Title: THERMAL WATER PURIFICATION SYSTEM AND METHOD FOR OPERATING SAID SYSTEM

Abstract: The present invention relates to a thermal water purification system (10) for producing a distillate liquid (Ld, Lf) comprising: a plurality of distilling units (la-lh) which are consecutively flowed through by the raw feed liquid (Lp, Lf); wherein each distilling unit (la-lh) comprises one boiling liquid section (2) and one vapor section (3) adjacent thereto; wherein any two consecutive distilling units, respectively an upstream distilling unit (la) and a downstream distilling unit (lb), are implemented such that the boiling liquid section (2) of the downstream distilling unit (lb) is separated from the vapor section (3) of the upstream distilling unit (la) by a liquid-tight and vapor-tight separation plate (6) and from the vapor section (3) of the downstream distilling unit (lb) by a liquid-tight and vapor-permeable membrane (7); a plurality of heat exchanger tubes (8) adapted to boil the raw feed liquid (Lp) inside the boiling liquid sections (2); a plurality of preheating tubes (9) adapted to preheat the raw feed liquid (Lp) before it flows inside the boiling liquid sections (2).
THERMAL WATER PURIFICATION SYSTEM AND METHOD FOR OPERATING SAID SYSTEM

FIELD OF THE INVENTION

The present invention relates to a thermal water purification system and a method for operating this thermal water purification system.

BACKGROUND OF THE INVENTION

Approximately 97 percent of water on the earth's surface is saline water. In view of the growing potable water consumption for domestic, agricultural or industrial applications, a need therefore exists to produce potable water from sources such as brackish water or seawater.

Different technologies permit to purify raw feed liquid, containing salt or other impurities, to produce potable water. The most commonly employed desalination techniques can be classified into two main categories, namely i) conventional thermal desalination such as Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), Vapor compression (VC) and ii) non-thermal membrane based separation such as Reverse Osmosis (RO), Nanofiltration (NF), Forward Osmosis (FO), Electrodialysis Reversal (EDR), etc. Each individual technique has its own limitation ranging from low thermal efficiency such as Multi-Stage Flash (MSF) plants, to inefficient boron removal capabilities of non-thermal membrane based separation systems, such as RO, NF or EDR.

Membrane Distillation (MD) is a non-isothermal membrane separation process which employs hydrophobic membranes, first published in patent no. US 3,361,645 A. With tremendous progress being directed towards membrane scientific research, efforts for industrial implementation of MD systems is currently gaining significant interest.

One objective of the present invention is to propose a membrane based high thermal efficiency water purification system having low thermal and electrical energy consumption with increased overall systemic membrane flux.
Potential industrial applications for such a system include desalination, industrial processes, wastewater treatment or water recovery processes that require the removal of dissolved solids or impurities from any raw feed liquid via the thermal separation process.

To improve the thermal efficiency of an existing thermal separation process, for example desalination, one solution consists to efficiently preheat the raw feed liquid.

EP 0088315 A1 discloses a desalination device and process comprising a spiral wound air gap membrane distillation device with heat recovery for raw feed liquid preheating. In this prior art, a spirally elongated vapor permeable membrane separates the feed liquid from the elongated vapor chamber while a vapor impermeable layer acting as a condensing sheet separates the condensing vapor from the raw feed liquid to be preheated. Internal raw feed liquid preheating is accomplished using thermal energy transferred from the condensing vapor. The condensed distillate then flows toward a distillate outlet located in the downstream direction of the hot feed liquid flow. In this embodiment, a single evaporation and condensation process is disclosed as opposed to multiple vaporization and condensation process presented in the current invention.

WO 2005/089914 A1 discloses a single spiral wound and multi-stage membrane distillation device and method with raw feed liquid preheating solution being accomplished externally using thermal energy from the condensing vapor, brine liquid and liquid distillate. In the plurality membrane distillation apparatus embodiment, the vapor produced in the evaporator and subsequent stages is channeled via a conduit from one stage to another stage for feed liquid reheat. One of the disadvantages is increased vapor transport resistance and transmission losses. The loss of vapor in the transmission conduit due to condensation within the conduit will result in a non-efficient heat recovery process for the feed liquid reheat and an overall loss in distillate yield.

DE 102009020179 discloses a multi-stage membrane distillation apparatus having an evaporator and multiple condensation/evaporation stages. Raw feed liquid preheating is accomplished via an external thermal energy
source. This solution does not implement any integrated compact raw feed liquid preheating configuration in the vapor chamber, which is the objective of the present invention.

