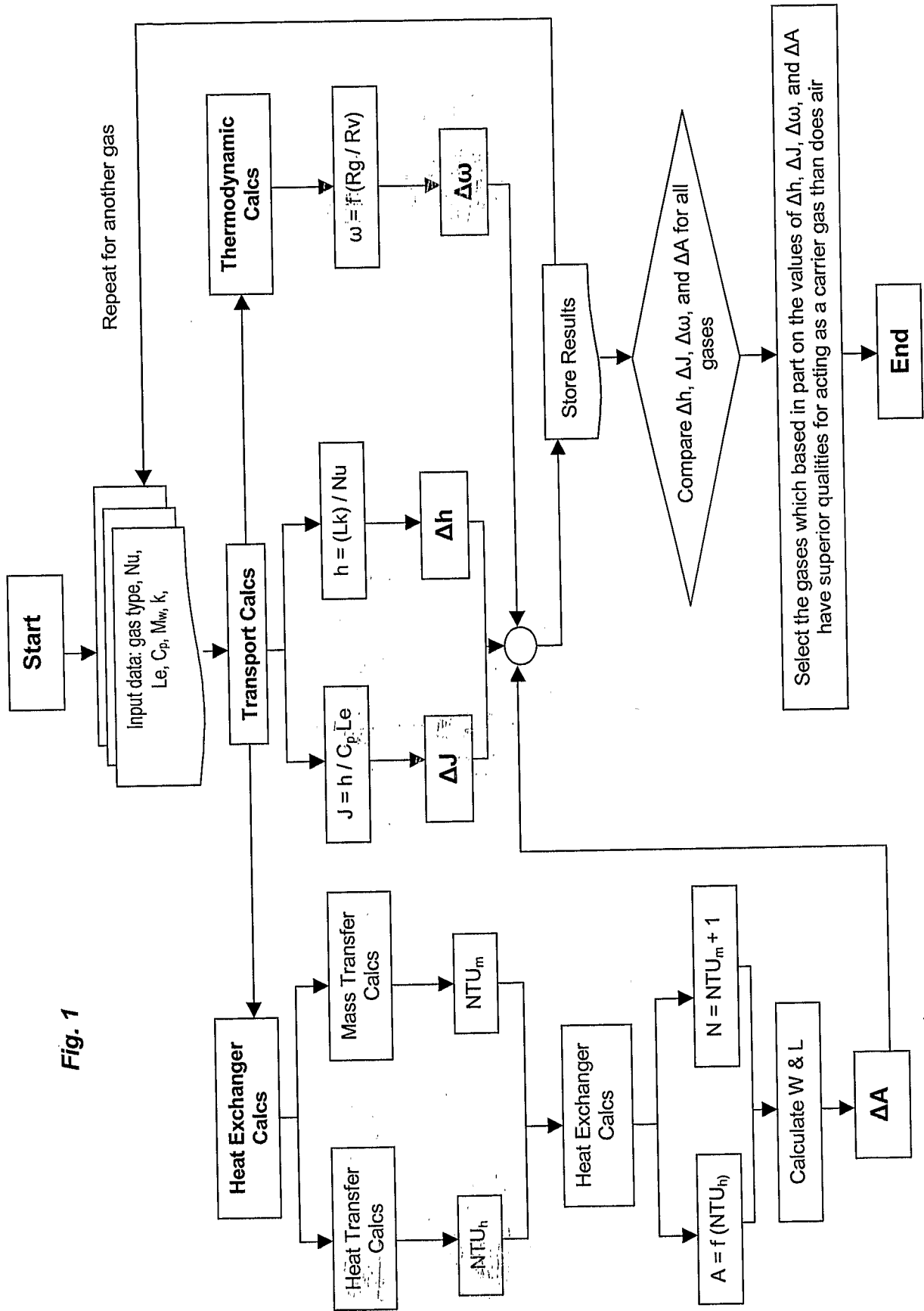
