(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
14 October 2010 (14.10.2010)

PCT

(10) **International Publication Number**
WO 2010/118276 A2

(51) **International Patent Classification**:
F24J 2/04 (2006.01) ***F03G 6/00*** (2006.01)
F24J 2/46 (2006.01) ***F01K 21/00*** (2006.01)

(21) **International Application Number**:
PCT/US2010/030459

(22) **International Filing Date**:
9 April 2010 (09.04.2010)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
61/212,390 10 April 2009 (10.04.2009) US
61/217,425 29 May 2009 (29.05.2009) US

(71) **Applicant** *(for all designated States except US)*: **VICTORY ENERGY OPERATIONS LLC** [US/US]; 10701 East 126th Street, North, Collinsville, OK 74021 (US).

(72) **Inventors; and**
(75) **Inventors/Applicants** *(for US only)*: **VISKUP, John, C., Jr.** [US/US]; 19620 E. Buttermere Road, Owasso, OK 74055 (US). **LIN, Bochuan** [CN/US]; 8306 N. 101st. E. Avenue, Owasso, OK 74055 (US).

(74) **Agents**: **WELLS, Harold** et al.; Kelley Drye & Warrner LLP, 400 Atlantic Street, 13th Fl., Stamford, CT 06901 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

[Continued on next page]

(54) **Title**: GENERATION OF STEAM FROM SOLAR ENERGY

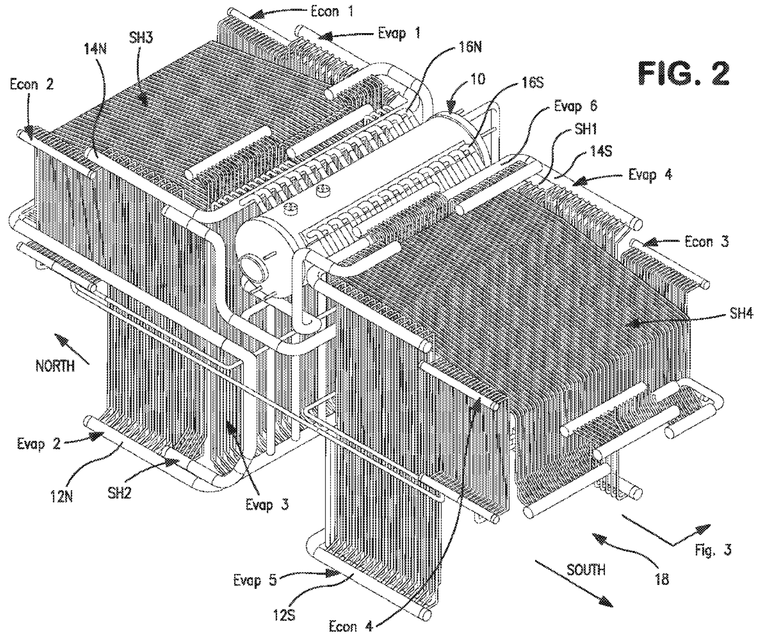


FIG. 2

(57) **Abstract**: A cavity-type solar energy receiver for generating high pressure steam, which includes panels of tubes defining a cavity within an outer enclosure. Concentrated solar energy provided by a heliostat enters the cavity opening in the enclosure and evaporates water within some of the tube panels. The evaporating tubes receive hot water from a steam drum by natural circulation and return a mixture of steam and hot water to the steam drum. Additional tube panels are positioned to receive reflected solar energy, which is used to preheat feed water and to superheat steam.

WO 2010/118276 A2

- *of inventorship (Rule 4.17(iv))*

Published:

- *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

GENERATION OF STEAM FROM SOLAR ENERGY

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority of US Provisional Applications 61/212,390 filed April 10, 2009 and 61/217,425 filed May 29, 2009 and incorporated herein by reference.

BACKGROUND OF THE INVENTION:

[0002] This invention relates to recovering solar energy in the form of steam, which may be used to generate electricity or in industrial processes. More particularly, the invention includes a novel method and apparatus for converting solar energy to high pressure steam; that is, a steam boiler that employs the sun's rays to produce steam.

[0003] Many proposals have been made to focus the sun's rays to concentrate solar energy. Electricity can be made directly by using heat engines that receive heat from focusing the sun's rays with a solar dish. Generating electricity with hot heat transfer liquids has been demonstrated for some years. Parabolic trough systems focus the sun's rays on receiving tubes running through the trough that carry heat transfer fluids. In what have been referred to as "power towers" an array of reflecting mirrors is used to focus the sun's rays on a central receiver that recovers the energy. If the concentrated solar energy can be applied to water at a high enough temperature, steam can be produced. While low pressure steam can be used for some purposes, such as heating buildings, high pressure steam is needed if it is to be used in a steam turbine to generate electricity. Thus, the problem addressed by the present inventors was how one could efficiently transfer concentrated solar energy to water at temperature of about 800-900° F and efficiently generate high pressure steam, for example at about 900 - 1000 psig.

[0004] Conventional steam boilers receive heat from two sources, radiant heat from the flames of fossil fuels and convective heat from hot combustion gases, both of which will vary with the amount and type of the fuel being burned and the air to fuel ratio. However, in applying solar energy only radiant heat is available, which must be transferred to the boiler tubes to generate steam. Furthermore, the energy density varies as the sun moves across the sky or with changing atmospheric conditions. The solar boiler design that will be described in detail below accommodates these conditions and can produce high pressure steam when solar energy is available.

[0005] The present invention is within the class of solar energy power systems referred to as power towers. As contrasted with the use of parabolic reflectors at ground level that focus the sun's rays on tubes running through the reflectors, a power tower uses an array of reflecting mirrors at ground level to focus the sun's rays onto a central receiver mounted on a tall tower. The solar energy is absorbed by a heat transfer medium, such as water, liquid sodium, molten salts, and organic liquids. Steam can be generated directly, or indirectly using another heat transfer medium, and used to drive a turbine generating electricity or in other uses. In order to maintain the electricity supply when the sun's energy is not available, a means for storing heat may be provided and used to produce steam and electricity. An example of such a solar energy system is Solar One, built and tested at Barstow, California in the 1980's, which successfully generated steam directly with the sun's rays. Heat was stored in oil and rock for later use. Cylindrical central receivers of the type used at Solar One to generate steam are described in US Patents 4,485,803; 4,245,618; and 4,789,114. Water was pumped through tube panels that formed a cylindrical receiver to preheat and evaporate feed water and then to superheat the steam produced. Solar Two converted the Solar One system to operate with molten salt as the heat transfer fluid, which had the advantage of more efficiently storing energy for generating steam when solar energy was not available.

[0006] The present invention relates to an improved method and apparatus for directly generating high pressure steam at the top of a power tower. In contrast with the cylindrical receiver mentioned above, in which water is pumped through the tubes, the present application includes a cavity type receiver which employs natural circulation of water. The source of the solar energy may be an array of reflecting mirrors such as described in U.S. Patents 6,959,993 and 7,192,146. The mirrors direct the sun's rays onto openings in the side of the steam generating apparatus, which is enclosed in a structure that confines the solar energy and limits heat losses from reflected solar radiation. The entire steam generating apparatus or steam boiler is completely enclosed. Only the entrance ports for the focused solar energy are open.

Summary of the Invention

[0007] The invention includes a cavity-type solar energy receiver for generating high pressure superheated steam in which panels of tubes are positioned inside an enclosure to receive concentrated solar energy through an opening in the enclosure. Water from a steam drum is passed by natural circulation through evaporator tubes exposed to concentrated solar energy to produce steam. The steam is separated from the steam/water mixture in the steam drum and then superheated before being supplied to a turbine driven electrical generator or used for other purposes.

[0008] In a preferred embodiment, two of the cavity-type solar energy receivers are positioned as mirror images, one facing north and the other south, both receiving concentrated solar energy from mirrors at ground level (a heliostat) reflecting light to the solar energy receivers mounted on a tower. A steam drum serving both receivers is mounted between them and within an enclosure for both receivers. In combination, the panels of tubes form a cavity within which concentrated solar energy is used to generate high pressure steam. Between the cavity formed by panels of tubes and the surrounding enclosure refractory insulation is provided to limit heat losses and to protect the outer enclosure. The solar energy receiver(s) has evaporator tubes mounted opposite the solar energy opening and against adjacent side walls. Economizer tubes for preheating boiler feed water may be included which, if used, could be positioned on the side walls and/or floor of the receiver adjacent the solar energy opening. Superheater tubes are positioned as a roof at the top of the cavity adjacent the evaporator tubes. Auxiliary superheater tubes may be added on the side walls as desired in some embodiments.

Brief Description of the Drawings

[0009] Fig. 1 is a process diagram.

[0010] Fig. 2 is a perspective view of a duplex steam boiler of the invention.

[0011] Fig. 3 is a sectional elevation view of the steam boiler of Fig. 2.

Description of the Preferred Embodiments

Design Problems

[0012] There are problems unique to the generation of high pressure steam from concentrated solar energy. They begin with the location of the steam generating equipment. Since the steam boiler and associated piping will be located atop a tower of one hundred feet or so, the weight of the equipment and environmental (e.g. wind and earthquake) forces on it must be accounted for in the design. Also, because access to the boiler equipment will be limited, especially when it is receiving the sun's rays reflected from mirrors at ground level, the design must be reliable and operated from a remote location. Some other problems are unique to the steam generating equipment itself.

[0013] Of first importance is the availability of solar energy. Since the amount of the sun's energy that falls on an array of mirrors will vary during the day and with the time of year, the amount of the sun's energy that can be reflected to the solar boiler equipment will change from minute to minute and day to day. In addition, the changing weather conditions will impact the available solar energy. This means that the amount of high pressure steam produced by a solar boiler can vary greatly and, consequently, control of the solar boiler operating conditions and of the reflecting mirrors is essential if optimum performance is to be attained. Thus, in contrast to most conventional boilers, the availability of the supply of energy (the sun) will be constantly varying, but the quality of the steam must be maintained to satisfy the turbine generator requirements or of other users of steam. Furthermore, since in many installations there will be multiple towers, each with its own steam boiler, changes in the solar energy available may be accommodated by starting up or shutting down individual solar boilers. Similarly, the electrical demand may vary, depending on customer use, which will affect demand for high pressure steam independently of the solar energy availability.

[0014] For each solar boiler, the steam quality will have to be maintained as conditions change. For example, a solar boiler will be designed to produce a given amount of high pressure steam at a given temperature using solar energy of a given maximum concentration. If the steam is to maintain its design quality (i.e. temperature and pressure) the ground-based mirrors can be adjusted to optimize the amount of the solar energy reaching the solar boiler. To a lesser degree, the steam temperature can be continuously adjusted by injecting boiler feed water into the superheated steam.

[0015] The tubes receiving solar energy will frequently expand and contract as the temperature of the tube walls varies with changes in the concentrated solar energy. It will be appreciated that excessive temperatures can cause tube failures so that adjusting the mirrors and maintaining water and steam flows is important. The tubes also must prevent solar energy from overheating the insulation and the external structure.

[0016] The solar receiver tubes may be subject to cyclic fatigue failure. This is a unique problem that results from the frequent heating up and cooling down due to unstable solar energy heat input. The worst operating conditions are expected to be in the superheater tubes, where the tube temperature may become very high, making the tubes more vulnerable to cyclic damage.

[0017] An important feature of this invention is that the superheater tubes are warmed with reflected heat from the evaporator panels, that is, an indirect method, rather than a direct method. The maximum heat flux in the reflected sun's rays is substantially less than that from direct rays. This reduces the maximum tube wall temperature and increases the reliability and life of the superheater panels.

[0018] Another important feature of this invention is natural water circulation. That is, water leaving the steam drum flows downward and enters the tubes. In the tubes the water it receives solar energy and a portion of the water becomes steam, rising up to the steam drum. The density difference between the water and the steam/water mixture creates a natural flow or circulation, which does not require the complication and expense of pumping and improves reliability of boiler operation.

General Arrangement of the Solar Energy Receiver

[0019] The solar energy receiver of the invention is referred to as a cavity-type solar energy receiver. It is deployed at the top of a "power tower" that receives concentrated solar energy from a heliostat, i.e. a set of ground-based mirrors. The solar energy receiver includes an external enclosure that protects the steam boiler and limits energy losses. When viewed from the outside, the steam boiler and other internals are not generally visible.

[0020] Inside the outer enclosure, a steam drum and its associated tubes are positioned so as to receive concentrated solar energy reflected from fields of ground-based mirrors. The steam drum and its associated tubes are generally referred to as a steam boiler. The tubes that receive solar energy are backed by insulation, which contains and helps to reflect the solar energy received from the heliostat and also protects the external structure

[0021] A cavity-type solar receiver by definition has an opening sized to receive energy focused on it by mirrors, which are usually located at ground level. The size of the cavity opening will be determined by the arrangement and positioning of the mirrors. The intensity of the focused solar energy will be determined by the number and size of the mirrors used and their reflective properties. Consequently, a cavity-type solar receiver would be designed to have a specific opening size and shape and to receive a specified quantity of solar energy. Within those basic parameters one must determine the arrangement of tubes to preheat and evaporate boiler feed water and to superheat the steam produced. Since the heat to evaporate water will be greater than the heat needed to preheat feed water and to superheat steam, the arrangement of the evaporator tubes will be of particular importance.

[0022] In the presently preferred embodiment shown herein, two cavity-type receivers are paired with a single steam drum. The evaporator tubes receive the focused solar energy directly by being placed opposite the cavity opening. Additional evaporator tube panels may be located on the side walls of the cavity adjacent the main panels, where they receive some reflected solar energy. However, the solar receiver of the invention is not limited by or require such adjacent panels. An embodiment that is shown in the drawings places preheat tube panels and superheater tube panels so that they receive solar energy reflected back from the evaporator tube panels opposite the cavity opening. While this arrangement of these panels is considered to provide a useful configuration, the location of such panels may be rearranged if desired. In a preferred embodiment the preheat panels are eliminated. Overall, the interior of the cavity receiver contains tube panels sized and arranged to receive a specified solar heat flux and to provide the specified amount of heat to water and steam.

Process Description

[0023] Fig. 1 is a process flow diagram that will assist the reader in understanding the description of the steam boiler which will follow. In this design, two sets of heat exchange panels forming two cavities are shown, one which typically would face north and the second one typically south, with ground-based mirrors reflecting solar energy into the cavity on each side. The position of the panels is also indicated, that is, whether the panels are on the east side, the west side, the roof, or on the floor of the cavity. Alternatively, a single cavity-type receiver having only one set of tube panels could be used if positioned at the edge of a field of mirrors. Electricity is generated at ground level by a turbine-generator (not shown) driven by the high pressure steam produced by the solar receivers. After leaving the turbine-generator, the steam is condensed and then pumped as hot water up the tower into the steam boiler 10 via the four economizer panels, shown as ECON 1-4. In a specific example, this water, which has a temperature of about 425°F and a pressure of about 998 psig, is reheated in the economizer panels ECON 1-4 to a temperature just below that of the steam drum 10, about 502°F. The steam drum 10 supplies the hot water via natural circulation to six evaporating panels, shown as EVAP 1-6, which generate steam at about 544°F, which returns to the steam drum 10. The saturated steam from steam drum 10 is then passed through the superheating panels, shown as SH 1-4, where the temperature is raised to about 825°F for use in the turbine-generator. A desuperheater is provided between SH 3 and 4, to adjust the temperature of the steam as required. The temperature also may be adjusted by changes to the position of the ground-based reflecting mirrors (not shown).

Arrangement of the Steam Boiler

[0024] Fig. 2 is a perspective view of a duplex steam boiler of the invention. In this design there are two mirror image receivers, one facing north and the other south, so that two sets of ground level mirrors can direct the sun's rays into the south opening 18 and north opening (not seen). Alternatively only one receiver could be used, positioned at the edge of one set of mirrors. The steam drum 10 is located between the north and south receivers and supplies water by natural circulation to the evaporating tube panels (EVAP 1-6), which return steam and water to the steam drum 10. After the saturated steam is separated from water returning to drum 10, it is superheated before being sent down the tower to be used. The heat exchange tube panels are backed by ceramic type insulation, which is adjacent to an outer enclosure (not shown).

[0025] Referring back to Fig. 1, focused solar energy enters the north and south openings and is partially reflected from the back wall to the side walls and the roof of the north and south units where the radiant energy is absorbed by three types of tube panels, which preheat boiler feed water, produce steam, and superheat the steam. The location of some of the tube panels are identified in Fig. 2. It should be understood that, except for superheater panels SH 1 and 2 which are on opposite sides of their respective units, the panels are mirror images. As was shown in Fig. 1, the preheater and superheater tube panels operate in series, water or steam passing through tube panels in both of the north and south units. The evaporator panels operate in parallel, three sets in each unit.

[0026] In the north unit economizer tube panels ECON 1-2 heat boiler feed water pumped from ground level and then send the heated water to ECON 3-4 in the south unit for additional heating before passing to the steam drum 10. These economizer tube panels are not required and may be omitted if desired. The evaporator tube panels EVAP 3 and 6 (not shown), which face the steam drum and are opposite the solar energy openings, are located where the solar energy is most concentrated, since they are directly exposed to the focused sun's rays. Evaporator tube panels EVAP 1-2 (north section) and EVAP 4-5 (south section) are located on the side walls of their cavities. The north unit has the same arrangement of tube panels except for superheater panel SH 2; the corresponding superheat panel SH1 is located on the east side of the south unit.

[0027] Using natural circulation through the evaporator tube panels, hot water from the steam drum 10 is vaporized and a mixture of steam and water is returned to the steam drum. After separating steam from hot water in the steam drum, the steam passes through superheater tubes SH 1-4 before being sent down the tower to the users. A desuperheater (not shown in Fig. 2) is provided to adjust the steam outlet temperature by spraying water into the superheated steam.

Steam Drum

[0028] The steam drum 10 is positioned between the north and south units as seen in Fig. 2. It receives heated feed water leaving economizer tube panel ECON 4 and entering the steam drum 10 though holes in a pipe extending into the drum (not shown). Water leaves the bottom of the steam drum 10 and enters the lower manifolds 12 N and 12 S, which each serve three evaporator tube panels, two which are seen in the north unit as EVAP 1 and 2 on the east and west walls. Evaporator tube panel EVAP 3 is seen in part in the north unit, where it is exposed to the most direct solar energy. The corresponding evaporator panels are EVAP 4-6 are in the south unit. The evaporator tube panels discharge into the upper manifolds 14 N and 14 S, which are generally U-shaped. From the upper manifolds multiple return pipes (16 N and S in Fig. 2), are used to provide uniform recirculation. The steam drum internals (not shown) include steam-water separators and demisters to remove water droplets from the saturated steam before leaving the drum and entering the superheat panels SH 1-4.

Economizer Tubes

[0029] Economizer tubes are not required but, when included, may be placed in locations not suited for evaporator or super heater tubes in order to complete the cavity. In the embodiment shown, the economizer tubes are positioned inside the solar energy openings (e.g. 18 in the south unit) as tube panels ECON 1-2 and ECON 3-4 on each side of each of the north and south units respectively. Economizer tube panels could be added at the floor of the cavity, although not preferred. The tubes in each panel receive boiler feed water from a manifold at one end of the tubes and deliver heated water to an outlet manifold at the other end of the tubes. The hot feed water enters panel ECON 1in the north unit, then leaves and proceeds to panels ECON 2-4 for further heating. The tubes enter horizontally with bends to each manifold as shown in Fig 2 in order to accommodate thermal expansion and contraction, which will occur during operation of the receiver as the concentration of solar energy or electrical load varies.

[0030] In one embodiment, the economizer tubes are expected to receive a maximum heat density of about 90,000 BTU/ft^2 per hour. Tubes have an outside diameter of 1.25 inches with a 0.165 inch thick wall (0.120 min) and are made of ASME SA-178A low carbon steel. Membrane bars, which are welded to the tubes to bind them together as a continuous heat transfer surface, are 0.25 inches thick and 0.825 inches wide. The cavity side of the economizer tubes are coated with a high emissivity coating to be discussed below.

Evaporator Tubes

[0031] Each of the north and south units has three sets of evaporator tube panels, operating in parallel in connection with the steam drum. Two panels EVAP 4 and 5 (south) and EVAP 1 and 2 (north) are located adjacent the wall opposite the solar energy opening. These panels principally receive reflected light, while panels EVAP 3 and 6 are located on the back wall of each section that receives direct exposure to the concentrated solar energy. EVAP 3 is shown in part of Fig. 2, but EVAP 6 is not visible due to the orientation of the two units. Each of the evaporator panels consists of a series of tubes receiving hot water by natural circulation from the steam drum through manifolds at the lower end of the tubes (12 N and 12 S). Steam is generated in the tubes and a mixture of steam and water passes up through each tube and into upper manifolds (14 N and 14 S). The steam/water mixture returns to the steam drum 10 from the upper manifolds through a series of tubes (16 N and 16 S) having a bend of about 90°, which will be described in more detail below. As with the economizer tubes, the evaporator tubes bend at both top and bottom to enter the manifolds horizontally.

[0032] Fig. 3 is an sectional elevation view of the east wall of the duplex steam solar boiler in Fig. 2, as viewed from the inside of the cavities. The north unit is at the left and the south unit at the right. Two of the economizer panels are shown (ECON 1 and 3 and the position of superheater panels (SH 3 and 4) atop the two cavities can be seen. Solar energy enters the north and south openings as indicated by the arrows. The natural circulation of water from the steam drum 10 through evaporator panels EVAP 1 (north side) and 4 (south side) is illustrated by arrows. (The main evaporator tube panels EVAP 3 and 6 are not visible in this sectional view). Water leaves the steam drum 10 through multiple nozzles at the bottom to join manifolds 12 N and 12 S and flows upward through the evaporator tube panels where solar energy evaporates a portion of the water. The mixture of steam and water enters outlet manifolds 14 N and 14 S, then passes back into the steam drum 10 again through multiple return pipes 16 N and 16 S. The return pipes have a bend of about 90 degrees, which helps to absorb thermal expansion and contraction during operation.

