US 20100000214A1

(19) United States
(12) Patent Application Publication
Nagurny et al.
(10) Pub. No.: US 2010/0000214 A1
(43) Pub. Date: Jan. 7, 2010

(54) **PETROLEUM-BASED THERMOELECTRIC ENERGY CONVERSION SYSTEM**

(75) Inventors: **Nicholas J. Nagurny**, Manassas, VA (US); **Natalie Levings**, Palm Beach Gardens, FL (US); **Lance Greer**, Nokesville, VA (US)

Correspondence Address:
Lockheed Martin c/o
DEMONT & BREYER, LLC
100 COMMONS WAY, Ste. 250
HOLMDEL, NJ 07733 (US)

(73) Assignee: **LOCKHEED MARTIN CORPORATION**, Bethesda, MD (US)

(21) Appl. No.: **12/495,943**

(22) Filed: **Jul. 1, 2009**

Related U.S. Application Data

(60) Provisional application No. 61/078,202, filed on Jul. 3, 2008.

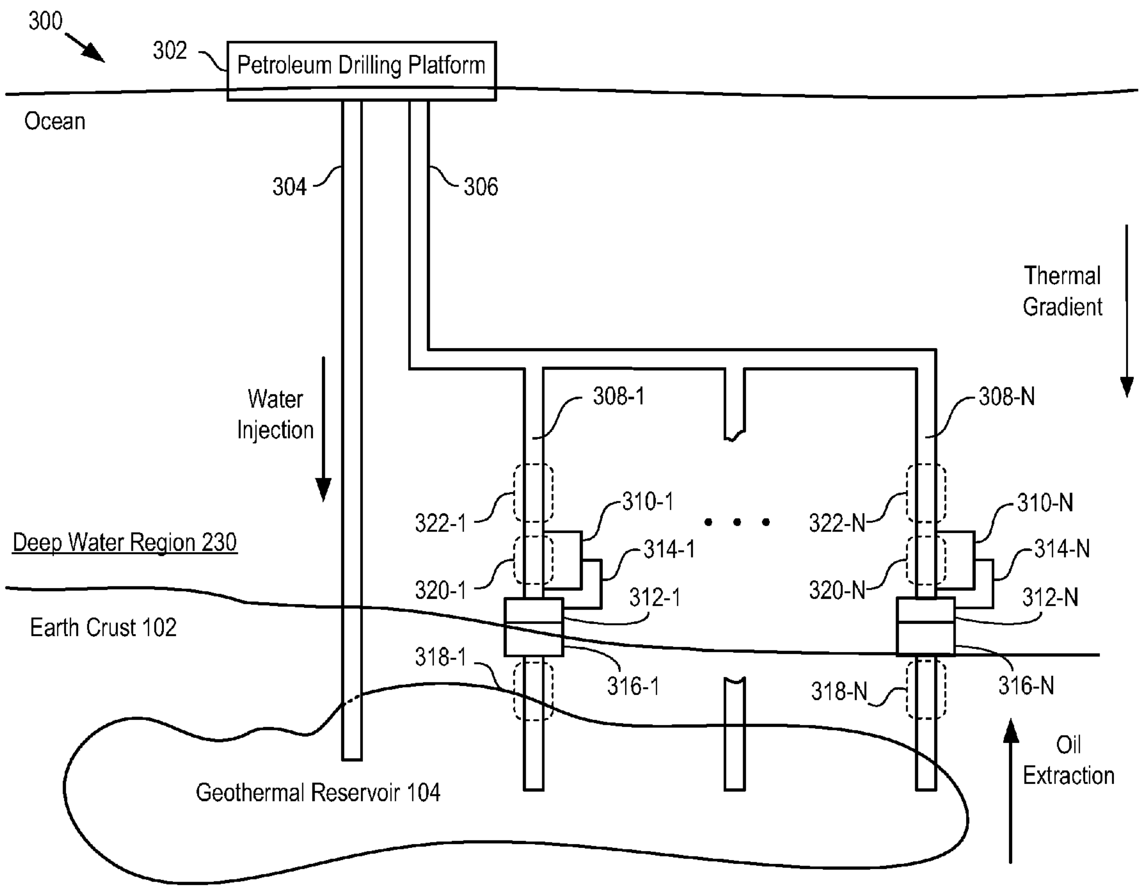
Publication Classification

(51) **Int. Cl.**
F03G 4/00 (2006.01)

(52) **U.S. Cl.** **60/641.2**

(57) **ABSTRACT**

A system for generating electrical energy based on a temperature differential between petroleum products extracted from a geothermal reservoir and water from a region of a body of water is disclosed. Some embodiments comprise a submerged pump and a submerged OTEC system, wherein the OTEC system provides locally generated electrical energy to the pump.



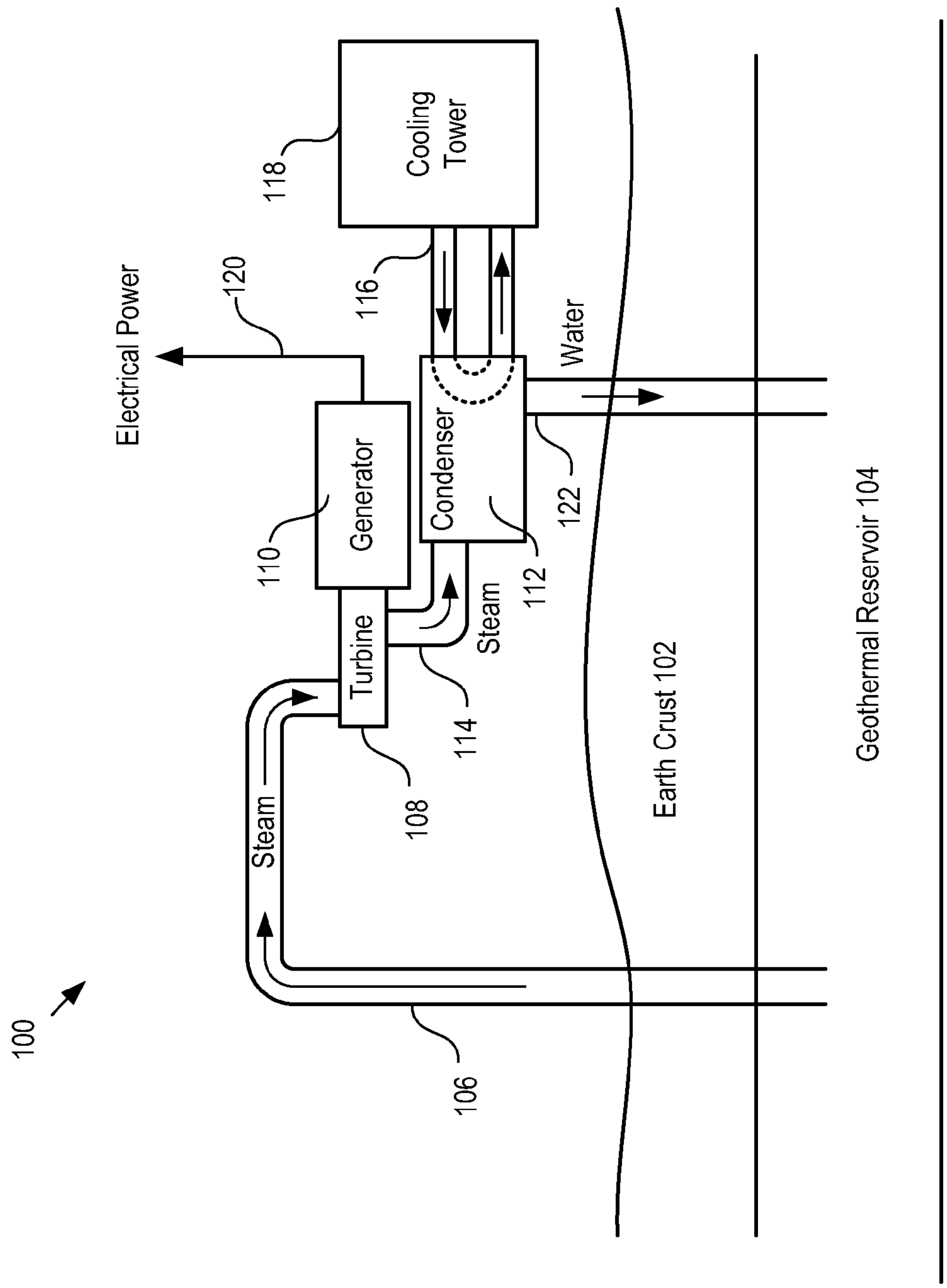


FIG. 1 (Prior Art)

FIG. 2 (Prior Art)

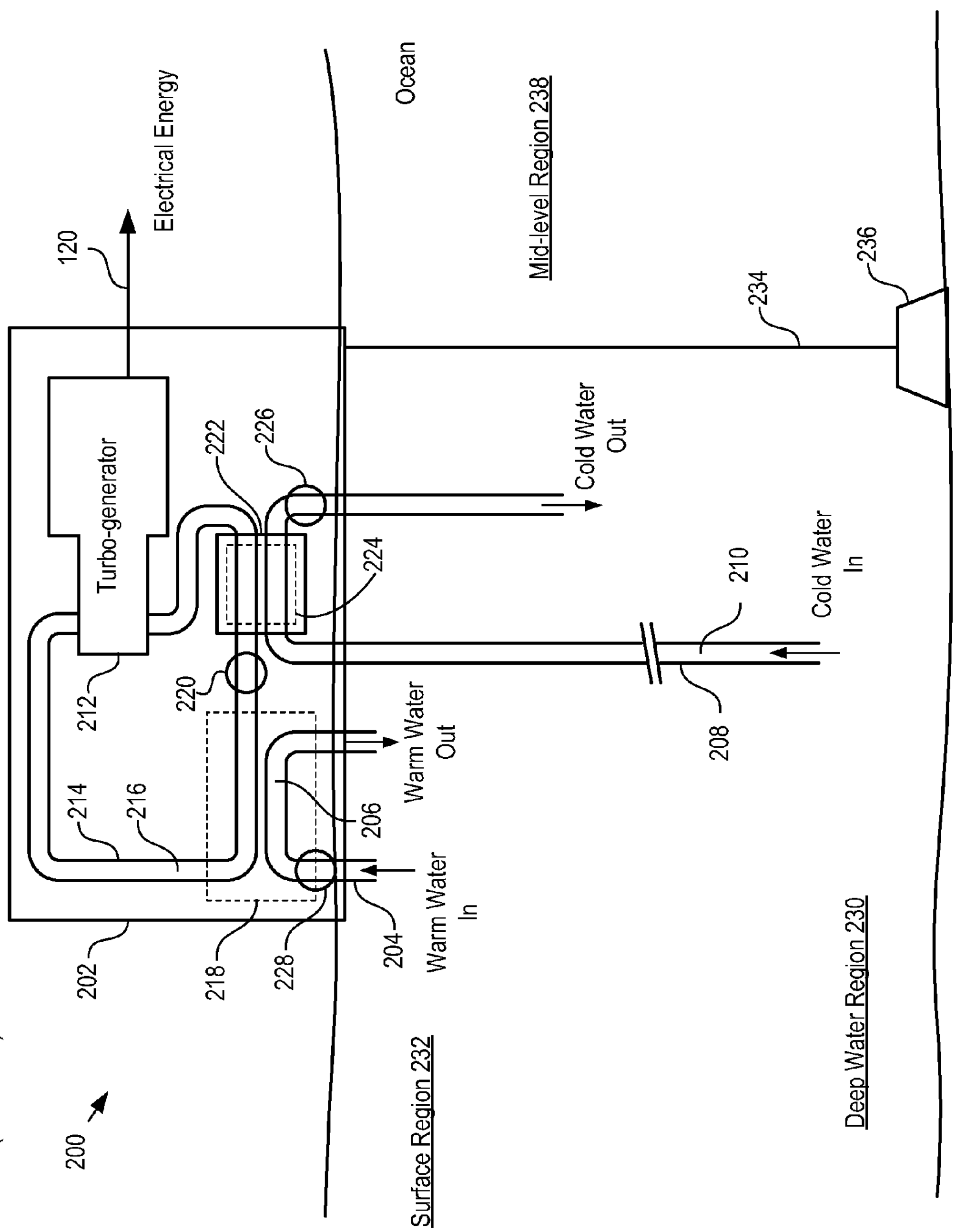
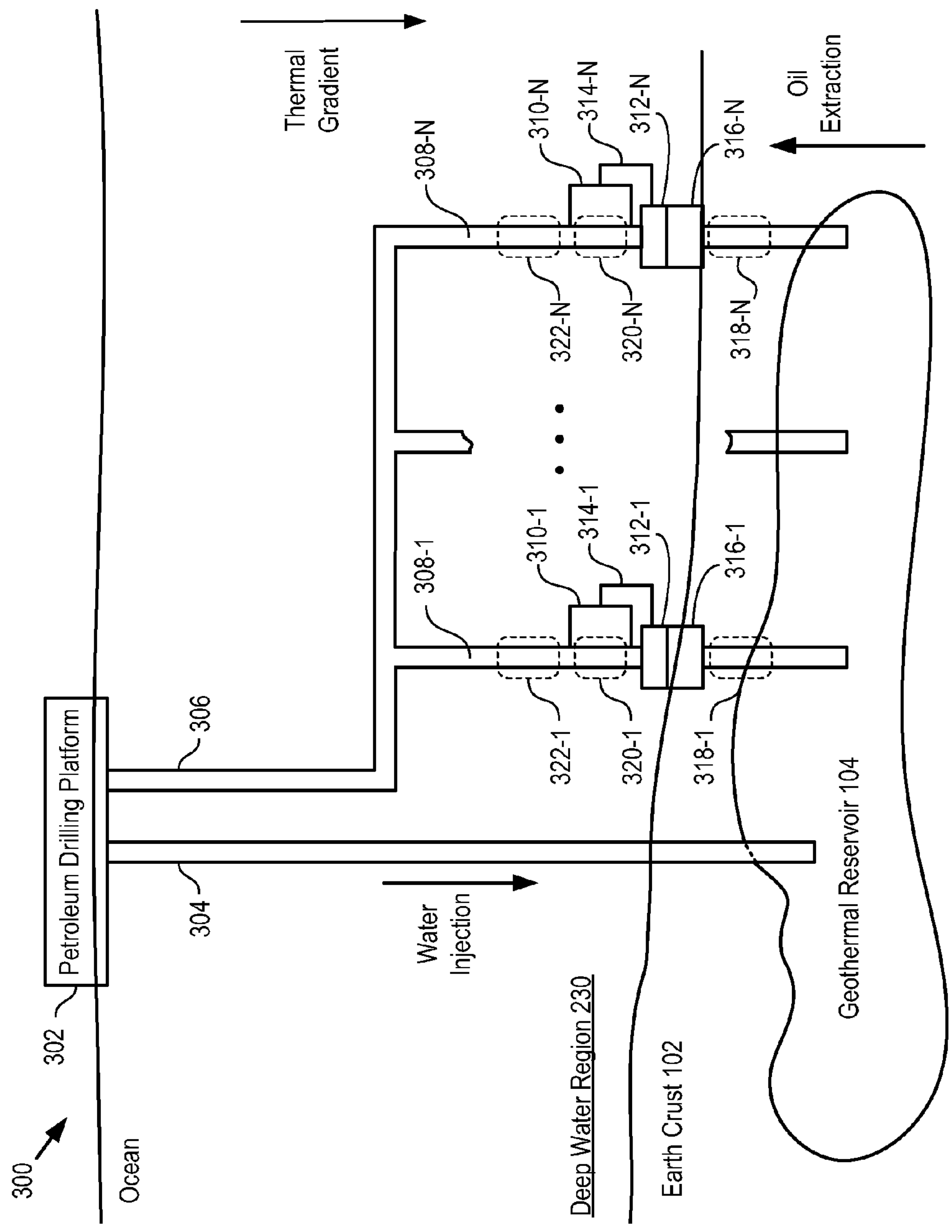


FIG. 3


300
302
Petroleum Drilling Platform
Ocean
304
306
Water Injection
Deep Water Region 230
Earth Crust 102
Geothermal Reservoir 104
308-1
310-1
314-1
312-1
316-1
318-1
320-1
322-1
308-N
310-N
314-N
312-N
316-N
318-N
320-N
322-N
Thermal Gradient
Oil Extraction

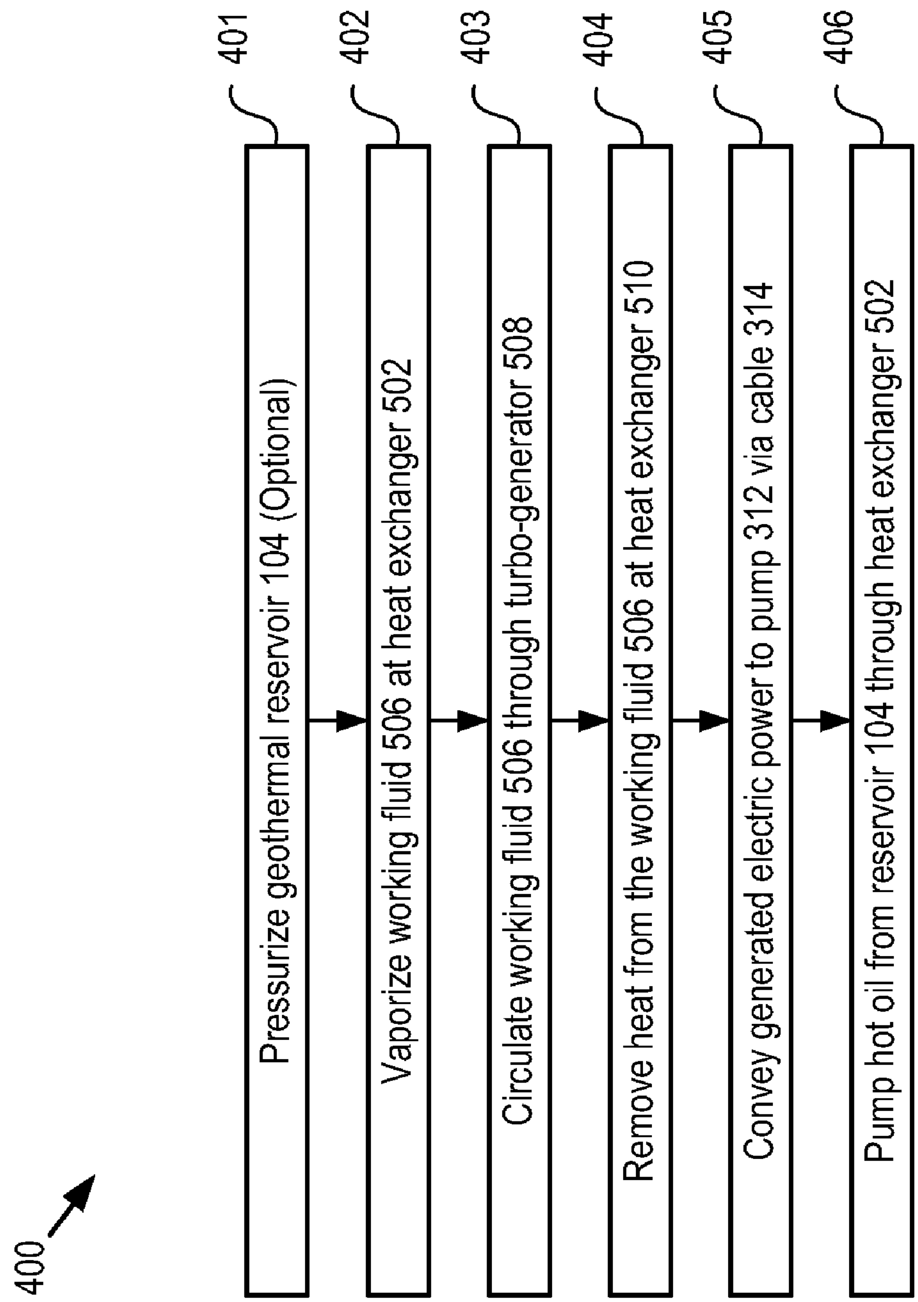

400
401
Pressurize geothermal reservoir 104 (Optional)
402
Vaporize working fluid 506 at heat exchanger 502
403
Circulate working fluid 506 through turbo-generator 508
404
Remove heat from the working fluid 506 at heat exchanger 510
405
Convey generated electric power to pump 312 via cable 314
406
Pump hot oil from reservoir 104 through heat exchanger 502

FIG. 4

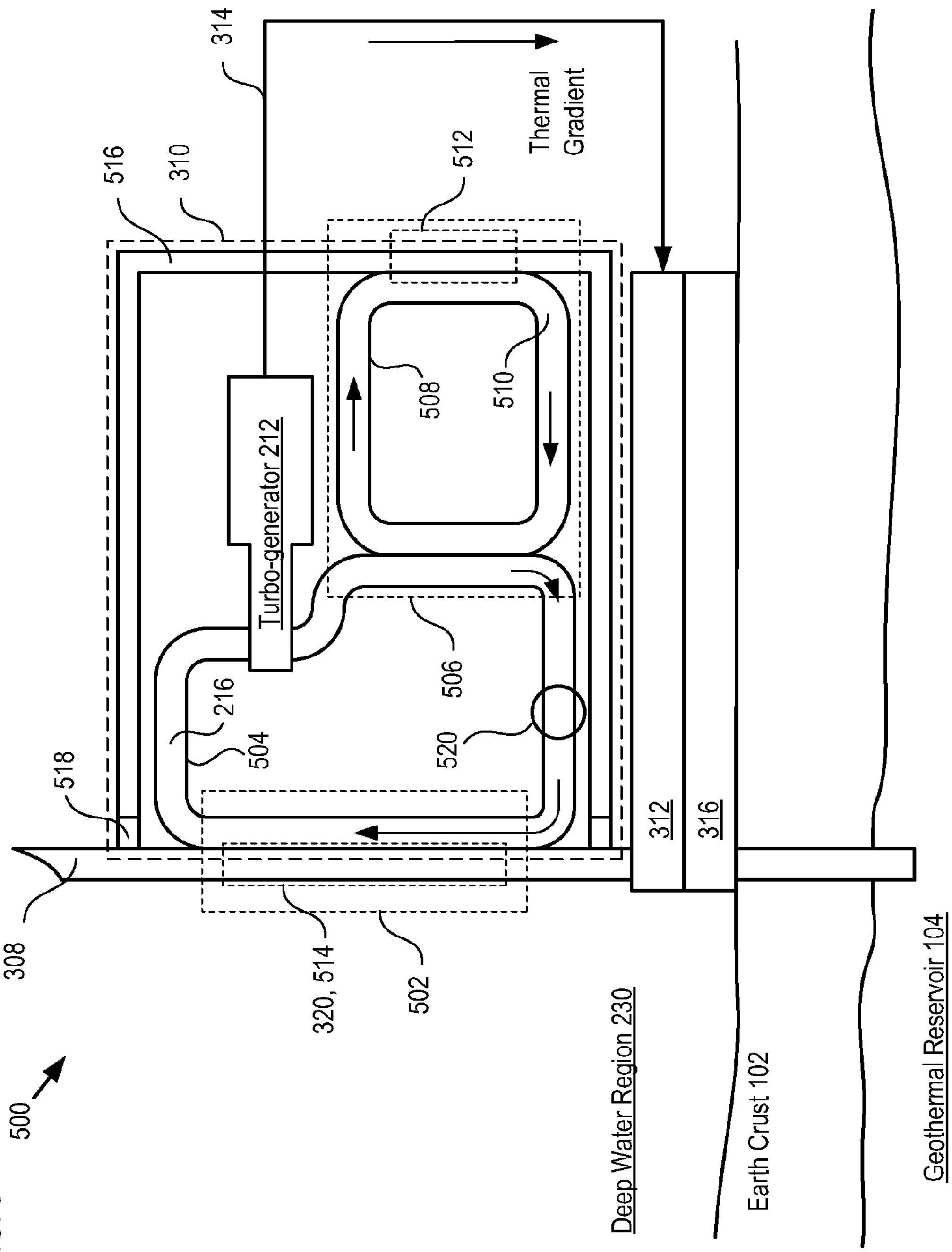

500
308
518
516
310
314
Thermal Gradient
512
508
510
Turbo-generator 212
506
216
504
520
320, 514
502
312
316
Deep Water Region 230
Earth Crust 102
Geothermal Reservoir 104

FIG. 5

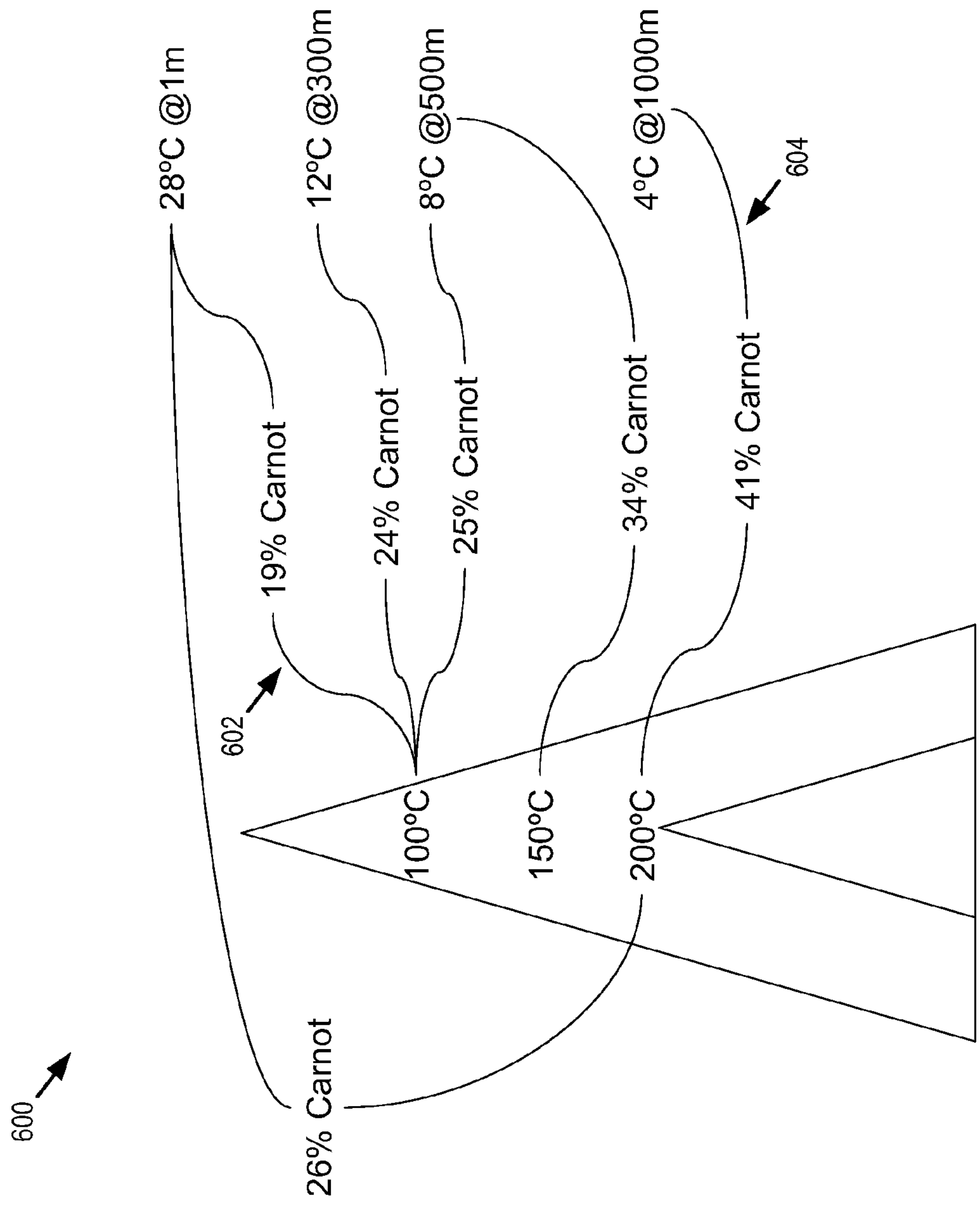

28°C @1m
12°C @300m
8°C @500m
4°C @1000m
604
19% Carnot
24% Carnot
25% Carnot
34% Carnot
41% Carnot
602
100°C
150°C
200°C
600
26% Carnot

FIG. 6

FIG. 7

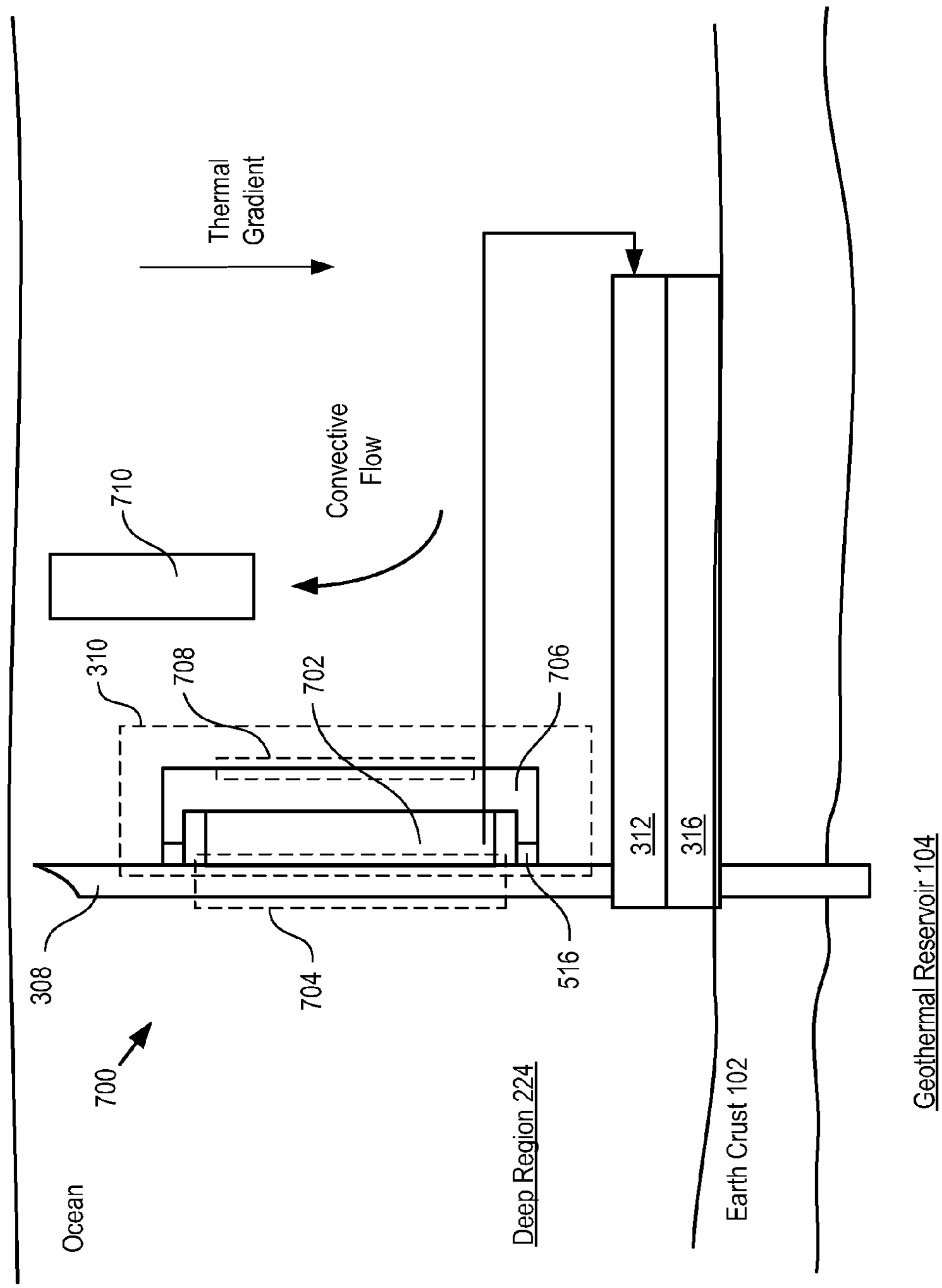
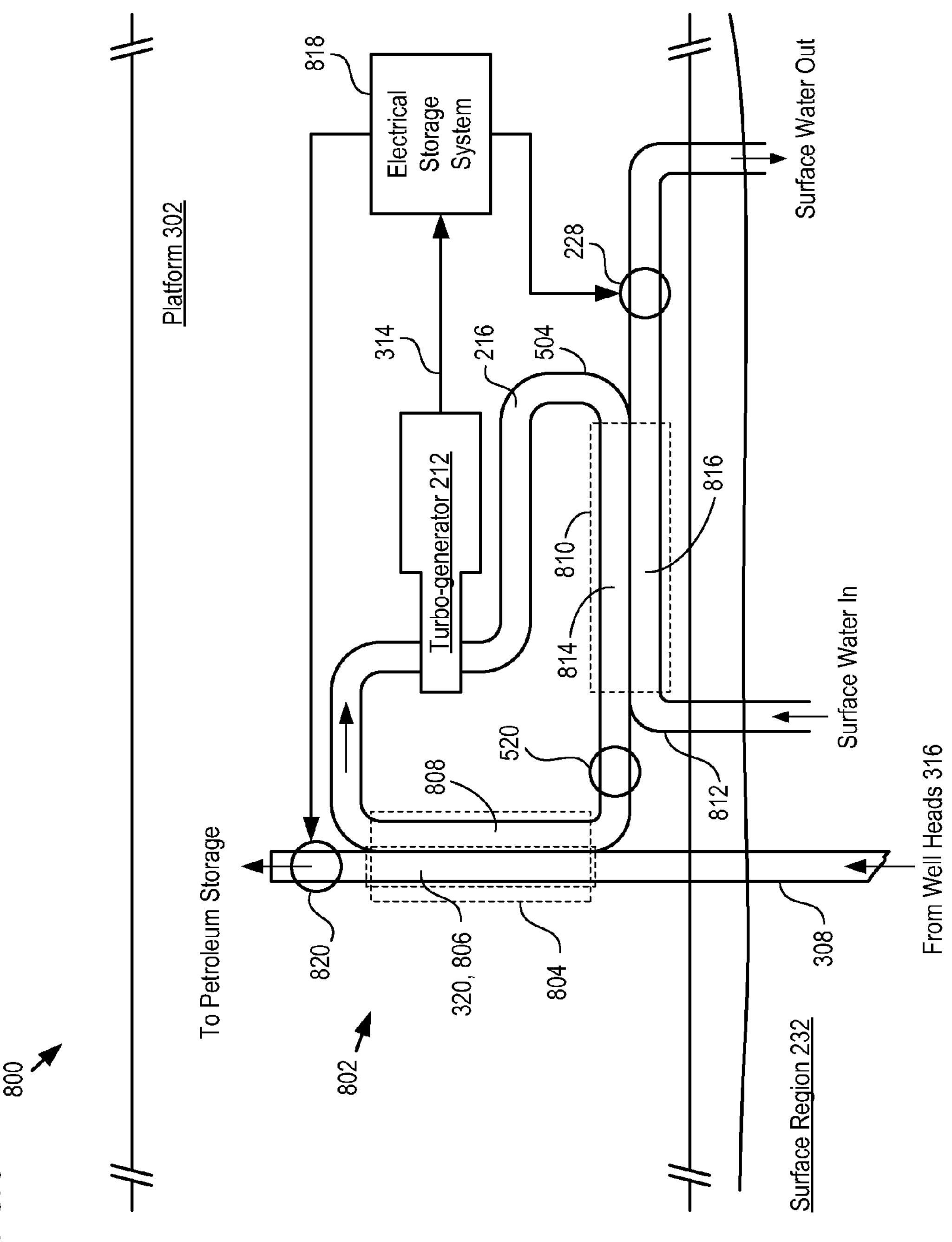

