



rexresearch.com

Richard PASHLEY, *et al.*

Bubble Desalination

<http://www.scidev.net/global/agriculture/news/bubble-desalination-boost-crop-growth.html>

27/07/15

Bubble desalination latest effort to boost crop growth

by Ian Randall

Researchers in Australia are seeking to build a prototype ‘Bubble-Greenhouse’ that could provide remote, arid places with a low-tech, low-maintenance way to turn salt water into fresh water to grow food.

The engineers from Murdoch University, who published their study last month in the journal *Desalination*, estimate that a 150 square metre Bubble-Greenhouse could produce around eight cubic metres of fresh water and up to 30 kilograms of crops each day. The sealed structure would protect crops from insects and disease, while the technology should be relatively simple to implement and use in isolated areas, they say.

“We believe that the concept is applicable to arid regions worldwide.” -- Mario Schmack, Murdoch University

The Bubble-Greenhouse idea develops an existing seawater greenhouse concept, which uses the evaporation and condensation of salt water to produce fresh water for irrigation and to create a cool, humid environment inside a greenhouse, meaning crops need less water to grow.

The new approach moves the evaporation and condensation processes outside the greenhouse. Inside two water-filled ‘bubble columns’, streams of thousands of tiny bubbles create a large surface for water to evaporate or condense. A unique property of seawater prevents the small bubbles joining to form big bubbles, thus maintaining a large surface area.

According to Mario Schmack, one author of the paper, unlike the seawater greenhouse that operates at the ambient temperature, the Bubble-Greenhouse’s separated evaporators/condensers allow the use of higher temperatures. “Therefore, much more water vapour can be held in that hotter air stream,” he says.

Not only does this make the process faster and more efficient, Schmack says, but the bubble process prevents salt build-up within the evaporation chamber, reducing the need for

maintenance.

“We believe that the concept is applicable to arid regions worldwide, where the social benefits and the simplicity of the concept will drive sustainable development of remote people,” says Schmack.

Emily Tow, a mechanical engineer at the Massachusetts Institute of Technology, United States, who was not involved in the study, says: “The desalination system employs bubble columns, which are more compact and inexpensive than conventional humidifiers/dehumidifiers because of the large area for phase change and high heat transfer coefficients.”

But Tow warns that the estimated cost of US\$10 for every 1,000 kilograms of water produced — which might be enough to grow up to 10 kilograms of food — means the concept may be uneconomical for growing staple crops. Other desalinisation techniques, such as solar-powered reverse osmosis, may be more efficient, she says.

Raphael Semiat, a chemical engineer at the Technion — Israel Institute of Technology, agrees, citing the higher energy requirements for evaporation/condensation-based desalination. “Solutions for remote, isolated places must be based on a technique that will [involve] a relatively large system ... using reverse-osmosis and distribution of the water in pipes,” he says.

But Schmack says the Bubble-Greenhouse concept might be useful for isolated communities because its simplicity would make it easy for local people to implement. With their preliminary study complete, the researchers are now looking to work with industry partners in Western Australia to develop a working prototype.

<http://www.sciencedirect.com/science/article/pii/S0011916415001885>

Desalination, Volume 365, 1 June 2015, Pages 250-260, ISSN 0011-9164,
dx.doi.org/10.1016/j.desal.2015.03.021

<http://phys.org/news/2015-07-salt-quirk-key-desalination.html#jCp>

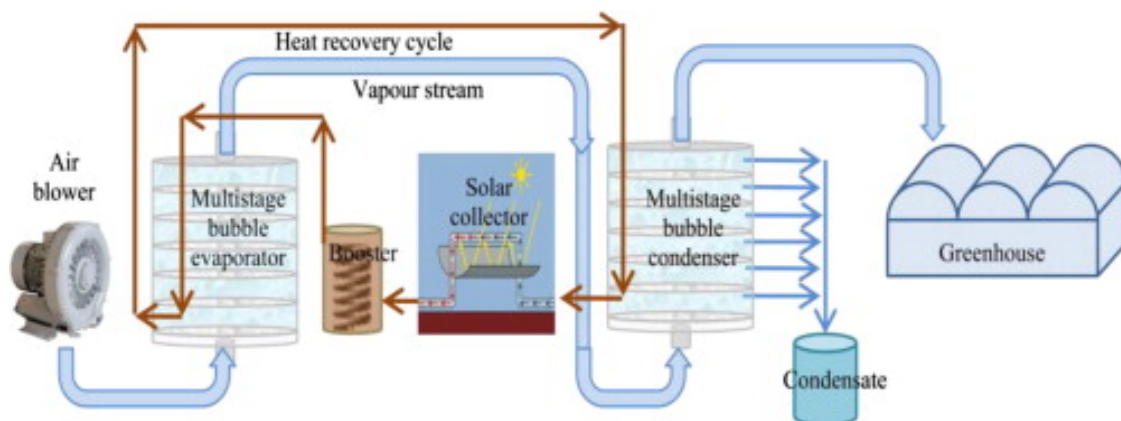
The Bubble-Greenhouse: A holistic sustainable approach to small-scale water desalination in remote regions

Mario Schmack, , Goen Ho, Martin Anda

Abstract

The Bubble-Greenhouse system combines the well established Seawater Greenhouse concept with a novel humidification–dehumidification (HD) process, based on the large air/water interface generated by bubbling air through a water filled column. Multistage bubble evaporators and multistage bubble condensers allow for effective recovery and reuse of latent heat via a heating/cooling circuit throughout all column stages. The system can operate with salinities of 5000–35,000 ppm. Following the HD process, cooled vapour provides the tropical type greenhouse with a humid environment for selected crops. Additional condensation occurs along the greenhouse skin and is gravity-fed to drip line irrigation. Low grade energy options such as solar-thermal, photovoltaic, wind, geo-thermal and salinity-

gradient solar ponds provide the energy for the Bubble-Greenhouse. Alternatively, waste heat from diesel power stations nearby can provide cogeneration of electricity and bubble evaporator heat and pressure requirements. Crops grown inside a greenhouse demonstrate a strongly reduced water demand and the closed environment protects crops from insects and diseases. As the technology is conceptually simple to implement, it holds great potential for community participation, empowerment, skills development and capacity building of local people in remote locations.



AU2009217223 Method for desalinating water

Also published as: WO2009103112

Inventor(s): PASHLEY RICHARD MARK

Applicant(s): UNIV MURDOCH

A method for desalinating water, the method comprising the steps of : passing gas bubbles through an aqueous saline solution; extracting water vapour from the aqueous saline solution into the gas bubbles; recovering the water vapour from the gas bubbles; and condensing the recovered water vapour thereby desalinating the water.

Field of the Invention

The present invention relates to a method for desalinating water. In particular, the present invention relates to a method for desalinating water without boiling the water.

Background Art

The production of potable water from saline water by desalination is becoming increasingly important as water becomes more precious. There are three main commercial desalination processes in current use based on reverse osmosis filtration, electro-dialysis and evaporation/distillation.

Reverse osmosis (RO) has become the most commonly used method in recent times but it has many disadvantages which add to its inefficiency and cost. Large volumes of concentrated saline retentate must be disposed of as only a fraction passes as clean water through the membranes. The membranes themselves are expensive and easily fouled and consequently,

the saline solution must be pre cleaned to protect the membrane, adding to the complexity and cost of the process. The osmotic pressure of sea water is about 28 atm and high pressure liquid pumping is required to generate water through reverse osmosis filtration.

As the salt accumulates, the osmotic pressure required increases and commercially, pressures up to 100 atm have to be applied which can increase the energy requirement to about 10 MJ/m³ of water produced or more. The minimum work required to desalinate sea water can be calculated from the work done by applying a pressure infinitesimally higher than the natural osmotic pressure of the sea and so obtain the reversible work done, at constant temperature, to move a semi-permeable membrane an infinitesimal distance, so desalinating a very small volume of solution. This provides a minimum work required of about 3 MJ/m³ of pure water. Commercial RO systems are less efficient, typically in the range of 10-20 MJ/m³. The best-practice commercial energy cost for the membrane desalination of sea water is currently at about 2.5 kWhr/m³ or 9 MJ/m³.

Electro-dialysis addresses some of the problems associated with reverse osmosis but still requires sophisticated equipment and specialised membranes.

The interface between water and air or vapour offers a natural barrier to the transport of salt. This transfer does not require a membrane and does not require the use of the very high pressures needed with membranes. The most common current commercial form of this natural evaporative process is called multi-stage flash distillation (MSF). In this process, salt water is heated close to its boiling point and the pressure reduced. The water spontaneously boils and the vapour produced is collected and condensed. Only a small proportion of the water boils off at each stage of the process and so a series of 'multi-stages' are required. No membranes are required but substantial energy costs are required to vaporise significant volumes. In addition, flash distillation essentially uses only the surface of the liquid as the main water vapour transfer barrier.

Boiling is a very common desalination process but it is an irregular process which is hard to control resulting in energy wastage.

The latent heat of vaporization of water is about 2.3 MJ/L at 100 C and about 2.4 MJ/L at room temperature. These values are not greatly affected by the addition of salt. Although these values are high, most of this thermal energy is, in practice, recycled on condensation of the water vapour and is used to heat the salt water feed which reduces the overall energy cost. Commercial thermal/evaporative units typically have energy costs in the range 20-200 MJ/m³, which reflects the high efficiency of their heat recycling processes.

The preceding discussion of the background to the invention is intended to facilitate an understanding of the present invention. However, it should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to was part of the common general knowledge in Australia. Further, throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

Throughout the specification, unless the context requires otherwise, the word "desalinating" or variations such as "desalination", will be understood to encompass the removal or partial removal of salts from aqueous solution. It will be understood that the word "desalinating" or

variations such as "desalination" will encompass the preparation of water of decreased levels of salinity including water that may or may not be potable.

Disclosure of the invention In accordance with the present invention, there is provided a method for desalinating water, the method comprising the steps of:
passing gas bubbles through an aqueous saline solution;
extracting water vapour from the aqueous saline solution into the gas bubbles;
recovering the water vapour from the gas bubbles; and condensing the recovered water vapour thereby desalinating the water.

Without being limited by theory, it is believed that the method of the present invention provides energy efficiencies over boiling as a desalination method.

Boiling only uses a small, chaotic water/air interface where the bubbles are formed, whereas the bubbles of the present invention extract water vapour from all regions of the aqueous saline solution.

Advantageously, the method of the present invention can be applied to aqueous saline solutions with very high saline levels without significantly affecting its efficiency, unlike reverse osmosis where much higher pumping pressures need to be used at higher saline levels. Further, the aqueous saline solution may not need pre-filtering as in reverse osmosis and there may be no requirement for high pressure pumping of the solution.

Commercial RO units are limited to the treatment of saline solution up to a saline concentration approximately twice that of sea water. In contrast, it is believed that the present invention may treat saline solutions with saline concentrations up to 4-6 times that of sea water.

Preferably, the temperature of the aqueous saline solution is less than the boiling point of the aqueous saline solution at the pressure of the aqueous saline solution.

In one form of the invention, the pressure of the aqueous saline solution is at least atmospheric pressure.

In another form of the invention, the pressure of the aqueous saline solution is greater than atmospheric pressure. It will be appreciated that where the pressure of the aqueous saline solution is greater than atmospheric pressure, the temperature of the aqueous saline solution may be greater than 100 °C.

Where the pressure of the aqueous saline solution is about atmospheric pressure, the temperature of the aqueous saline solution is preferably between about 40 °C and 95 °C. More preferably, the temperature of the aqueous saline solution is preferably between about 70 °C and 80 °C. More preferably still, the temperature of the aqueous saline solution is about 70 °C.

It will be appreciated that both the temperature and the pressure should be controlled to avoid boiling of the aqueous saline solution, regardless of the pressure.

It will be appreciated that the size of the bubbles influences their ability to pass through the aqueous saline solution and whilst smaller bubbles provide higher surface area to volume

ratios, under some circumstances, they may pass too slowly through the solution. It will be appreciated that the rate at which a bubble passes through the aqueous saline solution will be dependant on the temperature of the solution as well as the bubble size. Preferably, the bubbles are in the order of about 0.1 mm to several mm in diameter. More preferably, the bubbles are 1 to 5 mm in diameter. It will be further appreciated that the size of the bubbles will be influenced by the rate of gas flow through the aqueous saline solution.

It will be appreciated that the preferred flow rate of the bubbles through the aqueous saline solution will depend on many factors including the cross-sectional area and length of the vessel retaining the aqueous saline solution. The bubbles should be sufficiently buoyant to travel through the vessel at an appropriate rate but should also have sufficient residence time in the aqueous saline solution to reach an equilibrium vapour content.

Without being limited by theory, it is believed that bubbles with diameters above about 1.5 mm become non-spherical during travel and oscillate in shape, reducing the time taken to reach vapour equilibrium.

Preferably, the aqueous saline solution comprises sodium chloride at a concentration above about 0.1 M.

In one form of the invention, the aqueous saline solution is sea water.

In another form of the invention, the aqueous saline solution is ground water, which can comprise hypersaline ground water.

It is known that in saline water above a certain concentration of certain salts, bubbles have a decreased tendency to coalescence or collapse compared to bubbles in non saline water. Advantageously, sodium chloride does cause inhibition and this reaches a maximum effect above about 0.17 M. Further increases in the salt level are believed to have no greater effect. Salt levels in sea water vary but are typically around 0.55 M.

In one form of the invention, prior to the step of:
passing gas bubbles through the aqueous saline solution, the method comprises the additional step of:
passing a gas through a porous membrane, thereby producing gas bubbles.

Preferably, the gas is substantially insoluble in water and substantially non-toxic.

In particular, the gas is preferably substantially non-toxic to humans. In particular forms of the invention, the gas is selected from the group comprising air, nitrogen and oxygen. It will be appreciated that air may provide economic benefits.

The porous membrane may be provided in the form of a ceramic, plastic, glass or steel porous sinter.

It will be appreciated that selection of an appropriate membrane will be influenced by the diameter of the bubbles that are formed by the membrane. It will further be appreciated that the porosity of the membrane should be such to enable sufficient gas flow through the membrane.

In another form of the invention, the step of:
passing gas bubbles through the aqueous saline solution, comprises the step of:
passing a gas through a bubbling apparatus, thereby producing gas bubbles.

The bubbling apparatus may be provided in any form known in the art to prepare gas bubbles. The bubbling apparatus may be provided with means to control the sizes of the bubbles so produced. Said means for controlling bubble sizes may include a cutting blade.

In one form of the invention, the method comprises the further step of:
forming water clusters in the aqueous saline solution.

Without being limited by theory, it is believed that water may be recovered from saline solutions through vaporisation and condensation of clusters of water molecules. Water clusters are believed to have lower energy than single water molecules. In addition, water clusters containing Na⁺ and Cr ions are believed to have much higher energy and thus will only be present in low levels in the vapour phase.

Clusters are believed to form transiently throughout bulk water but only those in the vapour phase, inside the bubbles, will carry water over to the condenser.

However, the formation of clusters in the bulk water is important as they will equilibrate with vapour clusters in the bubbles. There will be a continuous exchange between clusters in the water and in the vapour phase.

Advantageously, the present invention provides conditions that favour cluster formation including lower temperature evaporation, turbulence in the liquid, rapid vapour removal and super-saturation of inert gases.

In one form of the invention, the method comprises the further step of:
adding a cluster forming agent to the aqueous saline solution.

It is anticipated that the cluster forming agent in the saline solution will adsorb on the surface of the bubbles and nucleate water clusters within the bubbles. Once the bubbles reach the top of the column, they will collapse and the water clusters will disperse into the vapour phase.

The cluster forming agent may be provided in the form of a clathrate-forming gas, a hydrophobic colloidal particle or a surfactant.

The skilled addressee will appreciate that there may be a large number of appropriate clathrate-forming gases. In specific forms of the invention, the clathrate-forming gas is selected from the group comprising methane, carbon dioxide, low molecular weight hydrocarbons such as propane or chlorofluorocarbons such as CHClF₂.

It is expected that the clathrate-forming gas will at least partially dissolve in the aqueous solution and equilibrate with the gas in the bubbles. The clathrate forming gas should freely transfer between the aqueous solution and the gas phase.

It will be appreciated that the clathrate-forming gas may be the same gas as the gas used in the step of:
passing gas bubbles through an aqueous saline solution;

The skilled addressee will appreciate that there may be a large number of appropriate colloidal particles. In specific forms of the invention, the colloidal particle is selected from the group comprising at least partially hydrophobic silica and silver iodide. Preferably, the particle is between 1 and 100 micron in diameter.

It is expected that the particles are adsorbed on the surface of the bubbles and nucleate water clusters inside the bubbles. On collapsing of the bubbles at the top of the column, the particles will be released back into the aqueous solution.

Where the cluster forming agent is a surfactant comprising a hydrophilic portion and a hydrophobic portion such as a hydrocarbon, it is advantageous if the surfactant comprises a weakly hydrophilic group, such as a hydroxyl and amine group at the end of the hydrocarbon tail. It is believed that the presence of the weakly hydrophilic group causes the surfactant molecules to aggregate and nucleate water clusters on the inside of the bubble. On collapsing of the bubbles at the top of the column, the surfactant will be released back into the aqueous solution.

Without being limited by theory, it is believed that the presence of the surfactant in the saline solution can improve control of bubbles sizes.

Preferably, the step of condensing the recovered water vapour thereby producing desalinated water, comprises the step of:
passing the water vapour through a heat exchange apparatus.

In one form of the invention, the heat exchange apparatus is provided in the form of a condenser such as a shell and tube condenser wherein the condensing water is passed through the shell of the condenser to condense the water vapour.

The condensing water of the condenser may be located from the same source as the aqueous saline solution undergoing desalination.

Preferably, the method of the present invention is a continuous process. Where the method of the invention is a continuous process, it will be appreciated that the vessel containing the aqueous saline solution being desalinated will need regular or continuous replenishing. In one form of the invention, the step of replenishing the aqueous saline solution comprises the step of:

replenishing the aqueous saline solution with condensing water leaving the condenser.

Advantageously, the condensing water leaving the condenser is hotter than the condensing water entering the condenser and the use of the heated condensing water to replenish the aqueous saline solution increases the energy efficiency of the desalination process.

In accordance with the present invention, there is provided an apparatus for desalinating water, the apparatus comprising a receptacle to retain saline water, means for producing gas bubbles, a water inlet and water vapour outlet.

The receptacle to retain saline water may be a glass, perspex or steel column.

In a preferred form of the invention, the column is about 0.5 m high and about 2 m in diameter.

The means for forming bubbles may be provided in any form known in the art including a porous membrane or a bubbling apparatus.

Where the means for forming bubbles is a porous membrane, the apparatus preferably further comprises means for passing a gas through the porous membrane.

The porous membrane may be provided in the form of a ceramic, plastic, glass or steel porous sinter.

Preferably, the apparatus further comprises a heat exchange apparatus adapted to condense the water vapour.

In one form of the invention, the heat exchange apparatus is provided in the form of a condenser. The condenser may be provided in the form of a shell and tube condenser wherein the condensing water is passed through the shell of the condenser to condense the water vapour.

The apparatus may be provided with means for heating the water. The means for heating the water may be provided internally or externally to the receptacle.

In accordance with the present invention, there is provided an apparatus for desalinating water, the apparatus comprising a plurality of receptacles to retain saline water, means for producing gas bubbles, a plurality of water inlets and a plurality of water vapour outlets.

The apparatus may comprise a plurality of vertically stacked receptacles. The apparatus may further comprise a plurality of laterally adjacent receptacles.

In one embodiment of the invention, the receptacles are provided in the form of columns 0.5 m tall and 2 m diameter. At a temperature of 70 °C, a bubble packing factor of 0.3, the gas residence time is expected to be less than 1 s. The columns are stacked four high to allow gas recovery between units and reduce the overall gas requirement and the space between each unit is 0.5 m. In this way a high volume, low pressure gas pump can be used, since the pressure drop across each unit will be less than 100 millibar. The stacked units can be repeated to produce a high output system using a high volume, low pressure pumping system.

In any thermal desalination process retention of the heat of condensation is of great importance. One of the most efficient methods of vapour condensation is mechanical vapour compression (MVC) and this technique can be combined with the invention to improve energy efficiency.

When a clathrate forming gas is added, the outlet gases need to be contained and recirculated through the system of bubble chambers in a closed gas system to prevent environmental emissions.

Brief Description of the Drawings

The present invention will now be described, by way of example only, with reference to three embodiments thereof and the accompanying drawings, in which:

Figure 1 is a schematic diagram of an apparatus for desalinating water in accordance

with one embodiment of the present invention;

Figure 2 is a schematic cross-sectional view of a portion of the apparatus of Figure 1;

Figure 3 is a schematic diagram of water clusters formed on the surface of a hydrophobic colloidal particle adsorbed to a bubble;

Figure 4 is a schematic diagram of water clusters formed adjacent a surfactant inside a bubble;

Figure 5 is a plot of the amount of water vapour carried in an air bubble against temperature;

Figure 6 is a schematic diagram of apparatus for desalinating water in series in accordance with a second embodiment of the present invention;

Figure 7 is a plot of estimated gas inlet temperature required to maintain bubble column temperature; and Figure 8 is a schematic diagram of an apparatus for desalinating water in accordance with a third embodiment of the present invention.

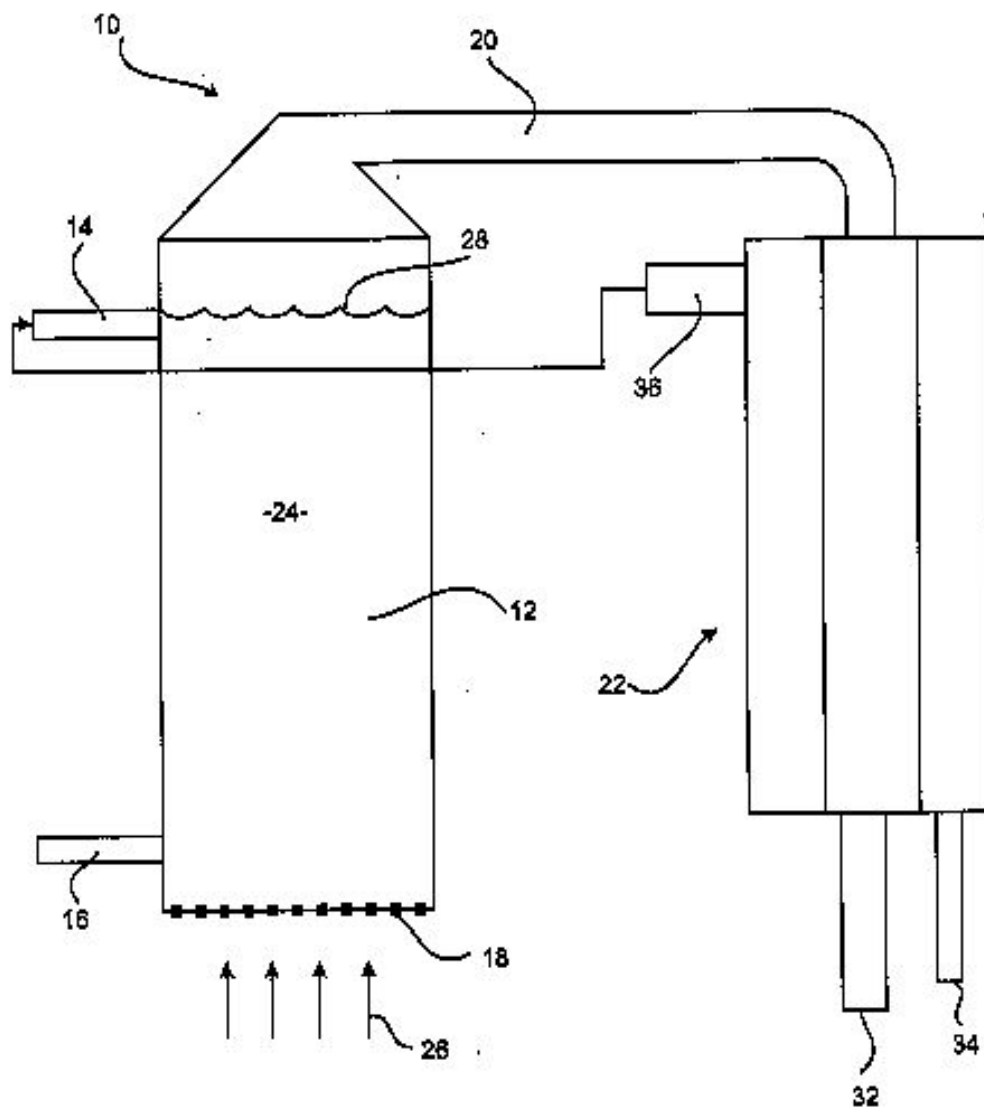


Fig. 1

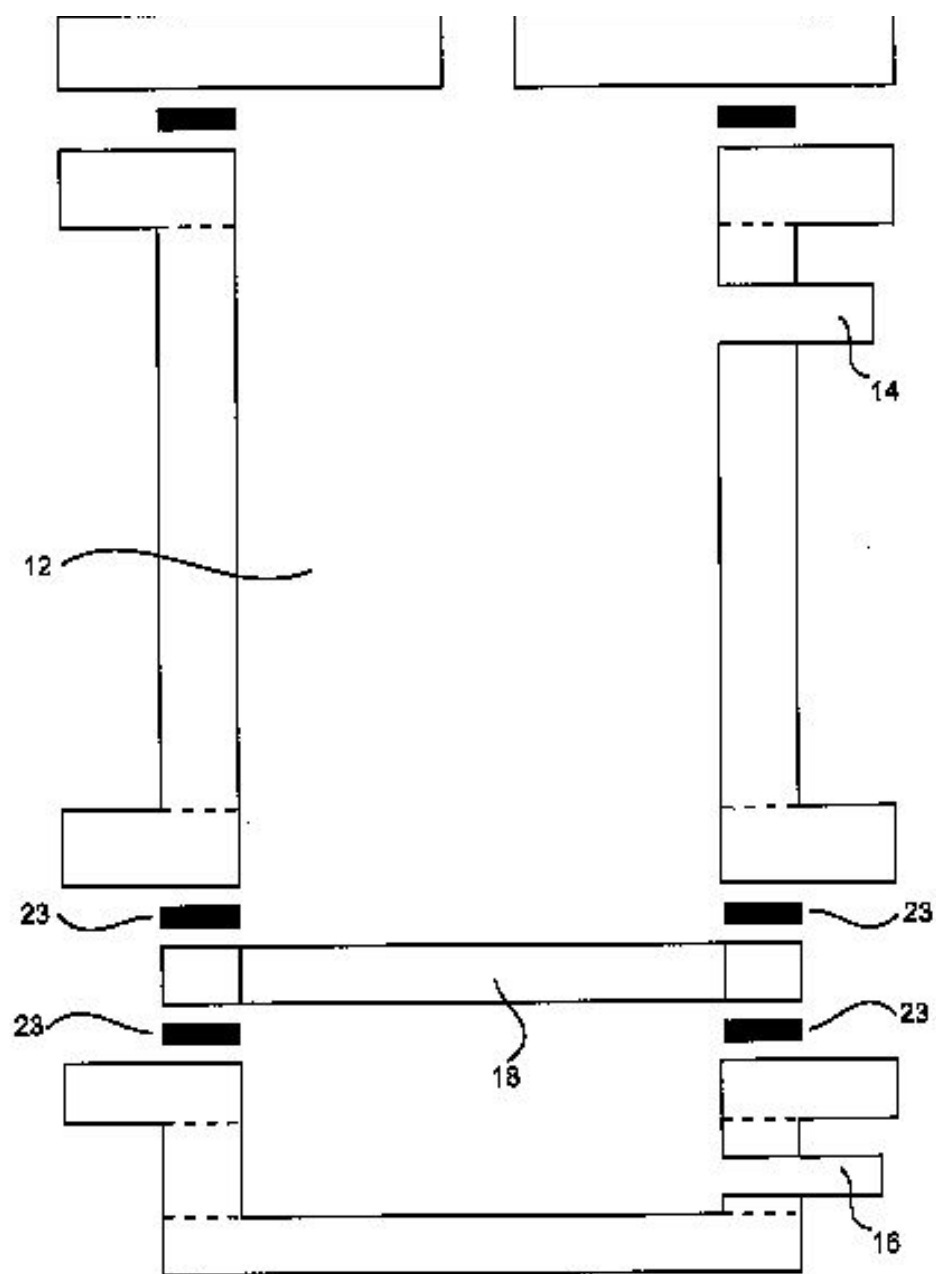
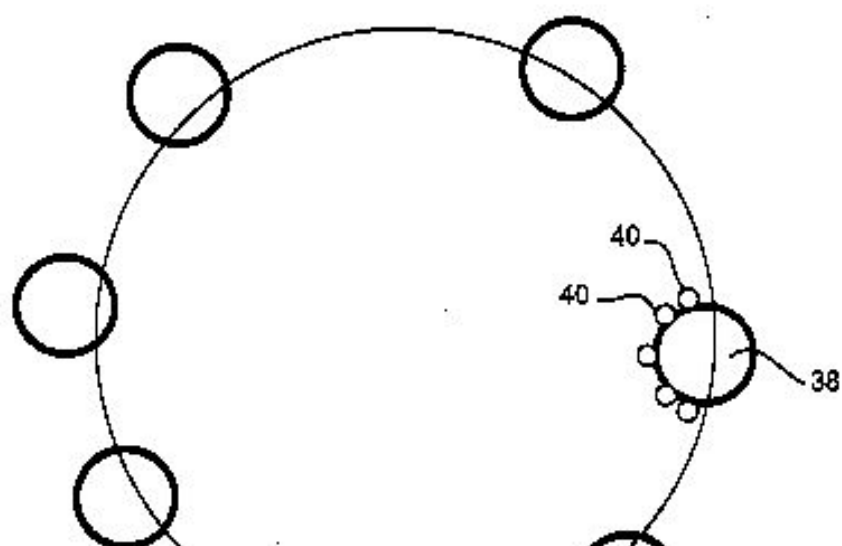


Fig. 2



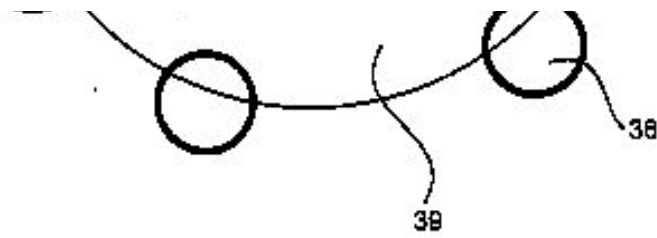


Fig. 3.

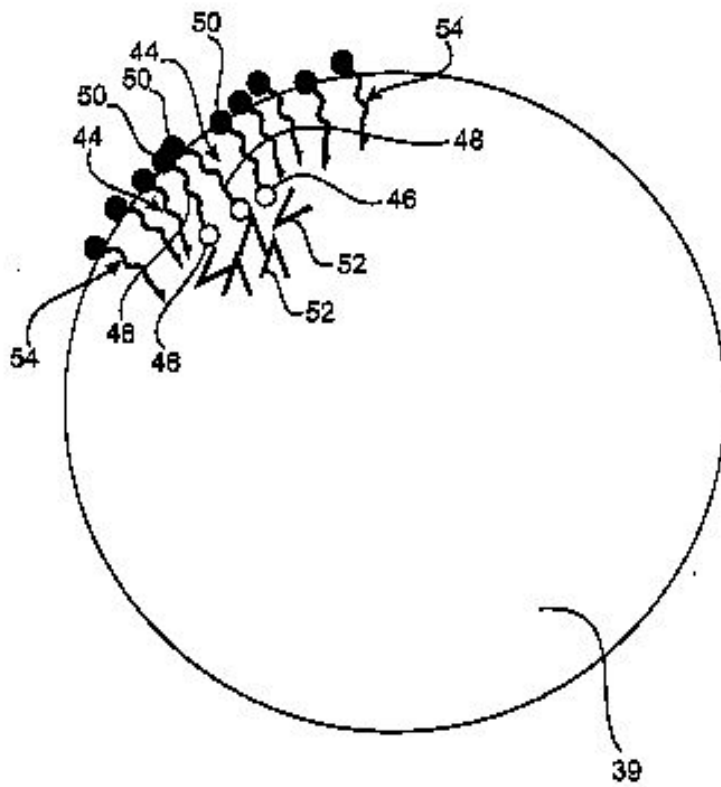
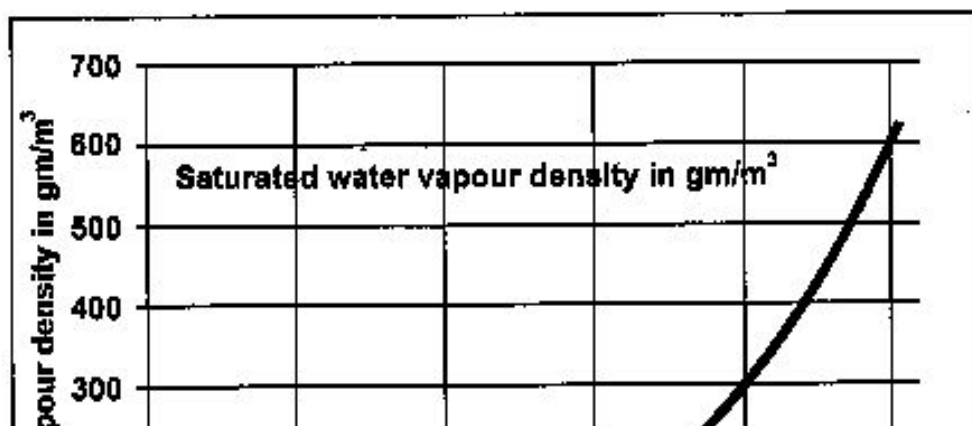


Fig. 4.



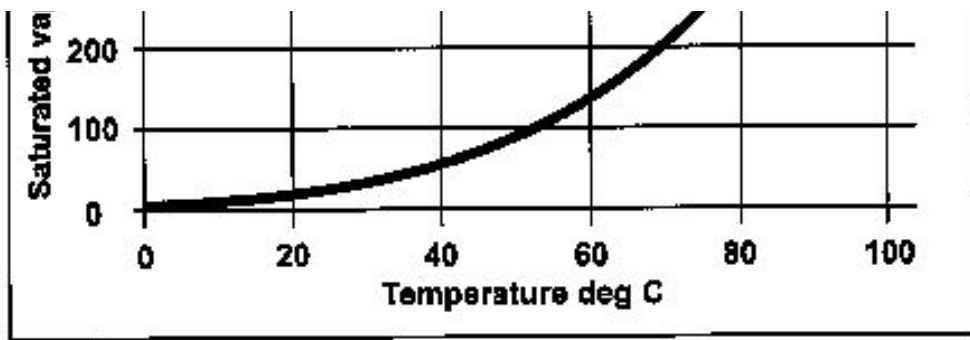


Fig. 5

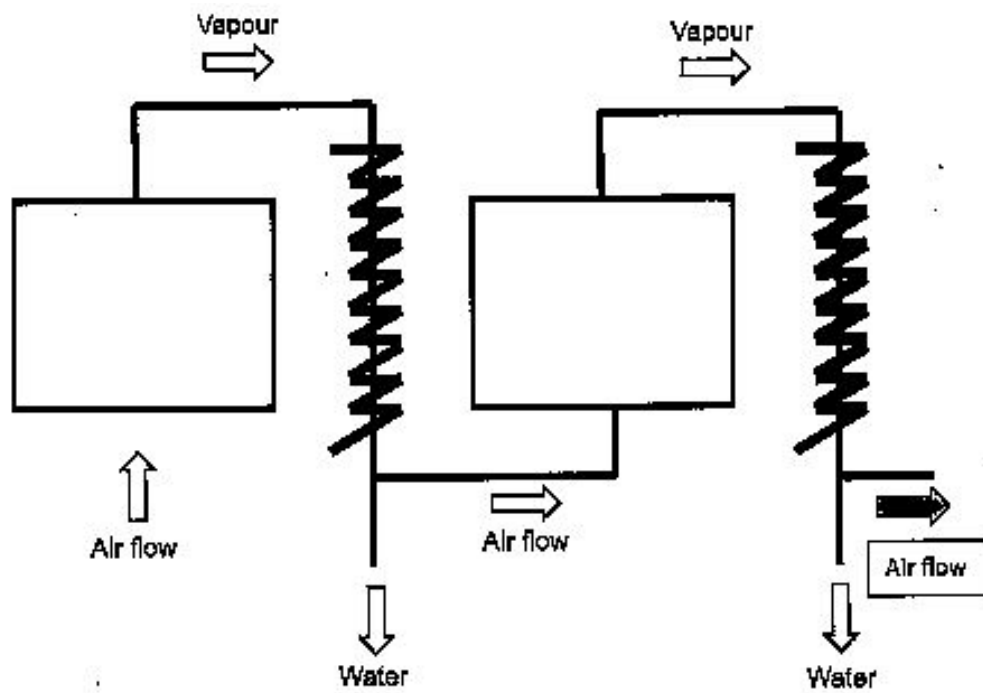


Fig. 6

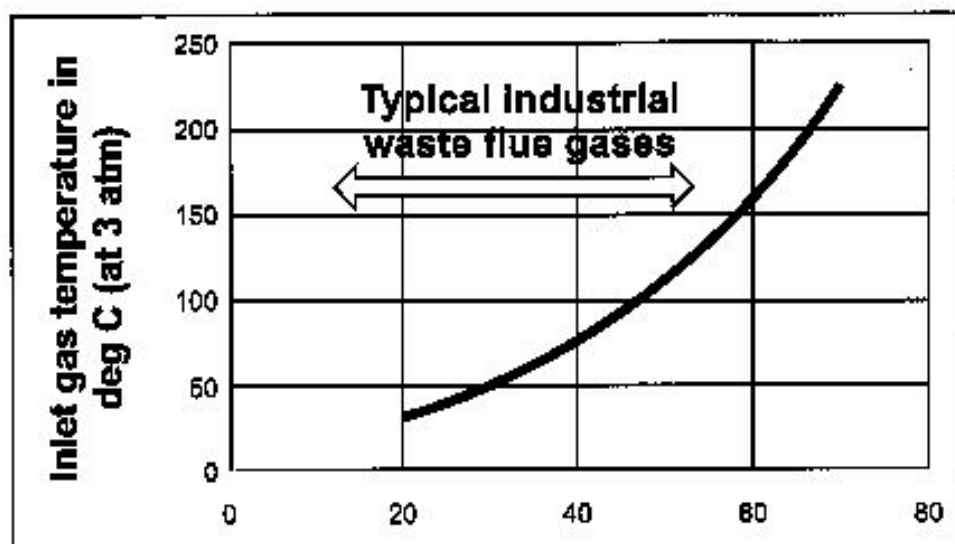


Fig. 7

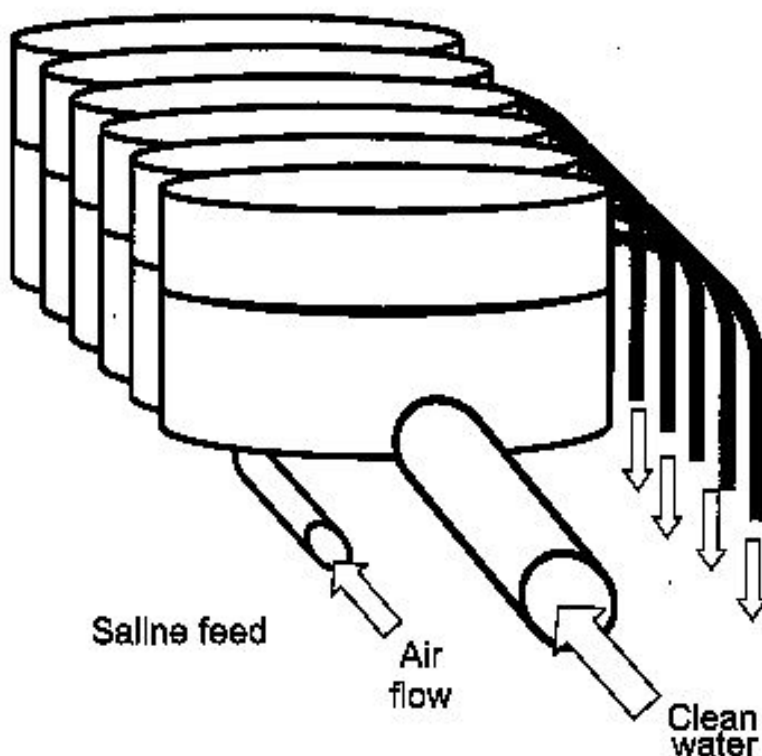


Fig. 8

Best Mode(s) for Carrying Out the Invention

Those skilled in the art will appreciate that the invention described herein is amenable to variations and modifications other than those specifically described.

It is to be understood that the invention includes all such variations and modifications. The invention also includes all of the steps, features, compositions and compounds referred to or indicated in the specification, individually or collectively and any and all combinations or any two or more of the steps or features.

In Figure 1 there is shown an apparatus 10 for desalinating an aqueous saline solution in accordance with the present invention. The apparatus 10 comprises a cylindrical column 12 at atmospheric pressure with a water inlet 14 and a water outlet 16. The column 12 is about 10 mm thick and 600 mm long with a diameter of 150 mm. Both the water inlet 14 and the water

outlet 16 may be provided with valves (not shown). At the bottom of the column 12 there is provided a porous membrane 18. The top of the column 12 is in fluid communication with a conduit which is in fluid communication with a condenser 22.

As shown in Figure 2, the column 12 is provided with rubber gaskets 23 to assist in sealing the junction where the membrane 18 meets the column 12.

In use, warm sea water 24, typically at a temperature between 40 °C to 95 °C is fed into the column 12 and a stream of air 26 is continuously fed into the column 12. As the stream of air 26 passes through the porous membrane 18, a stream of bubbles (not shown) forms in the sea water 24.

The bubbles pass through the sea water 24 rising to the surface 28 of the aqueous saline solution 24 due to density difference and due to the pressure of the stream of air 26 passing through the porous membrane 18. As the bubbles pass through the sea water 24, water vapour is extracted from the sea water 24 into the bubbles. Without being limited by theory, it is believed that if the sea water 24 is heated above ambient, the air bubbles will become saturated with water vapour during their passage through the column 12. Advantageously, the high density of gas bubbles flowing through the sea water 24 collect vapour in a regular, uniform process until the saturation point at that temperature and pressure. Without being limited by theory, it is believed that the amount of water vapour in an air bubble immersed and equilibrated with water close to its boiling point is almost identical to that in a bubble created by boiling.

As bubbles reach the surface 28 of the sea water 24, they may not collapse immediately, and a foam (not shown) may develop at the surface 28. As the foam develops, the uppermost bubbles ultimately collapse, releasing water vapour which is transported along the conduit 20 to the condenser 22. The incoming stream of air 26 facilitates the flow of the water vapour along the conduit 20. It will be appreciated that it would be advantageous to insulate the conduit 20 and to minimise its length. The water vapour condenses in the condenser 22 thereby providing desalinated water 32. It will be appreciated that the desalinated water 32 may still contain dissolved salts.

The condenser 22 comprises a condensing water inlet 34 and a condensing water outlet 36. The condensing water may be taken from the same source as the sea water 24, although it should be appreciated that it will be cooler than the sea water 24 in the column 12.

It will be appreciated that the volume of sea water 24 in the column 12 will need regular or continuous replenishing. Advantageously, the heated condensing water leaving the condenser 22 via the condensing water outlet 36 can be passed to the column 12 for desalination. In this regard, energy is conserved. It will be appreciated that the heated condensing water may need further heating prior to passing it to the column 12.

