United States Patent Application Publication	20250256245
Kind Code	A1
Publication Date	August 14, 2025
Inventor(s)	LAWAL; Dahiru Umar et al.

AIR GAP DISTILLATION SYSTEM AND HEAT EXCHANGER

Abstract

A distillation apparatus having a hot liquid block, a thermoelectric module (TEM), a condensation surface, a feed liquid chamber having a feed chamber inlet, a feed chamber outlet, and a membrane disposed on at least one side of the feed liquid chamber. One side of the membrane faces to the condensation surface. An air gap of 1 mm to 20 cm separates the condensation surface and the membrane. A permeate outlet in fluid communication with the air gap. A heating unit in fluid communication with the feed liquid chamber and the hot liquid block. A cooling unit in fluid communication with the permeate outlet. A multi-stage distillation apparatus with a plurality of distillation apparatuses. A process of distilling water, by feeding a liquid into the distillation apparatus through the hot block inlet and collecting distilled water from the permeate outlet.

Inventors: **LAWAL; Dahiru Umar (Dhahran, SA), FALLATAH; Wail Sulaiman (Dhahran, SA), ALJUNDI; Isam Hasan (Dhahran, SA), ANTAR; Mohamed Abdelkarim (Dhahran, SA)**

Applicant: **KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS** (Dhahran, SA)

Family ID: **1000008571926**

Assignee: **KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS (Dhahran, SA)**

Appl. No.: **19/184902**

Filed: **April 21, 2025**

Related U.S. Application Data

parent US continuation 17946543 20220916 parent-grant-document US 12303837 child US 19184902

Publication Classification

Int. Cl.: **B01D61/36** (20060101); **B01D63/08** (20060101); **B01D69/02** (20060101); **C02F1/44** (20230101); **C02F103/08** (20060101)

U.S. Cl.:

CPC **B01D61/366** (20130101); **B01D61/364** (20130101); **B01D61/3641** (20220801); **B01D63/08** (20130101); **B01D69/02** (20130101); **C02F1/447** (20130101); B01D2311/1031 (20220801); B01D2311/106 (20130101); B01D2325/0283 (20220801); C02F2103/08 (20130101)

Background/Summary

STATEMENT OF PRIOR DISCLOSURE BY THE INVENTOR

[0001] Aspects of the present disclosure are described in D. Lawal; "Thermoelectric Air Gap Membrane Distillation System and Process"; Dec. 19, 2021; King Fahd University of Petroleum & Minerals Mechanical Engineering Department, incorporated herein by reference in its entirety.

BACKGROUND

Technical Field

[0002] The present disclosure is directed to membrane distillation, and in particular, to an air gap membrane distillation device.

Description of Related Art

[0003] The "background" description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly or impliedly admitted as prior art against the present invention.

[0004] Membrane distillation is a separation process that is driven by phase change. A membrane provides a barrier for a liquid phase while allowing a vapor phase to pass through the membrane. Membrane distillation can be used, for example, in water treatment. Several membrane distillation methods exist. Some examples include direct contact membrane distillation, air gap membrane distillation, vacuum membrane distillation, sweeping gas membrane distillation, vacuum multi-effect membrane distillation, and permeate gap membrane distillation.

[0005] Accordingly, it is one object of the present disclosure to provide a membrane distillation apparatus which is able to improve the performance of air gap membrane distillation (AGMD) separation process by not requiring a cooling stream or coolant, thereby reducing manufacturing cost and energy consumption during operation.

SUMMARY

[0006] In one or more exemplary embodiments, a distillation apparatus is provided. The apparatus comprises a hot liquid block having a hot block inlet and a hot block outlet. The apparatus further comprises a thermoelectric module (TEM) having a first side and a second side opposite the first side. The hot liquid block is adjacent to the first side of the TEM. The apparatus further comprises a condensation surface having a first side and a second side opposite the first side. The first side of the condensation surface is adjacent to the second side of the TEM. The apparatus further comprises a feed liquid chamber having a feed chamber inlet, a feed chamber outlet, and a membrane disposed on at least one side of the feed liquid chamber. In an exemplary embodiment, one side of the membrane faces to the condensation surface. The apparatus further comprises an air gap of 1-200 mm separates the condensation surface and the membrane. A permeate outlet is in fluid communication with the air gap. The apparatus further comprises a heating unit in fluid communication with the feed liquid chamber and the hot liquid block. The apparatus further comprises a cooling unit in fluid communication with the permeate outlet.

[0007] In one or more exemplary embodiments, the heating unit comprises a first heat exchanger, and at least one module selected from the group consisting of (1) a drying unit (DU), a drying unit inlet to DU, and a drying unit outlet of DU, or (2) a space heating unit (SH), a space heating inlet to SH, and a space heating outlet of SH. In one or more exemplary embodiments, the first heat exchanger is fluidly connected to the feed liquid chamber through the feed chamber outlet. In one or more exemplary embodiments, the first heat exchanger is fluidly connected the hot liquid block through the hot block inlet.

[0008] In one or more exemplary embodiments, the cooling unit comprises a second heat exchanger, and at least one module selected from the group consisting of a cooling unit (CU) and a space cooling unit, wherein the CU comprises a cooling unit inlet and a cooling unit outlet, and wherein the SC comprises a space cooling inlet and a space cooling outlet. In one or more exemplary embodiments, the second heat exchanger is fluidly connected to the permeate outlet.

[0009] In one or more exemplary embodiments, the apparatus further comprises a first TEM and second TEM each having a first side and a second side opposite the first side, wherein the first side of the first TEM is adjacent to the hot liquid block and the second side of the second TEM is adjacent to the condensation surface.

[0010] In one or more exemplary embodiments, the membrane is a polytetrafluoroethylene flat sheet.

[0011] In one or more exemplary embodiments, the polytetrafluoroethylene flat sheet has a mean pore size between 0.1 μm and 10 μm.

[0012] In one or more exemplary embodiments, the air gap includes a rubber support to separate the second side of the condensation surface and the membrane.

[0013] In one or more exemplary embodiments, the first heat exchanger is at least one selected from the group consisting of plate heat exchanger, a tube in tube heat exchanger, a shell and tube heat exchanger, a plate and shell heat exchanger, a plate fin heat exchanger, a double tube heat exchanger, an adiabatic wheel heat exchanger, and a finned tube heat exchanger.

[0014] In one or more exemplary embodiments, the second heat exchanger is at least one selected from the group consisting of plate heat exchanger, a tube in tube heat exchanger, a shell and tube heat exchanger, a plate and shell heat exchanger, a plate fin heat exchanger, a double tube heat exchanger, an adiabatic wheel heat exchanger, and a finned tube heat exchanger.

[0015] In one or more embodiments, a multi-stage distillation apparatus comprising a plurality of the distillation apparatuses is provided.

[0016] In one or more exemplary embodiments, a first feed liquid chamber in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with a first hot liquid block in the first stage through a first hot block inlet.

[0017] In one or more exemplary embodiments, a first hot liquid block in a first stage and a second hot liquid block in an adjacent stage are both in fluid communication with a first feed liquid chamber in the first stage through a first feed chamber inlet.

[0018] In one or more exemplary embodiments, a first feed liquid chamber in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with an inlet of a first heat exchanger through feed chamber outlets.

[0019] In one or more exemplary embodiments, a first hot liquid block in a first stage and a second hot liquid block in an adjacent stage are both in fluid communication with an outlet of a first heat exchanger through hot block inlets.

[0020] In one or more exemplary embodiments, wherein the apparatus further comprises a plurality of thermoelectric modules (TEMs) each having a first side and a second side opposite the first side, wherein and a hot liquid block of a first stage is adjacent to a first side of the first TEM and the second side of the condensation surface of the first stage is adjacent to a second side of a second

TEM of the first stage.
[0021] In one or more exemplary embodiments, a first air gap in a first stage and a second air gap in an adjacent stage are both in fluid communication with an inlet of a second heat exchanger through air gap outlets.
[0022] In one or more exemplary embodiments, a first feed liquid chamber in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with an inlet of a first heat exchanger through feed chamber outlets. In one or more exemplary embodiments, a first air gap in a first stage and a second air gap in an adjacent stage are both in fluid communication with an inlet of a second heat exchanger through air gap outlets.
[0023] In one ore more exemplary embodiments, the TEM is powered by at least one source selected from the group consisting of solar photovoltaic module, wind power mill, geothermal power, ocean/wave mill, or any other form of energy.
[0024] In one or more exemplary embodiments, a process of distilling water, comprising feeding a liquid into a distillation apparatus through the hot block inlet and collecting distilled water from the permeate outlet is provided.
[0025] In one or more exemplary embodiments, the liquid is at least one selected from the group consisting of salty water, ocean/sea water, rejected brine, wastewater, brackish water, flowback/produced water, fruit juices, blood, milk, dyes, and waste flows.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0026] A more complete appreciation of this disclosure and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:
[0027] FIG. **1** is a schematic diagram of a single stage to thermoelectric driven air gap membrane distillation (TEM-AGMD) closed-loop apparatus.
[0028] FIG. **2** is a schematic diagram of a single stage TEM-AGMD closed/open-loop apparatus with a heating application apparatus, according to certain embodiments.
[0029] FIG. **3** is a schematic diagram of a single stage TEM-AGMD closed/open-loop apparatus with multiple thermoelectric modules (TEM) and a heating application apparatus, according to certain embodiments.
[0030] FIG. **4** is a schematic diagram of a single stage TEM-AGMD closed-loop apparatus with multiple TEMs and a cooling application apparatus, according to certain embodiments.
[0031] FIG. **5** is a schematic diagram of a single stage TEM-AGMD closed/open-loop apparatus with multiple TEMs with a cooling and a heating application apparatus, according to certain embodiments.
[0032] FIG. **6** is a schematic diagram of a multi-stage TEM-AGMD closed-loop apparatus.
[0033] FIG. **7** is a schematic diagram of a multi-stage TEM-AGMD closed/open-loop apparatus with heating application apparatus, according to certain embodiments.
[0034] FIG. **8** is a schematic diagram of a multi-stage TEM-AGMD closed/open-loop apparatus with multiple TEMs and a heating application apparatus, according to certain embodiments.
[0035] FIG. **9** is a schematic diagram of a multi-stage TEM-AGMD closed-loop apparatus with multiple TEMs and a cooling application apparatus, according to certain embodiments.
[0036] FIG. **10** is a schematic diagram of a multi-stage TEM-AGMD closed/open-loop apparatus with multiple TEMs for a cooling and a heating application apparatus, according to certain embodiments.
[0037] FIG. **11** is a schematic diagram of a thermoelectric cooling or heating based on the Peltier

effect in the TEM, according to certain embodiments.

[0038] FIG. **12**A is a schematic diagram of a thermoelectric heat absorption in the TEM, according to certain embodiments.

[0039] FIG. **12**B is a schematic diagram of a thermoelectric heat contribution in the TEM, according to certain embodiments.

[0040] FIG. **13** is an illustration of a thermoelectric cooler module, according to certain embodiments.

[0041] FIG. **14**A is an illustration of a single-stage TEM module, according to certain embodiments.

[0042] FIG. **14**B is an illustrative front view of a single-stage TEM module, according to certain embodiments.

[0043] FIG. **14**C is an illustrative back view of a single-stage TEM module, according to certain embodiments.

[0044] FIG. **15** is a graph of a permeate flux and membrane inlet feed water temperature against time.

DETAILED DESCRIPTION

[0045] In the drawings, like reference numerals designate identical or corresponding parts throughout the several views. Further, as used herein, the words “a,” “an” and the like generally carry a meaning of “one or more,” unless stated otherwise.

[0046] Furthermore, the terms “approximately,” “approximate,” “about,” and similar terms generally refer to ranges that include the identified value within a margin of 20%, 10%, or preferably 5%, and any values therebetween.

[0047] Membrane distillation (MD) is a combined thermal and membrane-based separation process which allows vapor permeation across a membrane and prevents liquid penetration. The MD separation process is commonly applied in water desalination by separating water vapor from a brine stream using a micro-porous membrane. The feed stream received by the feed side of the MD is usually warm to encourage evaporation, while the temperature of the coolant stream received by the coolant side of the MD is usually kept lower than that of the feed stream temperature to encourage condensation. The driving force for water vapor permeation across the membrane is the vapor pressure difference. The vapor pressure difference is induced by the temperature gradient across the membrane, Membrane distillation can be performed at a low feed temperature (usually less than 100° C.) and can be operated by renewable energy and low-grade energy sources, such as solar energy, wind energy, geothermal energy, and waste heat.

[0048] The MD module generally exist in four main configurations that include sweeping gas membrane distillation (SGMD), vacuum membrane distillation (VIVID), direct contact membrane distillation (DCMD) and air gap membrane distillation (AGMD). These MD configurations is operated by the same principle (vapor generation, vapor permeation across membrane and vapor condensation). The differences among these configurations lie in the design of their condensation chambers, while the feed side of the modules typically remain the same for all configurations. While the direct contact membrane distillation apparatus yields high permeate flux, it is characterized by high conductive heat loss and high temperature polarization effect. Permeate contamination is possible in DCMD. AGMD is characterized by low conductive heat loss and low temperature polarization effect. However, AGMD yields low permeate flux due to resistance to mass transfer by air in the distillate chamber.

[0049] Despite the introduction of innovative designs to MD and advancements in the membrane development, membrane distillation technology is still not commonly used at commercial scales. An objective of the current disclosure is to propose an apparatus in which the heating and cooling demand is provided by thermoelectric module at a commercial scale, rather than pumping a cooling stream or coolant. The subject matter described in this disclosure can be implemented, for example, in desalination, waste treatment, food, and medical applications. The subject matter described in this disclosure can be implemented in particular implementations, so as to realize one or more of the following advantages. The thermoelectric module (TEM) provides heating and cooling to the feed chamber and condensation surface of the membrane distillation module, without the need for a cooling stream or coolant. Further, the TEM-AGMD apparatus and process exhibited fewer number of components and needs no pumping power for coolant stream, which resulted in an apparatus with better energy efficiency, that was more compact, and was less expensive.

[0050] FIG. **1** is a schematic diagram of a single stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **100**. The apparatus **100** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **100** includes a housing (not shown) that protects the components of the apparatus **100** from an external atmosphere. The apparatus **100** includes a hot liquid block **102** with a hot block inlet **104** and a hot block outlet **106**. In FIG. **1**, the stream to be treated is fluidly connected in closed loop and is recirculated to the hot liquid block **102** immediately. Herein, the term “closed loop” refers to a system in which effluents are recycled, that is, treated and returned for reuse, being an automatic control system operating on a feedback principle. The apparatus **100** includes a thermoelectric module **108** (TEM) with a first side **110** and a second side **112** opposite the first side **110**. The hot liquid block **102** is adjacent to the first side **110** of the TEM **108**. The apparatus **100** includes a condensation surface **114** having a first side **116** and a second side **118** opposite the first side **116**. The first side of the condensation surface **116** is adjacent to the second side **112** of the TEM **108**. The apparatus **100** includes a feed liquid chamber **120** having a feed chamber inlet **122**, a feed chamber outlet **124**, and a membrane **126** disposed on at least one side of the feed liquid chamber **120**. One side of the membrane **126** faces to the condensation surface **114**, for instance in FIG. **1**, the right-most surface of the membrane **126** faces the second side **118** of the condensation surface **114**. The apparatus **100** includes an air gap **128** in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **114** and the membrane **126**. The apparatus **100** includes a permeate outlet **130** that is in fluid communication with the air gap **128**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **102**, the TEM **108**, the condensation surface **114**, the feed liquid chamber **120**, the membrane **126**, and the air gap **128** span from the first end to the second end.

[0051] The hot liquid block **102** includes a hot block inlet **104** and a hot block outlet **106**. The hot liquid block **102** is configured to receive a hot liquid stream that includes water. The hot liquid stream can be considered a feed stream. The hot liquid stream can be, for example, seawater, industrial wastewater, brackish water, produced water, fruit juice, blood, milk, dye, harmful waste flow, brine solution, non-condensable gas, non-potable water, or any liquid including dissolved salt, for example, a mixture of salts, a salt and organic contaminant mixture, a salt and inorganic contaminant mixture, or a combination of these. In some embodiments, feeding a liquid into the distillation apparatus **100** can occur through the hot block inlet **104** and can collect distilled liquid from the permeate outlet **130**. The hot block inlet **104** is configured to receive a liquid stream returned from the feed liquid chamber **120**. In some embodiments, a make-up feed of water is added to the water stream returned from the feed liquid chamber **120**. The hot block outlet **106** is configured to discharge the hot liquid stream from the housing. In some embodiments, the hot block outlet **106** discharges the liquid to the feed liquid chamber **120** through a feed chamber inlet **122**. In some implementations, the hot block inlet **104** is disposed at the first end of the housing on a top surface. In some implementations, the hot block outlet **106** is disposed at the first end of the housing as well, but on a bottom surface.

[0052] The thermoelectric module **108** (TEM) has a first side **110** and a second side **112** opposite the first side **110**. The hot liquid block **102** is adjacent to the first side **110** of the TEM **108**. The thermoelectric module **108** is any device that either converts heat directly into electricity (by the

Seebeck effect) or transforms electrical energy into thermal energy (by the Peltier effect). In some embodiments, the TEM **108** transforms electrical energy into thermal energy by the Peltier effect. In some embodiments, the TEM **108** collects energy from at least one source selected from the group consisting of solar photovoltaic module, wind power mill, geothermal power, and ocean/wave mill. The TEM **108** is configured to convert a colder liquid stream entering the hot liquid block **102** to a warm liquid stream with the converted thermal energy. The first side **110** of the TEM **108** is therefore configured to provide heating for the liquid stream in the hot liquid block **108**. The second side **112** is configured to provide cooling for the condensation surface **114**.

[0053] The condensation surface **114** is configured to condense the liquid vapor (from the hot liquid block **102** that passed through the membrane **126**) in the air gap **128** to form a permeate stream. In some implementations, the condensation surface **114** is in the form of a thin, metallic plate or a thin, polymeric plate. In some implementations, the condensation is in the form of thin, metallic tubes or thin, polymeric tubes. The condensation surface **114** can be made, for example, from metallic material, composite material, carbon fibers, carbon nanotubes, or sapphire. In some embodiments, the condensation surface **114** is made of copper. The permeate stream formed in the air gap **128** is discharged from the apparatus **100** via the permeate outlet **130**. The permeate stream has a water purity level that is greater than a water purity level of the hot liquid stream. The condensation surface **114** has a first side **116** and a second side **118** opposite the first side **116**. The first side of the condensation surface **116** is adjacent to the second side **112** of the TEM **108**. The first side **116** is cooled by the second side **112** of the TEM **108**.

[0054] The feed liquid chamber **120** includes a feed chamber inlet **122** and a feed chamber outlet **124**. The feed chamber inlet **122** is configured to receive a cold medium stream. The cold liquid stream can be considered a coolant. The cold liquid stream can be, for example, the hot medium liquid after the hot liquid stream exits the hot block outlet **106** and has been cooled for use as a coolant. In some implementations, the cold liquid stream includes water, air, oil, or a combination of these. In some implementations, the cold liquid stream includes a fluid other than water, air, or oil. The feed chamber outlet **124** is configured to return the cold liquid stream to the hot liquid block **102** through the hot block inlet **104**. In some implementations, the feed chamber inlet **122** is disposed at the second end of the housing, on a top surface. In some implementations, the feed chamber outlet **124** is disposed at the second end of the housing as well, but at a bottom surface. Having the hot block outlet **106** and the feed chamber inlet **122** at opposing ends of the housing and the hot medium inlet **104** and the feed chamber outlet **124** at opposing ends of the housing allows for the hot liquid stream and the cold liquid stream **152** to flow in a counter-current manner through the housing, which can improve heat transfer within the housing. In some implementations, the hot liquid stream and the cold liquid stream flow in a concurrent flow manner through the housing. In some implementations, the hot liquid stream and the cold liquid stream flow in a cross-flow manner through the housing.

[0055] The membrane **126** defines multiple pores that are sized to allow water vapor originating from the hot liquid stream to pass from the hot liquid block **102** through the membrane **126** to the air gap compartment **128**. The membrane **126** is configured to prevent liquid from passing through the membrane **126**. The membrane **126** can be, for example, a composite membrane, a nano-composite membrane, a hydrophobic membrane, an omniphobic membrane, a hydrophilic and hydrophobic composite dual layer membrane, a modified ceramic membrane, a porous ceramic membrane, a surface modified membrane, a polymer electrolyte membrane, a porous graphene membrane, or a polymeric membrane. In some embodiments, the membrane **126** is a polytetrafluoroethylene flat sheet. In some embodiments, the polytetrafluoroethylene flat sheet membrane **126** has a mean pore size between 10 nm and 10 μm, preferably between 50 nm to 5 μm, 0.1 to 1 μm, 0.2 to 0.75 μm, 0.25 to 0.5 μm, meanwhile, the upper or lower endpoints may be any of the prior or at least 25, 75, 125, 175, 225, 275, 300, 325, 350, 375, or 400 nm, and/or at most 25, 20, 15, 7.5, 2.5, 1.25, 0.9, 0.8, 0.75, 0.7, or 0.6 μm. In some implementations, the membrane **126** includes a support layer and an active layer. In some embodiments, the polytetrafluoroethylene flat sheet membrane **126** has an effective area in the range of 0.005 to 5 m.sup.2, preferably between 0.1 to 4 m.sup.2, preferably between 0.5 to 3 m.sup.2, preferably between 1 to 2 m.sup.2. In some other embodiments, the effective surface area of the hydrophobic membrane **126** is less than 0.005 m.sup.2, preferably between 0.001 to 0.05 m.sup.2, preferably between 0.005 to 0.01 m.sup.2, preferably about 0.007 m.sup.2. The membrane **126** can be made, for example, from a porous material. In some implementations, a contact angle of a droplet of the hot liquid stream on the membrane **126** is greater than 90 degrees (°).

[0056] The air gap **128** includes a permeate outlet **130**. The air gap **128** is substantially filled with air. In some implementations, the air filling the air gap **128** is humidified air. In some implementations, the width of the air gap **128** is in a range of from 1 millimeter (mm) to 200 mm, preferably between 25 mm and 175 mm, preferably between 50 mm and 150 mm, preferably between 75 mm and 125 mm, or 100 mm. In some implementations, the air gap **128** is a fixed gap compartment. For example, the width of the air gap **128** between the membrane **126** and the condensation surface **114** is uniform from the first end to the second end of the housing. In some implementations, the air gap **128** is a variable gap compartment. For example, the width of the air gap **128** between the membrane **126** and the condensation surface **114** is non-uniform from the first end to the second end of the housing. For example, the condensation surface **114** can be disposed at an angle deviating from the vertical, such that the width of the air gap **128** between the membrane **126** and the condensation surface gradually increases from the first end to the second end of the housing. In some embodiments, the air gap **128** includes a rubber support to separate the second side **118** of the condensation surface **114** and the membrane **126**. In some embodiments, the rubber support is fabricated of EDPM, neoprene, silicone rubber, nitriles, vinyls, silicones, or a combination of the like.

[0057] The hot liquid block **102**, the air gap **128**, the condensation surface **114**, TEM **108**, and the feed liquid chamber **120** of the apparatus **100** may be of any shape, such as rectangular, triangular, square, circular, cylindrical, hexagonal, or spherical. The housing can be made, for example, from metallic material, polymeric material, composite material, carbon fiber, carbon nanotube, or sapphire. In some implementations, the housing is made of steel, brass, copper, high density polyethylene (HDPE), acrylic, or polyvinyl chloride (PVC).

[0058] The apparatus **100** operates with a liquid feed stream to be treated that enters the hot liquid block **102** attached to the first side **110** of the TEM **108**. In some embodiments, the liquid feed stream is fixed and ranges between 0.1 liter/minute (L/min) and 1000 L/min, preferably between 0.5 L/min and 50 L/min, preferably between 5 L/min and 45 L/min, preferably between 10 L/min and 40 L/min, preferably between 15 L/min and 35 L/min, preferably between 20 L/min and 30 L/min, or 25 L/min. The liquid feed stream gets heated up in the hot liquid block **102** and exits the hot liquid block to the feed liquid chamber **120** at an elevated temperature. As the hot liquid stream passes over the surface of the membrane **126** in the feed liquid chamber **120**, vapor and a permeate is generated across the membrane pores. The permeated vapor through the membrane **126** travels across the air gap **128** and condenses into distillate/permeate upon contact with the cold condensation surface **114**. The condensation surface **114** is kept cold by the second side **112** of the TEM **108**. Therefore, the second side **112** of the TEM **108** provides heating to the liquid feed stream, while the first side **110** of the TEM **108** simultaneously provides cooling to the condensation surface **114** for effective vapor condensation and distillate production. In some cases, the liquid feed stream exiting the feed liquid chamber **120** is immediately recirculated to the hot liquid block **102** for reheating. In other cases, the liquid feed stream exiting the feed liquid chamber **120** carries thermal energy and exchanges heat with another stream for space conditioning or drying purposes. For the drying, the liquid feed stream is recircled to the hot liquid block **102** for reheating after exchanging heat with the drying or space conditioning stream. Also, in some cases, the distillate exits the air gap **128** at ambient temperature through the permeate outlet **130**, and in other cases, the distillate exits the air gap **128** at very low temperatures relative to ambient temperature.