Ocean
700
Deep Region 224
Earth Crust 102
Geothermal Reservoir 104
308
704
516
310
708
702
706
710
312
316
Thermal Gradient
Convective Flow

FIG. 8


800
Platform 302
818
Electrical Storage System
314
Turbo-generator 212
216
504
228
Surface Water Out
810
816
814
Surface Water In
520
808
812
From Well Heads 316
308
To Petroleum Storage
820
320, 806
804
802
Surface Region 232

PETROLEUM-BASED THERMOELECTRIC ENERGY CONVERSION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This case claims priority to: U.S. Provisional Patent Application Ser. No. 61/078,202, filed Jul. 3, 2008 (Attorney Docket: 711-214US), which is incorporated by reference.

[0002] In addition, the underlying concepts, but not necessarily the language, of the following cases are incorporated by reference:

[0003] (1) U.S. patent application Ser. No. 12/396,349, filed Mar. 2, 2009 (Attorney Docket: 711-260US); and

[0004] (2) U.S. patent application Ser. No. 12/411,824, filed Mar. 26, 2009 (Attorney Docket: 711-263US).

[0005] If there are any contradictions or inconsistencies in language between this application and one or more of the cases that have been incorporated by reference that might affect the interpretation of the claims in this case, the claims in this case should be interpreted to be consistent with the language in this case.

FIELD OF THE INVENTION

[0006] The present invention relates to pump systems in general, and, more particularly, to petroleum pumping systems.

BACKGROUND

[0007] As energy concerns grow, the cost-benefit ratio of petroleum exploration in difficult-access regions becomes more favorable. As a result, oil and natural gas exploration and extraction in remote areas is becoming more common.

[0008] A challenge associated with extraction of oil and natural gas in remote areas is powering the drilling and pumping equipment when there is no convenient means of providing electricity. The challenge of powering pumping equipment is exacerbated at deep-sea platforms where the pumps are ideally located at the well-heads themselves—often five or more miles below the ocean surface.

[0009] In some conventional deep-sea platforms, well pumps are located at the floating platform itself, thereby obviating the need to convey electrical energy to the seabed. Unfortunately, pumps located at the platform are less mechanically efficient. As a result, such a pump configuration increases operating costs as well as mechanical complexity.

[0010] In some conventional deep-sea platforms, electrical cables are run from diesel-based electrical generators located at the surface platform to submerged well pumps located on the ocean floor. This configuration has several drawbacks, however. First, diesel-based electrical generators produce CO_2 and assorted other pollutants. Second, these electrical cables are subject to damage from marine life, underwater currents, and stresses induced by weather disturbances. Third, the electrical efficiency of such a system is degraded by the long transmission distance from the surface platform to the sea bed pumps.

[0011] There exists a need, therefore, for a petroleum pumping system that mitigates some or all of the problems associated with the prior art.

SUMMARY OF THE INVENTION

[0012] The present invention provides a geo-thermal energy generation system that generates electrical energy based on a temperature differential between extracted petroleum products and a deep water layer. Some embodiments of the present invention are particularly well-suited for providing local electrical energy to submerged well pumps included in off-shore oil and gas production systems.

[0013] In some embodiments, an energy generation system comprises an energy conversion unit that includes a first heat exchanger, a second heat exchanger, and an energy conversion system for converting a temperature difference into electrical energy. The electrical energy is generated local to well pumps located at the ocean floor. In some embodiments, a closed-loop fluid system thermally couples a conduit carrying hot petroleum products and a hot zone of the first heat exchanger. The second heat exchanger comprises a cold zone that is thermally coupled to water in a deep-water region that acts as a heat sink for the heat exchanger. Preferably, the deep-water region exhibits a high heat capacity and a temperature that is substantially constant regardless of latitude, weather conditions, the annual solar cycle, or even the daily solar cycle. The energy conversion system interposes the first heat exchanger and the second heat exchanger and generates electrical energy based on the temperature differential between the hot zone of the first heat exchanger and the cold zone of the second heat exchanger.

[0014] In some embodiments, the energy conversion system comprises a Rankin-cycle engine that is thermally coupled to the hot petroleum products and the cold water in a deep-water region.

[0015] In some embodiments, the energy conversion system comprises a solid-state thermo-electric element that generates electrical energy by means of the Peltier effect. the energy conversion system comprises a quantum-well thermoelectric element.

[0016] In some embodiments, the energy conversion system removes enough heat from the petroleum products that flow through a conduit thermally coupled to the hot zone that the corrosive nature of the oil and/or natural is sufficiently reduced to obviate the need that the conduit comprises expensive corrosive-resistant materials.

[0017] An embodiment of the present invention comprises an apparatus for pumping petroleum products from a subterranean reservoir comprising: a first pump, wherein the first pump pumps the petroleum products from the subterranean reservoir, and wherein the first pump is physically adapted for operation in deep sea conditions; and a generator comprising a hot zone that is thermally coupled to a subterranean geothermal heat source, a cold zone that is thermally coupled to a first region of a body of water, and an energy conversion system that generates electrical energy based on a temperature differential between the hot zone and the cold zone; wherein the generator provides electrical energy to the first pump.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** depicts a schematic diagram of details of a prior-art geothermal energy conversion system.