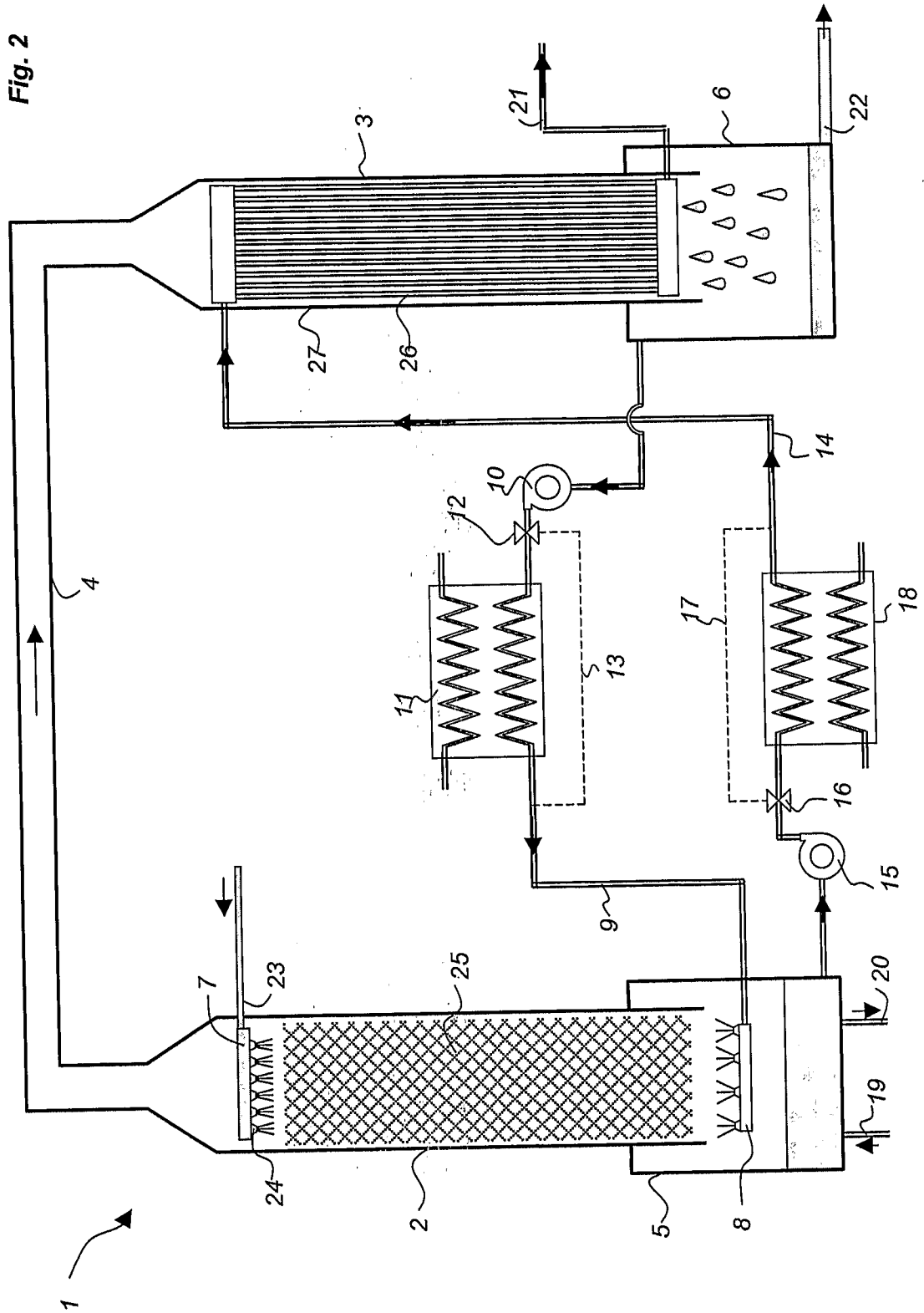


