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MULTI-EFFECT EVAPORATOR

FIELD OF THE INVENTION

This invention relates to distillation installations and methods, in particular a method using multi-effect evaporators.

BACKGROUND OF THE INVENTION

5 Distillation of water is a process in which various soluble materials such as salt, contaminants etc. are eliminated from water containing these materials, leaving clean, usually drinkable water. One known method for achieving such distillation relies on water evaporation, much like salt and scale being accumulated on the bottom of an electric kettle after water has evaporated. In this process during evaporation of the
10 water, soluble materials that are not volatile remain in a solid state residue, usually in the form of salt and scale, and are disposed of. The vapor can then be condensed back into a state of liquid, resulting in contaminant free water.

US3868308 to the Applicant discloses a multiple effect evaporator system, comprising a housing and a plurality of effects connected in a series to one another,
15 each effect having a plurality of bundles of tubes. The system is built such that high temperature steam is introduced into the tubes of the first effect, while non-distilled water is sprayed against the outside of the tubes, causing the vapor in the tube to condense while evaporating a part of the non-distilled water. The remainder of steam from the tubes of the first effect, along with the evaporated water outside the tubes
20 enters the tubes of the adjacent downstream effect, while the remainder of the non-distilled water which has not evaporated, is accumulated at the bottom of the effect housing in the form of a concentrate and is moved to be sprayed against the outside of the tubes of the adjacent upstream effect and so on and so forth.

Once water has completed its passage through all the effects of the evaporator
25 system, the process yields distilled water on the downstream end of the evaporator and a warm concentrate in the form of a highly concentrated water solution of soluble materials on the upstream end.

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SUMMARY OF THE INVENTION

According to the present invention there is provided a multi-effect evaporator adapted for distillation of water, comprising a plurality of effects connected in a series manner and arranged into groups including a most upstream group and subsequent downstream groups, each group having a most upstream effect and a most downstream effect and having a common parallel water feed inlet adapted to supply all effects in said group with feed water; the evaporator further including a main feed water line in fluid communication with the most upstream group; an array of heaters disposed along said line and adapted for heating said feed water before its entry into the effects of the most upstream group; each effect comprising heat transfer means adapted to receive an inlet vapor and produce from the feed water a first outlet vapor, leaving the remainder of the feed water as a concentrate, and to condense a part of the inlet vapor to produce distilled water, leaving the remainder of the first inlet vapor as a second outlet vapor; each effect comprising means for forwarding the first outlet vapor into an adjacent downstream effect, where it will constitute said first inlet vapor, and means for forwarding said second outlet vapor into one of said heaters for heating said feed water thereby; each group further comprising a pump adapted to extract the concentrate from the effects of said group and pump it into the common parallel water feed of an adjacent downstream group; and means for collecting the distilled water.

In one embodiment of the invention, the heat transfer means in each effect comprises a plurality of tubes with inter-tube spaces therebetween, the tubes being adapted for receiving the inlet vapor, and contacting the feed water to cause a heat transfer therebetween, resulting in the vaporization of a part of the feed water in the inter-tube spaces, to produce said first outlet vapor, leaving the remainder of the feed water as a concentrate, and resulting in the condensation of a part of the inlet vapor in the tubes, to produce the distilled water, leaving the remainder of the inlet vapor as the second outlet vapor. The tubes are further adapted for channeling the condensed water and the second outlet vapor from one side of the effect to the other.

The parallel water feed inlet in each group of the effects may comprise dispersion means adapted to introduce said feed into each of said effects of the group so as to allow its contact with the tubes. The water feed may be introduced into the dispersion means in various forms, e.g. thin film form, and temperatures, allowing optimization of the heat transfer and overall desalination process.

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The number of effects comprised in one group may vary according to the water feed rate, water temperature and additional factors. The group formation may hold up to 30 effects maintaining high efficiency factors.

The tube bundle may be of any material allowing reasonable heat transfer between the vapor inside the tube and water on the exterior of the tube, such as aluminum or other metals or metal alloys. In operation, the tubes may be positioned horizontally or tilted at an angle as to aid the condensed vapor within the tubes to flow down to the opposite end of the effect by force of gravity. The tube shape is not restricted to a circular cross section and may be of other shapes, for example oval.

