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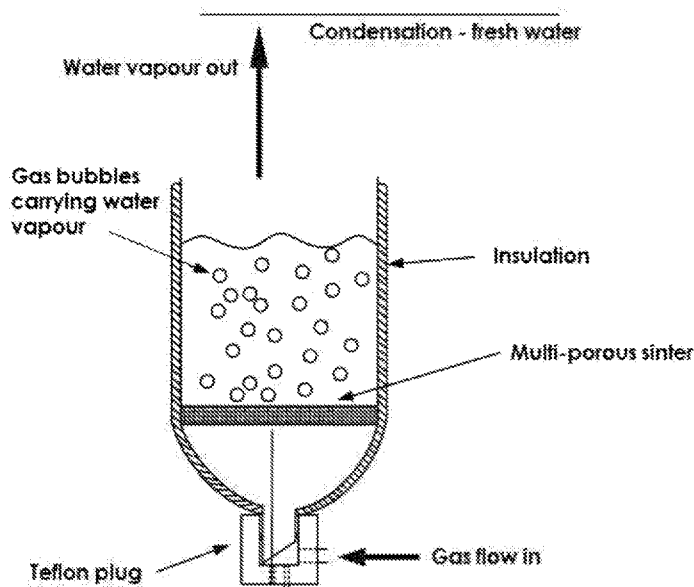
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(54) Title: CONDENSED WATER RECOVERY AND STERILISATION

Figure 1A: open condenser



(57) **Abstract:** A water treatment unit and processes for producing a first stream of water that is a (5) condensed, potable water product, and an optional second water stream that is sterilised. The water treatment unit of the invention comprises an inlet water tank, a gas inlet, an inlet gas, a means for producing gas bubbles, a condenser apparatus adapted to condense water vapour, a water vapour outlet; a condensed water collection receptacle and an optional sterilised water collection receptacle.



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Condensed water recovery and sterilisation

Field of the invention

The present invention relates to a water treatment unit and processes for producing a stream of water that is a condensed, potable water and optionally a second
5 stream from the same water treatment unit that is a sterilized water substantially free from pathogens.

Background of the invention

Water quality measures, can be grouped under three main categories: microbiological, physical, chemical. Unsanitary water remains one of the leading risks to
10 public health worldwide. The World Health Organisation (WHO) estimated that over 30 million cases of diseases and millions of deaths could be caused by pathogen infected water sources globally each year [1]. Not only is this as a result of direct infection from contaminated water, but also indirectly via food products that have been exposed to contaminated water.

15 The foodborne diseases are often linked to pathogen infected animal products, whereby the livestock were exposed to contaminated water and infectious effluents during the production [2, 3]. Another major contributing factor comes from the increased usage of recycled effluent water on farms and the presence of contaminants such as human and animal pathogens in that water [4]. The quality of the water fed to livestock
20 can also have a direct impact on the animal. For example, the quality of drinking water supplied to pigs can affect their performance. Poor quality water can inhibit growth, particularly in younger, more vulnerable animals. High levels of some elements present in water, can also have a detrimental effect on the effectiveness of some water medications.

25 Water conservation and recycling through effluent management is an important aspect of sustainable farming. Hence, effluent and water management have become more critical in crop and livestock farming, from both public health and business efficiency perspectives. Many farms, especially smaller sized livestock producers,

require specific water treatment equipment that is scalable, has simple engineering, and can produce potable water for the livestock.

Most water treatment technologies have been developed for the purpose of desalination. In this regard, there are effectively three categories of water treatment technologies, based on three different theoretical approaches. These are: thermal
5 processes, membrane processes, and ion-exchange processes (or hybrids thereof).

Thermal process can treat large quantities of water compared to other means, but at the same time, it cannot be scaled down to treat a small amount of water on a daily basis. The scale typically requires treatment of hundreds to thousands cubic
10 meters of water per day depending on the methodologies applied, and only the very large commercial farms use this much water. The process is also an energy-demanding process, and can become expensive if no cheap thermal source available. It is therefore difficult to locate a thermal-based water treatment process to use on most farms, and is difficult to adapt to generating condensed, potable water product.

15 Membrane processes, as the name suggests, utilise membrane technologies for water treatment, simply by passing saline or contaminated water through membranes. The most popular of these is reverse osmosis. But it has a complicated engineering base that is not very user-friendly and, like the thermal processes, is difficult to scale down to suit smaller producers. It is also expensive in treating water considering
20 operational and membrane cost, as well as technical support that is often not readily available, especially on remote farms. So this technology does not lend itself to adaptation to a process for generating condensed, potable water product

And whereas ion-exchange technology has found value in desalination because most solutes are charged ions, this technology has difficulties in removing the organic
25 compounds coming of out excrement, since most organic molecules are not present in ionic form.

There is therefore a need in the field for a technology that can produce potable water.

Reference to any prior art in the specification is not an acknowledgment or
30 suggestion that this prior art forms part of the common general knowledge in any

jurisdiction or that this prior art could reasonably be expected to be understood, regarded as relevant, and/or combined with other pieces of prior art by a skilled person in the art.

Summary of the invention

5 Water conservation and recycling is an important aspect of sustainable farming. Clean, potable and accessible water is essential. The present invention relates to a water treatment unit and processes for producing a stream of water that is a condensed, potable water product and optionally, from the same water treatment unit, a second
10 sterilised stream of water that is substantially free of pathogens but may still contain organic content.

 In one aspect of the invention there is provided a water treatment unit comprising an inlet water tank, a gas inlet, an inlet gas, a means for producing gas bubbles, condenser apparatus adapted to condense water vapour, a water vapour outlet; and a condensed water collection receptacle.

15 In a preferred embodiment the inlet gas is a combustion gas, and more preferably a combustion gas from biogas combustion or from pure gases such as methane, propane, ethane and butane.

 In another embodiment of the invention the condenser apparatus adapted to condense water vapour is closed condenser.

20 The means for producing gas bubbles is preferably sinter; the sinter may be metal or ceramic; preferably metal.

 In another aspect of the invention there is provided a process for condensing water from a water source comprising the steps of:

- a. adding water to the water treatment unit of the invention;
- 25 b. passing an inlet gas through the means for producing gas bubbles;
- c. collecting the gas bubbles via the water vapour outlet;
- d. condensing water from the collected gas bubbles via the condenser apparatus; and

- e. collecting the condensed water in the condensed water collection receptacle.

In one embodiment of this aspect of the invention, the process further includes collecting sterilised water from the water treatment unit. This collection step may occur
5 at any time after step (b).

Preferably the water source is a source of contaminated water, or salt water, or brackish water.

As used herein, except where the context requires otherwise, the term "comprise" and variations of the term, such as "comprising", "comprises" and
10 "comprised", are not intended to exclude further additives, components, integers or steps.

Further aspects of the present invention and further embodiments of the aspects described in the preceding paragraphs will become apparent from the following description, given by way of example and with reference to the accompanying drawings.

15 **Brief description of the drawings**

Figure 1: schematic of the water treatment unit components in the (A) open laboratory scale and the (B) process.

Figure 2A and B: CAD drawing (A – front and B – back) of a continuous flow reactor with inlet water tank, condenser, the water and gas inlets and the tank for
20 collecting the condensed water product.

Figure 3A: the mobile pilot plant consisting of two water treatment units of the invention with a liquid petroleum gas (LPG) generator attached as its source of hot gas to mimic biogas

Figure 3B: closed condenser.

25 Figure 4 A and B: the water treatment unit with 2 closed condensers in series.

Figure 5: schematic of the water treatment unit (illustrated with an open condenser) and the two streams of water (condensed and sterilised) generated following application of one embodiment of the process of the invention.

Figure 6: graph illustrating the amount of evaporated water after 1 hour of treatment of 0.5M NaCl solution in the pilot plant at 3 different temperatures. This experiment mimics the process of the invention for condensing water from salt water.

Figure 7: graph illustrating the amount of evaporated water after 1 hour of treatment of synthetic piggery solution in the pilot plant at 3 different temperatures. This experiment mimics the process of the invention for condensing water from a contaminated water source, being water contaminated with animal effluent.