Fig. 1

Fig. 2



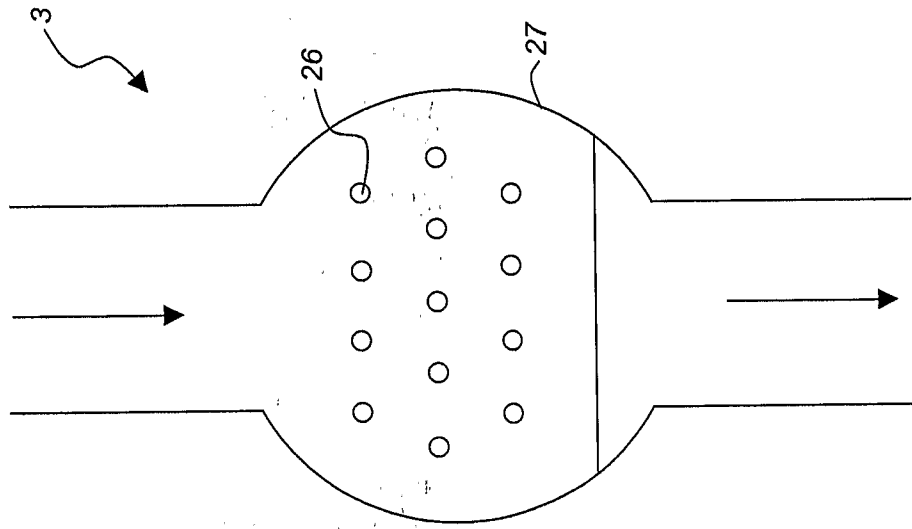


Fig. 3B

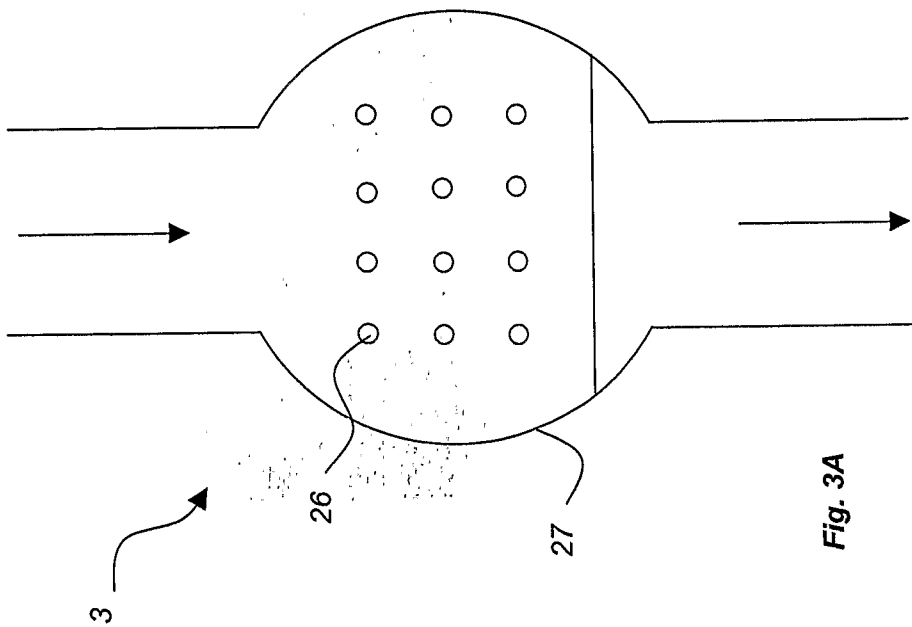


Fig. 3A

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2007/000597

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

C02F 1/04 (2006.01) **B01D 3/34** (2006.01) **C02F 1/14** (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)

DWPI: IPC (C02F 1/04, 1/14, B01D 3/34) and keywords (humid or evap, dehumid or condens, circulat or pump or fan or blower)

Goögle: desalination, humidification, dehumidification, hydrogen or helium or ammonia

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 3435614 A1 (LONGERICH) 10 April 1986 See whole document especially page 7 paragraph 3	1-6, 8-20, 22-28
X	FR 2536738 A (MITSUBISHI DENKI KK) 1 June 1984 See whole document, especially page 15 lines 34-36	1-4, 9-18, 23-24
X	WO 2001/007134 A (ARIZONA BOARD OF REGENTS) 1 February 2001 See whole document, especially page 14 lines 9-23	1-4, 8-18, 22-28

Further documents are listed in the continuation of Box C

See patent family annex

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

04 June 2007

Date of mailing of the international search report

08 JUN 2007

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2007/000597

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Arabi, M.K.A. et al "Performance evaluation of desalination processes based on the humidification/dehumidification cycle with different carrier gases", Desalination 156 (2003) 281-293, Elsevier See whole document	1-6, 8-20, 22-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU2007/000597

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Member
DE 3435614	
FR 2536738	
WO 0107134	US 6911121

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX