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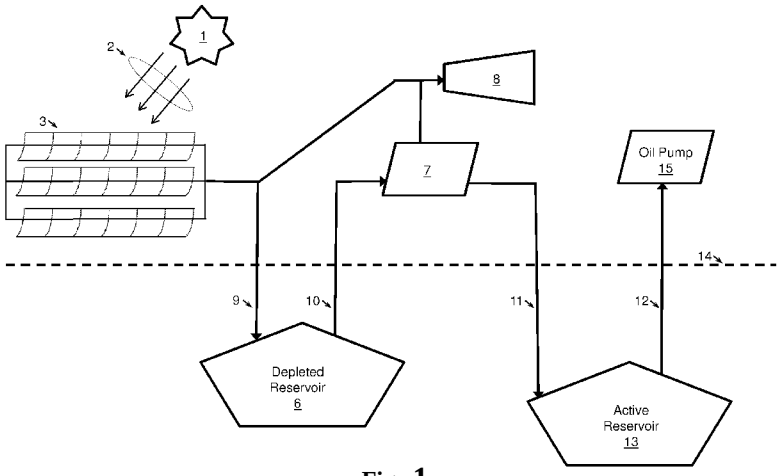

Fig. 1

(57) Abstract: Techniques for subsurface thermal energy storage of heat generated by concentrating solar power enable smoothing of available energy with respect to daily and/or seasonal variation. Solar thermal collectors produce saturated steam that is injected into a producing or wholly/partially depleted oil reservoir that operates as a heat storage reservoir. Some of the saturated steam generated by the collectors is optionally used to generate electricity. Heat is withdrawn from the reservoir as saturated steam and is used to operate an active thermal recovery project (such as a producing thermally enhanced oil reservoir) and/or to generate electricity. Withdrawn heat is optionally augmented by heat produced by firing natural gas. The reservoir is optionally one that has been used for thermally enhanced oil recovery and thus is already warm, minimizing heat losses.

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SUBSURFACE THERMAL ENERGY STORAGE OF HEAT GENERATED BY CONCENTRATING SOLAR POWER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Priority benefit claims for this application are made in the accompanying Application Data Sheet, Request, or Transmittal (as appropriate, if any). To the extent permitted by the type of the instant application, this application incorporates by reference for all purposes the following applications, all commonly owned with the instant application at the time the invention was made:

U.S. Provisional Application (Docket No. 310618-2001 and Serial No. 61/149,292), filed 02/02/2009, first named inventor Rod MacGregor, and entitled **Concentrating Solar Power with Glasshouses;**

U.S. Provisional Application (Docket No. CLEN-002/00US 310618-2002 and Serial No. 61/176,041), filed 05/06/2009, first named inventor Peter Von Behrens, and entitled **Concentrating PhotoVoltaics with Glasshouses;**

PCT Application (Docket No. GP-09-01PCT and Serial No. PCT/US 10/22780), filed 02/01/2010, first named inventor Roderick MacGregor, and entitled **Concentrating Solar Power with Glasshouses;**

U.S. Provisional Application (Docket No. GP-10-02 and Serial No. 61/361,509), filed 07/05/2010, first named inventor Peter Von Behrens, and entitled **Concentrating Solar Power with Glasshouses;**

U.S. Provisional Application (Docket No. GP-10-04 and Serial No. 61/361,512), filed 07/05/2010, first named inventor John Setel O'Donnell, and entitled **Direct Solar Oilfield Steam Generation;**

U.S. Provisional Application (Docket No. GP-10-04A and Serial No. 61/445,545), filed 2/23/201 1, first named inventor John Setel O'Donnell, and entitled **Direct Solar Oilfield Steam Generation;**

U.S. Provisional Application (Docket No. GP-10-07 and Serial No. 61/361,506), filed 07/05/2010, first named inventor Anthony Robert Kovscek, and entitled **Subsurface Thermal Energy Storage of Heat Generated by Concentrating Solar Power;**