Detailed description of the embodiments

From a resource management perspective, water conservation and recycling is an important aspect of sustainable farming. Water is not just getting scarcer, it has become more polluted and unsafe to drink. And agricultural water usage in particular faces the additional problems of the large quantities needed, the lack of natural water sources and for many farms, the remote location which makes water transport prohibitively expensive. The water treatment unit of the invention therefore provides, for the first time, the option to produce and collect two streams of water products from the same water treatment unit:

1. A condensed potable water product (herein referred to as stream 1 or condensed water); and
2. A treated or disinfected low health risk water product (herein referred to as stream 2 or sterilised water) that is suitable for farm usage, as the pathogens have been substantially removed but organic content is retained.

The water treatment unit and process of the invention, as will be detailed below, is derived from a laboratory scale bubble column evaporator (BCE). BCE is based on a mechanism whereby when air is pumped through a multi-porous sinter, with controlled salt concentrations, air bubbles of different sizes are created. Air bubbles can carry water vapour inside the bubble, and when the bubbles with the water vapour leave the

reactor, it can then be condensed into fresh water, while the contaminants will be left in the concentrate. The process also provides a sterilisation pathway to inactivate microorganisms and produce sterilised water.

The BCE process however, while commercialised for desalination, has not been
5 configured for large scale condensation or sterilisation of contaminated water, such as blackwater treatment, or for overcoming the problems associated with contaminated water treatment. Considerations such as solution type, gas and liquid flows, materials, gas type, temperature, insulation, and maintenance prevented the direct use of the BCE process for treating contaminated water. Nor was it possible or practical to implement a
10 unit in farm settings for reasons including, but not limited to:

- The BCE is an open-condenser and lacks water recovery performance;
- The BCE may not function adequately in cold temperatures;
- The BCE relies on retail electricity; and
- The BCE relies on economy of scale and is very energy inefficient at
15 smaller scale.

Blackwater is the wastewater discharged with excretory contamination. The treatment of blackwater is usually more complicated than the conventional discharged water sources such as greywater that comes from domestic waste, which only contains lower levels of organic matter and nutrients and is typically free of faecal matter.
20 Greywater is the waste water from showers, baths, hand basins, laundry tubs and washing machines, as opposed to toilets. Blackwater typically requires extra treatment processes. As a first step, suspended solids are removed (solid organic matters and non-dissolvable organics) at the pond that acts as a primary settlement tank. The secondary process treats dissolved organic materials that remain after the primary
25 stage and is often combined with the aid of aerobic bacteria. The generated bacteria can be readily removed by a secondary sedimentation. A tertiary treatment process is required for potable water recycling or sensitive water sources to remove the last traces of any unwanted particles and possible sterilisation. By 'potable water' it is meant water that is safe to drink or to use for food preparation.

The water treatment unit and process of the invention seeks to solve one or more of the problems of existing units and processes, or to offer advantages over the existing units and processes. And for the first time, provides the option for production of two different streams of water in the same treatment unit. In order to be useful for farms of variable sizes, the treatment unit and process of the invention is preferably scalable. In order to be useful on farms in remote locations and/or third world countries, it preferably has low set up and operational costs, and does not require extensive technical support from qualified engineers.

The current invention therefore seeks to provide a water treatment unit and process that can purify water into potable water. In accordance with the present invention, the water treatment unit comprises

an inlet water tank;

a gas inlet;

an inlet gas;

a means for producing gas bubbles;

a condenser apparatus adapted to condense water vapour;

a water vapour outlet;

a condensed water collection receptacle; and

optionally, a sterilised water collection receptacle.

A schematic of one embodiment of the water treatment unit column components is shown in Figure 1A, with a process schematic in Figure 1B. The column components are collectively and interchangeably referred to throughout the specification as 'bubble column reactors' and 'continuous flow reactors', and more simply, just 'reactors'. Figures 2 A and 2 B are a front and rear CAD drawing of a continuous flow reactor with inlet water tank, open condenser, the water and gas inlets and the tank for collecting the condensed water product.

A key element that impacts recovery yield is the loss of vapour into the external environment. Accordingly, to improve water recovery efficiency, the heat exchange apparatus adapted to condense water vapour (ie the condenser) is preferably a closed-

condenser. In one embodiment the condenser is in the form of a shell and tube condenser having an internal and external surface wherein the condensing water is passed through the shell of the condenser to condense the water vapour. In order to ensure the gas bubbles containing water vapour are captured and condense, the internal surface of the condenser is kept cold (at about 10-16°C preferably, but may vary outside of this range depending on the temperature of the input water/effluent) to facilitate condensation of the water vapour in the saturated gas, onto the internal surface. High-quality condensed water is recovered through the condenser outlet (see Figure 4B).

The inlet gas, also referred to interchangeably as input gas or air and inlet air, may be selected from ambient air, CO₂, and combustion gas. Subject to the gas selected, the water treatment unit of the invention may include a desiccator (for example silica gel) to de-humidify the gas. In a preferred embodiment the inlet gas is a 'clean' combustion gas, and more preferably a combustion gas from biogas combustion or from pure gases such as methane, propane, ethane and butane. By 'clean' combustion gas it is meant a gas that does not contain partially burnt hydrocarbons.

The means for producing gas bubbles is sinter, preferably metal or ceramic sinter; more preferably metal sinter. The skilled person would be aware of options for metal sinter guided by a preference for the metal or metal alloy to provide temperature and corrosion resistance. In this regard, an alloy like Hastelloy C-276 or Inconel 600 for example would be preferable compared to stainless steel. The skilled person will also know of appropriate sinter options and specifications. Sintered porous metal media provides long life, high strength and uniform porosity in media grades ranging from 0.1 to 100 micron, high heat tolerance of more than 900°C. Alternatively one exemplary ceramic sinter has a pore size 40~100 µm, an external diameter 150 mm, an internal diameter 100 mm, a heat tolerance of 1000°C, a porosity 30-43% and a Mo scale of hardness of 7.

Heating the gas inputted into the water treatment unit can increase the efficiency of water vapour production as the water treatment unit of the invention relies on heat transfer efficiency, the heat transfer rate between liquid and gas being 100 times more efficient in a gas-liquid bubble column than in a single phase flow [5]. When hot gas

bubbles form on the surface of the sinter, a thin layer of heated water is transiently formed around the surface of the bubbles. When the sinter-surface gas temperature increases, so does the thickness of the hot water layer around the bubbles. As the hot gas bubbles pass through the sinter in to the liquid contained in the inlet water tank, the transient hot surface layer of the bubbles causes vaporisation of some of the liquid which is picked up by the gas bubble. This results in cooling of the bubble. And as explained above, when the water vapour leaves the reactor, it can then be condensed into fresh water. The amount of water the bubble is carrying is a function of the temperature and type of gas supply.

10 Accordingly, in an embodiment of the invention, the water treatment unit includes a gas heater.

Alternatively, in a preferred embodiment, the gas inputted to the water treatment unit is already hot ie a hot combustion gas. For example, exhaust combustion gases can be used provided they do not contain partially burnt hydrocarbons. When using exhaust combustion gases the exhaust pipe of a generator can be attached to the water treatment unit.

In another alternative, the hot combustion gas comes from biogas combustion. The livestock industry often integrates biogas as part of their effluent management scheme. By 'biogas' it is meant the by-product of anaerobic digestion of organic waste. Given an anaerobic digestion biogas plant (ADBGP) can run on livestock manure, and biogas is around 60% methane, a gas engine can be adopted to burn the gas, and generate heat. The biogas waste gas has a temperature of approximately 450-520°C, which is an ideal source of inlet gas. Accordingly, in this embodiment of the invention, the inlet gas is biogas waste.

25 By using hot input gas, the water treatment unit of the invention has the advantage over other prior art units of not requiring any heating elements or heat exchangers, and of avoiding steam and/or vapour production. The water temperature in the water treatment unit of the invention does not reach beyond 70°C, and preferably not beyond 60°C, making the water treatment unit and the sterilisation process of the invention highly energy efficient, especially when compared to other units and processes. When the water treatment unit and the process of the invention uses

combustion gas, it preferably does so under atmospheric pressure. The inventors have determined that combustion gases at atmospheric pressure result in a maximum bubble surface area. Specifically, the combustion gases travel through a metal sinter that provides the right bubble size (1-3 mm). In addition, the use of atmospheric pressure makes the system much simple compared to, for example, prior art systems that use compressed CO₂ as a sterilization process. Air pumps are not required.

As will be appreciated, this embodiment can be applied to any with abundant waste heat sources at disposal, such as landfills and power plants. The application of the water treatment unit is not limited to farming and agriculture.

Using hot inlet gas and therefore heating the gas bubbles produced, the water treatment unit of the invention can be utilised to produce a sterilised stream of water in addition to the condensed water. The hot air used in the water treatment unit produces an inactivation mechanism based on the temperature of the inlet gases. With a temperature of, for example, 150-250°C for gas bubbles and approximately 55-60°C for contaminated water, the water treatment unit of the invention can kill up to, and with sufficient contact time of the water in the reactor, over 99% of living organisms by thermal inactivation. It does so by transferring heat from the hot bubbles to the cell surface of microbes in the inlet water, through collisions. Thermal inactivation is known in the art, and the skilled person is able to determine what a sufficient contact time will be for any given temperature. But as a guide, at 200°C, about 3-5 minutes residence time of the water in the reactor will be sufficient contact time to inactivate 99.9 % of pathogens in the solution and produce sterilised water. If less than 200°C, about 5-10 minutes would be recommended; if greater than 200°C 1-3 min would be recommended.

This sterilised water stream is preferably collected, as it can be utilised for all other needs other than drinking. For example, watering crops.

Lower external temperature will reduce the temperature of the inlet gas and affect the water recovery efficiency significantly. Hence the water treatment unit of the invention preferably includes one or more insulation layers. Insulation layers may be included, for example, as an outer layer to reduce exposure in cool climates.

The tubes of the water treatment unit of the invention must also be able to withstand the large scale of expanding and shrinking of the tubes under high temperature variations. The water treatment unit of the invention may therefore also include a buffer space.

- 5 The condensed water will be collected in the condensed water collection receptacle through a specifically designed outlet.

The water treatment unit of the invention also lends itself to digital integration. Sensory technology can monitor, for example, water treatment information in real-time and connect back to a water database.

- 10 Multiple water treatment units can be utilised to create a water treatment system. Such a water treatment system, called the 'pilot plant' was utilised in the examples and testing.

- As noted above, the water treatment unit of the invention therefore provides, for the first time, the option to produce and collect two streams of water products (see
15 Figure 5):

1. A condensed water product that is drinkable, via the water vapour being carried out by passing air bubbles, and condensing the water carried those bubbles (stream 1 in Figure 5).
2. A treated or disinfected low health risk sterilised water product that is
20 suitable for, for example, farm usage, via the pathogen inactivation effect of the water treatment unit of the invention (stream 2 in Figure 5).

- There is therefore also provided a process for condensing water (described and illustrated as stream 1 in the examples and figures), and a process for sterilising water (described and illustrated as stream 2 in the examples and figures), using the water
25 treatment unit of the invention as shown in Figure 5.

Both streams are produced simultaneously with the option to collect the sterilised stream in addition to the condensed stream. As described above, when the hot combustion gases produce bubbles in the solution, the collisions between these bubbles and the pathogens inactivate the pathogens, thereby sterilizing the water and

leading to the production of stream 2. To produce stream 2 the water in the reactor needs only about 1-10 minutes residence time at 150-250°C inlet temperature of the gas. This residence time is dependent on the temperature. For 200°C, 3-5 minutes will suffice to ensure that substantially all of the pathogens are inactivated. If the inlet gas temperature is increased the residence time can be reduced to achieve the same thermal inactivation; and vice versa [6-8]. By 'substantially all' it is meant an inactivation factor of 4, which equates to 99.99% of pathogens being inactivated.

The water added to the heat treatment unit via an inlet water tank may be any source of salt water, brackish water or contaminated water – or indeed aqueous solution - that requires sterilisation and/or from which water can be condensed. By 'contaminated' in this context it will be understood to mean to water that has an adverse water quality due to the presence of any physical, chemical, biological or radiological substance or matter in water. Drinking water may reasonably be expected to contain at least small amounts of some contaminants. Some contaminants may be harmful if consumed at certain levels in drinking water. Harmful contaminants may include, but are not limited to animal/human waste products, chemicals, soaps and disinfectants, microorganisms and macroscopic contaminants. The term 'water pollution' is similarly understood to be contamination of water.

The contaminated water may be blackwater, greywater, dam water, or water from any water bodies including lakes, rivers, oceans, aquifers and groundwater. The water treatment unit of the invention is not limited or specific to the source of the water. In addition to having use on farms as already discussed, the water treatment unit may equally be utilised in third world countries with contaminated drinking water, or for producing potable water from a salt or brackish water source.

When blackwater is the source of contaminated water, the blackwater may be contaminated with effluent from any, and mixed, livestock sources including pigs, cattle, chickens, sheep, camels, alpacas, horses and other equine species, goats and deer species.

It will be understood that the invention disclosed and defined in this specification extends to all alternative combinations of two or more of the individual features

mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the invention.

Examples

5 The following examples and tests were carried out on dam water, pig effluent and piggeries in Australia. It will of course be appreciated however that the technology can be readily applied to any source of contaminated water, salt water or brackish water. Ie there is nothing unique about dam water, pig effluent, or piggeries, such these examples and tests should be so limited.

10 Example 1: CONDENSED WATER (STREAM 1) RECOVERY AND STERILISATION PROCESS (STREAM 2)

1. The water treatment units

Two identical water treatment units of the invention were connected and installed to become a mobile “pilot plant” with a liquid petroleum gas (LPG) generator attached as its source of hot gas to mimic biogas in lab (Figure 3A).

15 Condensers were specifically designed and installed on top of the pilot plant to recover high-quality water from the pilot plant. The version shown in Figure 3A is the open-condenser embodiment; Figure 3B is the closed-condenser embodiment, specifically, a modified 0.85 m² tube and shell condenser. Figure 4A and B shows two angles of the water treatment unit with 2 closed condensers in series. Example 1 was
20 conducted on the open-condenser embodiment.

2. Experimental solutions and water samples

Due to Workplace Health and Safety (WHS) requirements of the University of NSW, contaminated water was not allowed to be brought on campus. Hence piggery dam water and effluent water samples were taken and analysed at the commercial lab
25 of ALS Water Resource Group for determination of contents. Synthetic samples were then made by mixing corresponding additives to produce the mimic of the actual piggery water and be used on campus. Real effluent water sample was also tested during the on-site experiment at a farm.

Secondary treated synthetic sewage and piggery water (dam water)

Synthetic sewage presents a mean dissolved organic carbon (DOC) concentration of about 100 mg/l and a chemical oxygen demand (COD) of about 300 mg/L in the influent. Secondary treated synthetic sewage was designed to meet the European standards by using the following ingredients: 120 mg of peptone, 90 mg of meat extract (we have replaced meat extract by Bovril® according to recommendations in Biology of Wastewater Treatment 24), 30 mg of urea, 13 mg of dipotassium hydrogen phosphate, 7 mg of sodium chloride, 2 mg of calcium chloride dehydrate and 2 mg of magnesium sulphate heptahydrate.

10 *Synthetic piggery effluent*

Water samples were also directly taken from a piggery effluent pond at a farm and the composition analysed for synthesis: 628 mg/L of BOD; 52.5 mg/L of total phosphorus; 2100 mg/L of total nitrogen; 1520 mg/L of sodium; 156 mg/L of calcium; and 59.9 mg/L of magnesium. The synthetic piggery water was made with the following ingredients in a litre of boiled tap water: 836 mg of peptone; 557.3 mg of meat extract (again replaced by Bovril®); 4506 mg of urea; 300 mg of dipotassium hydrogen phosphate; 3863 mg of sodium chloride; 572 mg of calcium chloride dehydrate; and 607 mg of magnesium sulphate heptahydrate in a litre of water.

Real piggery effluent

20 The real piggery effluent was obtained from a piggery farm where the final experiments were conducted.

3. Pathogen sample

Coliform bacteria (E. coli)

25 *Escherichia coli* was used in synthetic solutions to mimic micro-organisms presence in the sample.

E. coli is a gram-negative bacterium with a straight cylindrical rod shape, 2.0–6.0 µm in length and 1.1–1.5 µm diameter. It is found in the gastrointestinal tract of animals and humans. *E. coli* strains can be harmless or pathogenic to the host. As the result of faecal contamination, they can be found in water and soil. The strain *E. coli* C-3000 (ATCC15597) was selected as a representative model for bacterial contamination in

water. This strain, a biosafety Level-1 organism, can be used as a MS2 virus host, which is why it was selected for this work.

For each bacterial-growth experiment, two solutions were prepared (A and B).

Solution A: For the preparation of Solution A, we used 13 g of tryptone, 1 g of yeast extract, 6 g of NaCl and 1000 ml of Milli-Q water. A pH value of 6.9 was measured with a Thermos Scientific Orion Star A214 pH meter. This solution was dispensed aseptically into two vessels containing 1.41% agar and no agar, respectively; the agar used in the experiments was molecular-biology grade from Sigma-Aldrich. These solutions were heated to boiling to dissolve the agar and sterilized by autoclaving for 15 minutes in an Aesculap 420 at 15 psi and 121–124°C.

Solution B: This was used to improve the viability of the bacteria. It was prepared by adding 1 g of glucose and 0.010 g of thiamine to 50 ml of Milli-Q water and filtered through a 0.22µm filter for its sterilization. Once cooled to 50°C, it was added aseptically to Solution A in a proportion of 1:19.

The resulting 1.41% agar solution was poured into 100mm × 15mm petri dishes and dried above a Bunsen burner to maintain local environmental sterility, until the agar was not too dry nor too moist.

For a successful plaque assay, the *E. coli* C-3000 (ATCC 15597) must be in an exponential growth phase. This was achieved by growing two separate bacterial cultures: an overnight culture and a log-phase culture. The overnight culture was grown in 10 ml of the media without agar at 37°C for 18–20 hours in a Labtech digital incubator, model LIB-030M, while shaken at 110 rpm by a PSU-10i orbital shaker. The overnight culture resulted in high numbers of bacteria in the culture and was used as a reference standard.

To start the exponential phase in the *E. coli* culture, 1 ml of the overnight culture was transferred into 25–30 ml of Solution A without agar and incubated for 3 hr at 37°C, with gentle shaking at 110 rpm.

Pathogens in actual piggery effluent water sample

The real piggery effluent contains a number of different types of pathogens that can cause harm to people. These include major public health risks such as *E. coli*, *Salmonella* and *Coliforms*, etc. A detailed analysis of pathogen presence in the piggery

water sample is presented in Table 1, and corresponding treatment results are presented in the results section.

Table 1 Pathogens detected in the piggery effluent water

Pathogens	Units	Raw Piggery Water
<i>Giardia</i>	cysts/L	50
<i>Thermotolerant Faecal Coliforms</i>	CFU/100mL	179000
<i>Salmonella VIDAS</i>	NONE	Detected
<i>E. coli</i>	CFU/100mL	179000
<i>Cyanophyta</i>	Cells/mL	35600
<i>Enterovirus</i>	MPNIU	Not detected

5 4. Experimental procedure

The first round of experiments were performed using secondary-treated synthetic sewage and synthetic piggery effluent, with a gas flow inlet at 130°C, 185°C and 215°C, and combustion exhaust gas from an LPG generator at 47°C. The base of the rectangular stainless-steel pilot plant was fitted with a half cylinder of length 500 mm and an external ceramic sinter of diameter 150 mm and pore size 40–100 µm, with 30-43% porosity.

The experimental solution – synthetic sewerage and effluent - was poured into the pilot plant and the temperature of the solution was measured with a thermocouple in the centre of the column solution. The hot air travelled through the sinter into the 3500 ml of solution, inactivating the *E. coli*, in separate batch experiments. The evaluation of *E.coli* viability was performed using the plaque-assay method.

When using the combustion gases, the exhaust pipe of a gas generator (Greenpower) was attached to an isolated metal pipe with a valve that provided an exhaust gas flow rate of 120–140 L/min through the pilot plant.

The top of the pilot plant was fitted with a settlement/condenser tank that kept the lower surface of the condenser at 12-16°C; this facilitated condensation of the water vapour in the saturated gas, onto the internal surface. High-quality condensed water was recovered through the internal gathers.

The final round of experiments was conducted at the farm with real piggery effluent. Different types of bacteria were present in this effluent and so the testing pilot plant was deployed at the farm itself, where two experiments were conducted: the first one with combustion gas at 115°C and the second one with hot air at 175°C.

- 5 Potable water was collected via condensation in all experiments to analyse the water recovery yield.

5. Data analysis and Results

Water recovery with open condenser (Stream 1)

- 10 The water treatment unit that was used in the testing has an internal capacity of storing approximately 3500mL of contaminated water sample. The recovery yield was calculated mL per hour within all water samples used.

The three condensed water recovery experiments were conducted with 140 L/min of inlet hot air at three different temperatures (130°C, 175°C and 185°C) in 3.5 litres of two different solutions.

- 15 The condensed-water flow rate observed was about 106 ml/hr (Table 2) when running the plant in the laboratory at a sinter-surface air temperature of 130°C. When this temperature was increased to 185°C, the volume of pure condensed water was about 400 ml/hr (Table 2).

- 20 To test the new process, two pilot plants were installed at the farm to sterilize 3.5 L of piggery effluent each during 20 min; one with combustion gas at 115°C and another one with hot air at 175° C. The condensed water recovery experiment was conducted in the hot air plant, giving up to 80 ml/hour of pure water recovery (Table 2).

- 25 Possible explanations for the unexpected low recovery at the farm of only 80 ml/hour, were the external temperature (only 5°C), and the real piggery effluent that carries a much higher organic content than the secondary treated synthetic sewage that makes evaporation more difficult and produces more foam. Hence, based on this data, the inventors identified the preference for the water treatment units of the invention to include additional insulation.

Table 2 Pilot plant water recovery experiments with hot air

Location	Type of water	External temp (°C)	Inlet air temp (°C)	Water recovery (ml/hour)
Open condenser				
Lab experiment	Secondary treated synthetic sewage (dam water)	23	130	106
Lab experiment	Secondary treated synthetic sewage (dam water)	23	185	400
Farm	Real piggery effluent	5	175	80

Pathogen inactivation (Stream 2)

Pathogen inactivation calculation

- 5 Pathogen inactivation was presented in the *survival factor* or *inactivation factor* calculated as the following:

$$\text{Equation (2)} \quad \sigma_i = -\log_{10}\left(\frac{PFU_i}{PFU_{i0}}\right)$$

Where σ_i is the inactivation factor that represents the rate of remaining pathogen after treatment on pathogen i . PFU_{i0} and PFU_i are the Plate Forming Units of the pathogen i , which represents the number of pathogens, e.g. *E. coli* per unit volume before and after treatments. Hence, an inactivation factor of 4, means 99.99% pathogens are killed, or 0.01% pathogens are survived after treatment, depending how one may choose to interpret.

Two pilot plants were installed at a farm to sterilize 3.5 L of piggery effluent each during 20 min; one with combustion gas at 115° C and another one with hot air at 175 °-180° C.

When hot air at 175°C was used as an inlet gas in the pilot plant there was around a 4-log reduction (survival factor = 4) for *thermotolerant faecal coliforms* and *E. coli*; *Salmonella* was not detected. Other species like *Cyanophyta* was also inactivated with a survival factor of 0.66. Hot combustion gas at 115°C presented lower inactivation rates with a survival factor of 0.06 for *Cyanophyta*, and 0.05 survival factor for *thermotolerant faecal coliforms* and *E. coli*, *Salmonella* was still detected (Table 3).

Table 3 First inactivation results from the pilot plant study using real piggery effluent. Selected pathogens in piggery effluent before and after 20 minutes treatments at the farm.