Another example, US 2014/0216916 A1 discloses a membrane distillation device for the purification of a feed liquid, comprising a plurality of condensation/evaporation stages, in which the raw feed liquid is preheated in at least one additional vapor chamber, to which the vapor fed to one condensation/evaporation stage is supplied and in which the vapor is condensed. In this disclosure, the vapor produced is again channeled via a conduit from one stage to another stage. This incurs additional vapor transport resistance and, thus, can result in an increase in the vapor chamber pressure. This can result in a non-efficient vaporization process. Furthermore, this solution does not implement an integrated compact direct feed preheating configuration that minimizes heat/mass transport resistance, which is another objective of the present invention.

WO 2014/020461 A1 discloses a desalination system comprising a steam raising device, a membrane distillation device and a heat exchange device, wherein the liquid fed into the heat exchange device is heated by the brine liquid from the steam raising device. In this prior art, the vapor produced in the steam raising device is channeled via a conduit into another membrane distillation module. This causes increased heat and mass transfer resistance, resulting in a non-efficient condensation/evaporation process. Furthermore, the vapor condensation and preheating process is accomplished by means of external heat exchangers resulting in a non-compact structure for the system.

**SUMMARY OF THE INVENTION**

In this view, the present invention relates to a thermal water purification system for producing a distillate liquid from a raw feed liquid comprising:

- a plurality of distilling units which are consecutively flowed through by the raw feed liquid;
wherein each distilling unit comprises one boiling liquid section and one vapor section adjacent thereto;

wherein the boiling liquid section of each distilling unit comprises a plurality of inlet and outlet ports, through which respectively enters and exits the raw feed liquid;

wherein any two consecutive distilling units, respectively an upstream and a downstream distilling units, are implemented such that the boiling liquid section of the downstream distilling unit is separated from the vapor section of the upstream distilling unit by a liquid-tight and vapor-tight separation plate and from the vapor section of the downstream distilling unit by a liquid-tight and vapor-permeable membrane;

- a heat exchanger cavity adapted to transfer thermal energy to the raw feed liquid before said raw feed liquid enters into the boiling liquid section of one first distilling unit;

- a plurality of heat exchanger tubes extending through the boiling liquid sections of said first distilling unit and, preferably, further consecutive distilling units, i.e., said heat exchanger tubes being configured to transfer thermal energy from a hot medium contained thereinside to the raw feed liquid flowing thereoutside, thus leading the raw feed liquid to boil inside the boiling liquid sections;

- a plurality of preheating tubes extending through the vapor sections of the distilling units, said preheating tubes being consecutively flowed through by the raw feed liquid before said raw feed liquid flows inside the boiling liquid sections of the distilling units and being configured to heat the raw feed liquid contained thereinside by using thermal energy transferred by the vapor contained inside the vapor sections of the distilling units when said vapor condenses against the external surfaces of the preheating tubes, thus producing a distillate liquid that flows outside of the vapor section of each distilling unit through a distillate discharge port;

- a distillate conduit in fluidic communication with said distillate discharge ports, said distillate conduit supplying a storage tank with the distillate liquid.
Important features of the thermal water purification system are defined in
dependent claims 2 to 7.

The present invention relates also to the method for operating the
thermal water purification system according to any one of claims 1 to 7,
comprising the steps of:

a) channeling a raw feed liquid having initially a first temperature towards the
boiling liquid section of a first distilling unit through a plurality of preheating
tubes adapted to increase the temperature of the raw feed liquid from said first
temperature to a second temperature;

b) channeling the raw feed liquid having said second temperature towards
the boiling liquid section of said first distilling unit through a heat exchanger
cavity adapted to increase the temperature of the raw feed liquid from said
second temperature to a third temperature by using thermal energy transferred
from a hot medium;

c) channeling the raw feed liquid having initially said third temperature, or a
temperature slightly lower than said third temperature, into the boiling liquid
sections of said first distilling unit and, thereafter, of a plurality of consecutive
distilling units;

d) heating said raw feed liquid with a plurality of heat exchanger tubes
extending through the boiling liquid sections of said first distilling unit and,
preferably, i further consecutive distilling units, i>0, so as to boil the raw feed
liquid flowing inside said boiling liquid sections with a decrease of the
temperature of the raw feed liquid in each boiling liquid section due to the drop
in pressure inside each boiling liquid section from the inlet ports thereof to the
outlet ports thereof;

e) passing the vapor produced by the vaporization of the raw feed liquid
boiling in the boiling liquid section of each distilling unit through the liquid-tight
and vapor-permeable membrane into the vapor section adjacent thereto;

f) condensing said vapor into said vapor section to produce a distillate liquid;

g) channeling said distillate liquid into a storage tank.
Important features of the method of the present invention are defined in dependent claims 9 to 11.