[0019] FIG. **2** depicts a schematic diagram of a portion of a representative OTEC power generation system in accordance with the prior art.

[0020] FIG. **3** depicts a schematic diagram of details of a petroleum production system in accordance with an illustrative embodiment of the present invention.

[0021] FIG. **4** depicts a method for pumping petroleum products in accordance with the illustrative embodiment of the present invention.

[0022] FIG. **5** depicts a schematic diagram of details of a self-powered pump system in accordance with the illustrative embodiment of the present invention.

[0023] FIG. **6** depicts calculated efficiencies of energy conversion cycles versus temperature differential for an energy conversion system in accordance with the present invention.

[0024] FIG. **7** depicts a schematic diagram of details of a self-powered pump system in accordance with a first alternative embodiment of the present invention.

[0025] FIG. **8** depicts a schematic diagram of details of a self-powered pump system in accordance with a second alternative embodiment of the present invention.

DETAILED DESCRIPTION

[0026] FIG. **1** depicts a schematic diagram of details of a prior-art geothermal energy conversion system. Energy system **100** comprises inlet pipe **106**, turbine **108**, generator **110**, condenser **112**, couplings **114** and **116**, cooling tower **118**, and outflow pipe **122**. In some embodiments, a water pump is coupled to the outflow of condenser **112** to drive the return water to greater depths or to facilitate flow in a very long or narrow outflow pipe **122**.

[0027] In operation, steam from geothermal reservoir **104**, which resides below earth crust **102**, is conveyed to turbine **108** by inlet pipe **106**. The steam turns turbine blades within the turbine. Turbine **108** is operatively coupled to generator **110**. As turbine **108** turns generator **110**, the generator produces electrical energy. This electrical energy is conveyed to an end user on output cable **120**.

[0028] As the steam passes through turbine **108**, it is conveyed to condenser **112** via coupling **114**. At condenser **112**, the steam is cooled by refrigerant fluid that circulates through coupling **116** to and from cooling tower **118**. The steam then condenses into water within condenser **112**. The condensate is conveyed back to geothermal reservoir **104** via outlet pipe **122**. Cooling tower **118** releases heat by vaporizing water into the atmosphere cooling the refrigerant fluid before it is conveyed to the condenser **112**.

[0029] There are several problems with conventional direct geothermal systems, such as energy system **100**. First, the steam and/or hot water from the geothermal source is highly corrosive, which limits the lifetime of the turbine. Second, atmospheric temperature acts as the heat sink for conventional geothermal systems. The power generation capacity of a conventional geothermal system decreases as the ambient temperature at the turbine increases. This is due to the fact that the power generation is directly related to the temperature differential of the system. To further exacerbate matters, the reduction in power generation capacity tends to occur at times when such power is needed most (e.g., when it is hot out and air conditioning demand increases, etc.) Further, latitude and seasonal temperature variation cause variability in the power generation capability of these systems.

[0030] FIG. **2** depicts a schematic diagram of a portion of a representative OTEC power generation system in accordance with the prior art. OTEC system **200** comprises platform **202**, surface water conduit **204**, deep water conduit **208**, turbogenerator **212**, closed-loop conduit **214**, heat exchanger **218**, pump **220**, and condenser **222**.

[0031] Platform **202** is a conventional floating energy-plant platform. Platform **202** is anchored to the ocean floor by mooring line **234**, which is connected to anchor **236**. Anchor **236** is embedded in the ocean floor. In some instances, platform **202** is not anchored to the ocean floor and platform **202** is allowed to drift. Such a system is sometimes referred to as a "grazing plant." In other cases, platform **202** is a tension-leg platform, which is supported above the ocean floor by means of a plurality of rigid legs.

[0032] Surface water conduit **204** is a large-diameter conduit suitable for conveying relatively warmer water from surface region **232** into heat exchanger **218**. Surface water is pumped through conduit **204** by pump **228**.

[0033] Closed-loop conduit **214** is a closed-circuit loop of conduit that contains working fluid **216**. Ammonia is one commonly used working fluid; however, many other fluids can be suitably used as working fluid **214**.

[0034] Closed-loop conduit **214** and surface water conduit **204** are thermally coupled at heat exchanger **218**. As a result, working fluid **216** (e.g., ammonia) and surface water **206** are thermally coupled at heat exchanger **218**, where the heat of surface water **206** vaporizes working fluid **216**. The expanding vapor drives turbogenerator **212**, which rotates to generate electrical energy, which is provided on output cable **120**.

[0035] After the vaporized working fluid passes through turbogenerator **212**, it enters condenser **222**, which comprises heat exchanger **224**. At heat exchanger **224**, the vaporized working fluid **216** in closed-loop conduit **214** and cold water **210** flowing through deep water conduit **208** are thermally coupled. Cold water **210** is drawn from deep water region **230** by pump **226**. Typically, deep water region **230** is 1000+ meters below the surface of the body of water. Water at this depth is at a substantially constant temperature of a few degrees centigrade.

[0036] Cold water **210** absorbs heat from vaporized working fluid **216** at heat exchanger **224**, thereby cooling working fluid **216** so that it condenses back into its liquid state. Pump **220** recycles the condensed working fluid **216** back into heat exchanger **218** where it is vaporized again to continue the cycle that drives turbogenerator **212**.

[0037] After passing through heat exchanger **224**, cold water **210** is ejected into mid-level region **238** to avoid cooling the surface water near platform **202**.

[0038] Conventional OTEC systems have several drawbacks. First, it is difficult and energy intensive to pump cold water up from depths of 1000+ meters. This challenge is further exacerbated by the fact that cold water is more dense than warm water, which increases the energy required to draw it up to the surface. This significantly increases the cost and reduces the benefits of using an OTEC approach for power generation.

[0039] Second, for an OTEC generation system capable of generating 10's to 100's of megawatts, deep water conduit **208** typically has a diameter within the range of 3-10 meters and a length greater than 1000 meters. Such a conduit is difficult and expensive to manufacture.

[0040] Third, the size and length of deep water conduits makes them susceptible to damage from environmental conditions, such as strong currents, storms, and wave action. As a result, complicated and expensive infrastructure is required to protect these conduits from damage. For example, numerous recent efforts have been made to improve the reliability of cold water conduits. These include the development of flexible conduits, inflatable conduits, rigid conduits made from steel, plastics, and composites, and gimbal-mounted conduits. Even with such proposed innovations, long cold water conduits remain a significant reliability and cost issue.

[0041] The present invention exploits some of the benefits of conventional OTEC systems to power a petroleum pumping facility while avoiding some of the drawbacks of conventional OTEC. Embodiments of the present invention comprise an OTEC power generation system that is submerged in a deep water region of a large body of water (e.g., at the ocean floor) adjacent to a petroleum well head. The OTEC system generates electrical energy based on the temperature differential between a petroleum conduit coupled to the well head and the water in the deep water region. The electrical energy is used locally, at the well head, to power pumps that pump petroleum products to the surface through the conduit.

[0042] Systems in accordance with the present invention can operate with high conversion efficiency due to the high temperature of the petroleum products in the conduit and the stable low temperature of deep-level water. Further, the proximity of the OTEC system and the pump that it powers affords cost and reliability advantages to embodiments of the present invention over prior-art systems.

[0043] FIG. **3** depicts a schematic diagram of details of a petroleum production system in accordance with an illustrative embodiment of the present invention. Production system **300** comprises platform **302**, optional water conduit **304**, petroleum conduit **306**, feeder conduits **308-1** through **308**-N, well-heads **316-1** through **316**-N, energy conversion systems **310-1** through **310**-N, and pumps **312-1** through **312**-N. Production system **300** is described herein as an oil extraction system, although the present invention is equally suitable for extracting natural gas from geothermal reservoir **104**. The number, N, of well-heads **316** that tap into reservoir **104** is based on the size of reservoir **104**, desired production capacity for the pumping system. One skilled in the art, after reading this specification, will be able to determine a suitable number of well-heads for a production system in accordance with the present invention.

[0044] FIG. **4** depicts a method for pumping petroleum products in accordance with the illustrative embodiment of the present invention. Method **400** is described herein with continuing reference to FIG. **3**.