Pathogens	Units	Raw Piggery Water	Pilot Plant Treatments			
			175°C inlet air	Survival factor (175°C)	115°C inlet Combustion gas	Survival factor (115°C)
Thermotolerant Faecal Coliforms	CFU/100mL	179000	< 100	4	159000	0.05
Salmonella VIDAS	NONE	Detected	Not Detected	N/A	Detected	N/A
E. coli	CFU/100mL	179000	<100	4	159000	0.05
Cyanophyta	Cells/mL	35600	7800	0.66	30800	0.06

These results show that the water treatment unit of the invention offers a viable water sterilisation technology, able to sterilise different types of bacteria in the most heavily infected waters. *Cyanophyta* for example has been identified as a real threat for public health and the environment due to production of toxins that can affect humans and other vertebrates. During the hottest months the numbers of *Cyanophyta* will increase rapidly causing a considerable impact in recreational water quality and endemic bacterial species. In wastewater treatment plants this increase will reduce their efficiency. Therefore, the results of 0.66 *Cyanophyta* reduction when using the water treatment unit of the invention proves that this new technology can be effectively used to reduce the impact of this threat.

EXAMPLE 2: CLOSED CONDENSERS (Figures 3B and 4A)

Different experiments with hot gases (air and CO₂, i.e. biogas waste gas after flaring) were conducted at the laboratory with the water treatment unit of the invention to measure the amount of water evaporated. In this work, heated gases including air and CO₂, were introduced into the pilot plant containing 3500 ml of solution for 60 min and the total loss of the solution was measured using a weighing balance.

A series of experiments with inlet air at 80, 120 and 160 °C in two different solutions (0.5M NaCl simulating salt or brackish water and synthetic piggery effluent) were conducted to assess the maximum amount of water that can be evaporated in one hour. To calculate the evaporation rate the pilot plant was weighed every 5 minutes.

5 From the results, it can be clearly seen that inlet gas temperature plays a key role for water evaporation in the pilot plant for both solutions with 710 ml/h at 160°C, 328ml/h at 120°C and 150 ml/h at 80°C with synthetic piggery effluent and 690 ml/h at 160°C, 358ml/h at 120°C and 210 ml/h at 80°C with 0.5M NaCl solution (see Figures 6 and 7).

10 The results (Figures 6 and 7) indicated water had been captured by hot air bubbles in one hour and left the water treatment unit, waiting to be condensed, indicating that a close-condensation system is likely to increase the efficiency if combined with biogas flaring waste gas.

The modified stainless steel closed condensers of the water treatment unit (Figure 3B) have a surface area of 0.848 m², a length of 830 mm and width of 89 mm.
15 Comparing the surface area of the closed-condenser of 0.848 m² with the open design having 0.2m² the first laboratory experiments showed that amount of water recovery with the new closed condenser has been increased by almost 4 times.

Moreover, to improve the output efficiency, the piggery effluent was recirculated through the internal tubes of the closed condenser (see Fig. 4B) and from there was
20 introduced into the pilot plant. This improved the pilot plant sterilization by increasing the piggery effluent temperature. Piggery effluent temperature is about 14°C and the temperature of the saturated gas leaving the pilot plant is around 55 °C. This temperature difference of 41°C provides an adequate condensation on the internal tube surface of the condenser. The condensed water was collected through a specifically
25 designed outlet.

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CLAIMS

1. A water treatment unit comprising an inlet water tank, a gas inlet, an inlet gas, a means for producing gas bubbles, a water vapour outlet, a condenser apparatus adapted to condense water vapour and a condensed water collection receptacle.
- 5 2. A water treatment unit according to claim 1 wherein the inlet gas is a combustion gas.
3. A water treatment unit according to claim 2 wherein the combustion gas is from biogas combustion.
4. A water treatment unit according to any one of claims 1 to 3 wherein the
10 condenser apparatus adapted to condense water vapour is a closed condenser.
5. A water treatment unit according to any one of claims 1 to 4 wherein the means for producing gas bubbles is sinter.
6. A water treatment unit according to claim 5 wherein the sinter is metal.
7. A water treatment unit according to any one of claims 1 to 6 further comprising a
15 sterilised water collection receptacle.
8. A water treatment unit according to any one of claims 1 to 7 wherein the water to be treated is contaminated water, salt water or brackish water.
9. A process for condensing water from a water source comprising the steps of:
 - a. adding water to the water treatment unit of any one of claims 1 to 8,
 - 20 b. passing an inlet gas through the means for producing gas bubbles,
 - c. collecting the gas bubbles via the water vapour outlet,
 - d. condensing water from the collected gas bubbles via the condenser apparatus and
 - e. collecting the condensed water in the condensed water collection
25 receptacle.
10. A process according to claim 9 wherein the water is contaminated water, salt water or brackish water.

11. A process according to claim 9 or 10 wherein the inlet gas is a combustion gas.
12. A process according to any one of claims 9 to 11 further comprising collecting sterilised water at any time in the process after step (b).