[0059] FIG. **2** is a schematic diagram of a single stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **200** with a heating unit. The apparatus **200** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **200** includes a housing (not shown) that protects the components of the apparatus **200** from an external atmosphere. The apparatus **200** includes a hot liquid block **202** with a hot block inlet **204** and a hot block outlet **206**. In FIG. **2**, the stream to be treated is fluidically connected to the hot liquid block **202** in either a closed or open loop. Herein, the term “open loop” refers to a control system in which an input alters the output, but the output has no feedback loop and therefore no effect on the input. The apparatus **200** includes a thermoelectric module **208** (TEM) with a first side **210** and a second side **212** opposite the first side **210**. The hot liquid block **202** is adjacent to the first side **210** of the TEM **208**. The apparatus **200** includes a condensation surface **214** having a first side **216** and a second side **218** opposite the first side **216**. The first side of the condensation surface **216** is adjacent to the second side **212** of the TEM **208**. The apparatus **200** includes a feed liquid chamber **220** having a feed chamber inlet **222**, a feed chamber outlet **224**, and a membrane **226** disposed on at least one side of the feed liquid chamber **220**. One side of the membrane **226** faces to the condensation surface **214**, for instance in FIG. **2**, the right-most surface of the membrane **226** faces the second side **218** of the condensation surface **214**. The apparatus **200** includes an air gap **228** in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **214** and the membrane **226**. The apparatus **100** includes a permeate outlet **230** that is in fluid communication with the air gap **228**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **202**, the TEM **208**, the condensation surface **214**, the feed liquid chamber **220**, the membrane **226**, and the air gap **228** span from the first end to the second end. The apparatus **200** includes a first heat exchanger **232** and a drying unit (DU) **234**, which define a heating unit. The heating unit in fluid communication with the feed liquid chamber **220** and the hot liquid block **202**.

[0060] In some implementations, the apparatus **200** includes a heating unit defined by the first heat exchanger **232** in fluid communication with the feed liquid chamber **220** and the membrane **226** and a drying unit **234**. In some embodiments, the heating unit comprises a first heat exchanger **232**, and at least one module selected from the group consisting of a drying unit (DU) **234**, a drying unit inlet to DU, and a drying unit outlet of DU, or a space heating unit (SH), a space heating inlet to SH, and a space heating outlet of SH. In some embodiments, the first heat exchanger **232** is fluidly connected to the feed liquid chamber **220** through the feed chamber outlet **224**. In some embodiments, the first heat exchanger **232** is fluidly connected the hot liquid block **202** through the hot block inlet **204**. In such implementations, the first heat exchanger **232** can be configured to heat the hot liquid stream before the hot liquid stream is received by the hot block inlet **204**. The first heat exchanger **232** can utilize, for example, renewable energy, low-enthalpy geothermal energy, industrial waste heat, low or high-grade energy sources, an electric source, low-grade steam from nuclear power plants, heat from any thermal plants such as diesel engines, power plants, desalination plants, or a combination of these to heat the hot liquid stream. In some embodiments, the first heat exchanger **232** is at least one selected from the group consisting of plate heat exchanger, a tube in tube heat exchanger, a shell and tube heat exchanger, a plate and shell heat exchanger, a plate fin heat exchanger, a double tube heat exchanger, an adiabatic wheel heat exchanger, and a finned tube heat exchanger. In some implementations, the hot liquid stream is pressurized before being received by the hot block inlet **204**. In some cases, pressurizing the hot liquid stream can also result in increasing the temperature of the hot liquid stream. In some embodiments, the drying unit **234** may be embodied as, but not limited to, an electrical heater, a solar heater, resistive heating wires, resistive heating coils, visible or infrared heater or a hot water heat exchanger.

[0061] In apparatus **200**, the warm liquid feed stream exiting the feed chamber **220** passes through the first heat exchanger **232** where it exchanges heat with stream entering the drying unit or conditioning space **234** before it is recirculated back to the hot liquid block **202** for reheating. A make-up feed stream is added to replenish the lost liquid feed stream in the feed liquid chamber **220** in the form of vapor.

[0062] FIG. **3** is a schematic diagram of a single stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **300** with multiple thermoelectric modules (TEM) and a heating application apparatus. The apparatus **300** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **300** includes a housing (not shown) that protects the components of the apparatus **300** from an external atmosphere. The apparatus **300** includes a hot liquid block **302** with a hot block inlet **304** and a hot block outlet **306**. In FIG. **3**, the stream to be treated is fluidically connected to the hot liquid block **302** in either a closed or open loop. The apparatus **300** includes a first thermoelectric module **308** (TEM) with a first side **310** and a second side **312** opposite the first side **310**. The hot liquid block **302** is adjacent to the first side **310** of the first TEM **308**. The apparatus **300** includes a second thermoelectric module **315** (TEM) with a first side **311** and a second side **313** opposite the first side **311**. The hot liquid block **302** is adjacent to the second side **313** of the second TEM **315**. The apparatus **300** includes a condensation surface **314** having a first side **316** and a second side **318** opposite the first side **316**. The first side of the condensation surface **316** is adjacent to the second side **313** of the second TEM **315**. The apparatus **300** includes a feed liquid chamber **320** having a feed chamber inlet **322**, a feed chamber outlet **324**, and a membrane **326** disposed on at least one side of the feed liquid chamber **320**. One side of the membrane **326** faces to the condensation surface **314**, for instance in FIG. **3**, the right-most surface of the membrane **326** faces the second side **318** of the condensation surface **314**. The apparatus **300** includes an air gap **328** in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **314** and the membrane **326**. The apparatus **300** includes a permeate outlet **330** that is in fluid communication with the air gap **328**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **302**, the TEM **308**, the condensation surface **314**, the feed liquid chamber **320**, the membrane **326**, and the air gap **328** span from the first end to the second end. The apparatus **300** includes a first heat exchanger **332** and a drying unit (DU) **334**, which define a heating unit. The heating unit in fluid communication with the feed liquid chamber **320** and the hot liquid block **302**.

[0063] In some embodiments, the apparatus further comprises a first TEM **308** and second TEM **315** each having a first side and a second side opposite the first side, wherein the first side **310** of the first TEM **310** is adjacent to the hot liquid block **302** and the second side **313** of the second TEM **315** is adjacent to the condensation surface **314**. In some embodiments, the apparatus **300** has between 2 and 16 TEMs, preferably between 4 and 14 TEMs, preferably between 6 and 12 TEMS, preferably between 8 and 10 TEMs, or 9 TEMs. The maximum number of stages depends on the difference between the liquid feed stream temperature and condensation surface **314** temperature of the final stage, which must be maintained between 10° C. and 20° C., preferably between 11° C. and 19° C., preferably between 12° C. and 18° C., preferably between 13° C. and 17° C., preferably between 14° C. and 16° C., or 15° C. In some embodiments, the first TEM **308** and second TEM **315** are powered by solar voltaic cells. In some embodiments, the number of TEMs used in apparatus **300** is six. In some embodiments, the six TEMs in apparatus **300** range from 20 W of power to 600 W, preferably between 100 W and 250 W, preferably between 150 W and 200 W, or

175 W. In some embodiments, the number of TEMs used in apparatus **300** may be less or more than six. In some embodiments, there may be exactly one hot liquid block **302** for each TEM **308**.

[0064] In apparatus **300**, warm liquid feed stream exiting the feed liquid chamber **320** passes through the first heat exchanger **332** where it exchanges heat with a stream entering the drying unit or conditioning space **334** before it is recirculated back to the hot liquid block **302** for reheating. A make-up feed stream is added to replenish the lost liquid feed stream in the feed liquid chamber **320** in the form of vapor.

[0065] FIG. **4** is a schematic diagram of a single stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **400** with multiple thermoelectric modules (TEM) and a cooling application apparatus. The apparatus **400** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **400** includes a housing (not shown) that protects the components of the apparatus **400** from an external atmosphere. The apparatus **400** includes a hot liquid block **402** with a hot block inlet **404** and a hot block outlet **406**. In FIG. **4**, the stream to be treated is fluidly connected in closed loop and is recirculated to the hot liquid block **402** immediately for reheating. The apparatus **400** includes a first thermoelectric module **408** (TEM) with a first side **410** and a second side **412** opposite the first side **410**. The hot liquid block **402** is adjacent to the first side **410** of the first TEM **408**. The apparatus **400** includes a second thermoelectric module **415** (TEM) with a first side **411** and a second side **413** opposite the first side **411**. The hot liquid block **402** is adjacent to the second side **413** of the second TEM **415**. The apparatus **400** includes a condensation surface **414** having a first side **416** and a second side **418** opposite the first side **416**. The first side of the condensation surface **416** is adjacent to the second side **413** of the second TEM **415**. The apparatus **400** includes a feed liquid chamber **420** having a feed chamber inlet **422**, a feed chamber outlet **424**, and a membrane **426** disposed on at least one side of the feed liquid chamber **420**. One side of the membrane **426** faces to the condensation surface **414**, for instance in FIG. **4**, the right-most surface of the membrane **426** faces the second side **418** of the condensation surface **414**. The apparatus **400** includes an in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **414** and the membrane **426**. The apparatus **400** includes a permeate outlet **430** that is in fluid communication with the air gap **428**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **402**, the TEM **408**, the condensation surface **414**, the feed liquid chamber **420**, the membrane **426**, and the air gap **428** span from the first end to the second end. The apparatus **400** includes a second heat exchanger **436** and a space cooler **438**, which define the cooling unit.

