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(54) **SYSTEM AND METHOD FOR GENERATING STEAM USING A SOLAR POWER SOURCE IN CONJUNCTION WITH A GEOTHERMAL POWER SOURCE**

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(57) **ABSTRACT**

System and method for generating electrical power using a solar power system comprising pressurized pipes for transporting liquid water in conjunction with a geothermal power source. The pressurized pipes flow through solar collectors which concentrate light on the water flowing through the pipes. The pressurization in the pipes allows for the water to absorb large quantities of energy. The pressurized and heated water is then pumped to a heat exchanger where the thermal energy is released to produce steam for powering a steam turbine electrical generator. Thereafter, the water is returned to the solar collectors in a closed loop to repeat the process. In conjunction with the solar power system, heated water from the geothermal power source is directed through a second pipe that also traverses the heat exchanger to assist in the production of steam for powering the turbine electrical generator.

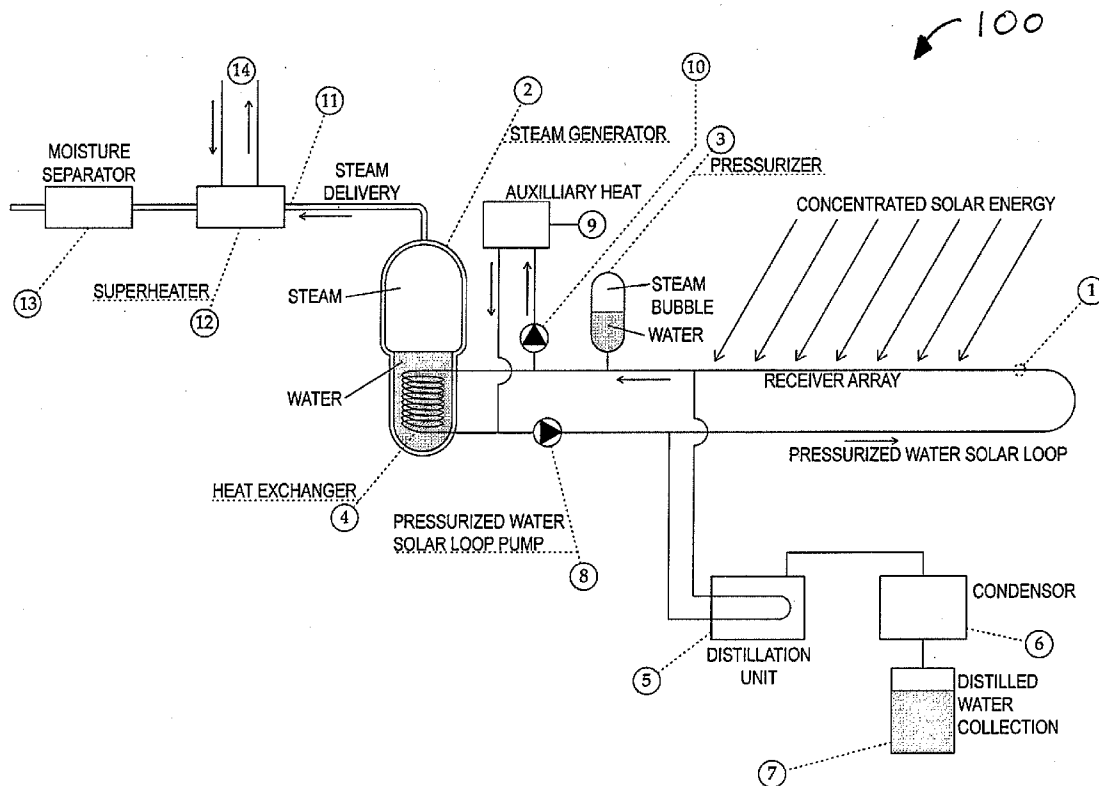
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(60) Provisional application No. 61/237,769, filed on Aug. 28, 2009.