[0045] Method **400** begins with optional operation **401**, wherein pressure in geothermal reservoir **104** in increased by injecting water into the reservoir through water conduit **304**. In response to the injection of water into the reservoir, oil is force upward through regions **318-1** through **318**-N and into regions **320-1** through **320**-N of feeder conduits **308-1** through **308**-N. The hot oil heats the conduit walls in regions **320-1** through **320**-N.

[0046] Each of energy conversion systems **310-1** through **310**-N is a substantially identical OTEC energy conversion system that is coupled to each of feeder conduits **308** near its well-head **316**. A representative energy conversion system **310** is described in detail below, and with respect to FIG. **5**.

[0047] Each of pumps **312-1** through **312**-N is a substantially identical pump **312** that is disposed at one of well-heads **316-1** through **316**-N that are located on the ocean floor. Each pump **312** is adapted for operation in deep-water region **230**. Each pump **312** is powered by electrical energy generated by a corresponding energy conversion system **310**. Each pump **312** and its corresponding energy conversion system **310** collectively define a self-powered petroleum pump system. In some embodiments, one or more energy conversion system **310** is augmented by an alternative power supply, such as a battery system.

[0048] FIG. **5** depicts a schematic diagram of details of a self-powered pump system in accordance with the illustrative embodiment of the present invention. Pump system **500** comprises one energy conversion system **310** and one pump **312**. In some embodiments, pump system **500** comprises one energy conversion system **310** and more than one pump **312**, wherein the energy system provides electrical energy to each of the plurality of pumps.

[0049] Energy conversion system **310** is an OTEC system that comprises heat exchanger **502**, closed-loop conduit **504**, turbogenerator **212**, heat exchanger **506** and pressure hull **516**. Heat exchanger **502**, closed-loop conduit **504**, turbogenerator **212**, and heat exchanger **506** collectively define a Rankine-cycle engine.

[0050] Pressure hull **516** is a shell of structural material with sufficient strength to withstand the pressures that exist at deep water levels. It encloses and protects heat exchanger **502**, closed-loop conduit **504**, turbogenerator **212**, and heat exchanger **506**. Hull **516** is thermally isolated from feeder conduit **308** by thermal isolators **518**. The specific design of hull **516** is based upon the intended application and deployment depth. For example, a pressure hull intended to be deployed at a depth of 1000 meters must be able to withstand water pressure that exceeds **100** atmospheres. In addition, hull **516** comprises an electrical feed-through for cable **314**. In some embodiments, hull **516** also encloses and protects pump **312**. In some embodiments, enclosure of pump **312** within hull **516** enables the pump to operate at depths greater than 1000 meters.

[0051] Heat exchanger **502** comprises hot zone **514** and a portion of closed-loop conduit **504**. Hot zone **514** is region **320** of feeder conduit **308**, which is thermally coupled with closed-loop conduit **504**. As a result, at heat exchanger **502**, working fluid **216** is thermally coupled with geothermal reservoir **104**.

[0052] At operation **402**, heat in the conduit wall of region **320** (i.e., hot zone **514**) vaporizes the working fluid **216** in closed-loop conduit **504**. The vaporized working fluid flows clock-wise through closed-loop conduit **504** to turbogenerator **212**. In some embodiments, a pump is included to induce or enhance circulation of working fluid **216** through conduit **504**.

[0053] At operation **403**, vaporized working fluid **216** circulates through turbogenerator **212** causing it to rotate and generate electrical energy.

[0054] At operation **404**, vaporized working fluid **216** circulates from turbogenerator **212** to heat exchanger **506**, which acts as a condenser. At heat exchanger **506**, working fluid **510** sinks heat from working fluid **216** by virtue of the thermal coupling of closed-loop conduit **504** and cooling conduit **508**. As a result, vaporized working fluid **216** cools and condenses back into its liquid state. The condensed working fluid **216** is then pumped back to heat exchanger **502** by pump **520**. Pump **520** is powered by electrical energy provided by turbogenerator **212** (not shown). In some embodiments, pump **520** comprises an auxiliary power supply, such as a battery system. In some embodiments, convective flow is sufficient to ensure circulation of working fluid **216** through closed-loop conduit **504** and pump **520** is not included.

[0055] Working fluid **510** is thermally coupled with cold zone **512**. As a result, working fluid **510** is thermally coupled with water in deep water region **230**.

[0056] It is an aspect of some embodiments of the present invention that the water at a deep level of an ocean or similar body of water provides a heat sink with sufficient heat capacity to enable it to maintain a substantially constant temperature at all times. It is well-known that ocean temperatures drop with depth. For example, tropical and semi-tropical ocean temperatures at depths of 500, 700, and 1000 meters remain substantially constant at 12, 8, and 4° C., respectively. Deep water levels, therefore, have a heat-sink capability that is well-suited to the present invention.

[0057] FIG. **6** depicts calculated efficiencies of energy conversion cycles versus temperature differential for an energy conversion system in accordance with the present invention. Plot **600** depicts Carnot cycle conversion efficiency for a range of temperature differentials that are based on water depths and geothermal heat source temperatures (i.e., the temperature of petroleum products flowing through regions **320**). As one skilled in the art will recognize, the Carnot cycle represents the most efficient cycle possible for converting a given amount of thermal energy into work.

[0058] Conversion cycle **602** depicts the efficiency for a thermoelectric energy conversion system based on the temperature differential between surface water (i.e., 1 m deep having a temperature of approximately 28° C.) and a relatively cool geothermal source (having a temperature of 100° C.). Although the systems in accordance with the present invention are operable for smaller temperature differentials, in some embodiments of the present invention, the temperature differential for conversion cycle **602** represents the smallest reasonable temperature cycle commonly available using a geothermal heat source. The energy conversion efficiency of conversion cycle **602** is a modest 19% of the Carnot cycle.

[0059] Conversion cycle **604**, on the other hand, represents the largest temperature cycle commonly available using a geothermal heat source. Conversion cycle **604** is based on the temperature difference between water at 1000 m depth (having a temperature of approximately 6° C.) and a hot geothermal source (having a temperature of approximately 200° C.), the energy conversion efficiency is approximately 61% of the Carnot cycle. Conversion cycle **604**, therefore, is characterized by a conversion efficiency that is 22% greater than that of conversion cycle **602**. This represents an efficiency improvement of more than 100%.

[0060] In some embodiments, sufficient heat is removed from the petroleum products flowing through region **320** (by virtue of working fluids **216** and **510**) to significantly decrease its temperature. In some embodiments, enough heat is removed that the temperature of the petroleum products in region **322** is lower than the temperature of the petroleum products in region **318** by 100° C. or more. This dramatic reduction in temperature can reduce the corrosive nature of the material in conduits **308** and **306** such that at least a portion of these conduits can be made from substantially conventional materials. As a result, the expense and complexity of conduits comprising specialized materials such as duplex stainless-steel, corrosion-resistant alloys, and the like is avoided.

[0061] In addition to reducing the temperature of the oil flowing through region **320**, the dissipation of heat from the working fluid at heat exchanger **506** serves to enhance the circulation of the working fluid through closed-loop conduit **504**. In some embodiments, this circulation is sufficient to obviate the need for pump **520**.

[0062] At operation **405**, electrical energy generated by turbogenerator **212** is conveyed to pump **312** on cable **314**. Since energy conversion system **310** and pump **312** are located in close proximity to one another, embodiments of the present invention do not incur the power loss that typically occurs in long cables used to convey electrical energy between the ocean surface and deep water region **230**. In addition, kilometer+ lengths of electrical cable, adapted for use in ocean environments, are not required. This further reduces the cost and complexity of embodiments of the present invention as compared to prior-art systems.

[0063] At operation **406**, pumps **312** pump hot oil from geothermal reservoir **104** into feeder conduits **308** and petroleum conduit **306**.

[0064] FIG. **7** depicts a schematic diagram of details of a self-powered pump system in accordance with a first alternative embodiment of the present invention. Pump system **700** comprises thermo-electric element **702**, hot zone **704**, pressure hull **706**, cold zone **708**, and chimney **710**.

[0065] Thermo-electric element **702** comprises a bismuth-telluride alloy that generates an open-circuit voltage in response to a thermal gradient placed across it. Commercial examples of thermo-electric element **702** include HZ modules available from Hi-Z Technology, Inc.

[0066] In some embodiments, thermo-electric element **702** is a solid-state element that generates electrical energy by means of the Peltier effect.