[0066] In some embodiments, the cooling unit in fluid communication with the permeate outlet **430**. In some embodiments, the cooling unit comprises a second heat exchanger **436**, and at least one module selected from the group consisting of a cooling unit (CU) and a space cooling unit **438**, wherein the CU comprises a cooling unit inlet and a cooling unit outlet, and wherein the SC comprises a space cooling inlet and a space cooling outlet. The second heat exchanger **436** is fluidly connected to the permeate outlet **430**. In some embodiments, the second heat exchanger **436** is at least one selected from the group consisting of plate heat exchanger, a tube in tube heat exchanger, a shell and tube heat exchanger, a plate and shell heat exchanger, a plate fin heat exchanger, a double tube heat exchanger, an adiabatic wheel heat exchanger, and a finned tube heat exchanger. In some implementations, the apparatus **400** includes a second heat exchanger **436** in fluid communication with the air gap **428** through the permeate outlet **430** and the condensation surface **414**. In such implementations, the second heat exchanger **436** can be configured to cool the cold liquid stream before the cold liquid stream is received by the feed chamber inlet **422**. In some embodiments, the space cooler **438** may be embodied as, but not limited to, an electrical cooler, a solar cooler, resistive cooling wires, resistive cooling coils, visible or infrared cooler or a cold-water heat exchanger. The cold permeate stream exiting the air gap **428** passes through the second heat exchanger **436** where it exchanges heat with stream entering the cooling unit or conditioning space **438**. A make-up feed stream is added to replenish the lost feed stream in the feed liquid chamber **420** in the form of vapor.

[0067] FIG. **5** is a schematic diagram of a single stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **500** with multiple thermoelectric modules (TEM), a heating application apparatus, and a cooling application apparatus. The apparatus **500** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **500** includes a housing (not shown) that protects the components of the apparatus **500** from an external atmosphere. The apparatus **500** includes a hot liquid block **502** with a hot block inlet **506** and a hot block outlet **504**. In FIG. **5**, the stream to be treated is fluidically connected to the hot liquid block **502** in either a closed or open loop. The apparatus **500** includes a first thermoelectric module **508** (TEM) with a first side **510** and a second side **512** opposite the first side **510**. The hot liquid block **502** is adjacent to the first side **510** of the first TEM **508**. The apparatus **500** includes a second thermoelectric module **515** (TEM) with a first side **511** and a second side **513** opposite the first side **511**. The hot liquid block **502** is adjacent to the second side **513** of the second TEM **515**. The apparatus **500** includes a condensation surface **514** having a first side **516** and a second side **518** opposite the first side **516**. The first side of the condensation surface **516** is adjacent to the second side **513** of the second TEM **515**. The apparatus **500** includes a feed liquid chamber **520** having a feed chamber inlet **522**, a feed chamber outlet **524**, and a membrane **526** disposed on at least one side of the feed liquid chamber **520**. One side of the membrane **526** faces to the condensation surface **514**, for instance in FIG. **5**, the right-most surface of the membrane **526** faces the second side **518** of the condensation surface **514**. The apparatus **500** includes in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **514** and the membrane **526**. The apparatus **500** includes a permeate outlet **530** that is in fluid communication with the air gap **528**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **502**, the TEM **508**, the condensation surface **514**, the feed liquid chamber **520**, the membrane **526**, and the air gap **528** span from the first end to the second end. The apparatus **500** includes a first heat exchanger **532** and a drying unit (DU) **534**, which define a heating unit. The heating unit in fluid communication with the feed liquid chamber **520** and the hot liquid block **502**. The apparatus **500** includes a second heat exchanger **536** and a space cooler **538**, which define the cooling unit.

[0068] In some implementations, the apparatus **500** includes a heating unit defined by the first heat exchanger **532** in fluid communication with the feed liquid chamber **520** and the membrane **526** and a drying unit **534**. In some embodiments, the heating unit comprises a first heat exchanger **532**, and at least one module selected from the group consisting of a drying unit (DU) **34**, a drying unit inlet to DU, and a drying unit outlet of DU, or a space heating unit (SH), a space heating inlet to SH, and a space heating outlet of SH. In some embodiments, the first heat exchanger **532** is fluidly connected to the feed liquid chamber **520** through the feed chamber outlet **524**. In some embodiments, the first heat exchanger **532** is fluidly connected the hot liquid block **502** through the hot block inlet **504**. In some embodiments, the drying unit **534** may be embodied as, but not limited to, an electrical heater, a solar heater, resistive heating wires, resistive heating coils, visible or infrared heater or a hot water heat exchanger.

[0069] In some embodiments, the cooling unit in fluid communication with the permeate outlet **530**. In some embodiments, the cooling unit comprises a second heat exchanger **536**, and at least one module selected from the group consisting of a cooling unit (CU) and a space cooling unit **538**, wherein the CU comprises a cooling unit inlet and a cooling unit outlet, and wherein the SC comprises a space cooling inlet and a space cooling outlet. The second heat exchanger **536** is fluidly connected to the permeate outlet **530**. In some implementations, the apparatus **500** includes a second heat exchanger **536** in fluid communication with the air gap **528** through the permeate outlet **530** and the condensation surface **514**. In such implementations, the second heat exchanger **536** can be configured to cool the cold liquid stream before the cold liquid stream is received by the feed chamber inlet **522**. In some embodiments, the space cooler **538** may be embodied as, but not limited to, an electrical cooler, a solar cooler, resistive cooling wires, resistive cooling coils, visible or infrared cooler or a cold-water heat exchanger.

[0070] The warm feed stream exiting the feed liquid chamber **520** passes through the first heat exchanger **532** where it exchanges heat with the stream entering the drying unit or conditioning space **534** before it is recirculated back to the hot liquid block **502** for reheating. Whereas the cold permeate stream exiting the air gap **528** passes through the second heat exchanger **536** where it exchanges heat with stream entering the cooling unit or conditioning space **538**. A make-up feed stream is added to replenish the lost feed stream in the feed liquid chamber **520** in the form of vapor.

[0071] FIG. **6** is a schematic diagram of a multi-stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **600**. The apparatus **600** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **600** includes a housing (not shown) that protects the components of the apparatus **600** from an external atmosphere. In some embodiments, each stage has its own housing. In some embodiments, the entire multi-stage apparatus has an external housing. The apparatus **600** includes a hot liquid block **602** with a hot block inlet **604** and a hot block outlet **606**. In FIG. **6**, the stream to be treated is fluidly connected in closed loop and is recirculated to the hot liquid block **602** immediately for reheating. The apparatus **600** includes a thermoelectric module **608** (TEM) with a first side **610** and a second side **612** opposite the first side **610**. The hot liquid block **602** is adjacent to the first side **610** of the TEM **608**. The apparatus **600** includes a condensation surface **614** having a first side **616** and a second side **618** opposite the first side **616**. The first side of the condensation surface **616** is adjacent to the second side **612** of the TEM **608**. The apparatus **600** includes a feed liquid chamber **620** having a feed chamber inlet **622**, a feed chamber outlet **624**, and a membrane **626** disposed on at least one side of the feed liquid chamber **620**. One side of the membrane **626** faces to the condensation surface **614**, for instance in FIG. **6**, the right-most surface of the membrane **626** faces the second side **618** of the condensation surface **614**. The apparatus **600** includes an air gap **628** in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **614** and the membrane **626**. The apparatus **600** includes a permeate outlet **630** that is in fluid communication with the air gap **628**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **602**, the TEM **608**, the condensation surface **114**, the feed liquid chamber **120**, the membrane **126**, and the air gap **128** span from the first end to the second end of a stage housing, which defines a single stage. In some embodiments, there are between 2 and 8 stages, preferably between 3 and 7 stages, preferably between 4 and 6 stages, or 5 stages. In some embodiments, there are more than 8 stages. In some embodiments, there is a membrane **626** between each adjacent stage.