**PRESSURIZED WATER SOLAR STEAM PRODUCTION SYSTEM**

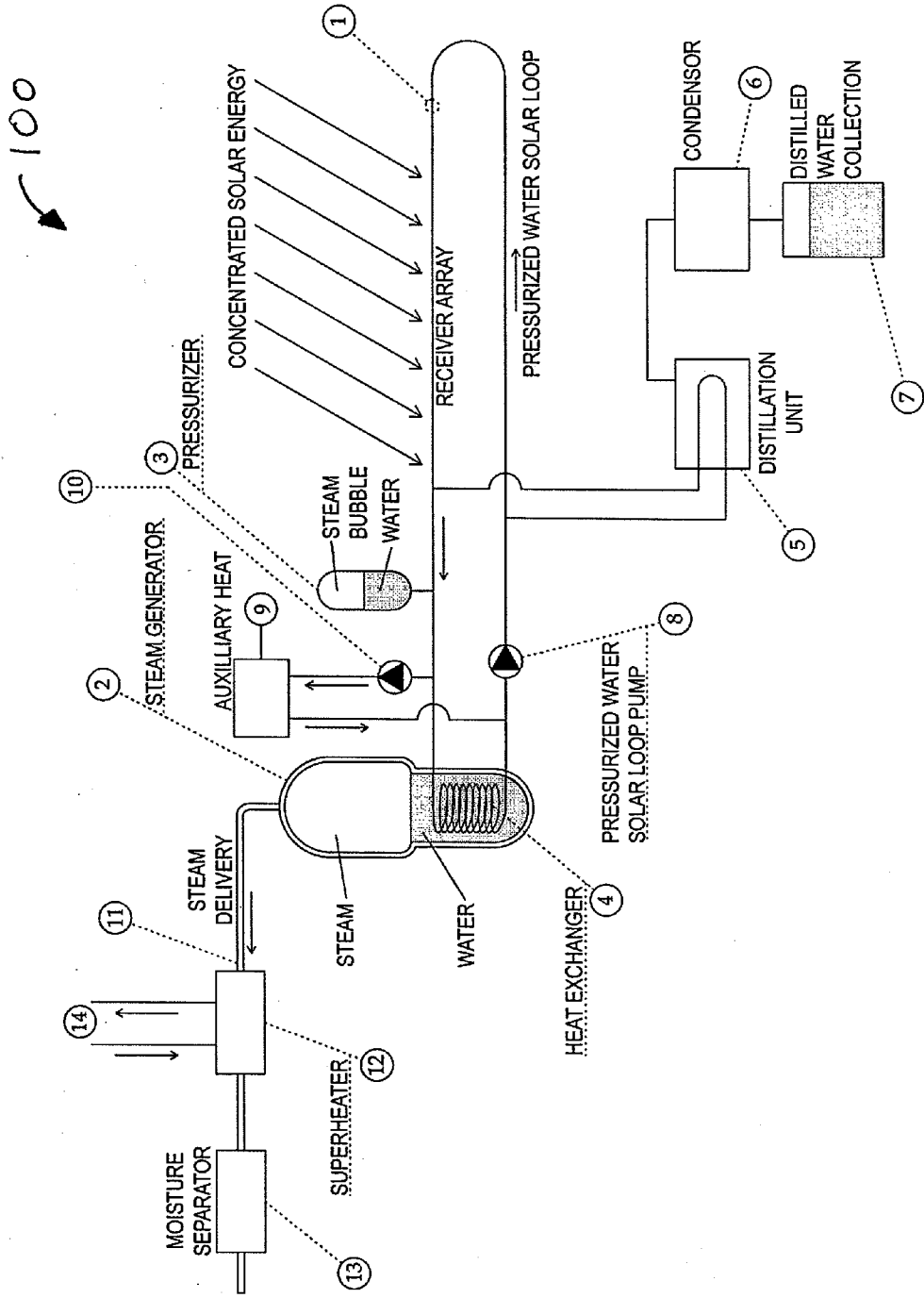


FIGURE 1. PRESSURIZED WATER SOLAR STEAM PRODUCTION SYSTEM

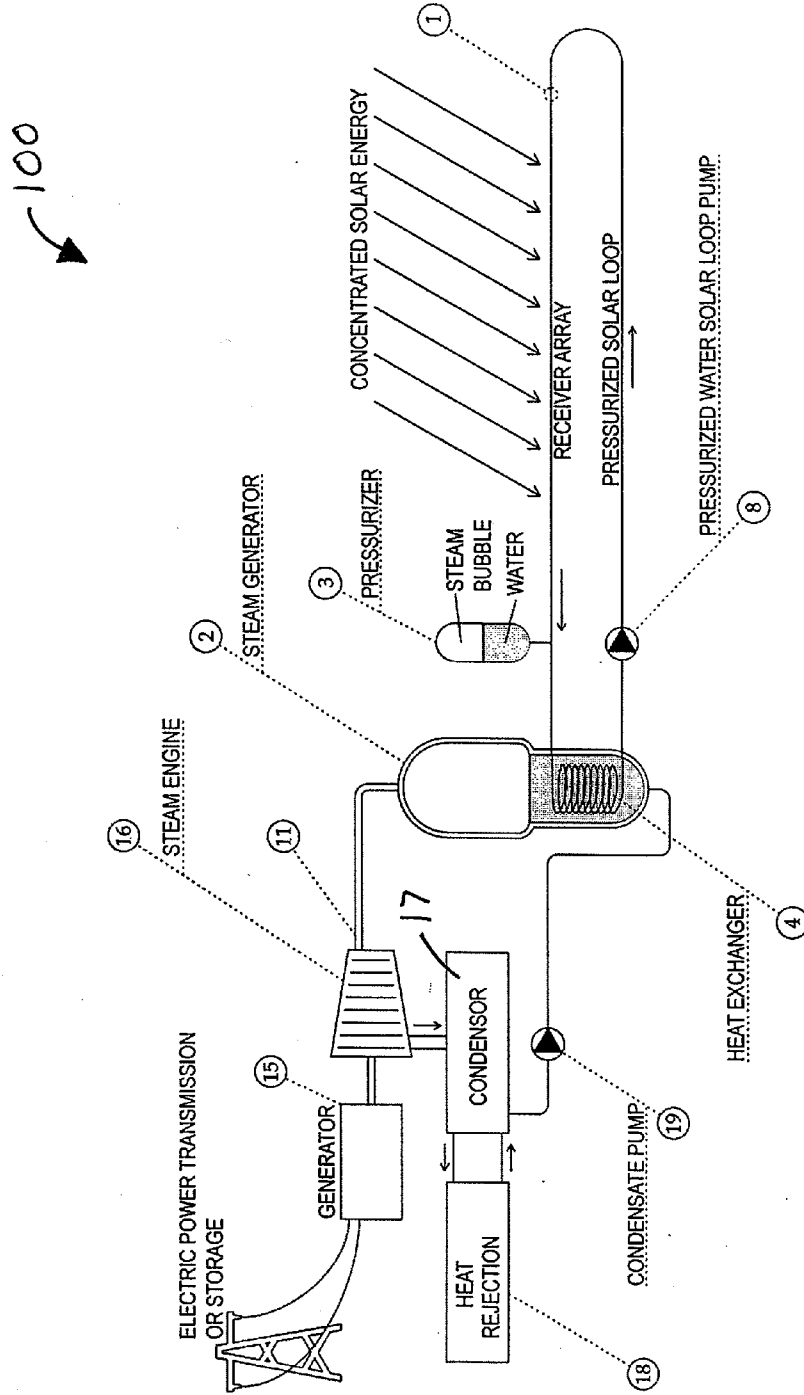


FIGURE 2. SIMPLE PRESSURIZED WATER SOLAR THERMAL POWER SYSTEM



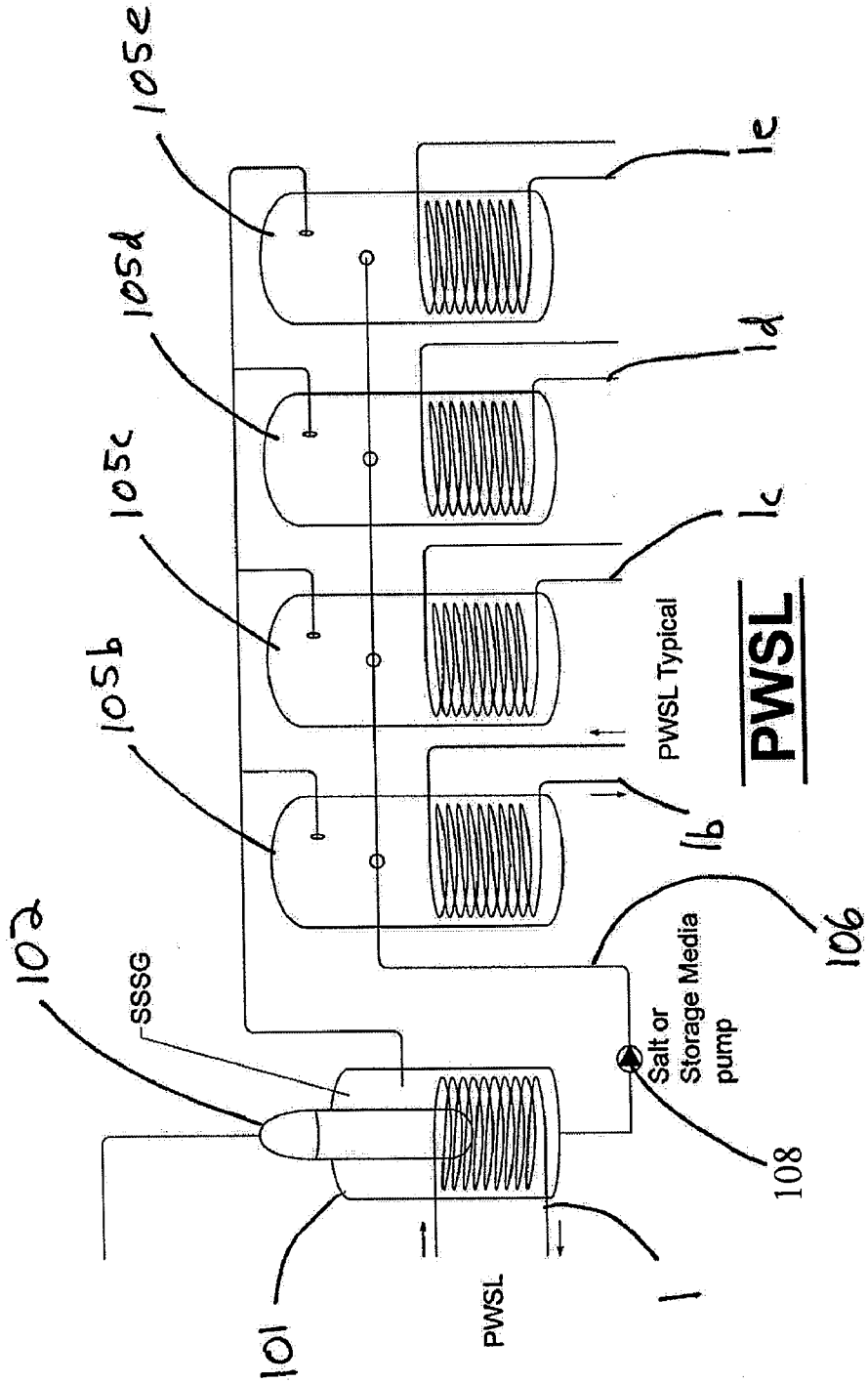


FIGURE 4.

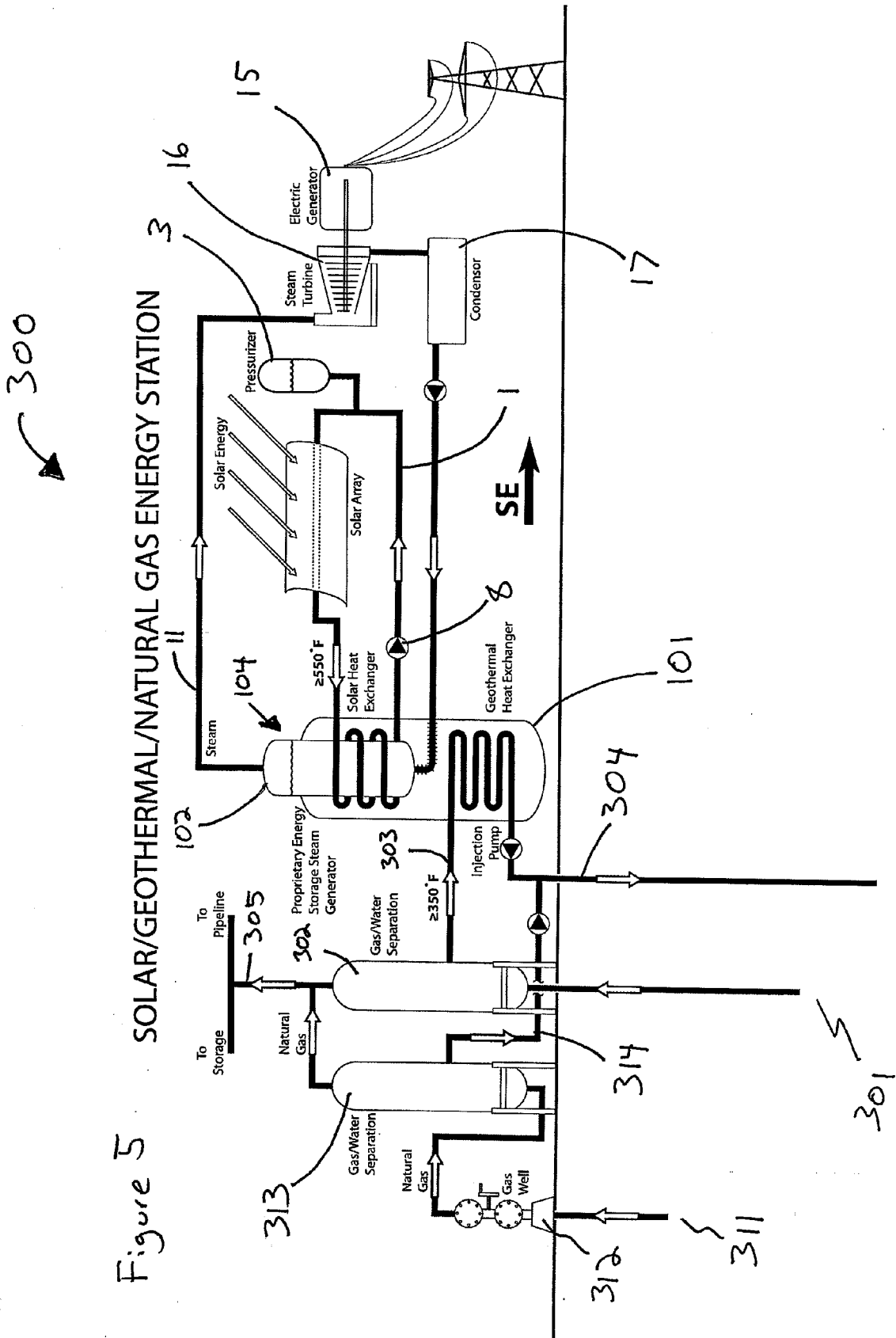


Figure 5 SOLAR/GEOTHERMAL/NATURAL GAS ENERGY STATION

**SYSTEM AND METHOD FOR GENERATING  
STEAM USING A SOLAR POWER SOURCE  
IN CONJUNCTION WITH A GEOTHERMAL  
POWER SOURCE**

**CROSS-REFERENCE TO RELATED  
APPLICATIONS**

[0001] This application is a divisional application of U.S. patent application Ser. No. 12/870,202, filed on Aug. 27, 2009 and currently pending, which claims priority to U.S. provisional application No. 61/237,769, filed Aug. 28, 2009, each application being incorporated herein by reference.

**BACKGROUND OF THE INVENTION**

[0002] Large scale solar power plants utilizing concentrating solar power (“CSP”) technology have been in production for over twenty years. The Solar Electric Generating Systems (“SEGS”) facilities in the Mojave Desert of California are a well-known example of solar power plants using such CSP technology. Concentrating solar power utilizes solar collectors comprising large mirrors or lenses which concentrate solar energy upon an unpressurized pipe or tube that contains a heat transfer fluid. Typically, a synthetic oil having a high boiling point is used as the heat transfer fluid. For example, the SEGS facilities utilize Therminol® from Solutia, Inc. as the heat transfer fluid.