[0033] In a preferred embodiment, the evaporator tubes are expected to receive a maximum heat density of about 100,000 BTU/ft^2 per hour.. The tubes have an outside diameter of 1.75 inches, with a 0.135 inch thick (0.120 min) wall and are made of ASME SA-178A low carbon steel. The tubes are joined by membrane bars, which are 0.25 inches thick and 0.5 inches wide. The cavity side of the evaporator tubes is also coated with a high emissivity coating.

Superheater Tubes

[0034] Each of the north and south sections has three sets of superheater tube panels SH 1-4, operating in series. The first panels, SH 1and 2, receive the higher heat density but, since they receive saturated steam leaving the steam drum, operate at a lower temperature. Tube panel SH 2 can be seen on the west wall of the north section in Fig. 2. Tube panel SH 1 can be seen on the east wall of the south section in Fig. 3. Superheater tube Panels SH 1and 2 are positioned adjacent evaporator tube panel EVAP 4 (south) and evaporator panel EVAP 2 (north). Superheater panels SH 3 and 4 are located at the top or roof of their respective cavities.

[0035] In a preferred embodiment, the first superheater panels SH 1 and 2 are expected to receive a maximum heat density of about 70,000 BTU/ft^2 per hour. The tubes are 1.25 inches in outside diameter, with a 0.15 inch thick wall, made of ASME SA-213T22 2 ¼ chrome, 1% molybdenum steel. They do not have membrane bars, but are positioned to abut adjacent tubes to limit passage of solar energy. The second superheater tube panels SH 3 and 4 are expected to receive a maximum heat density of about 60,000 BTU/ft^2 per hour. The tubes are 1.25 inches in outside diameter, with a 0.165 inch thick (0.165 min) wall and made of ASME SA-213T22 2 ¼ % chrome, 1% molybdenum steel. The cavity side of the superheater tubes are coated with a high emissivity coating. Each of the superheater tubes will bend at one or both ends to absorb thermal expansion.

High Emissivity Coating

[0036] The cavity side of the boiler tubes are coated to both improve heat transfer to the tubes and to reflect solar energy towards the other tubes, Since the heat density is high and steam temperatures reach as high as 825°F, a very durable coating is required. In a preferred embodiment, the coating is CORR-PAINT CP-40XX Series (AREMCO PRODUCTS, Valley Cottage, NY), which is a silicone-based material resisting temperatures up to 1100°F. In general, the coating should absorb between 50 and 99% of the solar energy received and have a reflectivity rating of 1 to 50%. The preferred coating is a mixture of 80% white and 20% black paint to produce a gray shade that reflects about 20% of the incident light. The coating used required high temperature curing.

Insulation

[0037] In order to contain the solar energy and limit losses, which are calculated to be about 3% of the energy received, the tube panels are backed by insulation inside the outer structure. The insulation is shielded from direct exposure to solar radiation by the tubes joined by the attached bars that make a continuous surface. Water passing through the tubes also limits the temperature at the surface of the insulation. The insulation thickness varies between 1 to 6 inches, depending on the temperature expected at each area of the solar receiver. In a preferred embodiment the insulation may be mineral wool on the back of the evaporator or economizer panels and ceramic fiber in back of the superheater panels.

Claims

1. A solar energy receiver for generating high pressure steam with concentrated solar energy comprising:

(a) a steam drum for receiving heated boiler feed water and discharging high pressure steam;

(b) at least one panel of evaporator tubes, said evaporator tubes for receiving hot water by natural circulation from said steam drum and returning steam and hot water into said steam drum; and

(c) at least one panel of superheater tubes, said superheater tubes for receiving steam from said steam drum and discharging superheated steam;

wherein said steam drum is mounted adjacent to an enclosure containing said tube panels of (b) and (c), said tube panels defining a cavity surrounding an opening in said enclosure for admitting concentrated solar energy.

2. A solar energy receiver of Claim 1 further comprising at least one panel of economizer tubes, said economizer tubes for receiving boiler feed water and discharging said heated boiler feed water into said steam drum;

3. A solar energy receiver of Claim 1 wherein said at least one panel of said evaporator tubes is positioned in said enclosure opposite said opening to receive concentrated solar energy directly.

4. A solar energy receiver of Claim 3 further comprising additional panels of evaporator tubes adjacent said at least one panel of evaporator tubes of Claim 2, said additional panels of evaporator tubes being positioned on the side walls of said cavity to receive reflected solar energy.

5. A solar energy receiver of Claim 2 wherein panels of economizer tubes are positioned on the side walls and/or floor of said cavity adjacent said opening for admitting concentrated solar energy.

6. A solar energy receiver of Claim 1 wherein said at least one panel of superheater tubes is positioned at the roof of said cavity.

7. A solar energy receiver of Claim 1 further comprising a second set of tube panels corresponding to tube panels (b) and (c) within a second enclosure positioned in a mirror image of said at least one tube panels of Claim 1, said steam drum being positioned between said first and second tube sets of tube panels.

8. A solar energy receiver of Claim 1 wherein at least one of said panel of tubes is disposed to present a continuous heat transfer surface exposed to solar energy, each of said tubes being joined to adjacent tubes by metal bars welded to each tube, thereby creating a continuous heat transfer surface.

9. A solar energy receiver of Claim 1 further comprising insulation positioned between each of said tube panels and said enclosure.

10. A solar energy receiver of Claim 1 wherein said at least one panel of evaporator tubes is in fluid communication with said steam drum via inlet and outlet manifolds.

11. A solar energy receiver of Claim 10 wherein said outlet manifold is in fluid communication with said steam drum through multiple pipes, said multiple pipes having a bend for accommodating thermal expansion and contraction.

12. A solar energy receiver of Claim 10 wherein said inlet manifold is in fluid communication with said steam drum via multiple down comer pipes between said steam drum and said inlet manifold.