Further modifications may be made to the evaporator such as galvanization of the condenser tubes, adding ion traps, using various alloys for the condenser tubes etc.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, one embodiment of the present invention will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic view of a multi-effect evaporator according to one embodiment of the present invention, showing only the first and last effects of each of the groups;

Fig. 2 is an enlarged view of group **20c** with upstream and downstream effects of the adjacent groups **20b**, **20d** of the evaporator shown in **Fig. 1**; and

Fig. 3 is a schematic view of a feed heater used in the multi-effect evaporator shown in **Figs. 1** and **2**.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Figs. 1 and **2** show a multi-effect evaporator system **10** together with its main water feed line **11** extending above and along the evaporator **10** from its downstream end **10b** to its upstream end **10a**, and with its main vapor feed line **11** associated with the upstream end **10a** of the evaporator. The evaporator **10** is adapted for the distillation of water entering it from the main water feed line **11** using vapor entering it from the main vapor feed line **12**.

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The evaporator **10** comprises a housing **8** and four groups of effects designated as **20a** to **20d**, disposed therein, group **20a** being the upstream-most group and group **20d** being the downstream-most group. The evaporator **10** further comprises a condenser **13** adapted to condense vapor remains from the distillation process, a distilled water main line **16** adapted to collect distilled water produced by the evaporator, a product pump **14** adapted to withdraw from the evaporator the distilled water, and a brine pump **15** adapted to withdraw from the evaporator brine left after the distillation. The condenser and both pumps are located at the downstream end of the system.

The water feed line **11** is provided with a plurality of heaters **24**, each having a heater vapor inlet **41** adapted to receive vapor from each group **20** and to heat thereby the water in the feed line **11**. Each heater **24** further comprises a first outlet **27** (shown in **Fig. 3** and in **Fig. 1** only for the most upstream and downstream heaters of the groups **20a** and **20d** respectively) used for removing non-condensable gasses (NCG) and remaining vapor, in fluid communication with an NCG and vapor removal line **17**, and a second outlet **44** for withdrawal of water therefrom.

Each group of effects **20a** to **20d** comprises a plurality of effects **30** and a plurality of inlet chambers **40** connected in series with the effects so that each effect **30** has on its upstream side an inlet chamber **40**. The effects are denoted **E1** to **E20**, the most upstream and downstream effects of each effects group **20** being designated as **30h** and **30t**, respectively. Groups **20a**, **20b**, **20c** and **20d** hold within them effects **E1** to **E6**, **E7** to **E11**, **E12** to **E16**, and **E17** to **E20** respectively.

Each of the effects groups **20** also comprises a common parallel water inlet **25** divided into dispersion means **26**, each adapted to introduce feed-water in a thin film form into one of the effects **30**. Each group **20** further comprises a concentrate drainage line **23** and a concentrate pump **21** connected therewith, both adapted to withdraw concentrate from the group **20**, the pump **21** being adapted to introduce the concentrate into the water inlet **25** of the subsequent downstream group.

Each effect **30** comprises at its top a main water inlet **31** adapted to receive water to be distilled from the dispersion means **26**; a vapor inlet **32** located on the upstream side of the effect; and a concentrate collector **33** at the bottom of the effect in fluid communication with the concentrate drainage line **23** of the effect's group. The vapor inlet **32** of the most upstream effect **30h** of the first group **20a** is in fluid

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communication with the main vapor line **12**, whilst the vapor inlet **32** of each of the other effects of each group is adapted to receive vapor, via its preceding inlet chambers **40**, from the immediately preceding adjacent upstream effect **30**.

Within the effect **30** is located a tube bundle **35**, consisting of horizontally
5 coextending condenser tubes **35a** of oval or circular cross-sections, with a space **35b** therebetween. The upstream ends of the tubes **35a** constitute the vapor inlet **32** of the effect, and the downstream ends of the tubes **35a** constitute a first, water and vapor outlet **34** of the effect, for vapor and distilled water exiting the tubes, whilst the space **35b** between the tubes constitutes a second, vapor outlet **36** of the effect for vapor
10 created from the feed water in the space **35b** between the tubes **35a**. The tubes are slightly downwardly inclined from the upstream side of the effect to its downstream side to allow water flow therein using gravitational forces. The tubes are located under the main inlet **31** to allow feed water from the dispersion means **26** to be sprayed thereon, to cause heat transfer between the vapor flowing within the tubes and the
15 sprayed water. The ends of the tubes **35** are supported by and arranged within vertical tube sheets **39**.

Each effect further comprises a concentrate outflow line **37** which connects the concentrate collector **33** of each effect **30** with the concentrate drainage line **23**. The concentrate pump **21** of each group **20** is connected to the downstream end of the
20 drainage line **23**.