[0003] As the heat transfer fluid flows through the unpressurized pipe inside the solar collectors, it is heated by the incident sunlight. One or more pumps are situated along the pipe to pump the fluid through the solar collectors and towards a boiler or heat exchanger. There, the transfer fluid is used to heat water in the boiler to produce steam. The steam is then used for powering a conventional steam turbine to produce electricity. After the heat transfer fluid releases its thermal energy in the boiler/heat exchanger, the heat transfer fluid is pumped back to the solar collectors to be heated once again.

[0004] One disadvantage of the use of a synthetic heat transfer fluid is that the fluid has a relatively low energy density. For example, Therminol® has an energy density of approximately 2100 J/kg° C. whereas ordinary water has an energy density of approximately 4200 J/kg° C. This relatively low energy density for Therminol® means that it can carry relatively less thermal energy from the solar collectors to the heat exchanger than water.

[0005] Another disadvantage of synthetic heat transfer fluids is that they are often flammable. As a result, care must be taken in handling the fluids and they must be prevented from overheating.

[0006] For these and other reasons, a number of solar power systems have recently been developed to produce steam directly from water rather than using a synthetic heat transfer fluid. Such systems—dubbed Direct Solar Steam generation (“DISS”) or Direct Steam Generation (“DSG”)—distribute water through the unpressurized pipes in the solar collectors rather than distributing a synthetic heat transfer fluid. Because water has a much lower boiling point than a synthetic heat transfer fluid, the water will eventually turn to steam after being heated a sufficient amount. Thereafter, the steam is directed to a steam turbine for generating electricity.

[0007] Such DSG systems have their own drawbacks, however. First, the presence of steam in the pipes of the solar collectors reduces the efficiency of the collectors because

steam has a significantly lower heat capacity than water. Thus, the steam can carry less thermal energy towards the turbine than can pressurized water. Second, the use of a two-phase (water/steam) flow within the pipes of the solar collectors creates a condition known as the Ledinegg Instability. This phenomenon results in a boiling front as the water moves through the pipes and flashes over to steam. To compensate for this instability, an undesirable pressure drop must be introduced into the system. Finally, DSG systems are more sensitive to variations in solar flux density and changes in atmospheric conditions because the systems will not function properly unless the water in the solar collectors is sufficiently heated to flash over to steam. Taken together, these drawbacks necessitate the use of larger, more expensive solar collectors to produce a given amount of electricity. Therefore, such DSG systems may have little or no cost savings in comparison to traditional CSP systems containing synthetic heat transfer fluid.

**SUMMARY OF THE INVENTION**

[0008] Disclosed herein are systems and methods for generating electrical power using a solar power system comprising pressurized pipes for transporting liquid water. The pressurized pipes flow through solar collectors which concentrate sunlight on the water flowing through said pipes. Because the pipes inside the solar collectors are pressurized, the water flowing therethrough can be heated well above the ordinary boiling point of water (100° C.). Advantageously, the systems and methods described herein rely upon the superior heat transfer capabilities of water in comparison to synthetic heat transfer fluids. Furthermore, the lack of synthetic heat transfer fluid minimizes the added costs and safety concerns associated with the use of such fluids.

[0009] Finally, the pressurized pipes described herein prevent the water flowing therethrough from flashing over to steam when heated to a high temperature. Accordingly, the instabilities and unwanted pressure drops associated with two-phase (water/steam) flow are eliminated. Furthermore, the use of water rather than steam for transporting thermal energy takes advantage of water’s superior energy carrying capacity in comparison to steam.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0010] FIG. 1 shows a detailed view of a pressurized solar power system according to one embodiment of the present invention.

[0011] FIG. 2 shows a view of the embodiment of FIG. 1 including the steam turbine and power generation portion of the system.

[0012] FIG. 3 shows a view of a second embodiment of a pressurized solar power system.

[0013] FIG. 4 shows the heat exchanger of FIG. 3 and a plurality of thermal storage tanks for use with the embodiment shown in FIG. 3.

[0014] FIG. 5 shows a view of a third embodiment of a pressurized solar power system.

**DETAILED DESCRIPTION**

[0015] FIGS. 1-4 show various embodiments and aspects of the present invention, with like reference numerals indicating like parts throughout the several views.

[0016] FIG. 1 shows a detailed view of a pressurized solar power system 100 in accordance with one embodiment of the

present invention. A pressurized solar loop 1 comprising a hollow pipe or tube is present. A portion of the pressurized solar loop 1 is positioned within a solar collector receiver array 20. The solar collector receiver array 20 may comprise any suitable means of concentrating solar energy on the pressurized solar loop 1 including, but not limited to, parabolic troughs, parabolic dishes, compact linear Fresnel reflectors, linear Fresnel reflectors, compound parabolic collectors, two axis tracking systems that focus solar energy on a tower or other structure, and any other solar energy concentration system.

[0017] The pressurized solar loop 1 forms a closed loop and preferably contains water within the loop 1. Other suitable heat transfer fluids known to those skilled in the art may be used instead of water, however. A pressurizer 3 is attached to the pressurized solar loop 1 to pressurize the solar loop 1 above normal atmospheric pressure.