Thus configured, the thermal water purification system of the present invention optimizes thermal energy and mass transfer process that improves the overall energetic efficiency of the system. The implementation of heat exchanger tubes in the boiling liquid sections in several consecutive distilling unit yields additional vapor in addition to vapor produced via membrane induced evaporation. The boiling liquid section which is adjacent to the vapor section eliminates any vapor transmission lines, thus reducing the vapor transport resistance and thermal energy losses due to condensation within the transmission lines.

Compactness is improved by implementing raw feed liquid preheating tubes in the vapor section for direct vapor condensation, improving the thermal energy recovery process and permitting increased vaporization of the boiling raw feed liquid in the boiling liquid sections. Furthermore, higher efficiency is achieved by implementing at least one internal boiling heat exchanger tube in the vapor section channeling the raw feed liquid flowing thereinside, optimizing the thermal energy recovery process even further via the reuse of thermal energy for additional vaporization of the raw feed liquid.

The present invention implements an integrated process of boiling-evaporation-direct condensation for efficient heat recovery and reuse within a compact distilling unit. Improvements in the heat and mass transfer process increases the overall thermodynamic efficiency of the system, thus permitting the integration of more distilling units for an increased systemic yield.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Other features and advantages of the present invention will appear more clearly from the detailed description of one embodiment of the invention which is presented solely by way of a non-restricted example and illustrated by the attached drawings in which:
Figure 1 is a perspective schematic view of a thermal water purification system according to an exemplary embodiment of the present invention, with four consecutive distilling units;

Figure 2 is a top view of two consecutive distilling units of the system illustrated in Figure 1;

Figure 3 is a side view of the distilling units illustrated in Figure 2;

Figure 4 is a side view of a vapor section of a distilling unit in a further embodiment of the present invention;

Figure 5 is a top schematic view of a thermal water purification system similar to the one illustrated in Figure 1, but with eight consecutive distilling units;

Figure 6 is a view similar to Figure 5, except that the temperatures of the liquid or vapor at each step of the purification process is shown;

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

In reference to Figure 1, there is shown an exemplary embodiment of the thermal water purification system according to the present invention.

In this embodiment, the thermal water purification system 10 comprises first to fourth adjacent distilling units 1a, 1b, 1c and 1d which are consecutively flowed by the raw feed liquid to be concentrated. This raw feed liquid can be brackish water, seawater or industrial process wastewater for example. This raw feed liquid flows inside the system according to a specific flow circuit and flow direction illustrated in Figure 1 by two types of arrows. The first type of arrows corresponds to conduits, pipes or conducts for transporting the raw feed liquid Lp from the fourth distilling unit 1d to the first distilling unit 1a. As detailed in the following paragraphs, the raw feed liquid Lp is thus preheated before flowing through a heat exchanger cavity, which is adapted to increase the temperature of the raw feed liquid Lp till said raw feed liquid is partially boiling or close to its boiling point. In the following paragraphs, to better distinguish the raw feed liquid exiting from the heat exchanger cavity, the term "boiling raw feed
liquid" and the reference $L_b$ will be used in replacement of the term "raw feed liquid" and the reference $L_p$. Further heat exchanger elements may advantageously be provided to heat the boiling raw feed liquid $L_b$. Such heat exchanger elements may consist in a plurality of heat exchanger tubes, through which is flowing a hot medium $H_{st}$, such as hot water or steam. As illustrated in Figure 1, these heat exchanger tubes are partially integrated to one or more distilling units, thus optimizing the space occupied by the system and limiting the thermal losses during the transport of the fluid. The second type of arrows corresponds to conduits, pipes or conducts for transporting the boiling raw feed liquid $L_b$ from the first distilling unit 1a to the fourth distilling unit 1d. During this transport, the vapor phase of said boiling raw feed liquid $L_b$ is separated from the liquid phase thereof, said vapor phase being afterwards condensed against cold surfaces of the system and collected as a distillate liquid.