[0072] In some embodiments, a first feed liquid chamber **620** in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with a first hot liquid block **602** in the first stage through a first hot block inlet. As shown in FIG. **6** with the arrows towards the bottom, a rightmost first feed liquid chamber in a rightmost first stage and an adjacent second feed liquid chamber in an adjacent second stage each discharge a cool liquid stream through a feed chamber outlet, that merges into one cool liquid stream, to a first cool liquid block in a first stage through a first hot block inlet. In some embodiments, a make-up water stream in the form of a vapor is added to the merged cool liquid stream to make up for liquid losses or transportation losses. In some embodiments, a first hot liquid block **602** in a first stage and a second hot liquid block in an adjacent stage are both in fluid communication with a first feed liquid chamber **620** in the first stage through a first feed chamber inlet **622**. As shown in FIG. **6** with the arrows towards the top, a rightmost first hot liquid block **602** in a rightmost first stage and an adjacent second hot liquid block in an adjacent second stage each discharge a hot liquid stream through a hot block outlet, that merges into one hot liquid stream, to a first feed liquid chamber **620** in a first stage through the feed chamber inlet **622**. In some embodiments, the permeate outlet discharged from permeate outlet **630** is collected for further use. In some embodiments, the permeate outlet is collected in a tank separate from the apparatus **600**. In some embodiments, a make-up feed stream is added to replenish the lost feed stream in the feed liquid chamber **620** in the form of vapor.

[0073] FIG. **7** is a schematic diagram of a multi-stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **700** with a heating unit. The apparatus **700** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **700** includes a housing (not shown) that protects the components of the apparatus **700** from an external atmosphere. In some embodiments, each stage has its own housing. In some embodiments, the entire multi-stage apparatus has an external housing. The apparatus **700** includes a hot liquid block **702** with a hot block inlet **704** and a hot block outlet **706**. In FIG. **7**, the stream to be treated is fluidically connected to the hot liquid block **702** in either a closed or open loop. The apparatus **700** includes a thermoelectric module **708** (TEM) with a first side **710** and a second side **712** opposite the first side **710**. The hot liquid block **702** is adjacent to the first side **710** of the TEM **708**. The apparatus **700** includes a condensation surface **714** having a first side **716** and a second side **718** opposite the first side **716**. The first side of the condensation surface **716** is adjacent to the second side **712** of the TEM **708**. The apparatus **700** includes a feed liquid chamber **720** having a feed chamber inlet **722**, a feed chamber outlet **724**, and a membrane **726** disposed on at least one side of the feed liquid chamber **720**. One side of the membrane **726** faces to the condensation surface **714**, for instance in FIG. **7**, the right-most surface of the membrane **726** faces the second side **718** of the condensation surface **714**. The apparatus **700** includes an air gap **728** in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **714** and the membrane **726**. The apparatus **700** includes a permeate outlet **230** that is in fluid communication with the air gap **728**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **702**, the TEM **708**, the condensation surface **714**, the feed liquid chamber **720**, the membrane **726**, and the air gap **728** span from the first end to the second end of a stage housing, which defines a stage. The apparatus **700** includes a first heat exchanger **732** and a drying unit (DU) **734**, which define a heating unit. The heating unit in fluid communication with the feed liquid chamber **720** and the hot liquid block **702**.

[0074] In some embodiments, a first feed liquid chamber **720** in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with an inlet of a first heat exchanger **732** through feed chamber outlets. In some embodiments, the cool liquid streams exiting each feed liquid chamber merge in each stage merge into one stream before entering the first heat exchanger **732**. As shown in FIG. **7**, each feed liquid chamber discharges a cool water stream through the feed chamber outlet to be sent to the first heat exchanger **732** to be reheated. In some embodiments, a first hot liquid block **702** in a first stage and a second hot liquid block in an adjacent stage are both in fluid communication with an outlet of a first heat exchanger through hot block inlets. As shown in FIG. **7**, the cool liquid stream sent to the first heat exchanger **732** from the feed liquid chambers is returned to each hot liquid blocks through each respective hot block inlet in their respective stages as a hot liquid stream. In some embodiments, a make-up stream in the form of a vapor is added to the returned hot liquid stream before entering the hot block inlet. As shown in FIG. **7** with the arrows towards the top, a rightmost first hot liquid block **702** in a rightmost first stage and an adjacent second hot liquid block in an adjacent second stage each discharge a hot liquid stream through a hot block outlet, that merges into one hot liquid stream, to a first feed liquid chamber **720** in a first stage through the feed chamber inlet **722**. In some embodiments, the drying unit **734** may be embodied as, but not limited to, an electrical heater, a solar heater, resistive heating wires, resistive heating coils, visible or infrared heater or a hot water heat exchanger. In some embodiments, the permeate outlet discharged from each stage is collected for further use. In some embodiments, the permeate outlet is collected in a tank separate from the apparatus **700**.

[0075] In apparatus **700**, the warm liquid feed stream exiting the feed chamber **720** passes through the first heat exchanger **732** where it exchanges heat with stream entering the drying unit or conditioning space **734** before it is recirculated back to the hot liquid block **702** for reheating. A make-up feed stream is added to replenish the lost liquid feed stream in the feed liquid chamber **720** in the form of vapor.

[0076] FIG. **8** is a schematic diagram of a multi-stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **800** with multiple thermoelectric modules (TEM) and a heating application apparatus. The apparatus **800** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **800** includes a housing (not shown) that protects the components of the apparatus **300** from an external atmosphere. In some embodiments, each stage has its own housing. In some embodiments, the entire multi-stage apparatus has an external housing. The apparatus **800** includes a hot liquid block **802** with a hot block inlet **804** and a hot block outlet **806**. In FIG. **8**, the stream to be treated is fluidically connected to the hot liquid block **802** in either a closed or open loop. The apparatus **800** includes a first thermoelectric module **808** (TEM) with a first side **810** and a second side **812** opposite the first side **810**. The hot liquid block **802** is adjacent to the first side **810** of the first TEM **808**. The apparatus **800** includes a second thermoelectric module **815** (TEM) with a first side **811** and a second side **813** opposite the first side **811**. The hot liquid block **302** is adjacent to the second side **813** of the second TEM **815**. The apparatus **800** includes a condensation surface **814** having a first side **816** and a second side **818** opposite the first side **816**. The first side of the condensation surface **816** is adjacent to the second side **813** of the second TEM **815**. The apparatus **800** includes a feed liquid chamber **820** having a feed chamber inlet **822**, a feed chamber outlet **824**, and a membrane **826** disposed on at least one side of the feed liquid chamber **820**. One side of the membrane **826** faces to the condensation surface **814**, for instance in FIG. **8**, the right-most surface of the membrane **826** faces the second side **818** of the condensation surface **814**. The apparatus **800** includes an air gap **828** in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **814** and the membrane **826**. The apparatus **800** includes a permeate outlet **830** that is in fluid communication with the air gap **828**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **802**, the TEM **808**, the condensation surface **814**, the feed liquid chamber **820**, the membrane **826**, and the air gap **828** span from the first end to the second end of the stage housing, which defines a stage. The apparatus **800** includes a first heat exchanger **832** and a drying unit (DU) **834**, which define a heating unit. The heating unit in fluid communication with the feed liquid chamber **820** and the hot liquid block **802**. In some embodiments, there are between 2 and 8 stages, preferably between 3 and 7 stages, preferably between 4 and 6 stages, or 5 stages. In some embodiments, there are more than 8 stages. In some embodiments, there is a membrane **826** between each adjacent stage.

[0077] In some embodiments, a plurality of thermoelectric modules (TEMs) each having a first