Figure 1A: open condenser

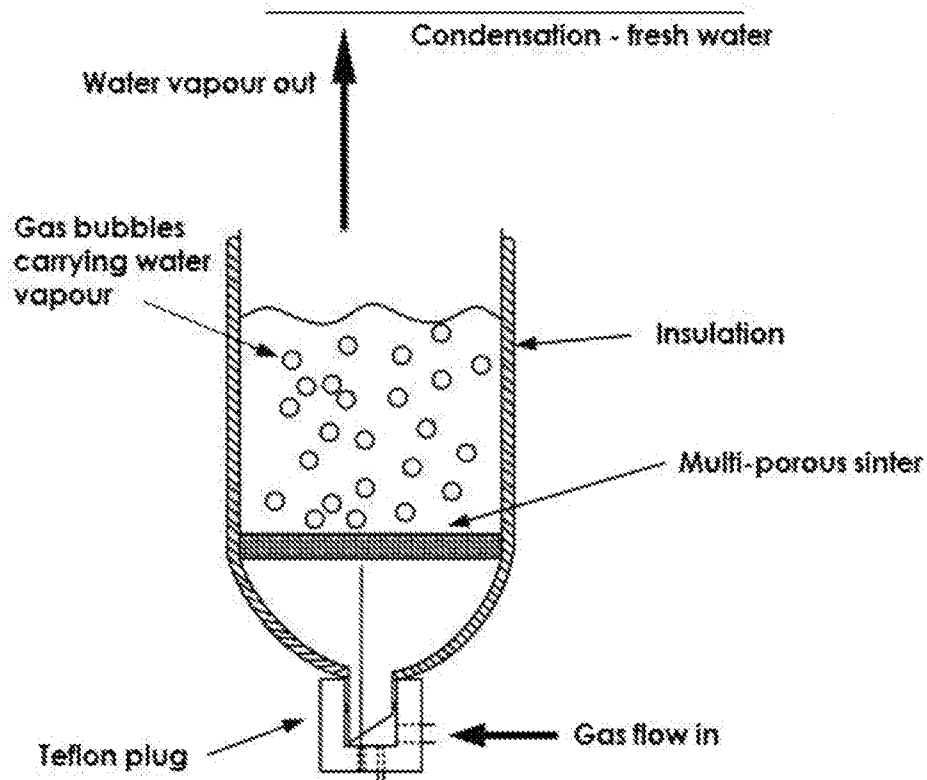


Figure 1B: Closed condenser

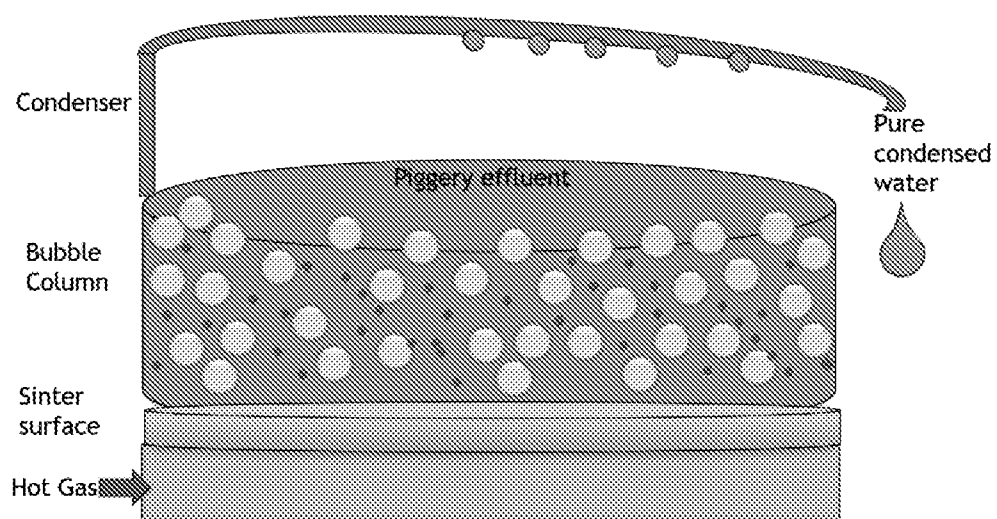


Figure 2A

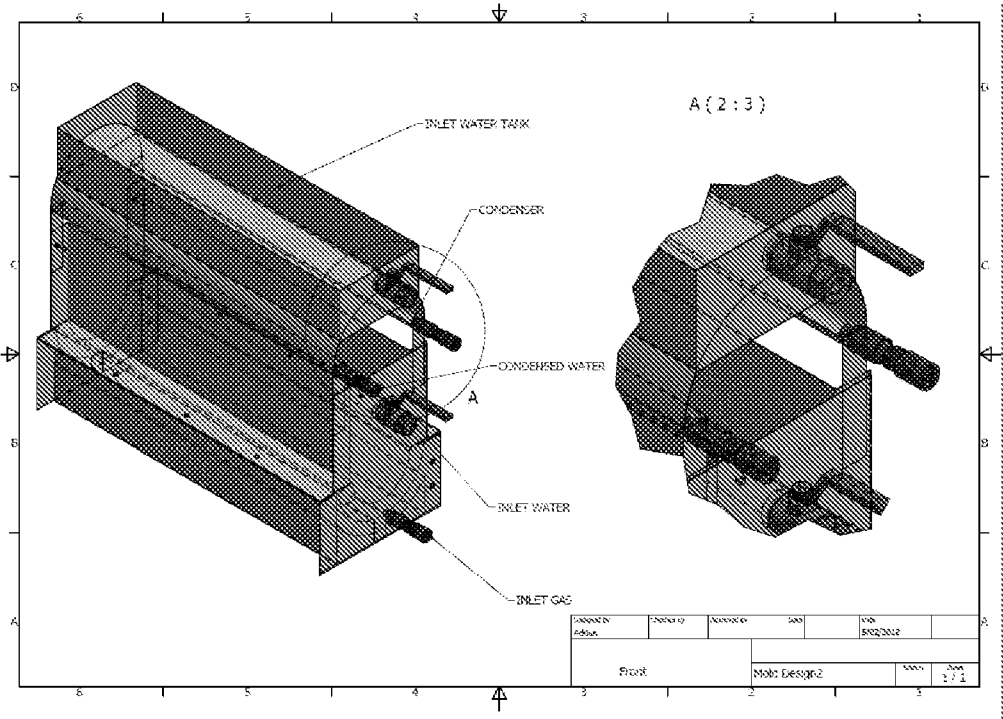


Figure 2B

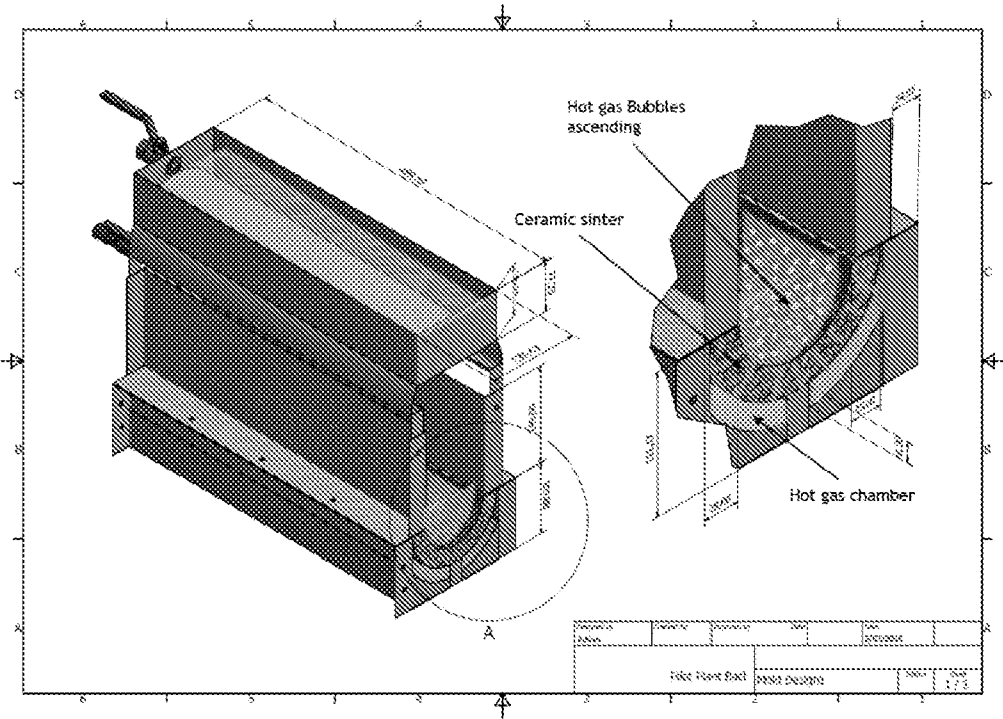