In reference to Figures 2 and 3, there is shown two consecutive, i.e. first and second, distilling units 1a, 1b of the system 10 shown in Figure 1.

Each distilling unit comprises one boiling liquid section 2 and one vapor section 3 adjacent thereto, said sections 2, 3 being separated by a liquid-tight and vapor-permeable membrane 7. This membrane 7 is configured to, on the one hand, prevent that the liquid phase of the boiling raw feed liquid $L_b$ flowing inside the boiling liquid section 2 to flow across to the vapor section 3, and, on the other hand, permit the evaporation of the boiling raw feed liquid $L_b$ on its surface 7a and allow the vapor phase of said boiling raw feed liquid $L_b$ to diffuse across into the vapor section 3 through its pores. The boiling liquid section 2 of the second distilling unit 1b is separated from the vapor section 3 of the first distilling unit 1a by a liquid-tight and vapor-tight separation plate 6, which may advantageously be provided with enhanced micro-structures such as micro-cavities or micro-projecting fins. This plate 6 is configured to prevent any fluid circulation between the two adjacent sections and permit the film wise condensation of the vapor phase of the boiling raw feed liquid $L_b$ flowing inside the vapor section 3 on the surface 6a that is oriented towards said vapor section. Furthermore, this plate 6, which is heated during the condensation process, has a hotter surface 6b that is oriented towards the boiling liquid
section 2 of the second distilling unit 1b. This hotter surface 6b, which is in contact with the boiling raw feed liquid $L_B$ flowing inside said boiling liquid section 2, may lead to flow boiling of said boiling raw feed liquid on surface 6b. To improve again the production of vapor in the boiling liquid section 2, a plurality of heat exchanger tubes 8 advantageously extend through said boiling liquid section 2. These heat exchanger tubes 8, which are flowed through by the hot medium $H_M$, transfer thermal energy via their external surfaces 8a to the boiling raw feed liquid $L_B$ flowing inside the boiling liquid section 2 so that this boiling raw feed liquid $L_B$ boils in contact to said external surfaces 8a. The heat exchanger tubes 8 may advantageously be provided with internally and externally enhanced structures such as projecting fins arranged along their external surfaces 8a and internal ribs so as to enhance the thermal transfer occurring between the outside of said tubes and the inside thereof, thus enhancing the boiling of the boiling raw feed liquid $L_B$ against the external surfaces of the said heat exchanger tubes 8.

The boiling raw feed liquid $L_B$ successively enters in the boiling liquid section 2 of the first distilling unit 1a through inlet ports 4, is partially vaporized via boiling and evaporation in said boiling liquid section 2, the vapor phase being diffused across the membrane 7 and the liquid phase exiting the boiling liquid section 2 through outlet ports 5. Thereafter, this liquid phase is channeled via conduits to the inlet ports 4 of the boiling liquid section 2 of the second distilling unit 1b. Throttle or flash valves 14 may advantageously be disposed along the conduits between the outlet ports 5 and the inlet ports 4 so as to reduce the pressure of the boiling raw feed liquid $L_B$. This process may be repeated for the second distilling unit 1b, and, thereafter, for each successive distilling unit of the system 10.

To preheat the raw feed liquid, the system 10 comprises a plurality of preheating tubes 9 extending through the vapor sections 3 of the distilling units 1a-1d, said preheating tubes 9 being consecutively flowed through by the raw feed liquid before said raw feed liquid flows through the heat exchanger cavity and, thereafter, through the boiling liquid sections 2 of said distilling units 1a-1d. These preheating tubes 9 permit to preheat the raw feed liquid contained
thereinside by using thermal energy transferred by the condensing vapor contained in the vapor sections 3 of the distilling units 1a-1d when said vapor condenses against external surfaces 9a of the preheating tubes 9. To enhance the thermal transfer occurring between the outside of said tubes and the inside thereof, said tubes 9 may advantageously be provided with projecting fins arranged along their external surfaces 9a and internal rib structures.

In the embodiment shown in Figures 2 and 3, three vertically spaced-apart preheating tubes 9 are disposed in each vapor section 3 of the distilling units 1a-1d. The distillate liquid produced by the condensation of the vapor against external surfaces 9a of said preheating tubes 9 and against surfaces 6a of the separation plate 6 flows downwards in the bottom part of said vapor sections 3 and exits therefrom through distillate discharge ports 11 provided in a bottom side of said vapor sections. Thereafter, this distillate liquid is channeled towards a storage tank via a distillate conduit that is in fluidic communication with the distillate discharge ports 11.