side and a second side opposite the first side, wherein and the hot liquid block **802** of a first stage is adjacent to a first side **810** of the first TEM **808** and the second side **818** of the condensation surface **814** of a first stage is adjacent to a second side **813** of a second TEM **815** of the first stage. In some embodiments, a first feed liquid chamber **820** in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with an inlet of a first heat exchanger **832** through feed chamber outlets. In some embodiments, the cool liquid streams exiting each feed liquid chamber merge in each stage merge into one stream before entering the first heat exchanger **832**. As shown in FIG. **8**, each feed liquid chamber discharges a cool liquid stream through the feed chamber outlet to be sent to the first heat exchanger **832** to be reheated. In some embodiments, a first hot liquid block **802** in a first stage and a second hot liquid block in an adjacent stage are both in fluid communication with an outlet of a first heat exchanger through hot block inlets. As shown in FIG. **8**, the cool liquid stream sent to the first heat exchanger **832** from the feed liquid chambers is returned to each hot liquid blocks through each respective hot block inlet in their respective stages as a hot liquid stream. In some embodiments, a make-up stream in the form of a vapor is added to the returned hot liquid stream before entering the hot block inlet. As shown in FIG. **8** with the arrows towards the top, a rightmost first hot liquid block **802** in a rightmost first stage and an adjacent second hot liquid block in an adjacent second stage each discharge a hot liquid stream through a hot block outlet, that merges into one hot liquid stream, to a first feed liquid chamber **820** in a first stage through the feed chamber inlet **822**. In some embodiments, the drying unit **834** may be embodied as, but not limited to, an electrical heater, a solar heater, resistive heating wires, resistive heating coils, visible or infrared heater or a hot water heat exchanger. In some embodiments, the permeate outlet discharged from each stage is collected for further use. In some embodiments, the permeate outlet is collected in a tank separate from the apparatus **800**.
[0078] In apparatus **800**, warm liquid feed stream exiting the feed liquid chamber **820** passes through the first heat exchanger **832** where it exchanges heat with a stream entering the drying unit or conditioning space **834** before it is recirculated back to the hot liquid block **802** for reheating. A make-up feed stream is added to replenish the lost liquid feed stream in the feed liquid chamber **820** in the form of vapor.
[0079] FIG. **9** is a schematic diagram of a single stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **900** with multiple thermoelectric modules (TEM) and a cooling application apparatus. The apparatus **900** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **900** includes a housing (not shown) that protects the components of the apparatus **900** from an external atmosphere. In some embodiments, each stage has its own housing. In some embodiments, the entire multi-stage apparatus has an external housing. The apparatus **900** includes a hot liquid block **902** with a hot block inlet **904** and a hot block outlet **906**. In FIG. **9**, the stream to be treated is fluidly connected in closed loop and is recirculated to the hot liquid block **902** immediately for reheating. The apparatus **900** includes a first thermoelectric module **908** (TEM) with a first side **910** and a second side **912** opposite the first side **910**. The hot liquid block **902** is adjacent to the first side **910** of the first TEM **908**. The apparatus **900** includes a second thermoelectric module **915** (TEM) with a first side **911** and a second side **913** opposite the first side **911**. The hot liquid block **902** is adjacent to the second side **913** of the second TEM **915**. The apparatus **900** includes a condensation surface **914** having a first side **916** and a second side **918** opposite the first side **916**. The first side of the condensation surface **916** is adjacent to the second side **913** of the second TEM **915**. The apparatus **900** includes a feed liquid chamber **920** having a feed chamber inlet **922**, a feed chamber outlet **924**, and a membrane **926** disposed on at least one side of the feed liquid chamber **920**. One side of the membrane **926** faces to the condensation surface **914**, for instance in FIG. **9**, the right-most surface of the membrane **426** faces the second side **918** of the condensation surface **914**. The apparatus **900** includes an air gap **928** in the range of 1 mm to 20 cm, preferably 2 mm to

5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **914** and the membrane **926**. The apparatus **900** includes a permeate outlet **930** that is in fluid communication with the air gap **928**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **902**, the TEM **908**, the condensation surface **914**, the feed liquid chamber **920**, the membrane **926**, and the air gap **928** span from the first end to the second end of the stage housing, which defines the stage. The apparatus **900** includes a second heat exchanger **936** and a space cooler **938**, which define the cooling unit. In some embodiments, there are between 2 and 8 stages, preferably between 3 and 7 stages, preferably between 4 and 6 stages, or 5 stages. In some embodiments, there are more than 8 stages. In some embodiments, there is a membrane **926** between each adjacent stage.

[0080] In some embodiments, a first air gap **928** in a first stage and a second air gap in an adjacent stage are both in fluid communication with an inlet of a second heat exchanger **936** through air gap outlets. As seen in FIG. **9**, each air gap discharges a distilled liquid stream through the permeate outlet to be sent to the second heat exchanger **936** to be heated to a desired temperature before further use. As shown in FIG. **9**, a rightmost first feed liquid chamber **920** in a rightmost first stage and an adjacent feed liquid chamber in an adjacent second stage each discharge a cool liquid stream through a feed chamber outlet, that merges into one cool liquid stream, to a first hot liquid block in a first stage through a first feed chamber inlet. In some embodiments, a water make-up stream is added to the merged cool liquid stream before entering the first feed chamber inlet. As shown in FIG. **9** with the arrows towards the top, a rightmost first hot liquid block **902** in a rightmost first stage and an adjacent second hot liquid block in an adjacent second stage each discharge a hot liquid stream through a hot block outlet, that merges into one hot liquid stream, to a first feed liquid chamber **920** in a first stage through the feed chamber inlet **922**. In some embodiments, the space cooler **938** may be embodied as, but not limited to, an electrical cooler, a solar cooler, resistive cooling wires, resistive cooling coils, visible or infrared cooler or a cold-water heat exchanger.

[0081] The cold permeate stream exiting the air gap **928** passes through the second heat exchanger **936** where it exchanges heat with stream entering the cooling unit or conditioning space **938**. A make-up feed stream is added to replenish the lost feed stream in the feed liquid chamber **920** in the form of vapor.

[0082] FIG. **10** is a schematic diagram of a multi-stage thermoelectric driven air gap membrane distillation (TEM-AGMD) apparatus **1000** with multiple thermoelectric modules (TEM), a heating application apparatus, and a cooling application apparatus. The apparatus **1000** can be an MD module having a configuration selected from a reinforced hollow tube configuration, a non-reinforced hollow tube configuration, a spiral wound configuration, a flat sheet configuration or non-flat configuration. The apparatus **1000** includes a housing (not shown) that protects the components of the apparatus **1000** from an external atmosphere. In some embodiments, each stage has its own housing. In some embodiments, the entire multi-stage apparatus has an external housing. The apparatus **1000** includes a hot liquid block **1002** with a hot block inlet **1006** and a hot block outlet **1004**. In FIG. **10**, the stream to be treated is fluidically connected to the hot liquid block **1002** in either a closed or open loop. The apparatus **1000** includes a first thermoelectric module **1008** (TEM) with a first side **1010** and a second side **1012** opposite the first side **1010**. The hot liquid block **1002** is adjacent to the first side **1010** of the first TEM **1008**. The apparatus **1000** includes a second thermoelectric module **1015** (TEM) with a first side **1011** and a second side **1013** opposite the first side **1011**. The hot liquid block **1002** is adjacent to the second side **1013** of the second TEM **1015**. The apparatus **1000** includes a condensation surface **1014** having a first side **1016** and a second side **1018** opposite the first side **1016**. The first side of the condensation surface **1016** is adjacent to the second side **1013** of the second TEM **1015**. The apparatus **1000** includes a feed liquid chamber **1020** having a feed chamber inlet **1022**, a feed chamber outlet **1024**, and a membrane **1026** disposed on at least one side of the feed liquid chamber **1020**. One side of the membrane **1026** faces to the condensation surface **1014**, for instance in FIG. **10**, the right-most surface of the membrane **1026** faces the second side **1018** of the condensation surface **1014**. The apparatus **1000** includes an air gap **1028** in the range of 1 mm to 20 cm, preferably 2 mm to 5 cm, preferably 4-15 mm, preferably 5-12 mm, preferably 6-9 mm, or 7 mm that separates the condensation surface **1014** and the membrane **1026**. The apparatus **1000** includes a permeate outlet **1030** that is in fluid communication with the air gap **1028**. In some implementations, the housing comprises a first end and a second end that is opposite the first end. In some implementations, each of the hot liquid block **1002**, the TEM **1008**, the condensation surface **1014**, the feed liquid chamber **1020**, the membrane **1026**, and the air gap **1028** span from the first end to the second end of the stage housing, which defines the stage. The apparatus **1000** includes a first heat exchanger **1032** and a drying unit (DU) **1034**, which define a heating unit. The heating unit in fluid communication with the feed liquid chamber **1020** and the hot liquid block **1002**. The apparatus **1000** includes a second heat exchanger **1036** and a space cooler **1038**, which define the cooling unit. In some embodiments, there are between 2 and 8 stages, preferably between 3 and 7 stages, preferably between 4 and 6 stages, or 5 stages. In some embodiments, there are more than 8 stages. In some embodiments, there is a membrane **1026** between each adjacent stage.

[0083] In some embodiments, a first feed liquid chamber in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with an inlet of a first heat exchanger through feed chamber outlets. As seen in FIG. **10**, outlets from the feed liquid chambers in their respective chambers merge into one stream before entering the first heat exchanger **1032**. The stream is then returned as a heated stream to respective hot liquid blocks through their hot block inlets. In some embodiments, a make-up stream is added to the returned stream. In some embodiments, a first air gap in a first stage and a second air gap in an adjacent stage are both in fluid communication with an inlet of a second heat exchanger through air gap outlets. As seen in FIG. **10**, the permeate outlets from respective air gaps in their respective stages merge into one stream to be sent to the second heat exchanger **1036** for cooling before further use. As shown in FIG. **10**, a rightmost first feed liquid chamber **1020** in a rightmost first stage and an adjacent feed liquid chamber in an adjacent second stage each discharge a cool liquid stream through a feed chamber outlet, that merges into one cool liquid stream, to a first hot liquid block in a first stage through a first feed chamber inlet. In some embodiments, the drying unit **1034** may be embodied as, but not limited to, an electrical heater, a solar heater, resistive heating wires, resistive heating coils, visible or infrared heater or a hot water heat exchanger. In some embodiments, the space cooler **1038** may be embodied as, but not limited to, an electrical cooler, a solar cooler, resistive cooling wires, resistive cooling coils, visible or infrared cooler or a cold-water heat exchanger.

