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(54) **HEAT EXCHANGER FOR MOLTEN SALT STEAM GENERATOR IN CONCENTRATED SOLAR POWER PLANT**

(57) A hairpin heat exchanger (1), wherein the bundle of parallel U-bent tubes (2) is extended out of the exchanger and connected, via bent tubes (11), respectively beyond an end of the internal shell (3) and of the external shell (4) at the first straight section to a first header (9) distributing the first fluid to the bundle of straight tubes

(2) and beyond an end of the internal shell (3) and of the external shell (4) at the second straight section to a second header (10) collecting the first fluid under the form of liquid, vapor or a mixture liquid /vapor from the bundle of straight tubes (2).

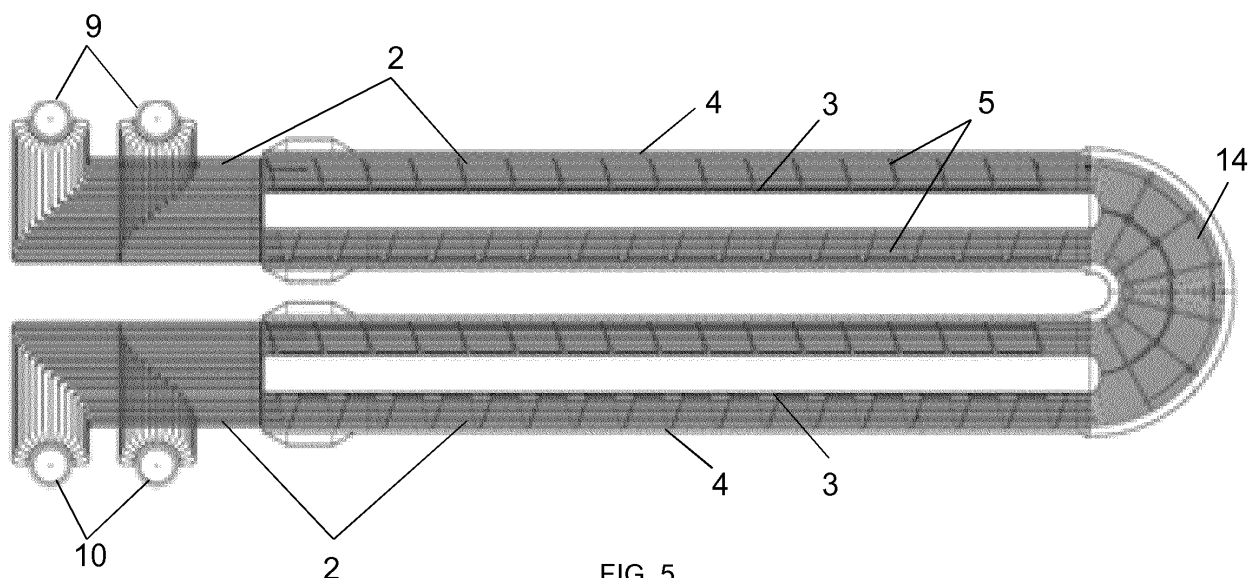


FIG. 5

Description

Field of the Invention

[0001] The present invention is related to the field of heat exchangers, in particular heat exchangers such as evaporators, superheaters, reheaters, and economizers intended to be used in thermal fluid steam generators such as Molten Salt Steam Generators (MSSG) of Concentrated Solar Power plants (CSP).

Prior Art

[0002] It is known that the CSP tower plants generally comprise one or more solar receivers which are situated at the apex of a central tower. These solar receivers are heated by concentrated incident solar rays and they generate a hot fluid that will be further used to produce high-pressure steam capable of driving a turbine and of producing electricity.

[0003] More specifically the CSP tower plant has as main components, namely, at least a heliostat solar field, a solar receiver installed on the top of the tower, a steam generator, a steam turbine and a storage system. In molten salt technology, the molten salt is heated typically to 565 °C in the solar receiver and stored in the hot storage tank. When a production of electricity is required, the hot salt flows from the hot tank to the Molten Salt Steam Generator (MSSG) to generate steam which will be injected into the steam turbine.

[0004] FIG. 1 diagrammatically shows the components of a typical so-called heat exchanger train for MSSG. The hot molten salt flows, from an inlet 100, through a reheater 101 and a superheater 104 to enter in an evaporator 102. Thereafter, the hot salt flows from the outlet of the evaporator 102 to the economizer 103 and further to the outlet 105.

[0005] So-called "shell and tube" heat exchangers refer in prior art to a class of heat exchanger designs suitable for higher pressure applications. This type of heat exchanger is consisting of a large pressure vessel called a "shell" having a set of tubes, called "bundle", inside it. A first fluid runs through the tubes while a second fluid flows inside the shell over the tubes, the first and the second fluid having different temperatures, with the aim of transferring heat from the second fluid to the first fluid or vice versa.

[0006] There are many variations on the shell and tube design. As an example, FIG. 2 diagrammatically shows a straight-tube heat exchanger (two pass tube-side). The ends of each tube 21 are connected to water boxes or plenums 29 through holes provided in separating plates called "tube sheets" 27. The tubes 21 may be straight, as depicted in FIG. 2, or bent in "U" (U-tubes).

[0007] To provide an improved heat exchange between the two fluids, the flow path of the second fluid is often determined by intermediate baffles 28 forming respective passages so that the second fluid flow changes

its direction in passing from one passage to the next one. The baffles are usually under the form of partial circular segments or annular rings and disks, installed perpendicular to the longitudinal axis of the shell 22 to provide a zigzag flow of the second fluid.

[0008] A prior art alternative of the above design, depicted in FIG. 3, is the horizontal hairpin heat exchanger. Hair pin heat exchanger 1 has two shells 22 containing the straight part of U-tubes. The head of the hairpin contains the 180° U-bent part of the tubes. The advantages of this hairpin design are :

- no need for a joint expansion system, as thermal expansion is naturally managed by the hairpin design ;
- easier draining and venting of the exchanger owing to the straight tubes and to the horizontal position of the exchanger.

[0009] Different concepts of steam generator are already known. A synthesis of these different concepts is reported in the Sandia report 93-7084 "Investigation of thermal storage and steam generator issues, Bechtel Corporation", in which are listed advantages and drawbacks of the existing steam generators.

[0010] In order to improve efficiency of the heat transfer in the heat exchangers, it is known since the 1920s that baffles mounted in the shell can have a specific shape intended to guide the fluid in a helical path. Moreover, with a continuous helical baffle, the heat transfer rate increases of about 10% compared with that of conventional segmental baffles for the same shell-side pressure drop (J. Heat Transfer (2007), Vol. 129(10), 1425-1431). This pattern allows to reduce leakage streams occurring in segmental baffles and further to increase the heat transfer coefficient greatly (J. Heat Transfer (2010), Vol. 132(10), 101801). Also, the flow stratification and stagnant zone are avoided (according to calculations), which allows a complete draining and decreases fouling susceptibility (lower fouling resistance and lower heat transfer area).