In the alternative embodiment shown in Figure 4, two vertically spaced-apart preheating tubes 9 are disposed in the bottom part of each vapor section 3 of the distilling units 1a-1d and two vertically spaced-apart internal boiling tubes 15 are disposed in the top part of each vapor section 3. These internal boiling tubes 15 are flowed through by the boiling raw feed liquid L_B exiting from the outlet port 5 of the boiling liquid section 2 disposed upstream thereof relative to the flow direction of said boiling raw feed liquid L_B and are in fluidic communication with the inlet port 4 of the boiling liquid section 2 disposed downstream relative to the flow direction of said boiling raw feed liquid L_B, preferably via a throttle or flash valve. The vapor contained in the vapor sections 3 condenses against the peripheral external surfaces of both said preheating tubes 9 and said internal boiling tubes 15, which induces flow boiling inside said internal boiling tubes 15. The distillate liquid produced by the condensation of the vapor against the external surfaces of the internal boiling tubes 15 may advantageously have a higher temperature than the distillate liquid produced by the condensation of said vapor against the preheating tubes 9. Therefore, when the hotter distillate liquid flows downwards around the
preheating tubes 9, it heats the raw feed liquid $L_p$ flowing inside said preheating tubes 9, thus improving the preheating process.

In the embodiment shown in Figures 5 and 6, the system 10 comprises eight consecutive distilling units 1a to 1h, said distilling units having substantially the same structure as the distilling units illustrated in Figure 1. However, in this embodiment, the heat exchanger tubes 8 extend only through the boiling liquid sections 2 of the first, second and third distilling units 1a, 1b and 1c. These heat exchanger tubes 8 are positioned downstream of a heat exchanger cavity 16 that comprises an insulation wall 17 and a heat transfer plate 18 horizontally spaced-apart therefrom, said heat transfer plate 18 being horizontally spaced-apart from the first separation plate 6' bordering the boiling liquid section 2 of the first distilling unit 1a. The insulation wall 17 and the heat transfer plate 18 define a first flow path for the preheated raw feed liquid $L_p$ exiting from the preheating tubes 9 of the first distilling unit 1a and the heat transfer plate 18 and the first separation plate 6' define a second flow path for the hot medium $H_M$. Thus configured, the heat exchanger cavity 16 permits to heat the raw feed liquid $L_p$ flowing through the first flow path via the heat transfer plate 18. As shown in Figure 6, due to the higher temperature $T_{HM}$ of the hot medium $H_M$ relative to the temperature $T_{10p}$ of the raw feed liquid $L_p$ exiting from the preheating tubes 9 of the first distilling unit 1a, the temperature of the raw feed liquid $L_p$ increases to reach temperature $T_{11p}$ at the exit of the first flow path and before said raw feed liquid $L_p$ is channeled via conduits towards the boiling liquid section 2 of said first distilling unit 1a. This final temperature $T_{11p}$ is substantially equal to or slightly higher than the initial temperature $T_{1LB}$ of the boiling raw feed liquid $L_B$ that flows through the successive boiling liquid sections 2 of the distilling units 1a to 1h. Therefore, this final temperature $T_{11p}$ may advantageously be equal to the boiling point of the raw feed liquid $L_B$ so that the boiling process occurs almost immediately when the boiling raw feed liquid $L_B$ enters in the boiling section 2 of the first distilling unit 1a.

The system 10 illustrated in Figures 5 and 6 also comprises a preheating chamber 20 disposed upstream of the last distilling unit 1h relative to the flow
direction of the raw feed liquid $L_P$. This preheating chamber 20 comprises an insulation wall 17' and a heat transfer plate 18' horizontally spaced-apart therefrom, said heat transfer plate 18' bordering the vapor section 3 of the last distilling unit 1h. The insulation wall 17' and the heat transfer plate 18' define a first flow path for the raw feed liquid $L_P$ supplied from a raw liquid source 23. Thus configured, the preheating chamber 20 permits to heat the raw feed liquid $L_P$ via the heat transfer plate 18' due to the higher temperature $T_{B,P,APOR}$ of the vapor flowing inside the vapor section 3 of the last distilling unit 1h relative to the temperature $T_{1L_P}$ of the raw feed liquid $L_P$ of the first flow path. Thus, the temperature of the raw feed liquid $L_P$ increases to reach a final temperature $T_{2L_P}$ of said first flow path and before said raw feed liquid $L_P$ is channeled via conduits inside the preheating tubes 9 of the last distilling unit 1h.