[0084] The warm feed stream exiting the feed liquid chamber **1020** passes through the first heat exchanger **1032** where it exchanges heat with the stream entering the drying unit or conditioning space **1034** before it is recirculated back to the hot liquid block **1002** for reheating. Whereas the cold permeate stream exiting the air gap **1028** passes through the second heat exchanger **1036** where it exchanges heat with stream entering the cooling unit or conditioning space **1038**. A make-up feed stream is added to replenish the lost feed stream in the feed liquid chamber **1020** in the form of vapor.

[0085] FIG. **11** is a schematic diagram showing the working principle of thermoelectric cooling/heating based on the Peltier effect. In some embodiments, TEM is applied to transform electrical energy into thermal energy (by the Peltier effect). The Peltier effect is produced when electric current flows through two different types of semiconductor metals, as shown in FIG. **11**. The Peltier effect is described as a temperature difference that can be produced in a circuit of two different electrical conductors by the applied current flow (FIG. **11**). In some embodiments, a current starts the heat transfer from one side to the other, while one side is getting cooler the other starts to heat up. If the direction of the current is changed, the heat transfer direction changes, too, hence Peltier cells can be used as heat pumps which can simultaneously provide heating and cooling. FIGS. **12**A and **12**B depict the Peltier effect explained for both current directions. In FIG. **12**A, heat is absorbed from lower part of the TEM and released into upper part of the TEM to heat the TEM. In FIG. **12**B, heat is released from lower part of the TEM and absorbed into upper part of the TEM to cool the TEM. FIG. **13** is an illustration of a thermoelectric cooler module with two types of semiconductor metals and respective anode and cathode for effective electrical energy to thermal energy conversion.

[0086] FIG. **14**A an illustration of a single-stage TEM module. Further, FIG. **14**A shows the condensation surface being drilled together to the TEM. FIG. **14**B an illustrative front view of a single-stage TEM module. Six thermoelectric modules with 50 watts of power were used as heat pump for supplying heating and cooling to the feed water and condensation surface, respectively. The thermoelectric modules were powered by solar photovoltaic (PV) system consisting of a 150 W solar panel, a 12V-20A solar charge controller and a 12V-26AH battery. The feed stream salts concentration was 50000 mg/L (50000 ppm) and the feed water flowrate was fixed at 0.85 L/min. FIG. **14**C an illustrative back view of a single-stage TEM module, depicting the air gap and condensation surface with respect to the TEM.

[0087] FIG. **15** is a graph of a permeate flux and membrane inlet feed water temperature against time. FIG. **15** demonstrates the permeate flux across the flat sheet PTFE membrane for a single stage TEM-AGMD system in accordance with an embodiment of this invention. The feed water temperature varies between 23.8° C. and 69.7° C. during the tested duration. For the tested duration, the permeate flux ranges between 1.06 kg/m.sup.2 hr to 8.20 kg/m.sup.2 hr, while the specific energy consumption varied between 638 kWh/m.sup.3 to 1350 kWh/m.sup.3. It should be noted that the recorded salt rejection efficiency was above 99% throughout the duration of the test.

[0088] Obviously, numerous modifications and variations of the present disclosure are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

Claims

1. An air gap distillation system, comprising: a hot liquid block having a hot block inlet and a hot block outlet; a thermoelectric module (TEM) having a first side and a second side opposite the first side, wherein the hot liquid block is adjacent to the first side of the TEM; a condensation surface having a first side and a second side opposite the first side, wherein the first side of the condensation surface is adjacent to the second side of the TEM; a feed liquid chamber having a feed chamber inlet, a feed chamber outlet, and a membrane disposed on at least one side of the feed liquid chamber; wherein one side of the membrane faces to the condensation surface; an air gap of 1-200 mm separates the condensation surface and the membrane; a permeate outlet in fluid communication with the air gap; a heating unit in fluid communication with the feed liquid chamber and the hot liquid block; and a cooling unit in fluid communication with the permeate outlet, wherein the heating unit comprises a first heat exchanger, and a space heating unit (SH), a space heating inlet to SH, and a space heating outlet of SH, wherein the first heat exchanger is selected from the group consisting of a plate heat exchanger, a shell and tube heat exchanger, a plate and shell heat exchanger, and a plate fin heat exchanger; wherein the first heat exchanger is fluidly connected to the feed liquid chamber through the feed chamber outlet; and wherein the first heat exchanger is fluidly connected the hot liquid block through the hot block inlet.

2. (canceled)

3. The distillation apparatus of claim 1, wherein the cooling unit comprises a second heat exchanger, and at least one module selected from the group consisting of a cooling unit (CU) and a space cooling unit, wherein the CU comprises a cooling unit inlet and a cooling unit outlet, and wherein the SC comprises a space cooling inlet and a space cooling outlet; wherein the second heat exchanger is fluidly connected to the permeate outlet.

4. The distillation apparatus of claim 1, wherein the apparatus further comprises a first TEM and second TEM each having a first side and a second side opposite the first side, wherein the first side of the first TEM is adjacent to the hot liquid block and the second side of the second TEM is adjacent to the condensation surface.
5. The distillation apparatus of claim 1, wherein the membrane is a polytetrafluoroethylene flat sheet.
6. The distillation apparatus of claim 5, wherein the polytetrafluoroethylene flat sheet has a mean pore size between 0.1 μm and 10 μm.
7. The distillation apparatus of claim 1, wherein the air gap includes a rubber support to separate the second side of the condensation surface and the membrane.
8. (canceled)
9. The distillation apparatus of claim 3, wherein the second heat exchanger is at least one selected from the group consisting of plate heat exchanger, a tube in tube heat exchanger, a shell and tube heat exchanger, a plate and shell heat exchanger, a plate fin heat exchanger, a double tube heat exchanger, an adiabatic wheel heat exchanger, and a finned tube heat exchanger.
10. A multi-stage distillation apparatus comprising a plurality of the distillation apparatuses according to claim 1.
11. The multi-stage distillation apparatus of claim 10, wherein a first feed liquid chamber in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with a first hot liquid block in the first stage through a first hot block inlet.
12. The multi-stage distillation apparatus of claim 10, wherein a first hot liquid block in a first stage and a second hot liquid block in an adjacent stage are both in fluid communication with a first feed liquid chamber in the first stage through a first feed chamber inlet.
13. The multi-stage distillation apparatus of claim 10, wherein a first feed liquid chamber in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with an inlet of a first heat exchanger through feed chamber outlets.
14. The multi-stage distillation apparatus of claim 10, wherein a first hot liquid block in a first stage and a second hot liquid block in an adjacent stage are both in fluid communication with an outlet of a first heat exchanger through hot block inlets.
15. The multi-stage distillation apparatus of claim 10, wherein the apparatus further comprises a plurality of thermoelectric modules (TEMs) each having a first side and a second side opposite the first side, wherein and a hot liquid block of a first stage is adjacent to a first side of the first TEM and the second side of the condensation surface of the first stage is adjacent to a second side of a second TEM of the first stage.
16. The multi-stage distillation apparatus of claim 10, wherein a first air gap in a first stage and a second air gap in an adjacent stage are both in fluid communication with an inlet of a second heat exchanger through air gap outlets.
17. The multi-stage distillation apparatus of claim 10, wherein a first feed liquid chamber in a first stage and a second feed liquid chamber in an adjacent stage are both in fluid communication with an inlet of a first heat exchanger through feed chamber outlets; and a first air gap in a first stage and a second air gap in an adjacent stage are both in fluid communication with an inlet of a second heat exchanger through air gap outlets.
18. The multi-stage distillation apparatus of claim 10, wherein the TEM is powered by at least one source selected from the group consisting of solar photovoltaic module, wind power mill, geothermal power, and ocean/wave mill.
19. A process of distilling water, comprising: feeding a liquid into the distillation apparatus of claim 1 through the hot block inlet and collecting distilled water from the permeate outlet.
20. The process of distilling water of claim 19, wherein the liquid is at least one selected from the group consisting of salty water, ocean/sea water, rejected brine, wastewater, brackish water, flowback/produced water, fruit juices, blood, milk, dyes, and waste flows.