Figure 3A

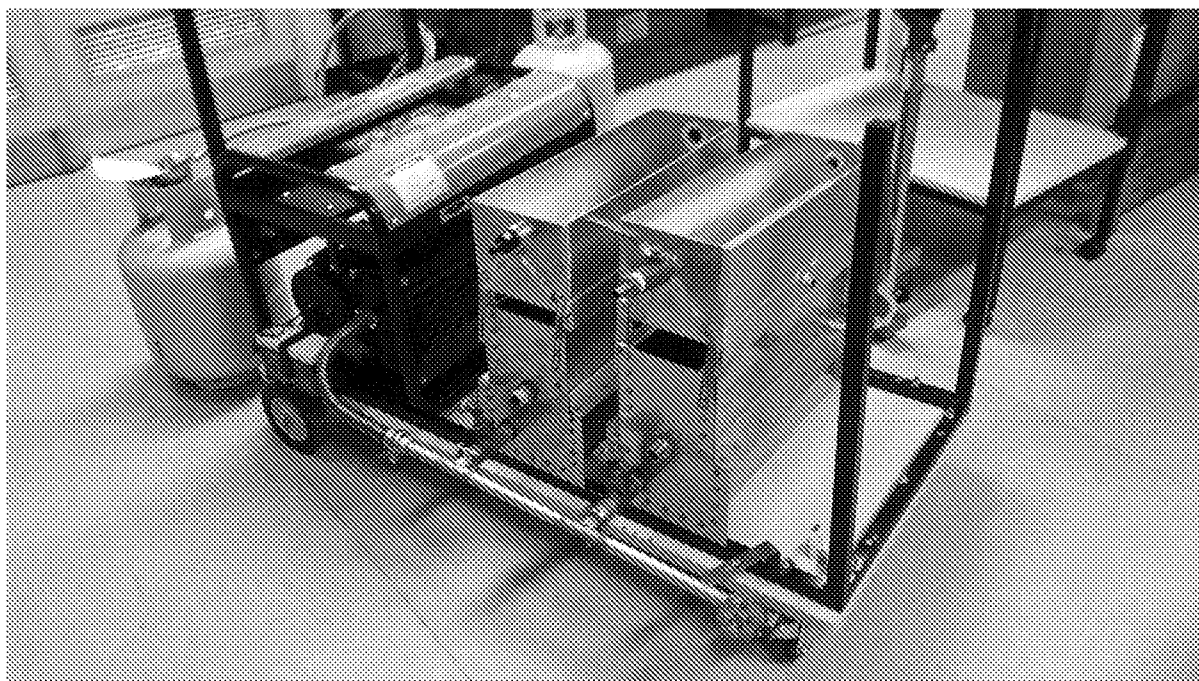


Figure 3B

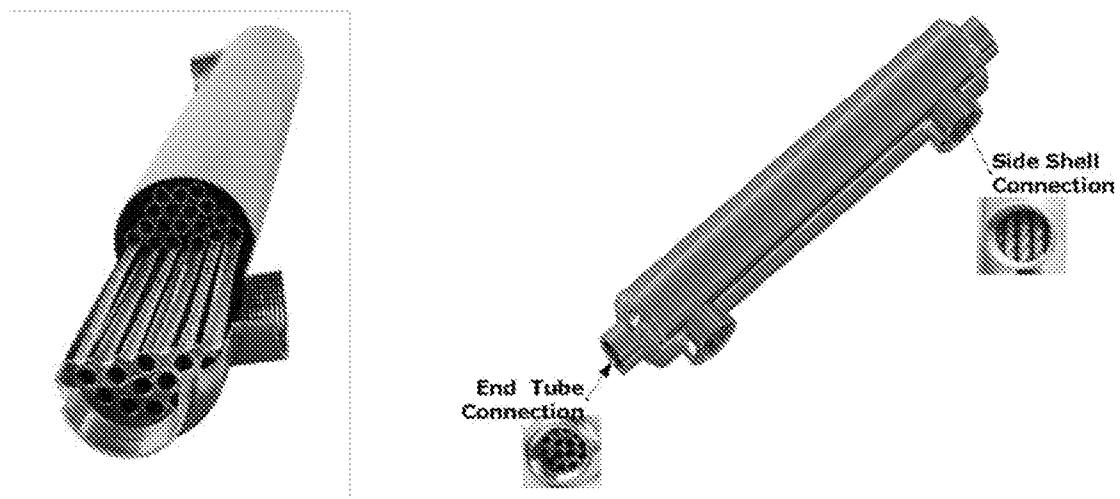


Figure 4A:

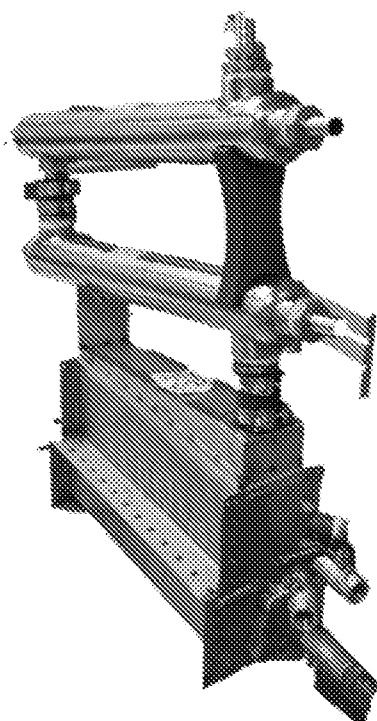
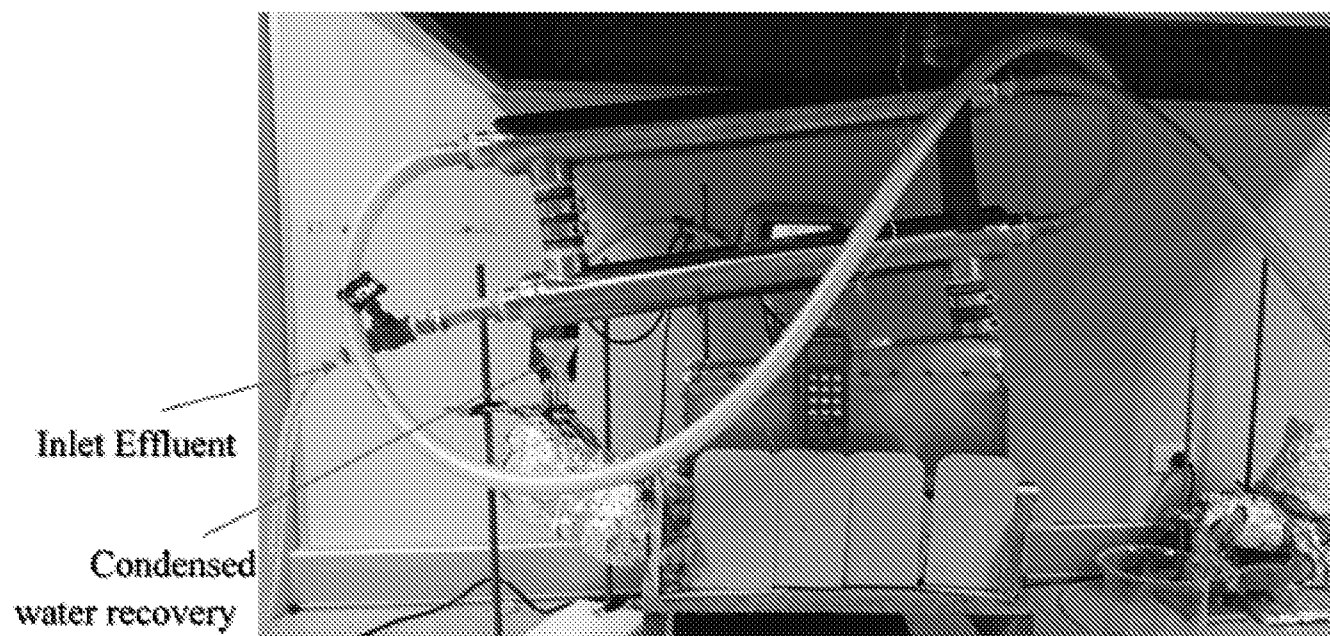


Figure 4B:



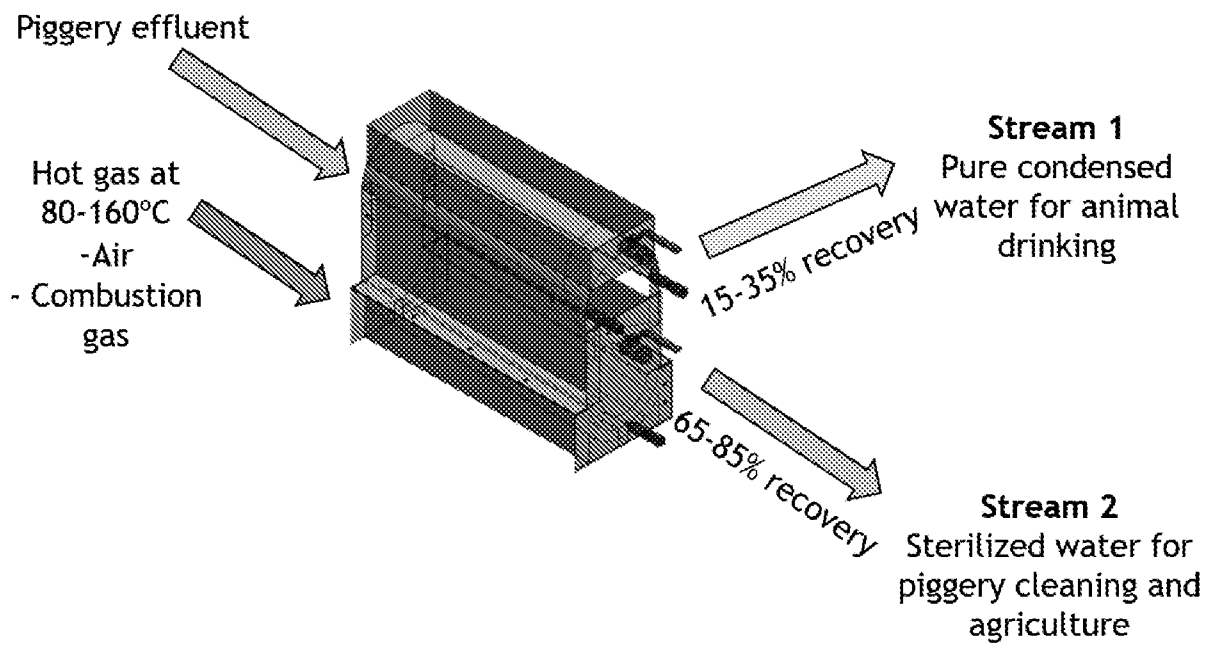


Figure 5

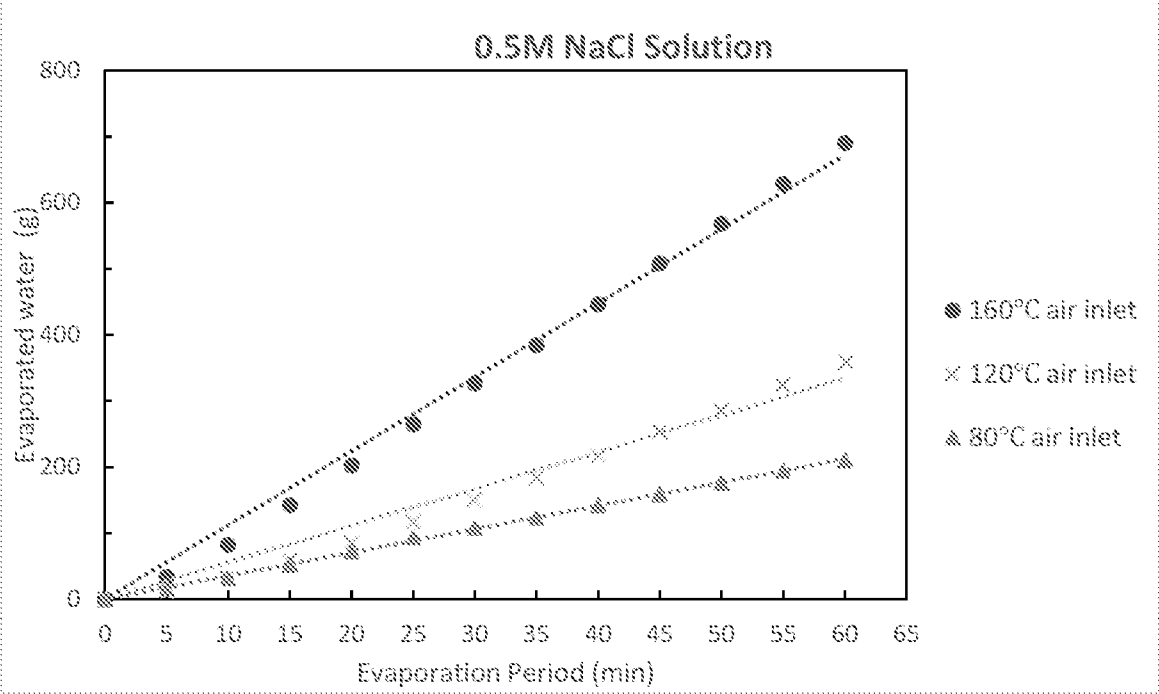


Figure 6

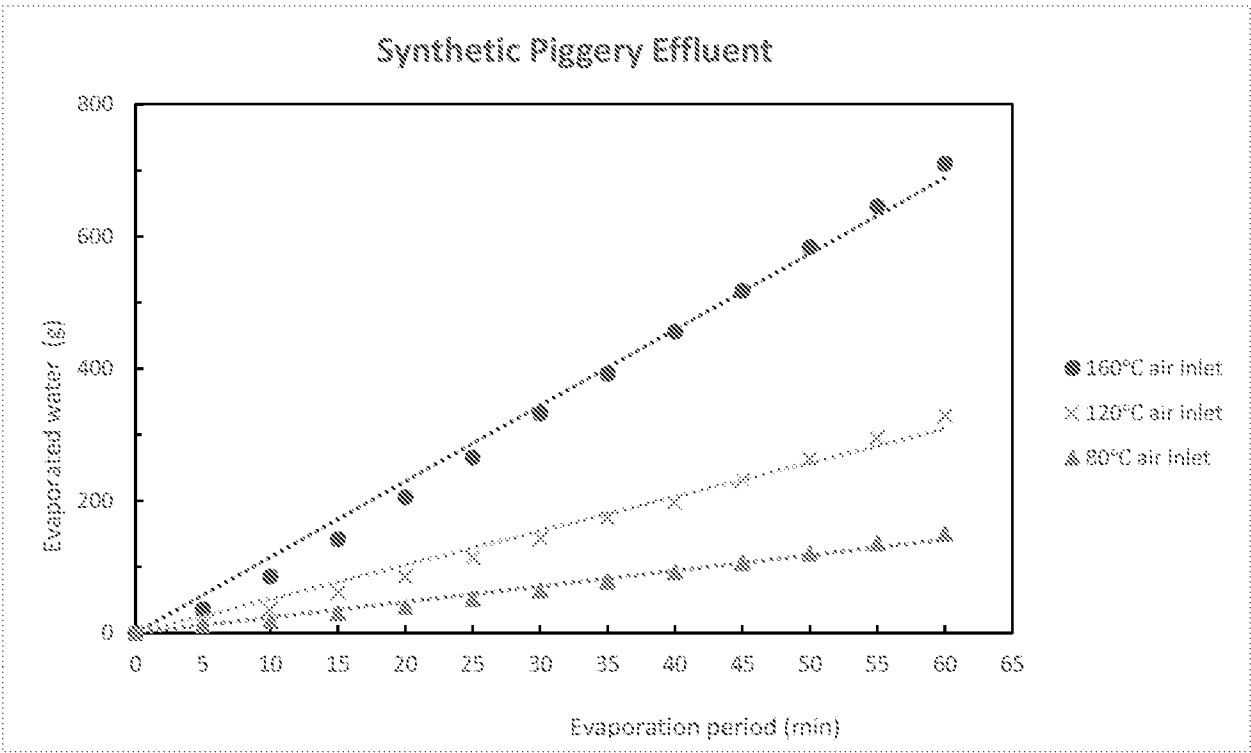


Figure 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2019/051420

A. CLASSIFICATION OF SUBJECT MATTER

B01D 1/14 (2006.01) B01D 3/16 (2006.01) C02F 1/04 (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)

PATENW (in EPOQUE Internal): IPCs & CPCs: C02F1/02/low, C02F1/06/LOW, C02F1/4606/LOW, C02F1/4604/LOW, B01D5/0063/LOW, C02F1/048/LOW, B01D3/16/LOW, B01D1/14/LOW; and key words: condense, gas, bubble, water and similar terms; Google Patent and ESPACENET with key words: gas, water, condense, vapour, tank, sinter, bubble, cool and similar terms; The applicants and inventor names searched in AUSPAT, ESPACENET and internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Date of the actual completion of the international search
12 February 2020

Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/AU2019/051420
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/0023804 A1 (GREAT OCEAN LTD.) 25 January 2018 Abstract; Fig. 14A; paras [0092], [0094]), [0113], [0208]	1, 4, 7-10, 12
X	US 2004/0231970 A1 (LEE ET AL.) 25 November 2004 Abstract; Fig. 1; para [0024]	1, 4, 7, 9, 12
X	US 2014/0158520 A1 (SOMLYAI) 12 June 2014 Abstract; Fig. 1; all claims; paras [0006]-[0007], [0053]-[0054]	1, 4-7, 9, 12
X	US 5032230 A (SHEPHERD) 16 July 1991 Abstract; Fig. 2; col. 6, line 36 - col. 7, line 59	1-4, 7-12
X	WO 2009/103112 A1 (MURDOCH UNIVERSITY) 27 August 2009 Abstract; Figs. 1-2; claims 15-17; page 5, lines 26-27; page 11, line 27 – page 13, line 32; claim 12	1-12

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Information on patent family members		PCT/AU2019/051420	
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Patent Document/s Cited in Search Report		Patent Family Member/s	
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WO 2009/103112 A1	27 August 2009	WO 2009103112 A1	27 Aug 2009
		AU 2009217223 A1	27 Aug 2009
		AU 2009217223 B2	24 Oct 2013
End of Annex			
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