As mentioned above, the inlet chamber **40** is disposed between each pair of two adjacent effects **30**, one effect being on the upstream side of the chamber and the other being on the downstream side of the chamber. The chamber **40** is adapted to receive water and vapor from first and second outlets **34** and **36** of the effect located on the
25 upstream side of the chamber. The chamber is designed to allow vapor from outlet **34** to flow into the vapor inlet **32** of the effect **30** located on the downstream side of the chamber. The chamber also has at its top a vapor outlet **43** via which the vapor from outlet **36** is diverted to the vapor inlet **41** of the corresponding heater **24**. The chamber **40** further comprises a droplet separator **38** located at the vapor outlets **34,36** of each
30 effect and a distilled water collector **42** located at the bottom of the chamber, adapted to receive the distilled water from the first outlet **34** of the effect on the upstream side of the chamber. Connected to each distilled water collector **42** is a distilled water outflow line **47** leading to the distilled water main line **16**.

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It should be appreciated that although described here to be common parallel drainages for both concentrate and distilled water, the concentrate collectors **33** may be connected in series to one another, and the distilled water collectors **42** may also be connected to one another in a series manner.

5 The heaters **24** may each be associated with one group **20** or with one inlet chamber **20** of each group **20**, as shown in the drawings.

 The main water feed line **11** and vapor feed line **12** are connected to the first effect **30h** of the first group **20a**. The condenser **13** is in fluid communication with the water and vapor outlet **34** of the last effect **30t** of the last group **20d** via pipe-line **13a**
10 and the brine pump **15** is in fluid communication with the concentrate drainage line **23** of the last group **20d** via pipe-line **15a**.

 In operation, feed water is introduced from an external source into the feed line **11** on the downstream end of the system, at about **25°C**, and passed along the feed line **11** through the heaters **24**. The heaters **24** gradually heat the feed water until it is
15 introduced into the common parallel water inlet **25** and the dispersion means **26** of the first group **20a**. The heating of the water is such that it reaches the first effect **30h** of the first group **20a** at its highest temperature which may reach **82-85°C**. At the same time, vapor at a temperature slightly above **85°C** is introduced into the vapor inlet **32** of the first effect, i.e. into the upstream ends of the tubes **35a** of the first group **20a**.

20 The water from the feed line is sprayed downwards from the main water inlet **25** using dispersion means **26** which spray it in thin film form, i.e. about **0.2-0.3 mm**, onto the tubes **35a** of each of the effects **30** of the first group **20a**. Upon the contact of the water film with the tubes **35a**, a heat transfer process takes place between this film and the vapor flowing within the tubes **35a**, resulting in partial condensation of the vapor in
25 the tubes **35** and partial evaporation of the feed water in the space **35b** between the tubes.

 The vapor that has condensed in the tubes **35a** constitutes the distilled water and flows by force of gravity down the tubes, which are inclined, into the inlet chamber **40** located at the downstream end of the tubes, where it drips down to the distilled water
30 collector **42**. The distilled water flows down from the collector **42** of each inlet chamber **40** to the distilled water main line **16** via the outflow line **47**. The remainder of the vapor that has not condensed in the tubes **35a**, flows into the inlet chamber **40** and is

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sucked via the vapor outlet **43** into the vapor inlet **41** of the respective heater **24** that utilizes the hot vapor to heat the feed water in the main water feed line **11**.

The feed water that has turned into vapor in the space **35b** between the tubes **35a** of the effect is forwarded via the chamber **40** to the vapor inlet **32**, and the upstream
5 ends of the tubes **35a**, of the next, immediately adjacent effect. The feed water that has not evaporated, namely the concentrate, drips down to the concentrate collector **33** at the bottom of the effect **30**, from which the concentrate flows down into the concentrate drainage line **23** of the first group **20a**.

The concentrate is then pumped from the concentrate drainage line **23** using a
10 concentrate pump **21** via pipe-line **22** into the common parallel water inlet **25** of the second group **20b**, where the process is repeated in this and subsequent groups, with the only difference between the first group **20a** and all the subsequent groups **20b** to **20d**, that the first group **20a** receives feed water from the main water feed line **11** while the other groups receive feed water from the concentrate pumps **21**. Thus, the feed water
15 and the vapor both move downstream during the process, the evaporator system thus being a forward feed flow multi-effect evaporator.

The feed heater **24** shown in **Fig. 3** is adapted to receive feed water through the inlet **11a** and hot vapor with NCG through the inlet **41** and allowing heat transfer between the two. This process yields heated feed water leaving the heater **24** through
20 the outlet **11b** and condensed vapor, constituting distilled water, leaving the heater **24** through outlet **44**. The vapor that has not condensed is removed through outlet **27** via NCG and vapor line **17**. The outlet **44** may be in fluid communication with the distilled water collector **42** of the inlet chamber **40** or with the distilled water main line **16**.