PCT Application (Docket No. GP-10-02PCT and Serial No. PCT/USll/42891), filed 07/02/201 1, first named inventor Peter Von Behrens, and entitled **Concentrating Solar Power with Glasshouses;** and

PCT Application (Docket No. GP-10-04APCT and Serial No. PCT/US 11/42906), filed 07/03/201 1, first named inventor John Setel O'Donnell, and entitled **Direct Solar Oilfield Steam Generation.**

BACKGROUND

[0002] Field: Advancements in energy storage of heat generated by concentrating/collecting solar power are needed to provide improvements in performance, efficiency, and utility of use.

[0003] Related Art: Unless expressly identified as being publicly or well known, mention herein of techniques and concepts, including for context, definitions, or comparison purposes, should not be construed as an admission that such techniques and concepts are previously publicly known or otherwise part of the prior art. All references cited herein (if any), including patents, patent applications, and publications, are hereby incorporated by reference in their entireties, whether specifically incorporated or not, for all purposes.

SYNOPSIS

[0004] The invention may be implemented in numerous ways, including as a process, an article of manufacture, an apparatus, a system, and a composition of matter. In this specification, these implementations, or any other form that the invention may take, may be referred to as techniques. The Detailed Description provides an exposition of one or more embodiments of the invention that enable improvements in performance, efficiency, and utility of use in the field identified above. The Detailed Description includes an Introduction to facilitate the more rapid understanding of the remainder of the Detailed Description. As is discussed in more detail in the Conclusions, the invention encompasses all possible modifications and variations within the scope of the issued claims.

Brief Description of Drawings

[0005] Fig. 1 illustrates an overview of an embodiment of a subsurface storage system for thermal energy.

DETAILED DESCRIPTION

[0006] A detailed description of one or more embodiments of the invention is provided below along with accompanying figures illustrating selected details of the invention. The invention is described in connection with the embodiments. The embodiments herein are understood to be merely exemplary, the invention is expressly not limited to or by any or all of the embodiments herein, and the invention encompasses numerous alternatives, modifications, and equivalents. To avoid monotony in the exposition, a variety of word labels (including but not limited to: first, last, certain, various, further, other, particular, select, some, and notable) may be applied to separate sets of embodiments; as used herein such labels are expressly not meant to convey quality, or any form of preference or prejudice, but merely to conveniently distinguish among the separate sets. The order of some operations of disclosed processes is alterable within the scope of the invention. Wherever multiple embodiments serve to describe variations in process, method, and/or features, other embodiments are contemplated that in accordance with a predetermined or a dynamically determined criterion perform static and/or dynamic selection of one of a plurality of modes of operation corresponding respectively to a plurality of the multiple embodiments. Numerous specific details are set forth in the following description to provide a thorough understanding of the invention. The details are provided for the purpose of example and the invention may be practiced according to the claims without some or all of the details. For the purpose of clarity, technical material that is known in the technical fields related to the invention has not been described in detail so that the invention is not unnecessarily obscured.

INTRODUCTION

[0007] This introduction is included only to facilitate the more rapid understanding of the Detailed Description; the invention is not limited to the concepts presented in the introduction (including explicit examples, if any), as the paragraphs of any introduction are necessarily an abridged view of the entire subject and are not meant to be an exhaustive or restrictive description. For example, the introduction that follows provides overview information limited by space and organization to only certain embodiments. There are many other embodiments, including those to which claims will ultimately be drawn, discussed throughout the balance of the specification.

[0008] Subsurface thermal energy storage of heat energy generated by concentrating and/or collecting solar power uses subsurface pore volume in producing, depleting, or depleted oil fields for large volume storage of heat generated by concentrating solar collectors. Fluid for transfer of heat energy from the surface to an underground storage volume (such as a depleted oil field) is saturated steam. Heat energy is injected or removed from a reservoir using wells. Injection and production wells, a reservoir, and any ancillary equipment for heat transfer are referred to as the energy storage system.