The cluster forming agent (not shown) is added to the column 12 and mixes with the sea water 24 to nucleate water clusters. The water clusters are carried away with the bubbles to the surface 28 to be collected and condensed. As the mixtures of air and vapour leave the surface 28 of the sea water 24, the vapour is condensed in the condenser 22 providing desalinated water 32 while the air is recycled into the column 12, in a continuous cycle.

Where the cluster forming agent is a clathrate-forming gas, the clathrate-forming gas is added

to the column 12 with the stream of air 26 passing through the porous membrane 18. The clathrate-forming gas dissolves in the sea water 24 and forms clathrates which will equilibrate with clathrates in the vapour phase inside the bubbles. There will be a continuous exchange between clathrates in the aqueous phase and in the vapour phase in the bubbles. The vapour in the bubbles and water clusters are carried to the surface 28 to be collected and condensed. The clathrate-forming gas may be collected from the condenser and recycled with the air stream 26.

Where the cluster forming agent is a hydrophobic colloidal particle, the hydrophobic colloidal particles are added to the column 12 with the stream of air 26 passing through the porous membrane 18. It is believed that the particles 38 adsorb on the surface of the bubbles 39 and nucleate water cluster 40 inside the bubbles as shown in Figure 3.

Where the cluster forming agent is a surfactant, the surfactant 44 is added to the column 12 with the stream of air 26 passing through the porous membrane 18.

The surfactant 44 comprises a weakly hydrophilic group 46 such as a hydroxyl or amine group at the end of the hydrocarbon tail 48, the weakly hydrophilic group 46 being proximal to the hydrophilic portion 50 of the surfactant 44. The weakly hydrophilic group 46 causes the surfactant molecules to aggregate and nucleate water clusters 52 on the inside of the bubble 39 as shown in Figure 4. Also depicted in Figure 4 are surfactants 54 lacking a weakly hydrophilic group at the end of the hydrocarbon tail. The surfactants 54 do not aggregate to the same extent as surfactants 44 and do not nucleate water cluster as well.

Advantageously, the surfactants stabilise the bubble surface and so encourage the formation of smaller bubbles and inhibit bubble coalescence.

It will be appreciated that over time, foam may accumulate at the surface 28 of the column 12 and require destabilising and removal. Silicone oils and ethanol may assist in this regard.

Close to the boiling point of water at atmospheric pressure, about 34 L of air bubbles can carry about 20 mL of liquid water as vapour. This is due to the vapour pressure of water increasing uniformly from room temperature to 100 °C, where the vapour pressure becomes equal to normal atmospheric pressure.

Hence, bubbling air into a laboratory sized column of heated sea water at the rate of 1 L/s, would give a water production rate of approximately 50 L per day.

At equilibrium, the vapour content in a bubble is determined by the temperature alone, and does not depend- on whether the water- is at its-boiling point. Hence, the vapour pressure of water in an air bubble immersed in water at 70 °C is exactly the same as that in a boiling bubble created in water boiling under a reduced pressure at the same temperature. Further, at an even higher applied pressure of, for example, about 15 atm, the vapour weight increases significantly to nearly 8000 gm/m³, even when the temperature is maintained slightly below the boiling point of 200 °C.

It will be appreciated that the column 12 must be of sufficient length to allow equilibrium vapour transfer into the bubbles. The rise rate of bubbles under normal steady flow and at room temperature is given by Stokes' law and the buoyancy equation, i.e.: $6\pi\eta r v = \frac{4}{3}\pi r^3 \Delta\rho g$. Using this equation, bubbles of about 3-2 mm diameter can be calculated to rise at a

reasonable rate of between roughly 1-2 m/sec. However, experimental studies have shown that for air bubbles above about 0.7mm radius the rate of rise is limited to about 25cm/sec in water because these larger bubbles become non-spherical (I. Leifer et al., J.

Atmos. & Oceanic Tech., 17, 1392, (2000)). As the temperature increases, the bubbles will rise faster, due to the decrease in viscosity (η) of water. The actual bubble contact time can be increased using baffles. For bubbles of this size, the effects of Laplace pressure (the pressure differential generated across any curved 27 30 interface) can be reasonably ignored. Using the Laplace equation: $\Delta P = \frac{2\sigma}{r}$, the pressure difference ΔP for a 1 mm radius (r) bubble corresponds to 144 Nm⁻², which is negligible compared to atmospheric pressure (of 105 Nm²).

It will be appreciated that if the saline fluid is subject to rapid motion, such as circular motion generated in a vortex, bubbles of many sizes (very fine, i.e. microns to several mm) will be carried along by the 'viscous' forces generated by the fluid flow and not solely by gravity.

The time required to reach vapour equilibrium within a rising bubble can be estimated, very roughly, using Fick's laws of diffusion and the experimental value for the diffusion coefficient for water vapour in air (i.e. $D = 0.28 \text{ cm}^2/\text{sec}$). For simplicity, consider only one-dimensional diffusion and calculate the concentration profiles along a particular direction, perpendicular to the water-air surface. The equation that describes this situation is given by:

$C = C_0 [1 - \text{erf}(\frac{x}{\sqrt{Dt}})]$ where x is the distance from the interface and t the time. At time $t = 0$ at $x = 0$, it is assumed that the bubble starts to fill with vapour. For bubbles of 1-2 mm diameter, saturated vapour pressure will be reached within 1-2 seconds, according to this estimate. However, experimental studies have shown that for larger air bubbles in water, with a diameter of 1 mm or more, the rate of equilibration is much faster than that expected from simple, quiescent diffusion.

When these larger bubbles become non-spherical, they oscillate in shape and in trajectory as they rise in water (ibid) which reduces the time taken to reach vapour equilibrium to several tenths of a second.

Water vapour densities as a function of temperature, at a pressure just preventing boiling are shown in Figure 5. Atmospheric pressure evaporative methods usually operate around 60 °C, where the water density is about 130 gm/m³. At the higher temperature of about 200 °C and at a pressure of about 15 atm, the water density is increased to about 8,000 gm/m³, representing an increase in water vapour transfer of over 60x.

It will be appreciated that the equipment required to maintain a pressure greater than 1 atm may be more complicated than the equipment required for operation at 1 atmospheric pressure. For example, whilst at atmospheric pressure it may be possible to utilise a perspex chamber, at higher pressures, a stainless steel chamber with substantial wall thickness may be required. Further, there will be greater requirement for the use of safety pressure release valves, pressure nozzles and pumps in the use of pressures greater than 1 atm.

The pressure may be increased by heating water in a confined stainless steel chamber. As the water is heated up above 100 °C, the pressure will increase to the desired pressure, for example, 15 atm. The chamber should be provided with a vent system to control the pressure at the desired pressure, for example, 15 atm.

Example 1

A high surface area air/water interface was continuously produced by pumping air through a 40-100 pm pore size glass sinter into a 14 cm diameter Perspex column and, in a separate study, into a 4 cm diameter glass column. Bubbling at a modest rate of about 5 L/min into a column filled with salt water at the level of sea water produced fine bubbles (1-3 mm diameter) and an opaque column, compared with the relatively clear column produced in drinking water, which produced larger bubbles.

The bubbles rose at a limited rate of between about 15 and 35 cm/sec in quiescent, clean water because they undergo shape oscillations which dampen their rise rate. These oscillations are believed to accelerate the transfer of water vapour into the bubbles and so enhance the rate of vapour collection. Equilibrium vapour pressure is therefore attained quite quickly, within a few tenths of a second. As a consequence, it is believed that these bubbles reach saturated vapour pressure within a travel distance of 10 cm or less.