[0018] Preferably, pressurizer 3 is a steam bubble pressurizer comprising a large internal chamber where steam can form in the upper section of the chamber but cannot be released. As the water in the solar loop 1 is heated due to the concentrated sunlight directed towards solar loop 1, a steam bubble will form in the upper portion of steam bubble pressurizer 3. The steam bubble can also be formed by pre-heating the water in solar loop 1. After forming, the steam bubble in the upper section of the pressurizer 3 keeps pressure on the water in the pressurized solar loop 1. Advantageously, this pressure increases the boiling point of the water in the pressurized solar loop 1, thus preventing the water from flashing over to steam. As solar energy increases the temperature of water circulating in solar loop 1, the steam bubble in the pressurizer 3 increases in pressure thereby creating a self-regulating pressure control system.

[0019] As described above, the use of a single-phase (water only) pressurized solar loop 1 prevents Ledinegg Instability and unwanted pressure drop. Water also has an increased energy carrying capacity in comparison to steam. Thus, the pressurized water in pressurized solar loop 1 can carry more energy than a comparable DSG system with a two-phase (water/steam) energy transport mechanism.

[0020] One or more pumps 8 are present along the pressurized solar loop 1. These pumps 8 act to circulate water through the solar collector receiver array and to the heat exchanger 4. Control mechanisms known to those skilled in the art operate to control the pumps 8 and the flow rate of water flowing through pressurized solar loop 1.

[0021] An auxiliary heating device 9 can be attached to pressurized solar loop 1, preferably near the point where the pressurized solar loop 1 enters the heat exchanger 4. One or more pumps 10 can be provided to pump water from the solar loop 1 into the auxiliary heating device 9. The auxiliary heating device 9 can be used to heat the water in the solar loop 1 if there is insufficient solar energy to heat the water to an appropriate operating temperature such as on cloudy days or during the nighttime hours.

[0022] In some embodiments, an optional distillation unit 5, condenser 6, and water collector 7 can be connected to the pressurized solar loop 1. The distillation unit 5 can use the hot water from the pressurized solar loop 1 to boil water to create steam. This steam can then be transferred to condenser 6 where it will be cooled and condensed into clean distilled water. Such distilled water can be collected in water collector 7. The distilled water can later be used for any number of

purposes including, but not limited to, providing makeup water for the heat exchanger 4 or the pressurized solar loop 1.

[0023] After the water is heated in the portion of pressurized solar loop 1 that lies inside the solar collectors, the water travels to the heat exchanger 4. The heat exchanger 4 preferably comprises a pressurized steam generator vessel 2 with liquid water in the lower portion of the steam generator vessel 2. Preferably, the pressurized solar loop 1 will enter the lower portion of the steam generator vessel 2. A sizeable length of solar loop 1 will be present within the lower portion of the steam generator vessel 2, preferably in a coil, loop, or other configuration so as to expose a substantial surface area of the solar loop 1 to the water contained in the lower portion of heat exchanger 4. The hot water contained in solar loop 1 will transfer its heat to the water in the bottom of heat exchanger 4, thus causing the water in the heat exchanger 4 to boil and produce steam. The steam generator vessel 2 of heat exchanger 4 preferably comprises suitable ports or openings for releasing steam and for introducing makeup water into the heat exchanger 4. Preferably, the makeup water is cooler than the water present in the pressurized solar loop 1 so as to facilitate the transfer of thermal energy inside the heat exchanger 4. As described in more detail below, cooling towers or other means for cooling water can be used to sufficiently cool water for use as makeup water.

[0024] After the hot water in the pressurized solar loop 1 transfers its thermal energy to create steam inside the heat exchanger 4, the cooled water exits the heat exchanger 4 and returns to the solar collectors. In such a manner, the water inside pressurized solar loop 1 continuously circulates through solar loop 1, absorbing thermal energy from the sunlight at the solar collectors and releasing thermal energy inside the heat exchanger 4.

[0025] With reference to FIGS. 1 and 2, the steam produced inside heat exchanger 4 exits the steam generator vessel 2 and proceeds through steam piping 11 towards a steam turbine 16. As known to those skilled in the art, the steam turbine 16 utilizes the energy contained in the steam to generate rotary motion. This motion, in turn, is used by generator 15 to produce electricity.

[0026] As shown in FIG. 1, an optional superheater 12 may be attached to steam piping 11 prior to entry into steam turbine 16. The superheater 12 can be used to add additional heat to the steam from any external heat source 14 including, but not limited to, additional solar heating sources. An optional moisture separator 13 can also be attached to steam piping 11.

[0027] Returning to FIG. 2, after powering the steam turbine 16, the steam will exit the turbine 16 and enter a condenser 17 where it will be condensed back into water. The water then is transferred to a heat rejection device 18 such as a cooling tower. The cooled water will then flow back into the steam generator vessel 2 of heat exchanger 4. One or more pumps 19 may act to pump the water back to the heat exchanger 4. In such a manner, the water is ready to again be heated by the pressurized solar loop 1 to form steam inside the heat exchanger 4.

[0028] As described above, the pressurized water in pressurized solar loop 1 allows for the water to absorb substantial energy and rise to a temperature well above 100° C. without flashing over to steam. Advantageously, this allows the pressurized solar power system 100 to carry more energy than a two-phase (water/steam) DSG system or a system using a synthetic heat transfer fluid in a non-pressurized solar loop.