[0009] In some embodiments and/or usage scenarios, a subsurface storage system replaces, or greatly reduces, a size of an above ground thermal storage (such as implemented with insulated tanks using molten salts as an energy storage medium).

SUBSURFACE THERMAL ENERGY STORAGE OF HEAT GENERATED BY CONCENTRATING AND/OR COLLECTING SOLAR POWER

[0010] Concentrating and/or collecting solar power produces ample amounts of thermal energy but is intermittent throughout the course of a 24-hour day as well as a year. An effective thermal energy system would provide energy storage for daily as well as seasonal usage. Various embodiments of subsurface storage systems are characterized by one or more of: providing short and/or long term storage, not using heat transfer fluids engineered for purpose in each particular storage system, permitting a heat transfer fluid to flow from a reservoir to the surface with minimal load (e.g., without introduction of a parasitic load), and having minimal or reduced heat loss to surrounding subsurface strata (such as strata that are relatively cool).

[0011] Selection, design, execution, and management of a subsurface thermal energy storage system is based on saturated steam as a heat transfer fluid and is further based on selection of large subsurface reservoirs where the reservoir thickness and volume minimize heat loss from the reservoir to surrounding subsurface strata. The design of solar collectors is generally independent of the subsurface thermal energy storage system. The system operates with current collectors such as parabolic troughs, compact linear Fresnel reflectors, power towers, and so on, and is envisioned to operate with future collectors also.

[0012] Fig. 1 illustrates an overview of an embodiment of a subsurface storage system for thermal energy. When illuminated by light **2** from sun **1,** a battery of solar thermal collectors

3 produces (directly or indirectly) saturated steam at a suitable pressure for injection via steam distribution lines **9** into storage reservoir **6.** There is no need for further pressurization. Storage reservoir **6** is a depleted oil reservoir that has been subjected to thermally enhanced oil recovery and so already has steam distribution lines **9** and wellhead **10** in place and is already warmed, thereby minimizing heating of cold formation and heat losses to overburden and underburden. Steam injection raises temperature and pressure of the storage reservoir. In various embodiments, storage of thermal energy smoothes daily variations of available energy, seasonal variations of available energy, or both. Relatively large amounts of thermal energy are storable in a storage reservoir, in some embodiments. In some usage scenarios, stored thermal energy enables continuous energy delivery, such as at a relatively constant rate, or at varying rates. In some usage scenarios, stored thermal energy enables intermittent or non-smooth energy delivery and/or withdrawal, for example in a context of time-of-day energy costs.

[0013] Heat is withdrawn from storage reservoir **6** as saturated steam by establishing a wellhead pressure that is suitable for steam to flow to the surface. Additional energy is enabled to be withdrawn by pumping fluid out of the reservoir using appropriate geothermal and oil field technology 7. Produced saturated steam is optionally injected directly into a producing thermally enhanced oil reservoir **13** through existing steam distribution lines **11** if the pressure and temperature of the steam enable the direct injection. Higher temperature and pressure steam (and/or backup generation of steam) are also enabled by using a natural gas fired boiler within oil field technology 7 to adjust steam conditions to meet specifications. Saturated steam produced by solar thermal collectors **3** and/or withdrawn from storage reservoir **6** is optionally used by industrial process 8, such as (i) to generate electricity that is then distributed for sale via an electrical power distribution grid or (ii) as process heat (for oil field separations, for example).

[0014] Reservoir minerals and other solids are appreciably soluble in hot water and, in some usage scenarios, deposit on wellbore equipment and tubulars as liquid moves up the wellbore and flashes to steam at lower pressure. Formation of scale on wellbore equipment is mitigated with chemical inhibitors applied to a production well as is done commonly in the geothermal energy industry.