[0011] Document WO 2009/148822 discloses baffles mounted in the shell to guide the fluid into a helical flow pattern, with different helix angles when the baffle is proximate the inlet and the outlet respectively. Documents US 2,384,714, US 2,693,942, US 3,400,758, US 4,493,368 and WO 2005/019758 each disclose each different kinds of baffles, but with the same aim of providing a helical flow pattern of the fluid. Document US 1,782,409 discloses a continuous helical baffle.

[0012] The current solutions are not satisfactory for example in terms of thermal gradient flexibility, efficiency (pressure drop, heat transfer coefficient), drainability, natural circulation, etc. and newly designed steam generator and/or individual heat exchangers thereof should meet technical requirements such as :

- improved thermal efficiency by reducing internal

- leakages and bypass streams ;
- improved pressure drop by reducing local stream obstacles ;
- improved ramp-up capability ;
- improved reliability ;
- improved fouling behavior, etc.

[0013] Moreover forced-recirculation evaporator material and manufacturing costs are higher than those for natural-circulation evaporators due to the recirculation pump capital cost.

Aims of the Invention

[0014] The present invention aims to overcome the drawbacks of the heat exchangers of prior art intended for steam generators.

[0015] In particular, the invention aims to obtain a reduced-size evaporator presenting high flexibility in terms of thermal gradient as well as improved efficiency thanks to optimized hydrodynamic salt flow leading to lower pressure drop, lower internal leakage (by-pass), improved heat transfer coefficient, lower tendency to foul, easily drainable molten salt, natural circulation (i.e. without circulation pump), long lifetime, and competitive cost.

[0016] Another purpose of the present invention is to avoid the utilization of thick components such as current tube sheets necessary in the shell-and-tube classical heat exchangers leading to the drawback that a high pressure zone is adjacent a low pressure zone.

Summary of the Invention

[0017] A first aspect of the present invention relates to a hairpin heat exchanger having a first straight section, a second straight section and a bent section linking the first straight section and the second straight section, each straight section comprising a part of an internal cylindrical shell and of an external cylindrical shell, both forming an intershell space enclosing a bundle of parallel U-bent tubes having each a first and a second straight part respectively located in said first and second straight section of the exchanger and a 180°-bent part located in said bent section of the exchanger, wherein, in use, a first fluid to be heated and vaporized is flowing, said external cylindrical shell being provided respectively at one end with an inlet and at another end with an outlet for a second fluid which is a hot thermal fluid, so that, in use, said second fluid is flowing in the intershell space and cooling down by exchanging heat with the first fluid flowing in the straight tubes, said intershell space enclosing also baffles to guide the second fluid, wherein the bundle of parallel U-bent tubes is extended out of the exchanger and connected, via bent tubes, respectively beyond an end of the internal shell and of the external shell at the first straight section to a first header distributing the first fluid to the bundle of straight tubes and beyond an end of the internal shell and of the external shell at the second

straight section to a second header collecting the first fluid under the form of liquid, vapor or a mixture liquid /vapor from the bundle of straight tubes.

[0018] According to preferred embodiments of the invention, the hairpin heat exchanger also comprises one of the following characteristics or a suitable combination thereof:

- the hairpin heat exchanger is horizontal and the flow of the second fluid with respect to the flow of the first fluid therein is either co-current or counter-current;
- the first header and the second header are straight and cylindrical, or spherical ;
- said first fluid is a fluid comprising feedwater or supercritical carbon dioxide ;
- said second fluid is a molten salt or a mixture of molten salts, a thermal oil or liquid sodium ;
- the baffles are under the form of a continuous helical baffle ;
- the baffles are assembled, preferably welded or bolted, to the internal cylindrical shell ;
- a tube sheet is provided between the first header, the second header respectively, and the hairpin section of the exchanger containing the internal and external cylindrical shells ;
- the tube sheet is of elliptical shape or the like and is provided with passageways for allowing sealed passage of the U-bent tubes through the tube sheet;
- the tube sheets are designed with low thickness suitable to withstand low pressure ;
- a sealing means is provided between the external shell and the baffles ;
- the hairpin exchanger is equipped with a distribution jacket for uniformly feeding the second fluid from the thermal fluid inlet to the heat exchanger;
- the distribution jacket has a plurality of openings distributed at 360° over an internal face thereof, said openings preferably feeding the second fluid into a first turn of the helical baffle.

[0019] A second aspect of the invention relates to an evaporator made of a hairpin heat exchanger as described above.

[0020] A third aspect of the invention relates to a superheater made of a hairpin heat exchanger as described above.

[0021] A fourth aspect of the invention relates to a re-

heater or economizer made of a hairpin heat exchanger as described above.

[0022] A fifth aspect of the invention relates to a molten salt steam generator (MSSG) comprising at least one heat exchanger train made of an evaporator, a superheater, a reheater and economizer as described above. Advantageously, the superheater, the reheater and/or the economizer are running counter-current, while the evaporator is running co-current.

[0023] Still under the scope of the present invention, the molten salt steam generator is a once-through or a forced circulation steam generator.

Brief Description of the Drawings

[0024]

FIG. 1 diagrammatically represents the components of a typical heat exchanger train for a Molten Salt Steam Generator.

FIG. 2 schematically represents an embodiment for a "shell-and-tube" straight tube heat exchanger according to prior art.

FIG. 3 represents a perspective view of a horizontal hairpin generator of prior art.

FIG. 4A and 4B respectively show a plane view and an elevation view for a preferred embodiment of a heat exchanger according to the present invention.

FIG. 5 is a longitudinal cross-sectional view of the heat exchanger according to the embodiment of FIG. 4.

FIG. 6A and 6B respectively show views corresponding to FIG. 4 but with a supporting system of the heat exchanger.

FIG. 7 is a longitudinal cross-sectional detailed view of the exchanger according to the invention, focusing on the elliptical tube sheet.

FIG. 8A and 8B respectively show a perspective view and a cross sectional view of the above-mentioned elliptical tube sheet.

Description of Preferred Embodiments of the Invention

[0025] The present invention relates to a new design for a horizontal hairpin heat exchanger 1, as depicted in FIG. 4 to 8.

[0026] The heat exchanger has a reciprocating flow between two fluids. A first fluid, generally a mixture of water and water steam, circulates through a first bundle of parallel horizontal straight tubes sections 2 located in

the first straight part of the hairpin and further through a second bundle of parallel horizontal straight tubes sections 2 located in the second straight part of the hairpin. The tubes 2 of the first bundle are connected to the tubes 2 of the second bundle by 180° bent tube sections located in the head of the hairpin, forming thereby U-bent tube sections.