The nature of the present invention means that a wide variety of experimental conditions can be selected, such as, gas flow rate and column operating temperature.

Example 2

A vertical Perspex column of internal radius 7 cm and height 0.5 m was filled with sea water and the water heated to 70 C. Air bubbles were passed through the glass sinter at the base of the column at a rate of about 13 L/min. The fine bubbles produced occupied about 20-30 % of the total volume in the column.

After bubbling for 60 min, the temperature of the solution in the column had fallen to about 52°C. The starting and finishing temperatures were used to estimate the theoretical yield expected for complete collection and condensation of the water vapour, at the average temperature of the column. Relative humidity monitoring indicated that very little vapour was lost to the atmosphere after passing through the condenser. The results showed that vapour collection and transport observed using the apparatus was close to that expected from available equilibrium vapour data. In addition, the conductivity of the water produced, typically at about 6 ptS/cm, was better than that required for drinking water. The 'distilled' water quality product was easily obtained with the method of the present invention using feed water with a salt level similar to that found in sea water, with an electrical conductivity of about 49 mS/cm.

Calculations based on the depletion of thermal energy in the column and the capture of thermal energy, during the vapour condensation process (at 95% efficiency, consistent with industry reports), indicate that the laboratory scale apparatus produced high quality water at an energy cost of about 50 MJ/m³, which is well within the range reported for commercial thermal, evaporative desalination plants.

Example 3

In the third example, both evaporation and condensation were contained within the same column by maintaining a significant temperature differential across the column. A glass column of internal diameter 4 cm and height 1.2 m was preheated to a starting temperature of 65 C. Air bubbles were passed through the glass sinter at the base of the column at a rate of

about 3 L/min. The air bubbles flowed upwards in the column in a reasonably laminar, ordered manner with minimal mixing turbulence. Under these conditions, the average bubble volume fraction was once again about 0.3. The bubble sizes were between 1-3 mm diameter, with a bubble rise rate of about 15 cm/s. The salt solution feed had a concentration of about 0.4 M NaCl and an electrical conductivity of 40mS/cm, at 25 C. The top section of the glass column was cooled using a glass condenser with cooling water flow rate of 0.48 L/min, at an inlet temperature of 0.173 C and an outlet temperature of 6.112 C. The temperature at the top of the column was maintained at 20.0 C. After 5 hr, the conductivity at the top of the column was reduced to 15.9 mS/cm corresponding to a salt concentration of 0.15 M. The conductivity in the middle of the column was 47.3 mS/cm at a temperature of 25 C (measured using an IR detector, so as not to affect the measurements) and the conductivity at the base of the column was 52.4 mS/cm at a temperature of 42 C (measured-by IR).- After-several hours, this column of modest height and with a relatively small temperature differential of only just over C, produced a significant concentration gradient of 0.6 M at the base to 0.15 M at the top. This dilution rate of about 4x, was very close to that expected from the estimated amount of water vapour carried over for the flow rate and temperature.

Hence, in this system, water vapour was carried from the hot salt solution at the bottom of the column, which becomes more concentrated, and was condensed in the cooler, top section of the column, where the salt solution becomes increasingly diluted. A steady state could be created by removing both the (bottom) concentrate and the (top) diluent at a combined rate equal to the rate at which sea water is fed into the column.

It would be expected that extending the column length, increasing the temperature differential and increasing the gas flow rate would further increase the dilution rate within the column. Advantageously, this method may be used to vary the quality of the water produced.

Example 4

The costs of pumping air for bubble column desalination must be considered when carrying out a second embodiment of the present invention. The fourth example provides an estimate of blower costs when employing, for example, amongst others, a basic laboratory pump (Republic HRB402-1) to produce the bubbles for the desalination process in a method of the present invention. The Republic HRB402-1 1.65kW air pump produces 192m³/hr at a pressure of 340mBar. This pressure is sufficient to run ten 0.34m high bubble columns in series, as illustrated in Figure 6.

Each m³ of incoming pumped air at, for example, 200C expands by 22% (at 850C) capturing 0.43L of water at 850C, assuming 100% condensation. Therefore, in 1 hour 192m³ of air enters each column and so collects about 82L of water from each column, that is about 820L overall at a blower energy cost of 1.65kWhr, which corresponds to about 2kWhr/1000L. Commercial thermal systems produce water in the range 6-28kWhr/1000L. The best commercial RO systems produce water at about 3kWhr/1000L and in this regard, the bubble system of the present invention would be significantly cheaper to build and operate. In addition, more energy efficient blowers will be commercially available over time. Further, the low pressure air flow required can be supplied directly from a wind turbine, further reducing energy costs. This analysis in this example is based on the almost full recovery of the latent heat of vaporisation, which is achieved by current commercial thermal units. However, further energy savings could be made using heat pumps, sustainable sources of heat, such as solar (black pipe systems) or industrial waste flue gases or waste heat. The method of the

present invention has many potential advantages over other desalination processes including the potential to harness sustainable energy sources directly, for example, from solar heating and wind turbines and the use of industrial waste flue gases. For example, a typical calciner plant produces 500 tons of waste gas, per hour, at a temperature of 165 °C. It is interesting to calculate the operating temperature of a bubble column heated entirely by hot feed gases. In this situation, steady state is reached when the thermal heat capacity of the inlet (hot) gas precisely equals the latent heat of vaporization required to produce the equilibrated water vapour. The results of this calculation are given in Figure 7. As an example, the calciner flue gases pumped into the column at 3 atm pressure would be sufficient to maintain the column temperature at an operating temperature of 60 °C. Such a system would be capable of producing high quality water from sea water at a rate of about 0.15 litres per cubic metre of gas (see Figure 5). It is interesting to note that the ability of the vaporizing water to withdraw heat from the bubble column means that the column cools to temperatures well below the temperature of the inlet gas (eg see Figure 7). If the inlet air had a temperature of 300C the column would cool to a steady state temperature of about 100C. The bubble column behaves like an efficient evaporative cooler.

Advantageously, the method of the present invention has substantially reduced energy demands compared with RO membrane methods. This is because most commercial sea water RO treatment plants produce a 2x concentrate reject stream, typically returned several km out to sea or discarded. This increase in concentration corresponds to a higher operating osmotic pressure (i.e. over 2x the osmotic pressure of sea water) and significantly higher energy costs. This concentration level is used because the feed salt water must be thoroughly filtered prior to exposure to the RO membranes to reduce the extensive fouling caused by dirty water. However, the method of the present invention can be used to concentrate the reject stream to, for example, only 20% above sea salt levels because this method does not require costly pre-filtration and so it can be operated with much larger reject volumes. This is partly because the column acts as a self-cleaning, flotation column where contaminants float to the surface and are swept away. Suitable biocides could also be added to prevent algal growth.

A process producing only 20% enhanced salt solution has the potential to almost halve the minimum energy required per litre of drinking water produced and will also allow disposal of the concentrate closer to shore, at a reduced cost and with little environmental impact.

In Figure 8, there is shown an apparatus for desalinating water in accordance with a third embodiment of the present invention. The apparatus comprises a plurality of columns in fluid communication.

Applications of the present invention may vary in size from commercial desalination plants to personal use units for example, for use on a small boat.



Your Support Maintains this Service --

BUY

The Rex Research Civilization Kit

**... It's Your Best Bet & Investment in Sustainable Humanity on Earth ...
Ensure & Enhance Your Survival & Genome Transmission ...
Everything @ rexresearch.com on a Thumb drive or Download !**

[ORDER PAGE](#)