As illustrated in Figure 5, the system 10 may advantageously comprise a distillate conduit 12 in fluidic communication with the distillate discharge ports 11 of the distilling units 1a to 1h, said distillate conduit 12 channeling the distillate liquid towards a storage tank 13 via a plurality of constrictions 19, said constrictions 19 permitting to isolate the varying pressures occurring inside the distillate conduit 12. Indeed, from the first distilling unit 1a to the last distilling unit 1h, the pressure of the distillate liquid tends to decrease. The system 10 may also comprise a brine discharge 21 for collecting the concentrated boiling raw feed liquid $L_B$ exiting from the boiling liquid section 2 of the last distilling unit 1h and a non-condensable gas line 22 for collecting the non-condensable gasses exiting from the vapor sections 3 of the distilling units 1a to 1h.

Thus, the operating steps of the system 10 shown in Figures 5 and 6 are successively:

a) channeling the raw feed liquid $L_P$ having initially a first temperature $T_{1L_P}$ towards the boiling liquid section 2 of a first distilling unit 1a through a plurality of preheating tubes 9 adapted to increase the temperature $T_{(n)L_P}$ of the raw feed liquid $L_P$ from said first temperature $T_{1L_P}$ to a second temperature $T_{11L_P}$;

b) channeling the boiling raw feed liquid $L_B$ having initially a temperature $T_{1L_B}$, said temperature $T_{1L_B}$ being equal to or slightly lower than said second
temperature $T_{1 L P}$, into the boiling liquid sections 2 of said first distilling unit 1a and, thereafter, of the consecutive distilling units 1b to 1h;

c) heating said boiling raw feed liquid $L_B$ with a plurality of heat exchanger tubes 8 extending through the boiling liquid sections 2 of said first distilling unit 1a and two further consecutive distilling units, 1b and 1c, so as to boil the raw feed liquid $L_B$ flowing inside said boiling liquid sections 2, with a decrease in the temperature $T(n)_{L B}$ of the boiling raw feed liquid $L_B$ in each boiling liquid section 2 due to the drop of pressure inside each boiling liquid section 2 from the inlet port 4 thereof to the outlet port 5 thereof;

d) passing the vapor produced by the boiling raw feed liquid $L_B$ boiling in the boiling liquid section 2 of each distilling unit through the liquid-tight and vapor-permeable membrane 7 into the vapor section 3 adjacent thereto;

e) condensing said vapor into said vapor section 3 to produce a distillate liquid;

f) channeling said distillate liquid into the storage tank 13.

As defined in independent claim 8, these operating steps can be adapted to any systems 10 having at least one distilling unit.

Furthermore, these operating steps can be adapted to a system 10 having the specific embodiment illustrated in Figure 4. Thus, simultaneously to step b), a further step b') may consist in channeling the boiling raw feed liquid $L_B$ exiting from the outlet ports 5 of the boiling liquid section 2 of an upstream distilling unit into the vapor section 3 thereof through at least one internal boiling tube 15 before channeling said boiling raw feed liquid $L_B$ into the boiling liquid section 2 of a downstream distilling unit, said upstream and downstream distilling units being any two consecutive distilling units of the system.

The above detailed description with reference to the drawings illustrates rather than limits the invention. There are numerous alternatives, which fall within the scope of the appended claims.

In particular, in a further embodiment of the present invention, the thermal water purification system may include a plurality of consecutive modules, each module comprising several consecutive distilling units and being
in a fluidic communication with an adjacent module via bifurcating flow configuration for the boiling raw feed liquid flowing inside the boiling liquid sections. The raw feed liquid flowing inside the preheating tubes can advantageously be in a bifurcating flow configuration.
CLAIMS

1. Thermal water purification system (10) for producing a distillate liquid from a raw feed liquid (L_P, L_B) comprising:

5  - a plurality of distilling units (1a-1h) which are consecutively flowed through by the raw feed liquids (L_P, L_B):
       wherein each distilling unit (1a-1h) comprises one boiling liquid section (2) and one vapor section (3) adjacent thereto;
       wherein the boiling liquid section (2) of each distilling unit (1a-1h) comprises a plurality of inlet ports (4) and outlet ports (5), through which respectively enters and exits the raw feed liquid (L_P, L_B):
       wherein any two consecutive distilling units (1a, 1b), respectively an upstream distilling unit (1a) and a downstream distilling unit (1b), are implemented such that the boiling liquid section (2) of the downstream distilling unit (1b) is separated from the vapor section (3) of the upstream distilling unit (1a) by a liquid-tight and vapor-tight separation plate (6) and from the vapor section (3) of the downstream distilling unit (1b) by a liquid-tight and vapor-permeable membrane (7);
       - a heat exchanger cavity (16) adapted to transfer thermal energy to the raw feed liquid (L_P) before said raw feed liquid enters into the boiling liquid section (2) of one first distilling unit (1a);
       - a plurality of heat exchanger tubes (8) extending through the boiling liquid sections (2) of said first distilling unit (1a) and, preferably, i further consecutive distilling units (1b-i), i>0, said heat exchanger tubes (8) being configured to transfer thermal energy from a hot medium (H_m) contained thereinside to the raw feed liquid (L_B) flowing thereoutside, thus leading the raw feed liquid (L_B) to boil inside the boiling liquid sections (2);
       - a plurality of preheating tubes (9) extending through the vapor sections (3) of the distilling units (1a-1h), said preheating tubes (9) being consecutively flowed through by the raw feed liquid (L_P) before said raw feed liquid flows inside the boiling liquid sections (2) of the distilling units (1a-1h) and being configured to heat the raw feed liquid (L_P) contained thereinside by using thermal energy
transferred by the vapor contained inside the vapor sections (3) of the distilling units (1a-1h) when said vapor condenses against the external surfaces (9a) of the preheating tubes (9), thus producing a distillate liquid that flows outside of the vapor section (3) of each distilling unit (1a-1h) through a distillate discharge port (11);
- a distillate conduit (12) in fluidic communication with said distillate discharge ports (11), said distillate conduit (12) supplying a storage tank (13) with the distillate liquid.

2. Thermal water purification system (10) according to claim 1,
wherein said first distilling unit (1a) is positioned upstream from the other distilling units (1b-1h) of the system (10), thus leading to a decrease of the temperature (T(i)), of the raw feed liquid (LB) when it flows from said first distilling unit (1a) to said other distilling units (1b-1h).

3. Thermal water purification system (10) according to any one of the preceding claims, wherein i+1 represents less than 40% of the total number of the distilling units of the system.

4. Thermal water purification system (10) according to any one of the preceding claims, wherein any two consecutive distilling units, respectively an upstream distilling unit (1a) and a downstream distilling unit (1b), are implemented such that the inlet ports (4) of the boiling liquid section (2) of the downstream distilling unit (1b) is in fluidic communication with the outlet ports (5) of the boiling liquid section (2) of the upstream distilling unit (1a), preferably via a throttle or flash valve (14).

5. Thermal water purification system (10) according to any one of claims 1-3, wherein any two consecutive distilling units, respectively an upstream distilling unit (1a) and a downstream distilling unit (1b), are implemented such that the outlet port (5) of the boiling liquid section (2) of the upstream distilling unit (1a) is in fluidic communication with at least one internal boiling tube (15) extending through the vapor section (3) of said upstream distilling unit (1a) and such that the inlet port (4) of the boiling liquid section (2) of the downstream distilling unit (1b) is in fluidic communication with said internal boiling tube (15), preferably via a throttle or flash valve (14).
6. Thermal water purification system (10) according to any one of the preceding claims, wherein the separation plate (6) separating the vapor section (3) of an upstream distilling unit (1a) from the boiling liquid section (2) of a downstream distilling unit (1b) is configured to heat the raw feed liquid (L_B) contained inside said boiling liquid section (2) by using thermal energy transferred by the vapor contained inside said vapor section (3) when said vapor condenses against said separation plate (6), thus leading the raw feed liquid (L_B) to boil inside said boiling liquid section (2).

7. Thermal water purification system (10) according to any one of the preceding claims, wherein the preheating tubes (9) are provided with projecting fins and ribs arranged along their periphery, said fins and ribs enhancing the heat transfer between the outside of the tube and the inside thereof.