[0027] Supercritical carbon dioxide is another example of usable first fluid in the present invention.

[0028] According to one alternate embodiment, the straight tubes sections of the first bundle can discharge fluid into a bonnet through a thick(er) tube shell into which also end the straight tubes sections of the second bundle. Thus, according to this particular embodiment the tubes have no U-bent tube sections.

[0029] According to the invention, the bundle of tubes 2 in each straight part is located between an internal cylindrical shell 3 and an external cylindrical shell 4, as represented in FIG. 5.

[0030] The internal space 5 delimited by the two shells 3, 4 permits to hold a heat source, preferably a second fluid, within an annular flow path. This second fluid is a thermal fluid, for example molten salt(s) having been heated by the solar receivers at the apex of a CSP tower plant. The thermal fluid, by having its flow in contact with the bundle(s) of tubes 2, will transfer heat to the parallel-flowing first fluid running through the tubes 2. The first fluid and the second fluid can be co-current or counter-current, without departing from the scope of the present invention. Similarly the heat source or the second fluid can be any thermal fluid such as water, thermal oil, liquid sodium, fluidized bed, etc.

[0031] As illustrated by FIG. 6, the external cylindrical shell 4, or a distribution jacket coupled therewith is provided at one end with an inlet nozzle 6, respectively an outlet nozzle 6, through which the thermal fluid enters into, respectively leaves the heat exchanger 1. Similarly, an outlet nozzle 7, respectively inlet nozzle 7, is provided at another end of the external cylindrical shell 4 in order to discharge the cooled thermal fluid, respectively admit the hot fluid.

[0032] Advantageously, as mentioned above, the thermal fluid is uniformly distributed on the shell at 360° (inlet, circulation, fluid temperature) thanks to a distribution jacket located at the inlet nozzle of the heat exchanger (see below).

[0033] In order to improve the efficiency of heat transfer, as shown in FIG. 6, space 5 is provided in the straight parts of the hairpin exchanger with an enclosed continuous helical baffle 8 allowing to guide the flow of the thermal fluid. The thermal fluid then helically flows in the heat exchanger, which is for example an evaporator running under natural circulation, between the internal and the external shell, according to an annular flow path. The continuous helical baffle configuration ensures a gentle flowing of the second fluid, without any sharp direction change or dead zones as in the exchangers having flow-perpendicular baffles. In this manner, the heat transfer

rate is greatly increased and the pressure drop is greatly lowered compared with that of exchangers with conventional segment baffles (see above).

[0034] According to one embodiment, the internal cylindrical shell 3 and the baffles 8 can be welded or bolted. Further a sealing means can be provided between the external shell 4 and the baffles 8 to avoid parasitic streams.

[0035] As shown on FIG. 7, on each external end of the hairpin exchanger straight part, the annular bundle of parallel straight tubes 2 is connected, via suitably bent tubes 11, located outside the internal and the external shells 3, 4 to at least one cylindrical linear header 9, 10. The header axis is orthogonal to the hairpin exchanger axis.

[0036] More specifically, as shown on FIG. 4 to FIG. 6, at a first end of the exchanger, the bundle of straight tubes 2 is connected to at least a first cylindrical linear header 9, or entry header 9, which feeds the straight tubes 2 with the first fluid, while, at a second end of the exchanger, the first fluid which is running inside the bundle of tubes 2 is collected by at least a second cylindrical linear header 10, or exit header 10, from the bundle of tubes 2. The need of more than one entry header 9 or exit header 10 may appear when there is a large number of tubes 2 in the bundle.

[0037] Furthermore as shown on FIG. 7, the bundle of straight tubes 2 is connected, either to the entry header 9 or to the exit header 10 by suitably bent tubes 11, in an area which is outside the internal and external shells 3, 4 of the hairpin exchanger. In this way, the use of tube sheets and/or high pressure spherical collectors, bonnets and headers, as in the so-called "shell-and-tube" heat exchangers of prior art, is avoided in the present invention because it is simply replaced by the use of cylindrical headers moved outside of the hairpin heat exchanger.

[0038] In the shell-and-tube configuration, the first fluid, usually water, is generally under high pressure in quasi-spherical vessels or plenums. On the other side of the tube sheet, the salt flowing around the tube bundles is maintained under much lower pressure, requiring very thick tube sheets to withstand the pressure difference. The invention configuration provides prolonged tubes connected to standard headers (cylindrical, spherical, etc.) at the ends of the exchanger, in which the high pressure fluid is circulating. This allows to reduce the thickness of the tube sheets, if any, the pressure being limited. More specifically, in the rectangular section on FIG.7, one sees that the pressure drop supported by the tube sheet 16 is governed by the difference of the external (air) pressure 12 and the internal thermal fluid pressure 13.

[0039] According to one embodiment of the present invention shown on FIG. 7 and FIG. 8, a tube sheet is preferably used under the form of a elliptical tube sheet 16 or the like, having orifices or passages 17 for the parallel tubes 2. The tubes 2 are welded to the elliptical tube

sheet 16 only with the sole purpose to ensure fluid tightness. These elliptical tube sheets 16 advantageously have lower thickness than prior art flat tube sheets for the reasons explained above.

[0040] Today, increased speed for ramp-up and stop are often required by the client. Thick vessel walls or headers are not suited for accepting higher temperature gradients and are more subject to fatigue leading to shorter lifetime of the heat exchanger. In this context the present invention provides extended lifetime of the heat exchanger components.

[0041] FIG. 7 also shows a detailed view for an embodiment of the entry/exit distribution jacket 30 from the fluid inlet/outlet 6, 7 into the hairpin heat exchanger. A uniform distribution of the second fluid at its entry/exit in the heat exchanger is ensured by a series of distribution openings 31 located at 360° over the internal side of the distribution jacket 30, preferably in a first turn 32 of the helical baffle 8.

[0042] The present invention is flexible and intended to be applied to a series of heat exchanger design used in MSSG technology, such as reheater, superheater, preheater and evaporator devices, wherein all the common components are made according to the generic heat exchanger design of the invention.

[0043] As mentioned above, a hot molten salt with decreasing temperature flows for example firstly in parallel through a reheater and a superheater to recombine and enter into the evaporator and further in the preheater/economizer in series.

[0044] In current embodiments, hot molten salt is entering the system at high temperature, for example 563°C and certainly below 565°C which is the degradation temperature for the usual molten salts. However it is under the scope of the present invention that the thermal fluid can withstand a temperature up to 700°C. All metal parts are advantageously made of stainless steel or noble metals which can withstand temperatures up to 600°C and above.