13. A solar energy receiver of Claim 11 wherein said bends have an angle of about 90°.

14. A solar energy receiver of Claim 10 wherein the evaporator tubes enter said inlet manifold and exit into said outlet manifold through horizontal connections.

15. A solar energy receiver of Claim 1 wherein a reflective coating is located on each of said tube panels of (b)(c), and (d).

16. A solar energy receiver of Claim 15 wherein said reflective coating is a silicone-based material resisting temperatures up to about 1100°F.

17. A solar energy receiver of Claim 16 wherein said reflective coating reflects up to 50% of incident light.

18. A solar energy of Claim 16 wherein said reflective coating is a mixture of black and white coatings.

19. A solar energy receiver of Claim 18 wherein said reflective coating reflects about 20% of incident light.

20. A solar energy receiver of Claim 9 wherein said insulation is ceramic fiber in back of said superheater tube panels and mineral wool in back of said evaporator and economizer tube panels.

21. A cavity-type solar energy receiver for generating high pressure steam from concentrated solar energy comprising:

(a) a steam drum for receiving heated boiler feed water and discharging high pressure steam;

(b) two cavities having openings for receiving concentrated solar energy and facing in opposite directions, said cavities located on opposite sides of said steam drum, said cavities defined by panels of tubes forming the sides of said cavities, said panels of tubes for receiving solar energy and generating high pressure steam therefrom;

(c) at least one panel of evaporator tubes in each of said cavities for receiving hot water by natural circulation from said steam drum and for returning steam and hot water into said steam drum; and

(d) at least one panel of superheater tubes in each of said cavities for receiving steam from said drum and discharging superheated steam.

22. A cavity-type solar energy receiver of Claim 21 further comprising at least one panel of economizer tubes in each of said cavities for preheating boiler feed water and discharging said heated boiler feed water into said steam drum;

23. A cavity-type solar energy receiver of Claim 21 wherein said at least one panel of evaporator tubes in each of said cavities is located opposite said openings for receiving concentrated solar energy directly.

24. A cavity-type solar energy receiver of Claim 22 further comprising additional panels of evaporator tubes located adjacent said at least one panel of evaporator tubes of Claim 21, said additional panels of evaporator tubes being positioned on the side walls of said cavity to receive reflected energy.

25. A cavity-type solar energy receiver of Claim 22 wherein said panels of economizer tubes for each of said cavities are located on the side walls of said cavities adjacent the openings for admitting concentrated solar energy.

26. A cavity-type solar energy receiver of Claim 21 wherein said at least one panel of superheater tubes are located at the top of each of said cavities.

27. A cavity-type solar energy receiver of Claim 21 wherein at least one of said panels of tubes is disposed to present a continuous heat transfer surface exposed to solar energy, each of said tubes being joined to adjacent tubes by metal bars welded to each tube, thereby creating a continuous heat transfer surface.

28. A cavity-type solar energy receiver of Claim 21 further comprising insulation positioned between each of said cavities and an enclosure surrounding both of said cavities and said steam drum.

29. A cavity-type solar energy receiver of Claim 21 wherein said at least one panel of evaporator tubes in each cavity is in fluid communication with said steam drum via inlet and outlet manifolds.

30. A cavity-type solar energy receiver of Claim 29 wherein said outlet manifold is in fluid communication with said steam drum through multiple pipes, said multiple pipes having bends for accommodating thermal expansion and contraction.

31. A cavity-type solar energy receiver of Claim 29 wherein said inlet manifold is in fluid communication with said steam drum via multiple downcomer pipes between said steam drum and said inlet manifold.

32. A cavity-type solar energy receiver of Claim 30 wherein said bends have an angle of about 90°.

33. A cavity-type solar energy receiver of Claim 29 wherein the evaporator tubes enter said inlet manifold and exit into said outlet manifold through horizontal connections.

34. A cavity-type solar energy receiver of Claim 21 wherein a reflective coating is located on each of said tube panels in (b), (c), and (d).

35. A cavity-type solar energy of receiver of Claim 34 wherein said reflective coating is a silicone-based material resisting temperatures up to about 1100°F.

36. A cavity-type solar energy receiver of Claim 35 wherein said reflective coating reflects up to 50% of incident light.

37. A cavity-type solar energy receiver of Claim 35 wherein said reflective coating is a mixture of black and white coatings.

38. A cavity-type solar energy receiver of Claim 37 wherein said reflective coating reflects about 20% of incident light.

39. A cavity-type solar energy receiver of Claim 28 wherein said insulation is ceramic fiber in back of said superheater tube panels and mineral wool in back of said evaporator and economizer tube panels.