The enhanced efficiency of the pressurized solar power system **100** described herein also allows for the use of smaller and/or fewer solar collectors than in prior art systems. The efficiency of the pressurized solar power system **100** can be further increased by placing the steam turbine **16** and the heat exchanger **4** in the center of the array of solar collectors, thus reducing the length of piping between the solar collectors and the heat exchanger **4** as well as the length of piping **11** between the heat exchanger **4** and the steam turbine **16**.

[0029] Turning to FIG. 3, a second embodiment of a pressurized solar power system **200** is shown. The embodiment shown in FIG. 3 is similar in many respects to the embodiment shown in FIGS. 1-2, with like reference numerals indicating like parts between the two embodiments. The pressurized solar power system **200** of FIG. 3 generally comprises a pressurized solar loop **1** that preferably contains pressurized water. The pressurized water in solar loop **1** absorbs thermal energy from the concentrated solar energy produced by one or more solar collectors and transports said thermal energy to a heat exchanger **104**.

[0030] Heat exchanger **104** preferably comprises two vessels: a pressurized steam generator vessel **102** and a non-pressurized storage media vessel **103**. The storage media vessel **103** contains a substance suitable for storing and transporting thermal energy such as molten salt. The steam generator vessel **102** contains water in the lower portion of the vessel **102** which, when heated sufficiently, will boil and produce steam in the upper portion of steam generator vessel **102**.

[0031] A portion of the pressurized solar loop **1** preferably enters the storage media vessel **103** near the lower end of the storage media vessel **103** and forms a coil, loop, or other shape to expose a substantial surface area of the solar loop **1** to the surrounding salt inside the storage media vessel **103**. The hot water in the pressurized solar loop **1** advantageously heats the molten salt contained in the storage media vessel **103**. In turn, the molten salt is in contact with the exterior portion of steam generator vessel **102** and transfers heat from the molten salt to the steam generator vessel **102**. This causes the water inside steam generator vessel **102** to heat up and eventually turn to steam. As described above with respect to FIGS. 1 and 2, the steam can be used to drive a steam turbine **16** and produce electrical energy at an electrical generator **15**.

[0032] Turning to FIG. 4, a plurality of thermal storage tanks **105b-105e** are shown. One or more of such thermal storage tanks **105** may optionally be used in conjunction with the pressurized solar power system **200** of FIG. 3. Advantageously, the thermal storage tanks **105** can be used to store heat energy during the day for use during the night or on cloudy days.

[0033] The thermal storage tanks **105** preferably contain molten salt or any other substance suitable for storing heat including, but not limited to, eutectic salts, brines, and graphite. Each storage tank **105b-105e** also has disposed therein a portion of a pressurized solar loop **1b-1e**. Similar to the pressurized solar loop **1** that heats the molten salt in the heat exchanger **104**, the pressurized solar loops **1b-1e** are utilized to absorb solar energy as thermal energy, transport that thermal energy to a storage tank **105**, and heat the molten salt contained in the storage tank **105**. That is, each of the pressurized solar loops **1b-1e** are connected at one end of the loop to one or more solar collectors and are connected at the other end of the loop to a storage tank **105**. In such a manner, solar

energy can be absorbed during a sunny day, converted to thermal energy, and stored in a storage tank **105** for use during the night or on cloudy days.

[0034] As shown in FIG. 4, a storage media loop **106** travels from the storage media vessel **101** of heat exchanger **104** to the storage tanks **105**. The storage media loop **106** continues from the storage tanks **105** back to the storage media vessel **101**. One or more pumps **108** are present along the storage media loop **106** to pump the molten salt. On cloudy days or during the night, hot molten salt from the storage tanks **105** can be pumped into the storage media vessel **101** of heat exchanger **104** to produce steam in steam generator vessel **102**. As such, the pressurized solar power system **200** can continue to produce electricity even when there is little or no sunlight.

[0035] Returning to FIG. 3, an optional co-generation or combined cycle power generation aspect of the present invention is shown. Specifically, the pressurized solar power systems **100**, **200** described herein may be used in conjunction with conventional power generation systems (such as natural gas or coal fired power generation plants) to supplement the power produced by the pressurized solar power system **100**, **200**. As shown in FIG. 3, hydrocarbon fuel such as natural gas can be used with a conventional gas turbine **112** to power an electrical generator **111**. One or more heat recovery coils **113** can advantageously be used to recover waste heat from the gas turbine **112** to heat water in the pressurized solar loop **1**. Similarly, one or more heat recovery coils **114** may be used to pre-heat the water before it enters the steam generator vessel **102** of heat exchanger **104**.

[0036] Turning to FIG. 5, a third embodiment of a pressurized solar power system **300** is shown. The embodiment shown in FIG. 5 is similar to the embodiment shown in FIG. 3, with like reference numerals indicating like parts between the two embodiments. The pressurized solar power system **300** comprises an array of solar collectors (solar array), a pressurized solar loop **1**, a heat exchanger **104**, a steam turbine **16**, and an electric generator **15**. The heat exchanger **104** comprises a steam generator vessel **102** and a storage media vessel **101** and functions in a manner similar to the heat exchanger **104** of FIG. 3.