[0045] Cold salt leaves the preheater at a temperature typically in the range of 290-300°C, or above a minimum temperature which is either the solidification temperature of the heat transfer fluid (as low as 240°C for the molten salts such as sodium derivatives). Alternately any thermal fluid, e.g. thermal oil, can be used instead of molten salt with an operating temperature range in this case going for example from 80°C (condensation and/or crystallization temperature) to 380°C (example of degradation temperature).

[0046] Water at high pressure flows in tubes or pipes not in the shell side which allows lower thickness for the tube sheets and headers/shells and consequently a higher thermal gradient capability.

[0047] Although the design of the exchanger according to the present invention is optimized for natural circulation running, it could also be used in once-through or forced circulation steam generators.

List of reference symbols

[0048]

1	Hairpin heat exchanger	5
2	Straight tube (section)	
3	Internal cylindrical shell	
4	External cylindrical shell	
5	Intershell space	
6	Thermal fluid inlet	10
7	Thermal fluid outlet	
8	Helical baffle	
9	Inlet straight header	
10	Outlet straight header	
11	Bent tube (section)	15
12	First low pressure fluid (air)	
13	Second low pressure fluid (molten salt)	
14	U-bent tube	
15	High pressure fluid (water/steam)	
16	Elliptical tube sheet	20
17	Tube passageway	
18	Front closure	
19	Rear closure	
20	Support	
21	Straight tube	25
22	Shell	
23	Shell-side fluid in	
24	Tube-side fluid in	
25	Tube-side fluid out	
26	Shell-side fluid out	30
27	Tube sheet	
28	Baffle	
29	Water box or plenum or bonnet	
30	Distribution jacket	
31	Distribution openings to the first helical turn (or pitch) of the baffle	35
32	First helical turn of the baffle	
100	Molten salt inlet of the MSSG	
101	Reheater of the MSSG	
102	Evaporator of the MSSG	40
103	Economizer of the MSSG	
104	Superheater of the MSSG	
105	Molten salt outlet of the MSSG	45

Claims

1. A hairpin heat exchanger (1) having a first straight section, a second straight section and a bent section linking the first straight section and the second straight section, each straight section comprising a part of an internal cylindrical shell (3) and of an external cylindrical shell (4), both forming an intershell space (5) enclosing a bundle of parallel U-bent tubes (2) having each a first and a second straight part respectively located in said first and second straight section of the exchanger and a 180°-bent part located in said bent section of the exchanger, wherein, in

use, a first fluid to be heated and vaporized is flowing, said external cylindrical shell (4) being provided respectively at one end with an inlet (6) and at another end with an outlet (7) for a second fluid which is a hot thermal fluid, so that, in use, said second fluid is flowing in the intershell space (5) and cooling down by exchanging heat with the first fluid flowing in the straight tubes (2), said intershell space (5) enclosing also baffles (8) to guide the second fluid, wherein the bundle of parallel U-bent tubes (2) is extended out of the exchanger and connected, via bent tubes (11), respectively beyond an end of the internal shell (3) and of the external shell (4) at the first straight section to a first header (9) distributing the first fluid to the bundle of straight tubes (2) and beyond an end of the internal shell (3) and of the external shell (4) at the second straight section to a second header (10) collecting the first fluid under the form of liquid, vapor or a mixture liquid /vapor from the bundle of straight tubes (2).

2. The hairpin heat exchanger (1) according to claim 1, wherein it is horizontal and in which the flow of the second fluid with respect to the flow of the first fluid is either co-current or counter-current.
3. The hairpin heat exchanger (1) according to claim 1, wherein the first header (9) and the second header (10) are straight and cylindrical, or spherical.
4. The hairpin heat exchanger (1) according to claim 1, wherein said first fluid is a fluid comprising feed-water or supercritical carbon dioxide.
5. The hairpin heat exchanger (1) according to claim 1, wherein said second fluid is a molten salt or a mixture of molten salts, a thermal oil or liquid sodium.
6. The hairpin heat exchanger (1) according to claim 1, wherein the baffles (8) are under the form of a continuous helical baffle.
7. The hairpin heat exchanger (1) according to claim 1, wherein the baffles (8) are assembled, preferably welded or bolted, to the internal cylindrical shell (3).
8. The hairpin heat exchanger according to claim 1, wherein a tube sheet (16) is provided between the first header (9), the second header (10) respectively, and the hairpin section of the exchanger containing the internal and external cylindrical shells (3, 4).
9. The hairpin heat exchanger according to claim 8, wherein the tube sheet (16) is of elliptical shape or the like and is provided with passageways (17) for allowing sealed passage of the U-bent tubes (2) through the tube sheet (16).

10. The hairpin heat exchanger according to claim 8, wherein the tube sheets (16) are designed with low thickness suitable to withstand low pressure.
11. The hairpin heat exchanger according to claim 1, wherein a sealing means is provided between the external shell (4) and the baffles (8). 5
12. The hairpin heat exchanger according to claim 1, wherein it is equipped with a distribution jacket (30) for uniformly feeding the second fluid from the thermal fluid inlet (6, 7) to the heat exchanger. 10
13. The hairpin heat exchanger according to claim 12, wherein the distribution jacket (30) has a plurality of openings (31) distributed at 360° over an internal face thereof, said openings (31) preferably feeding the second fluid into a first turn (32) of the helical baffle (8). 15
- 20
14. An evaporator made of a heat exchanger according to claim 1.
15. A superheater made of a heat exchanger according to claim 1. 25
16. A reheater or an economizer made of a heat exchanger according to claim 1.
17. A molten salt steam generator (MSSG) comprising at least one heat exchanger train made of an evaporator according to claim 14, a superheater according to claim 15, and a reheater and/or economizer according to claim 16. 30
- 35
18. A molten salt steam generator according to claim 17, wherein the superheater, the reheater and/or the economizer are running counter-current, while the evaporator is running co-current. 40
19. A molten salt steam generator according to claim 17, wherein it is a once-through or a forced circulation steam generator. 45