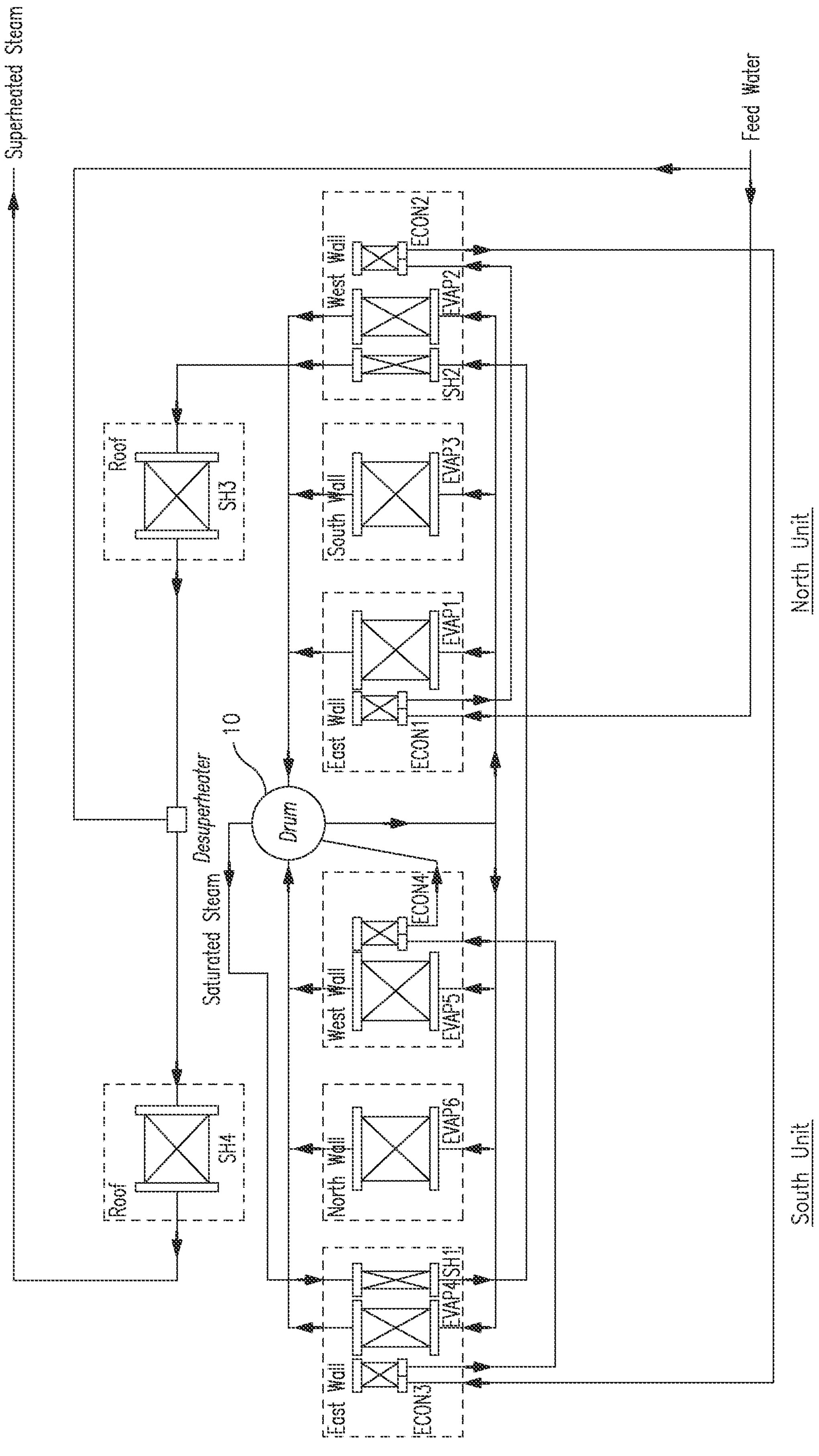
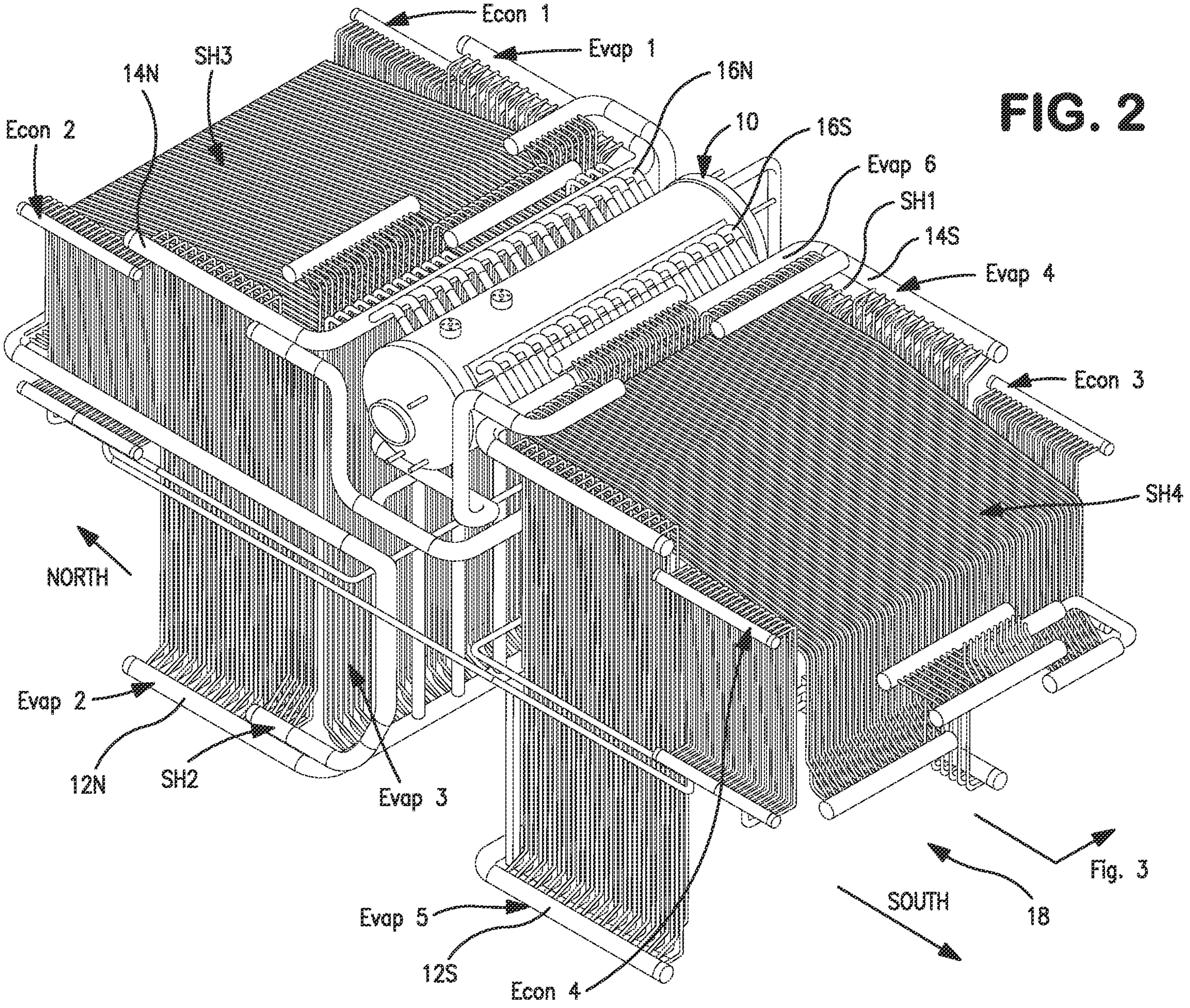