[0067] Hot zone **704** and cold zone **708** are analogous to hot zone **514** and cold zone **512**, as described above and with respect to FIG. **5**. Cold zone **708** comprises a portion of pressure hull **706**, which is analogous to pressure hull **516**.

[0068] In some embodiments, convective flow of cold water across cold zone **708** is constrained by chimney **710**, thereby facilitating heat flow between the heat exchanger and seawater. The length of the chimney **710** would be designed to account for the temperature difference between the convecting seawater as it passes by cold zone **708** and the depth of the average thermocline at that temperature. The heat sink included in cold zone **708** would be designed to exhibit less head loss than the pressure difference (inside and outside) at the bottom of the chimney **710**, minus the fluid drag up the chimney **710**. In some embodiments, chimney **710** is not used since the rate at which the convective flow of cold water flows across cold zone **708** is sufficient to ensure that the ambient temperature of the water in the local area of cold zone **708** does not substantially increase during operation of thermo-electric generator **700**.

[0069] FIG. **8** depicts a schematic diagram of details of a self-powered pump system in accordance with a second alternative embodiment of the present invention. Pump system **800** comprises platform **302**, energy conversion system **802**, and electrical energy storage system **818**. Energy conversion system **802** and electrical energy storage system **818** are located on platform **302**.

[0070] Energy conversion system **802** is analogous to energy conversion systems **310**; however, energy conversion system **802** is located at the surface of the body of water. Because of the high temperature difference between the petroleum products and the temperature of the surface water, energy conversion system **802** can operate effectively without adaptation for deep-level operation. As depicted in FIG. **6**, conversion efficiency as high as 19% can be achieved using surface water at a temperature of approximately 28° C. The operation of energy conversion system **802** is analogous to the operation of energy conversion system **310**, described above, as well as that described in detail in U.S. patent application Ser. No. 12/411,824, which is incorporated herein by reference.

[0071] Heat exchanger **804** portion **808** of closed-loop conduit **504** comprises and hot zone **806**. Hot zone **806** is region **320** of feeder conduit **308**, which is thermally coupled with closed-loop conduit **504**. As a result, at heat exchanger **804**, working fluid **216** in portion **808** is thermally coupled with hot petroleum product pumped from geothermal reservoir **104**.

[0072] Heat exchanger **810** comprises portion **814** of closed-loop conduit **504** and cold zone **816**. Cold zone **816** is a region of surface water conduit **812**, which is thermally coupled with portion **814**. As a result, at heat exchanger **810**, working fluid **216** in portion **814** is thermally coupled with cold surface water pumped from surface region **232**. The cold surface water in surface water conduit **812** sinks sufficient heat from working fluid **216** at heat exchanger **810** to condense vaporized working fluid into its liquid state.

[0073] Surface water conduit **812** is analogous to surface water conduit **204** described above and with respect to FIG. **2**. Surface water conduit **812**, however, draws surface water from region **818** and ejects it to region **820**, which is located far enough away from region **818** that the water drawn by surface water conduit **204** remains cool enough to condense working fluid **216** at heat exchanger **810**.

[0074] Electrical energy generated by energy conversion system **802** is provided to electrical storage system **818**. In some embodiments, electrical energy storage system provides the energy that drives pump **820**, which pumps petroleum products from well heads **316** to one or more petroleum storage tanks or oil tankers. In some embodiments, the electrical energy generated by energy conversion system **802** is used to power some or all of the facilities located on platform **302**.

[0075] By virtue of its use of water from surface region **232** in its condenser (i.e., heat exchanger **810**), system **800** obviates the need for an expensive deep water conduit, such as conduit **280**, described above and with respect to FIG. **2**. As a result, system **800** can provide electrical energy without some of the expense and complexity of prior-art OTEC systems. In addition, since system **800** comprises a petroleum pump located on platform **302**, pump **820** is powered locally and system **800** derives some or all of the advantages of a locally powered submerged self-powered petroleum pump. Further, energy conversion system **802** enables local power for other facility infrastructure in addition to, or instead of, pump **820**.

[0076] It is to be understood that the disclosure teaches just one example of the illustrative embodiment and that many variations of the invention can easily be devised by those skilled in the art after reading this disclosure and that the scope of the present invention is to be determined by the following claims.

What is claimed is:

1. An apparatus comprising:

a first conduit, wherein the first conduit conveys a petroleum product from a geothermal reservoir through a first conduit region; and

an energy conversion system that generates electrical energy based on a first temperature differential between the first conduit region and water from a first region of a body of water.

2. The apparatus of claim **1** wherein the energy conversion system further comprises:

a hot zone that comprises the first conduit region, wherein the first conduit region is thermally coupled to the petroleum product; and

a cold zone that is thermally coupled to the water from the first region of the body of water;

wherein the temperature of the hot zone and the temperature of the cold zone define a second temperature differential that is based on the first temperature differential, and wherein the energy conversion system is thermally coupled to the hot zone and the cold zone; and further wherein the energy conversion system generates electrical energy based on the second temperature differential.

3. The apparatus of claim **1** wherein the apparatus further comprises a pump that pumps the petroleum product from the subterranean reservoir through the first conduit region, and wherein the energy conversion system provides electrical energy to the pump.

4. The apparatus of claim **3** wherein the pump is physically adapted for operation in a deep sea environment.

5. The apparatus of claim **1** wherein the first conduit comprises a second conduit region that is duplex stainless-steel-free.

6. The apparatus of claim **1** wherein the first conduit comprises a second conduit region that is corrosion-resistant alloy-free.

7. The apparatus of claim **1** wherein the first conduit further comprises a second conduit region and a third conduit region, and wherein the first conduit region interposes the second conduit region and the third conduit region, and further wherein the energy conversion system sinks heat from the first conduit region such that the temperature of the petroleum products in the third conduit region is at least 100° C. lower than the temperature of the petroleum products in the second conduit region.

8. The apparatus of claim **1** wherein the energy conversion system comprises a Rankine-cycle engine.

9. The apparatus of claim **1** wherein the energy conversion system comprises a solid-state thermo-electric element.

10. The apparatus of claim **9** wherein the thermo-electric element generates electrical energy by means of the Peltier effect.

11. The apparatus of claim **9** wherein the thermo-electric element comprises a quantum-well energy conversion system.

12. An apparatus comprising an energy conversion system that generates electrical energy based on a temperature differential between a first conduit region and water from a first region of a body of water, wherein the first conduit region is thermally coupled to a petroleum product from a geothermal reservoir, and wherein the petroleum product is cooled by at least 100° C. as it traverses the first conduit region.

13. The apparatus of claim **12** further comprising a pump for pumping the petroleum product, wherein the energy conversion system provides electrical energy to the pump.

14. The apparatus of claim **13** wherein the pump is physically adapted for operation in a deep sea environment.

15. The apparatus of claim **12** wherein the energy conversion system comprises a Rankine-cycle engine.

16. The apparatus of claim **12** wherein the energy conversion system comprises a solid-state thermo-electric element.

17. A method comprising:
- conveying a petroleum product from a subterranean reservoir through a first conduit region of a first conduit;
- thermally coupling the first conduit region and the petroleum product;
- thermally coupling the first conduit region and an energy conversion system;
- thermally coupling water from a first region of a body of water to the energy conversion system; and
- generating electrical energy based on a temperature differential between the first conduit region and the water.

18. The method of claim **17** further comprising:
- conveying the petroleum product through the first conduit region from a second conduit region of the first conduit to a third conduit region of the first conduit; and
- removing heat from the petroleum product in the first conduit region such that the temperature of the petroleum product is at least 100° C. lower in the third conduit region than in the first conduit region.

19. The method of claim **17** further comprising providing the generated electrical energy to a pump, wherein the pump pumps the petroleum product through the first conduit.

20. The method of claim **19** further comprising providing the pump, wherein the pump is physically adapted for operation in a deep-sea environment.

21. The method of claim **17** wherein the electrical energy is generated by a Rankine-cycle engine that is thermally coupled to a hot zone and a cold zone, and wherein the hot zone comprises the first conduit region, and further wherein the cold zone is thermally coupled to the water.

22. The method of claim **17** wherein the electrical energy is generated by a solid-state thermo-electric device that is thermally coupled to a hot zone and a cold zone, and wherein the hot zone comprises the first conduit region, and further wherein the cold zone is thermally coupled to the water.

* * * * *