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PRIOR ART

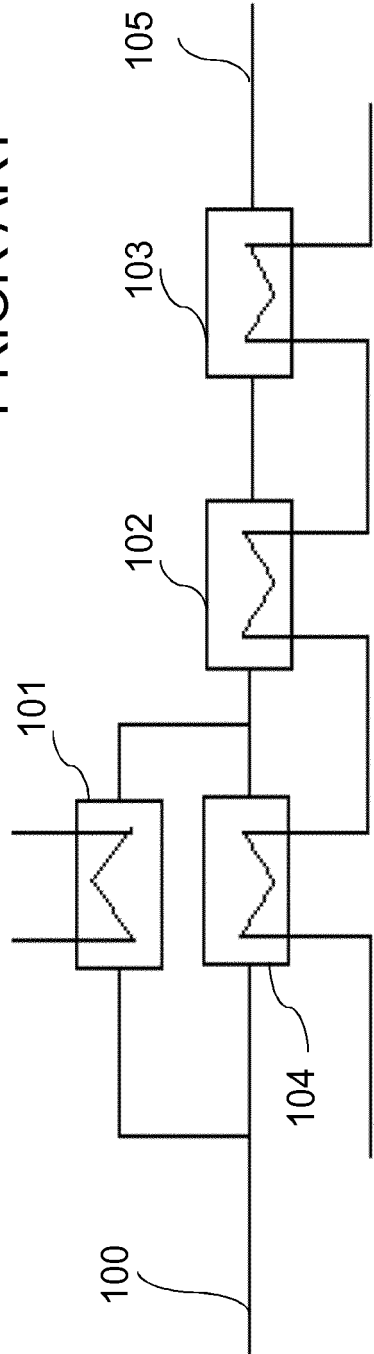


FIG. 1

PRIOR ART

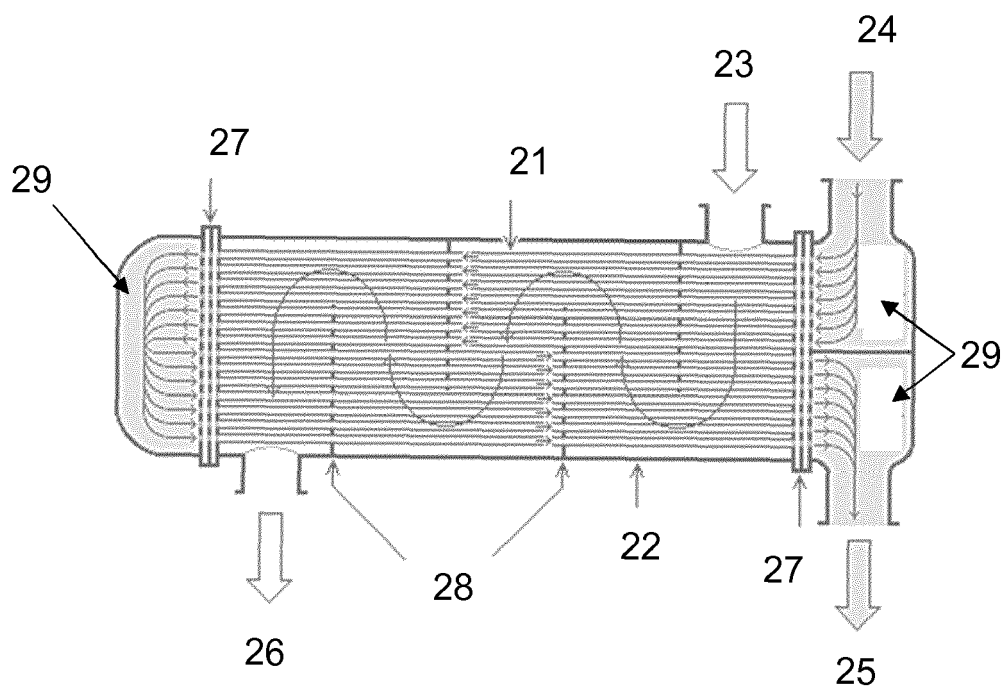


FIG. 2

PRIOR ART

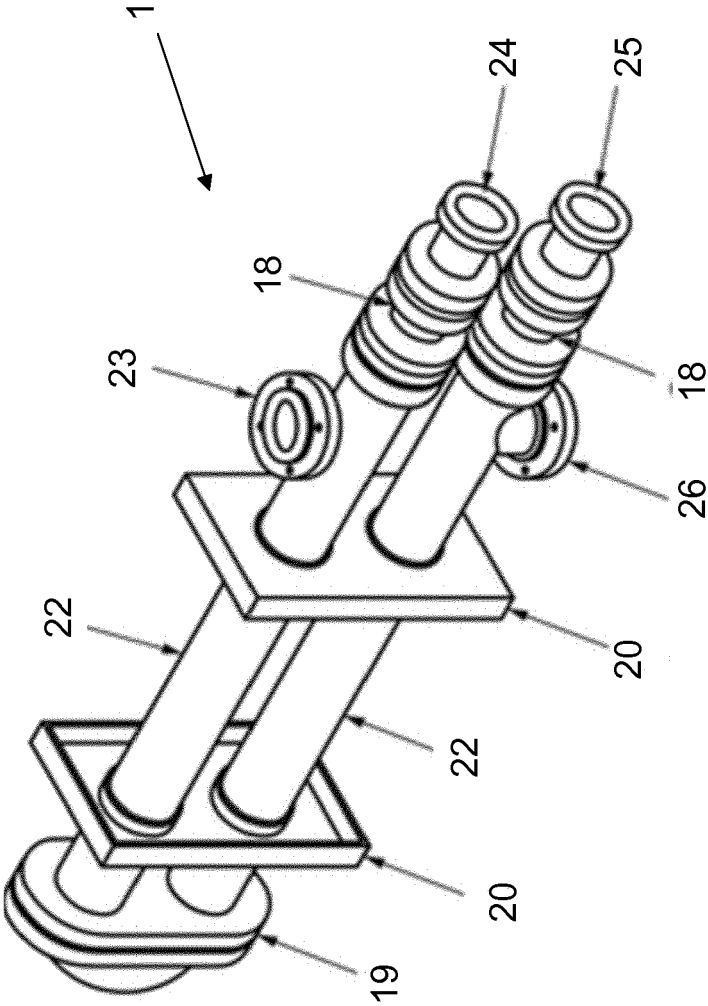
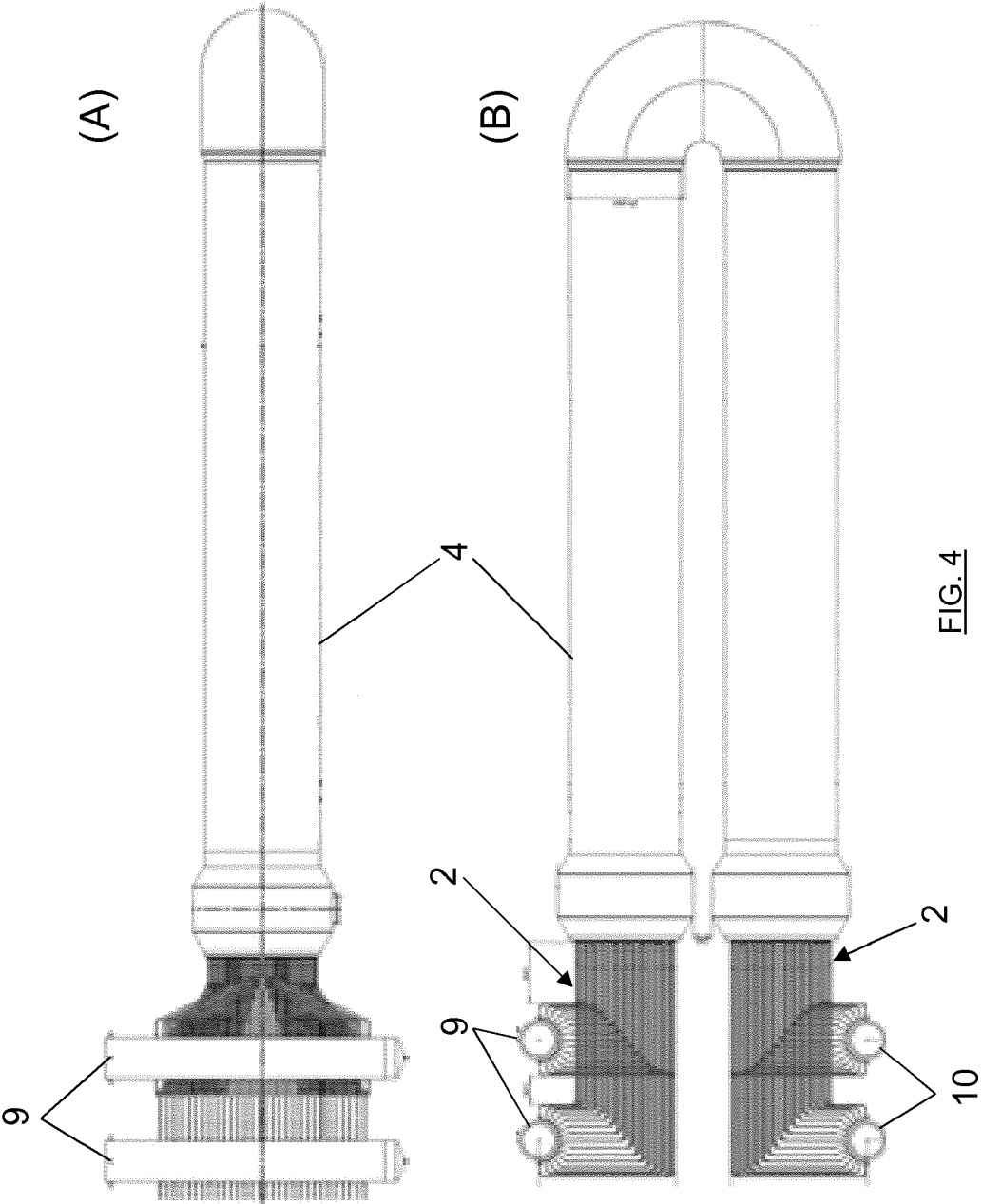