[0015] Storage reservoir **6** and active reservoir **13** are below ground level geological **14** structures. Oil is extracted from active reservoir by standard enhanced oil recovery well head equipment **15** through well **12.**

CONCLUSION

[0016] Certain choices have been made in the description merely for convenience in preparing the text and drawings and unless there is an indication to the contrary the choices should not be construed per se as conveying additional information regarding structure or operation of the embodiments described. Examples of the choices include: the particular organization or assignment of the designations used for the figure numbering and the particular organization or assignment of the element identifiers (the callouts or numerical designators, e.g.) used to identify and reference the features and elements of the embodiments.

[0017] The words "includes" or "including" are specifically intended to be construed as abstractions describing logical sets of open-ended scope and are not meant to convey physical containment unless explicitly followed by the word "within."

[0018] Although the foregoing embodiments have been described in some detail for purposes of clarity of description and understanding, the invention is not limited to the details provided. There are many embodiments of the invention. The disclosed embodiments are exemplary and not restrictive.

[0019] It will be understood that many variations in construction, arrangement, and use are possible, consistent with the description, and are within the scope of the claims of the issued patent. The names given to elements are merely exemplary, and should not be construed as limiting the concepts described. Also, unless specifically stated to the contrary, value ranges specified, maximum and minimum values used, or other particular specifications, are merely those of the described embodiments, are expected to track improvements and changes in implementation technology, and should not be construed as limitations.

[0020] Functionally equivalent techniques known in the art are employable instead of those described to implement various components, sub-systems, operations, functions, or portions thereof.

[0021] The embodiments have been described with detail and environmental context well beyond that required for a minimal implementation of many aspects of the embodiments described. Those of ordinary skill in the art will recognize that some embodiments omit disclosed components or features without altering the basic cooperation among the remaining elements. It is thus understood that much of the details disclosed are not required to implement

various aspects of the embodiments described. To the extent that the remaining elements are distinguishable from the prior art, components and features that are omitted are not limiting on the concepts described herein.

[0022] All such variations in design are insubstantial changes over the teachings conveyed by the described embodiments. It is also understood that the embodiments described herein have broad applicability to other applications, and are not limited to the particular application or industry of the described embodiments. The invention is thus to be construed as including all possible modifications and variations encompassed within the scope of the claims of the issued patent.

WHAT IS CLAIMED IS:

1. A system comprising:

means for concentrating solar power;

means for storing thermal energy enabled to receive solar-generated steam from the means for concentrating solar power; and

wherein the means for storing thermal energy comprises an underground reservoir.

2. The system of claim 1, wherein the underground reservoir comprises one or more of a producing reservoir, a depleting reservoir, and a depleted reservoir.

3. The system of claim 1, wherein the underground reservoir comprises one or more of a producing oil reservoir, a depleting oil reservoir, or a depleted oil reservoir.

4. The system of claim 1, further comprising a means for using thermal energy enabled to receive stored thermal energy as steam from the means for storing thermal energy.

5. The system of claim 4, wherein the means for using thermal energy comprises a means for generating electricity enabled to couple to an electrical power distribution grid.

6. The system of claim 4, wherein the means for generating electricity comprises a steam turbine generator.

7. The system of claim 6, wherein the steam turbine generator is enabled to receive a portion of the solar-generated steam.

8. The system of claim 4, wherein the means for using thermal energy comprises a means for thermally enhanced resource recovery.

9. The system of claim 4, wherein the means for using thermal energy comprises a producing thermally enhanced oil reservoir.

10. The system of claim 4, wherein the means for using thermal energy is enabled to provide saturated steam to a thermally enhanced oil reservoir that is producing, the saturated steam being at least in part from the stored solar energy and at least in part from a natural gas fired boiler.