The above described process produces distilled water and obtains the most
25 highly concentrated brine at its lowest temperature due to the forward feed flow, as opposed to backward feed flow where the brine is produced at the highest temperature. Low temperature brine allows preventing the danger of scale and corrosion of the installation. The brine is removed from the system using a brine pump **15** via pipe-line **15a** connected to the last concentrate drainage **23d**. At the downstream end of the
30 system the distilled water from the distilled water main line **16** is introduced into a condenser **13** via the pipe-line **13a**, where it utilized to condense the vapor coming from the last effect **30t** of the last group **20d**. From the condenser **13**, the product pumps **14** pumps out the distilled water using the pipe-line **14a**.

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The operation of the above described multi-effect evaporator **10** may be further modified and enhanced by various means such as ion traps for heavy metals, pre-de-aeration of the water in a titanium tube, galvanic insulation of tubes from tube plates by elastomer grommets and incorporating sacrificial aluminum-magnesium anodes in the submerged section of each effect. Furthermore, various types of water may be used for the process, the most common of which is sea-water. In addition, various numbers of effects for each group and, and a various number of effects altogether may be used in order to yield different results.

Those skilled in the art to which this invention pertains will readily appreciate that numerous changes, variations and modifications can be made without departing from the scope of the invention *mutatis mutandis*.

CLAIMS:

1. A multi-effect evaporator adapted for distillation of water, comprising a plurality of effects connected in a series manner and arranged into groups including a most upstream group and subsequent downstream groups, each group having a most upstream effect and a most downstream effect and having a common parallel water feed inlet adapted to supply all effects in said group with feed water; the evaporator further including a main feed water line in fluid communication with the most upstream group; an array of heaters disposed along said line and adapted for heating said feed water before its entry into the effects of the most upstream group; each effect comprising heat transfer means adapted to receive an inlet vapor and produce from the feed water a first outlet vapor, leaving the remainder of the feed water as a concentrate, and to condense a part of the inlet vapor to produce distilled water, leaving the remainder of the inlet vapor as a second outlet vapor; each effect further comprising means for forwarding the first outlet vapor into an adjacent downstream effect, where it will constitute said inlet vapor, and means for forwarding said second outlet vapor into one of said heaters for heating said feed water thereby; each group further comprising a pump adapted to extract the concentrate from the effects of said group and pump it into the common parallel water feed of an adjacent downstream group; and means for collecting the distilled water.
2. An evaporator according to Claim 1, wherein the heat transfer means in each effect comprises a plurality of tubes with inter-tube spaces therebetween, the tubes being adapted for receiving said inlet vapor, and contacting the feed water to cause heat transfer therebetween, resulting in the vaporization of a part of the feed water in the inter-tube spaces, to produce said first outlet vapor, leaving the remainder of the feed water as a concentrate, and resulting in the condensation of a part of the inlet vapor in the tubes, to produce said distilled water, leaving the remainder of the inlet vapor as said second outlet vapor.
3. An evaporator according to Claim 2, wherein said tubes are further adapted for channeling the condensed water and the second outlet vapor from one side of the effect to the other.
4. An evaporator according to any one of Claims 1 to 3, wherein the parallel water feed inlet in each group of the effects comprises dispersion means adapted to

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introduce said feed water into each of said effects of the group so as to allow its contact with the tubes.

5. An evaporator according to Claim 4, wherein the feed water is introduced into the dispersion means in a thin film form.

5 6. An evaporator according to any one of Claims 1 to 5, wherein the number of effects comprised in one group varies.

7. An evaporator according to any one of Claims 1 to 6, wherein the total number of said effects is more than 20, in particular more than 25, more particularly 30.

8. An evaporator according to Claims 1 to 7, wherein the evaporator comprises an
10 NCG removal line.

9. An evaporator according to Claim 2 or any one of Claims 3 to 8, when dependent on Claim 2, wherein the tubes are made of metals or metal alloys.

10. An evaporator according to any one of Claims 1 to 9, wherein each group further comprises a concentrate drainage line in fluid communication with said pump.

15 11. An evaporator according Claim 2 or any one of Claims 3 to 10 when dependent on claim 2, wherein each effect has an upstream end and a downstream end, and the tubes are inclined so as to cause said distilled water within the tubes to flow down to the downstream end of said effect by force of gravity.

12. An evaporator according Claim 2 or any one of Claims 3 to 11 when dependent
20 on claim 2, wherein the tubes are have galvanic insulated using elastomer grommets.

13. An evaporator according to claim 2 or any one of Claims 3 to 12 when dependent on Claim 2, wherein the tube shape is oval.

14. An evaporator according to Claim 1, further comprising ion traps used for removal of heavy metals from the water.

25 15. An evaporator according to Claim 1, further comprising a titanium tube for pre-de-aeration of the feed water.

16. An evaporator according to Claim 1, wherein each effect comprises a collector constituting a submerged section of the effect, and sacrificial aluminum-magnesium anodes incorporated therein.