Superheated Steam
Feed Water
West Wall
ECON2
EVAP2
SH2
Roof
SH3
South Wall
EVAP3
EVAP1
East Wall
ECON1
10
Drum
Desuperheater
Saturated Steam
ECON4
West Wall
EVAP5
North Wall
EVAP6
Roof
SH4
East Wall
ECON3
EVAP4
SH1
North Unit
South Unit

FIG. 1

FIG. 2


Econ 1
Evap 1
16N
10
16S
Evap 6
SH1
14S
Evap 4
Econ 3
SH4
14N
SH3
Econ 2
NORTH
Evap 2
12N
SH2
Evap 3
Evap 5
12S
Econ 4
SOUTH
18
Fig. 3

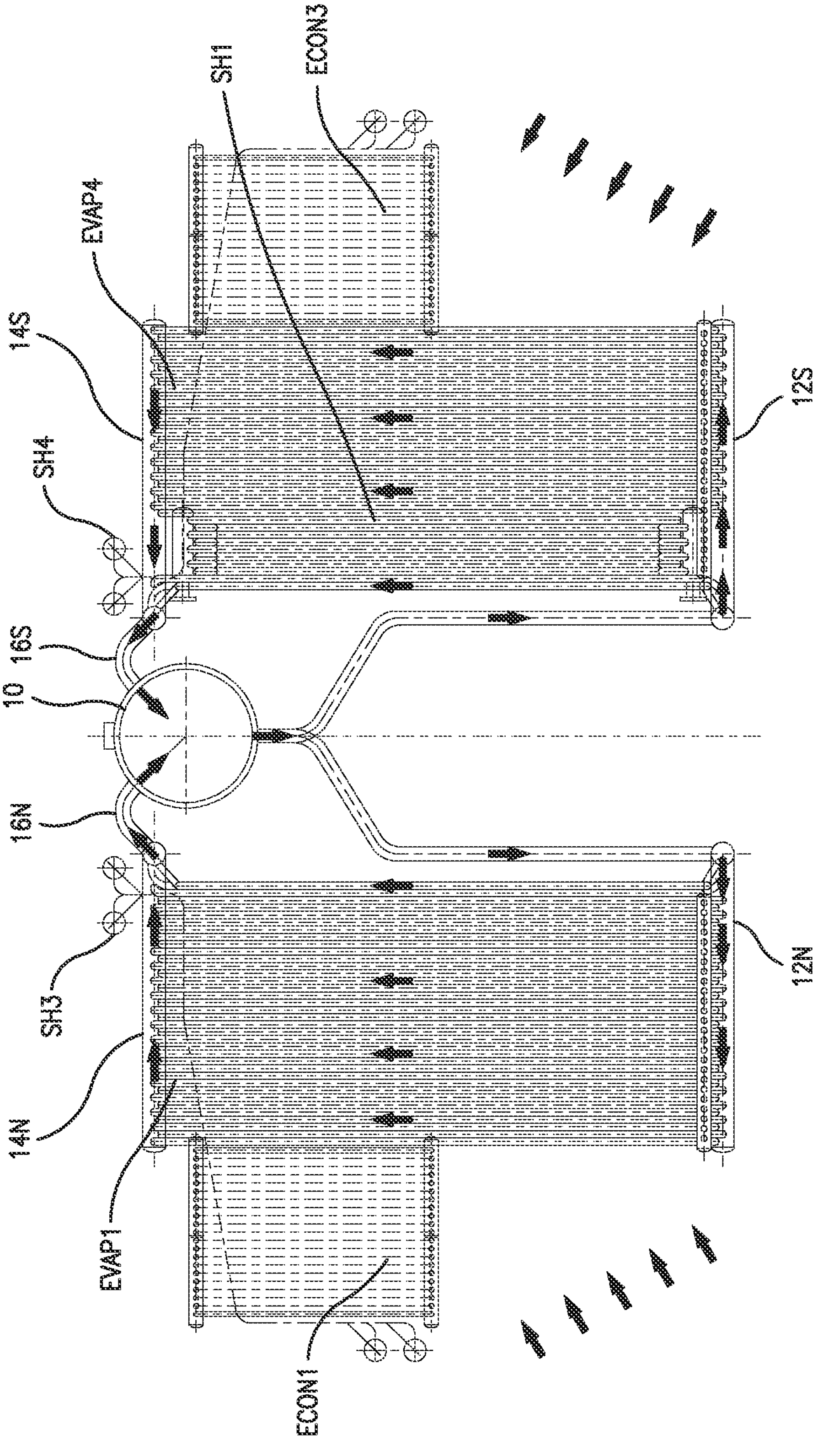


FIG. 3