FIG. 3



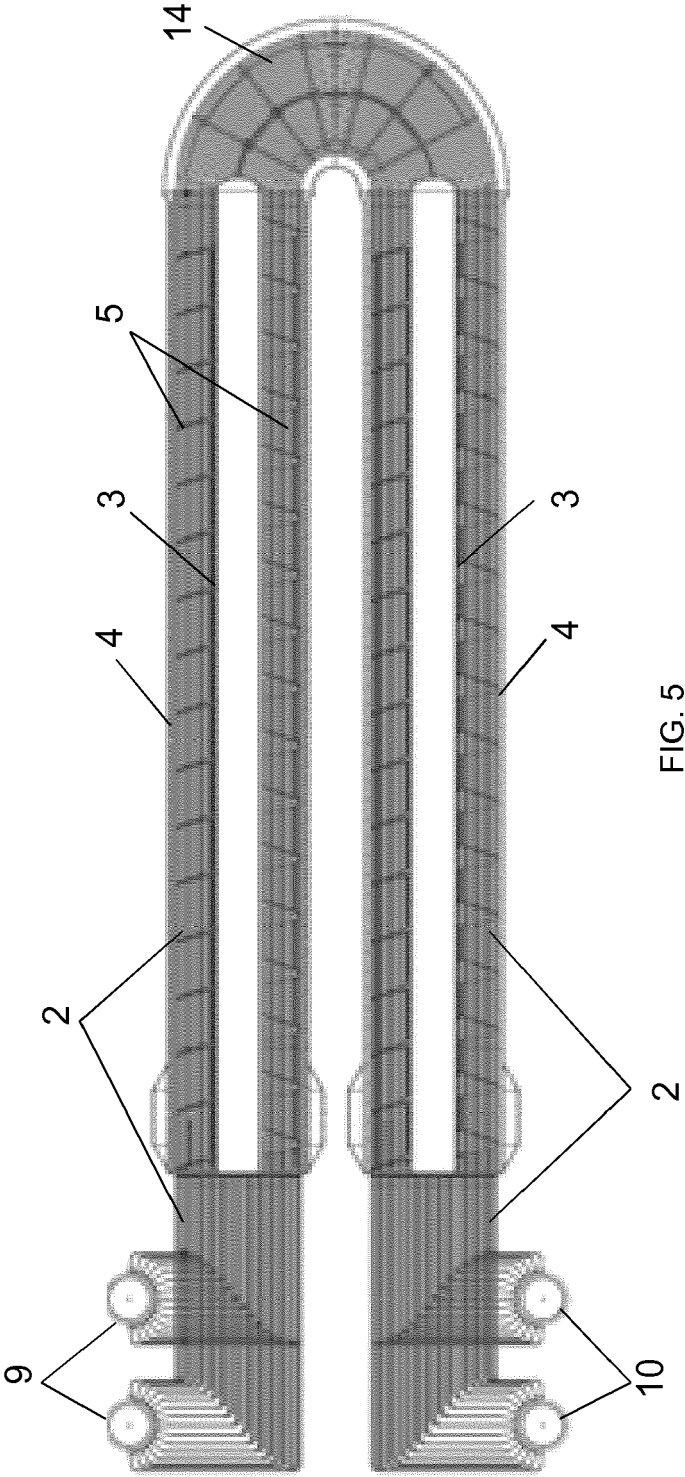


FIG. 5

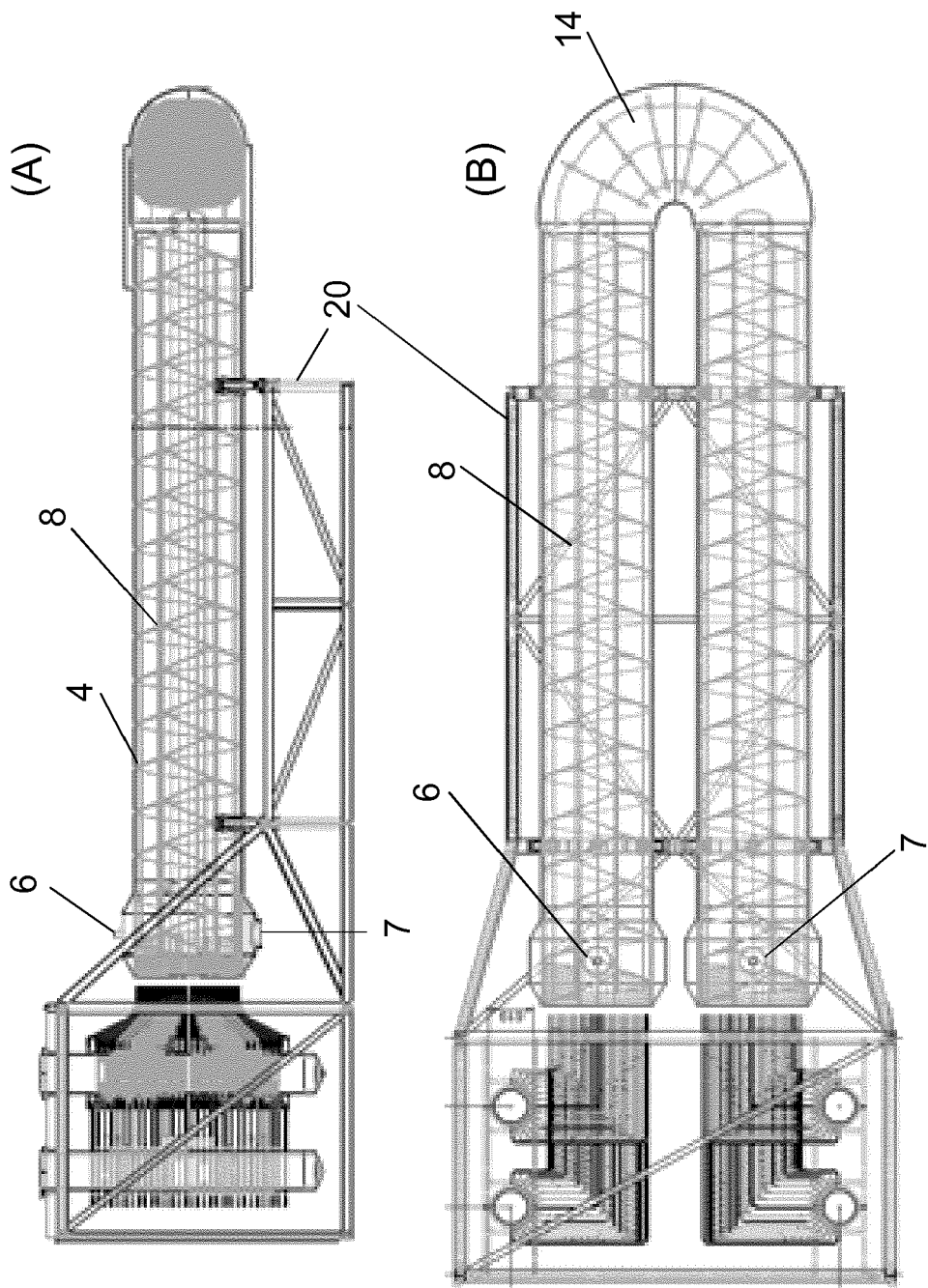


FIG. 6

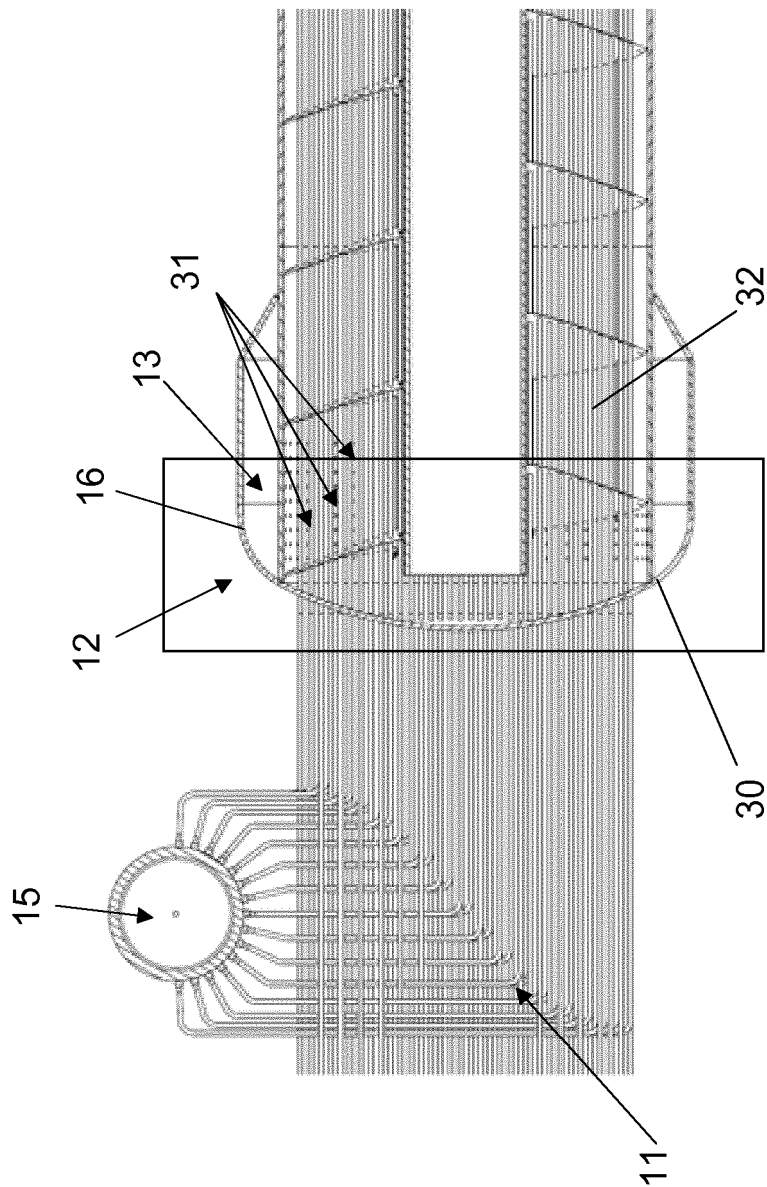


FIG. 7

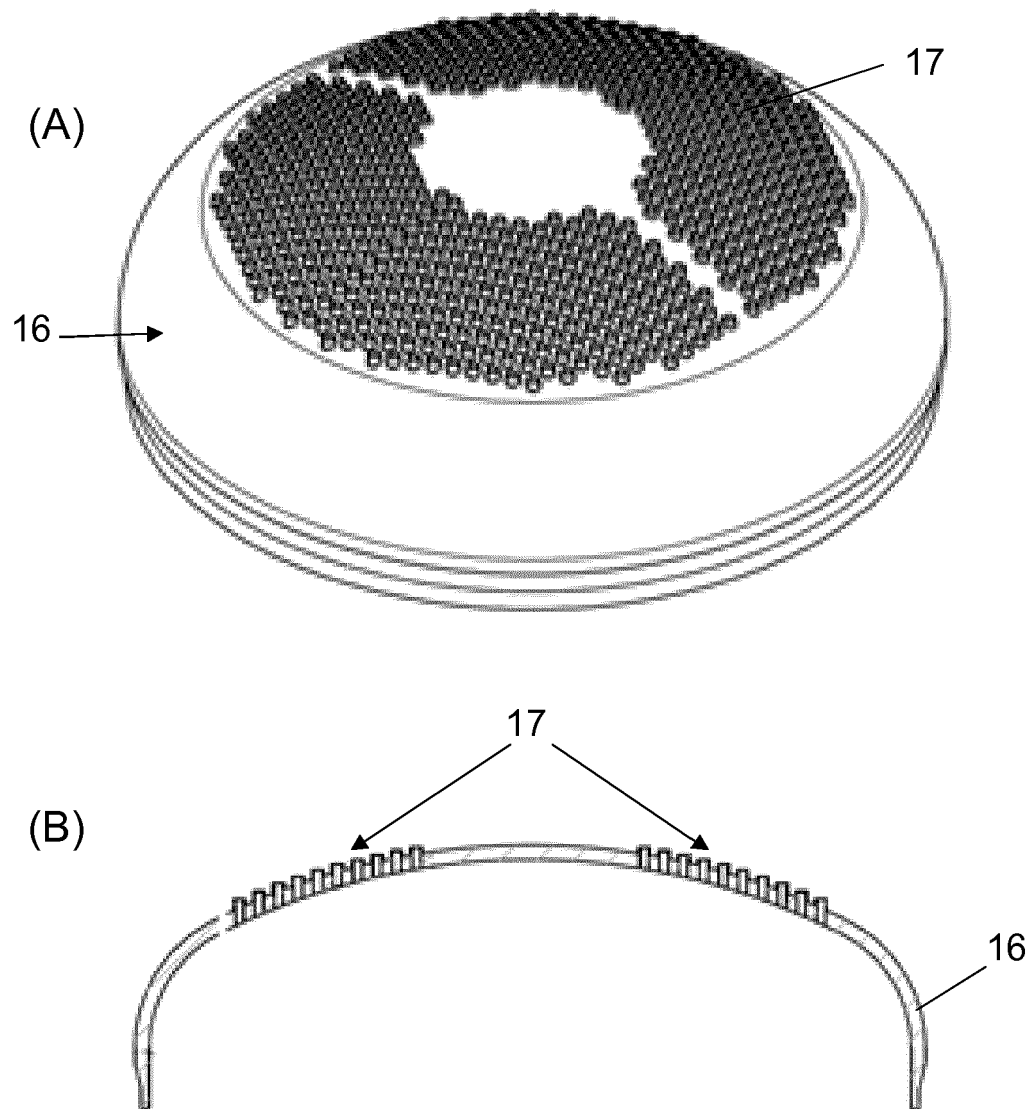


FIG. 8



EUROPEAN SEARCH REPORT

Application Number
EP 17 17 2695

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EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP S60 4790 A (BABCOCK HITACHI KK) 11 January 1985 (1985-01-11) * figure 4 *	1-19	INV. F28D7/06 F22B1/00 F22B1/06 F28F9/22 F01K25/00
X	DE 839 945 C (ESCHER WYSS AG) 26 May 1952 (1952-05-26) * figures 1-4 *	1-19	
X	DD 276 521 A1 (BRENNSTOFFINSTITUT FREIBERG) 28 February 1990 (1990-02-28) * figure 1 *	1-4	
X	US 3 168 136 A (AMMON JOHANNES H) 2 February 1965 (1965-02-02) * figures 1-3 *	1	
A	WO 2012/156350 A2 (SIEMENS AG [DE]; HOFFMANN WALDEMAR [DE]; BECKESCH GUENTHER [DE]; CZIMC) 22 November 2012 (2012-11-22) * page 1 - page 8 *	5	