8. Method for operating a thermal water purification system (10) according to any one of the preceding claims, comprising the steps of:

a) channeling a raw feed liquid (L_P) having initially a first temperature (T1_LP) towards the boiling liquid section (2) of a first distilling unit (1a) through a plurality of preheating tubes (9) adapted to increase the temperature (T(n)_LP) of the raw feed liquid (L_P) from said first temperature (T1_LP) to a second temperature (T1_0_LP);

b) channeling the raw feed liquid (L_P) having initially said second temperature (T1_0_LP) towards the boiling liquid section (2) of said first distilling unit (1a) through a heat exchanger cavity (16) adapted to increase the temperature of the raw feed liquid (L_P) from said second temperature (T1_0_LP) to a third temperature (T1_1_LP) by using thermal energy transferred from a hot medium (H_M);

c) channeling the raw feed liquid (L_B) having initially said third temperature (T1_1_LP), or a temperature (T1_L_B) slightly lower than said third temperature (T1_1_LP), into the boiling liquid sections (2) of said first distilling unit (1a) and, thereafter, of a plurality of consecutive distilling units (1b-1h);

d) heating said raw feed liquid (L_B) with a plurality of heat exchanger tubes (8) extending through the boiling liquid sections (2) of said first distilling unit (1a) and, preferably, i further consecutive distilling units (1b-1c), i>0, so as to boil the
raw feed liquid \((L_B)\) flowing inside said boiling liquid sections (2), with a
decrease in the temperature \((\nabla (\Pi ) \Theta )\) of the raw feed liquid \((L_B)\) in each boiling
liquid section (2) due to the drop of pressure inside each boiling liquid section
from the inlet ports (4) thereof to the outlet ports (5) thereof;

e) passing the vapor produced by the raw feed liquid \((LB)\) boiling in the
boiling liquid section (2) of each distilling unit \((1a-1 h)\) through the liquid-tight and
vapor-permeable membrane (7) into the vapor section (3) adjacent thereto;
f) condensing said vapor into said vapor section (3) to produce a distillate
liquid;
g) channeling said distillate liquid into a storage tank (13).

9. Method according to claim 8, further comprising, simultaneously to
step c), the step c') consisting in channeling the raw feed liquid \((L_B)\) exiting from
the outlet ports (5) of the boiling liquid section (2) of an upstream distilling unit
\((1a)\) into the vapor section (3) thereof through at least one internal boiling tube
\((15)\) before channeling said raw feed liquid \((L_B)\) into the boiling liquid section (2)
of a downstream distilling unit \((1b)\), said upstream and downstream distilling
units \((1a, 1b)\) being any two consecutive distilling units of the system.

10. Method according to any one of claims 8-9, wherein, during step
c), the raw feed liquid \((LB)\) is boiling.

11. Method according to any one of claims 8-10, wherein, during step
f), the condensation of the vapor occurs against the preheating tubes (9) and
the separation plates (6) of the system (10) and/or external surface of the
internal boiling tubes (15).
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
C02F1/04 B01D61/36 C02F1/44
C02F103/08

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)
C02F B01D

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category Citation of document, with indication, where appropriate, of the relevant passages Relevant to claim No.

X US 2010/072135 Al (HANEMAAIJE JAN HENDRIK) [NL] ET AL) 25 March 2010 (2010-03-25) abstract; figures paragraphs [0049] - [0052] 1, 2, 4, 6, 8, 10, 11

X EP 2 606 953 Al (AQUAVER B V [NL]) 26 June 2013 (2013-06-26) paragraphs [0034] - [0067] ; figures 1, 2, 4, 6, 8, 10, 11

X Wo 2014/163507 Al (AQUAVER B V [NL]) page 14, line 11 - page 21, line 17; figures 2-5 page 14, line 11 - page 21, line 17; figures 2-5

Y Wo 2014/058305 Al (AQUAVER B V [NL]) page 9, line 14 - page 10, line 35; claims; figures 1, 4, 5 page 9, line 14 - page 10, line 35; claims; figures 1, 4, 5

X Further documents are listed in the continuation of Box C. See patent family annex.

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**&** document member of the same patent family

Date of the actual completion of the international search 11 November 2016

Date of mailing of the international search report 15/12/2016

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax. (+31-70) 340-3016

Kurtul ayn Dogan , M

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<td>US 2014/216916 Ai (HEINZL WOLFGANG [DE]) 7 August 2014 (2014-08-07) cited in the application</td>
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