[0037] The pressurized solar power system **300** in FIG. 5 is shown operating in conjunction with a geothermal power source or energy **301** and a natural gas source **311**. Hot water, steam, natural gas, and/or other carriers or forms of geothermal substances from the geothermal power source **301** are directed to a separation tank **302** where natural gas can be separated from the hot water generated by the geothermal power source **301**. The natural gas can be directed through a distribution pipe **305** to a natural gas pipeline or natural gas storage tank for suitable use, including as a fuel for a conventional gas turbine for use in combined cycle power operations.

[0038] After separating the natural gas from the hot water inside separation tank **302**, the hot water can be directed through pipe **303** to heat exchanger **104**. There, the hot water can supplement the thermal energy produced by the pressurized solar power system **300**. After the hot water from the geothermal source **301** has released much of its heat in heat exchanger **104**, the water can be injected into the ground through pipe **304**.

[0039] Advantageously, this injection of water into the ground can be used to bring natural gas to the surface from natural gas source **311**. A natural gas well **312** can collect the natural gas and transport it to a separation tank **313**. Any water

mixed with the natural gas can be removed through pipe 314 and injected into the ground through pipe 304. The recovered natural gas can be collected through pipe 305 and used in any suitable manner, including for combined cycle power operations.

[0040] Accordingly, while the invention has been described with reference to the structures and processes disclosed, it is not confined to the details set forth, but is intended to cover such modifications or changes as may fall within the scope of the following claims.

What is claimed is:

- 1. A system for generating energy comprising:
  - a heat exchanger for producing steam;
  - at least one solar collector to generate heat from light;
  - a first pipe containing a heat transfer fluid, a first portion of said first pipe positioned such that the heat from said solar collector may be focused on a portion of said pipe and a second portion of said pipe extending through said heat exchanger to produce steam;
  - a pressurizer attached to said pipe capable of pressurizing the heat transfer fluid contained in said pipe;
  - a geothermal power source;
  - a separation tank connected to said geothermal power source to separate geothermally heated water from other geothermal matter; and
  - a second pipe positioned between said separation tank and a water disposal site and traversing said heat exchanger, said second pipe containing geothermally heated water from said separation tank to heat said heat exchanger.
- 2. The system of claim 1 further comprising:
  - a steam turbine; and
  - an electrical generator;
  - wherein said heat exchanger produces steam from thermal energy stored in said heat transfer fluid in said closed loop pipe and said heated water in said second pipe;
  - wherein said steam drives said steam turbine; and
  - wherein said steam turbine powers said electrical generator to produce electricity.
- 3. The system of claim 1 wherein said heat transfer fluid is water.
- 4. The system of claim 1 wherein said heat exchanger comprises a steam generator vessel partially filled with water, and wherein heat from said closed loop pipe and said second pipe heats the water in said steam generator vessel to produce steam.
- 5. The system of claim 1 wherein said heat exchanger comprises:
  - a non-pressurized storage media vessel containing a thermal storage medium substance; and
  - a pressurized steam generator vessel partially filled with water;
  - wherein heat from said closed loop pipe and said second pipe heats the thermal storage medium substance and wherein said thermal storage medium substance heats said steam generator vessel.
- 6. The system of claim 5 wherein said thermal storage medium substance is a salt.

- 7. The system of claim 6 further comprising:
  - at least one thermal storage tank; and
  - a storage media loop connecting said thermal storage tank to said storage media vessel;
  - wherein said thermal storage medium substance is capable of travelling from said storage tank to said storage media vessel.
- 9. The system of claim 1 further comprising a gas dispersion pipe connected to said separation tank to distribute the geothermal matter separated from the water for suitable use.
- 10. A method for producing pressurized steam comprising the steps of:
  - a) heating a portion of a pressurized closed loop pipe containing a heat transfer fluid using at least one solar collector;
  - b) transporting said heat transfer fluid through said pipe to a heat exchanger;
  - c) obtaining geothermally heated water and any other geothermal substances from a geothermal power source;
  - d) separating geothermally heated water from other geothermal substances in a separation tank;
  - e) transporting said geothermally heated water in a second pipe through said heat exchanger; and
  - f) boiling water in said heat exchanger using the heat contained in said heat transfer fluid in said closed loop pipe and the water in said second pipe to produce steam.
- 11. The method of claim 10, wherein after step c) further comprising the step of:
  - directing the other geothermal substances to a distribution pipeline for suitable use.
- 12. The method of claim 11 further comprising:
  - directing the other geothermal substances comprised of natural gas to a storage facility.
- 13. The method of claim 10 wherein after step e) further comprising the step of:
  - injecting the geothermally heated water from the second pipeline into a ground surface to force additional geothermally heated water and any other geothermal substances to the ground surface for further collection.
- 14. The method of claim 10 wherein said heat transfer fluid is water.
- 15. The method of claim 10 wherein said heat exchanger comprises a steam generator vessel partially filled with water, and wherein heat from said closed loop pipe and said second pipe heats the water in said steam generator vessel to produce steam.
- 16. The method of claim 10 wherein said heat exchanger comprises:
  - a non-pressurized storage media vessel containing a thermal storage medium substance; and
  - a pressurized steam generator vessel partially filled with water;
  - wherein heat from said pipe heats the thermal storage medium substance and wherein said thermal storage medium substance heats said steam generator vessel.
- 17. The method of claim 13 wherein said thermal storage medium substance is a salt.

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