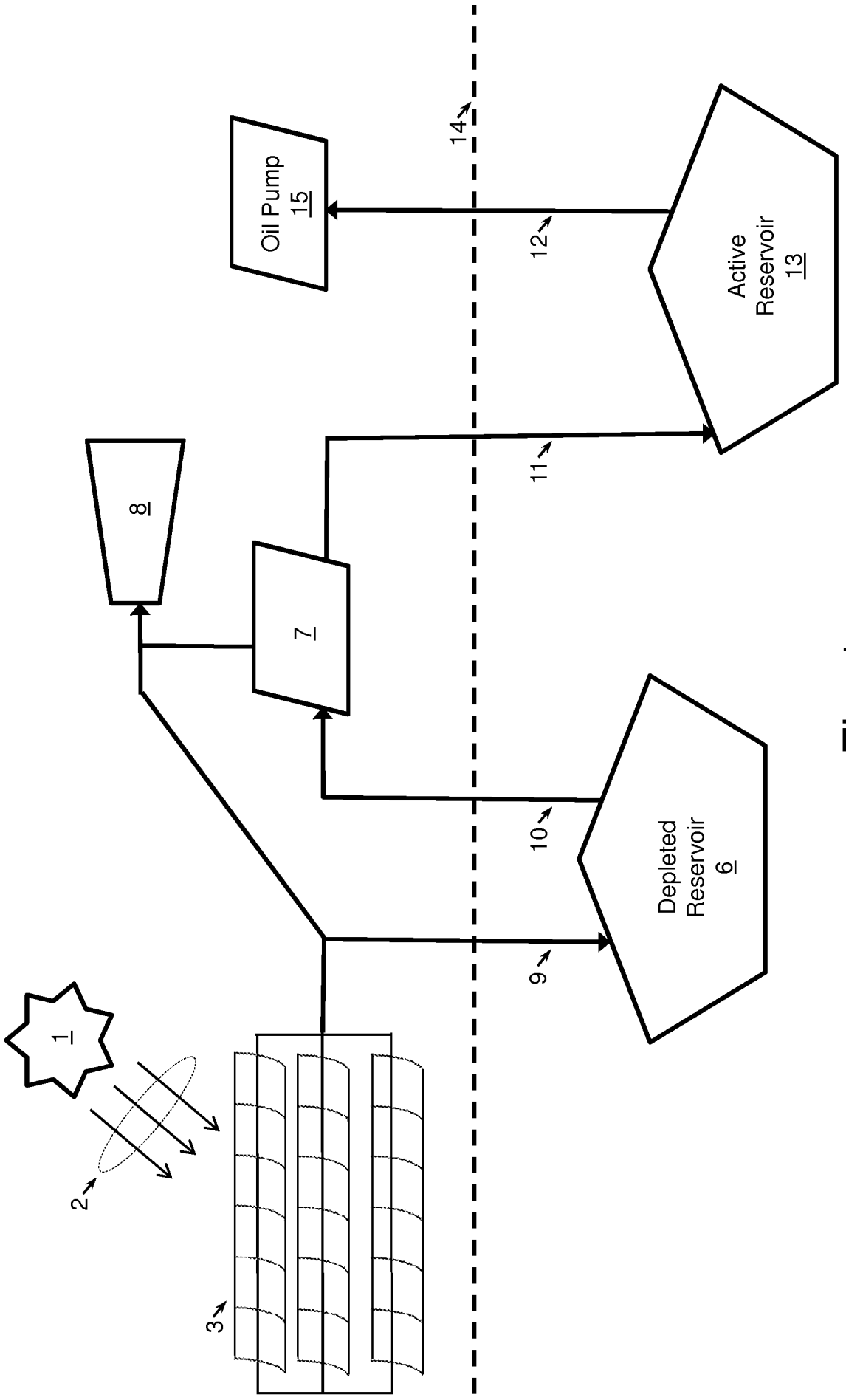
1
2
3
8
7
Depleted Reservoir 6
Active Reservoir 13
Oil Pump 15
9
10
11
12
14

Fig. 1