A	EP 3 159 649 A1 (HAMILTON SUNDSTRAND CORP [US]) 26 April 2017 (2017-04-26) * abstract; figures 1-3 *	6	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2008/190593 A1 (WANG QIUWANG [CN] ET AL) 14 August 2008 (2008-08-14) * abstract; figures 1-13 *	6	F28D F22B F28F F01K
A	US 6 827 138 B1 (MASTER BASHIR I [US] ET AL) 7 December 2004 (2004-12-07) * abstract; figures 2-4 *	6	
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 3 November 2017	Examiner Bloch, Gregor
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 17 17 2695

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

03-11-2017

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15

20

25

30

35

40

45

50

55

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP S604790 A	11-01-1985	NONE	
DE 839945 C	26-05-1952	NONE	
DD 276521 A1	28-02-1990	NONE	
US 3168136 A	02-02-1965	NONE	
WO 2012156350 A2	22-11-2012	DE 102011075930 A1 WO 2012156350 A2	22-11-2012 22-11-2012
EP 3159649 A1	26-04-2017	EP 3159649 A1 US 2017115072 A1	26-04-2017 27-04-2017
US 2008190593 A1	14-08-2008	US 2008190593 A1 US 2011094720 A1	14-08-2008 28-04-2011
US 6827138 B1	07-12-2004	AT 410655 T AT 527512 T CA 2535395 A1 CN 1584482 A CN 2791574 Y CN 101598509 A CN 101598510 A DK 1668306 T3 DK 1965165 T3 EP 1668306 A1 EP 1965165 A2 ES 2315706 T3 ES 2373797 T3 JP 4401388 B2 JP 2007502963 A KR 20060090972 A MX PA06001731 A PT 1668306 E PT 1965165 E RU 2319917 C2 SI 1668306 T1 US 6827138 B1 WO 2005019758 A1	15-10-2008 15-10-2011 03-03-2005 23-02-2005 28-06-2006 09-12-2009 09-12-2009 08-12-2008 02-01-2012 14-06-2006 03-09-2008 01-04-2009 08-02-2012 20-01-2010 15-02-2007 17-08-2006 12-05-2006 03-11-2008 10-11-2011 20-03-2008 28-02-2009 07-12-2004 03-03-2005

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2009148822 A [0011]
- US 2384714 A [0011]
- US 2693942 A [0011]
- US 3400758 A [0011]
- US 4493368 A [0011]
- WO 2005019758 A [0011]
- US 1782409 A [0011]

Non-patent literature cited in the description

- *J. Heat Transfer*, 2007, vol. 129 (10), 1425-1431 [0010]
- *J. Heat Transfer*, 2010, vol. 132 (10), 101801 [0010]