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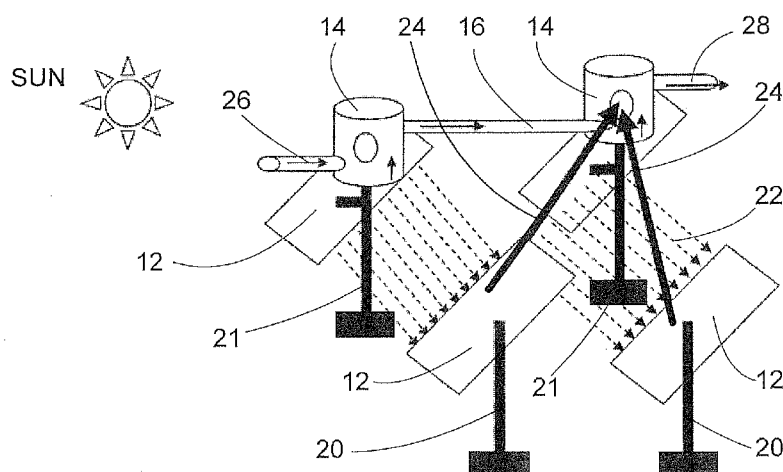


Fig. 3

(57) **Abstract:** A solar energy collecting system arranged to gradually and stepwise heat a thermal fluid in thermal receivers, interconnected via an insulated tube and configured in parallel serially connected subgroups. The receivers are heated by optical elements arranged to reflect solar radiation upon the receivers, aligned according to specified temporal-spatial patterns, relating to the terrain and the solar motion. Receivers and optical elements may be positioned at specified locations and heights that maximize the energy yield. The configuration of the receivers and the optical elements may be adapted to storage and transport requirements. The system is highly modular and efficient in energy production and storage.

A SOLAR ENERGY COLLECTING SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

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This application claims the benefit of U.S. Provisional Patent Application No. 61141022 filed on December 29th 2008, which is incorporated herein by reference.

BACKGROUND

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1. TECHNICAL FIELD

The present invention relates to the field of renewable energy, and more particularly, to a concentrated solar power plant.

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2. DISCUSSION OF RELATED ART

Concentrated solar thermal technology for generation of electric power is one of the most promising clean technologies, and is expected to become competitive with generation of electricity from fossil fuel within a decade. Reducing the cost of the produced electricity (Dollar per kWh) depends on two main factors, namely equipment cost and system efficiency.

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Three main technologies exist in this field: the trough technologies, including the sub technologies of parabolic troughs and Fresnel mirrors; the Sun tower technology, and the dish technology.

Figures 1A, 1B and 1C illustrate solar systems according to the prior art.

Figure 1A illustrates a trough technology which has various implementations, most notably parabolic troughs and Fresnel mirrors. The illustration shows parabolic troughs technology. This technology uses single-axis tracking and a long tube receiver as a heat collecting element (HCE). The heat transfer fluid (HTF) used is usually thermal oil or water/steam. The efficiency of this technology is limited by two factors: the single-axis tracking, which allows only a medium concentration factor of the Sun's energy (not exceeding 100) and the long receiver which, due to its large overall surface area, emits heat at high temperature and therefore limits the maximum operating temperature. Lower temperature results in lower thermal-to-electrical thermodynamic conversion efficiency.

5 The maximum operating temperature in this technology is estimated to be 450 °C.

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Figure 1B illustrates a central receiver (Sun tower) technology, using a field of concentrating optics, such as heliostats which track the position of the Sun in order to direct the sun rays onto a heat receiver located on top of a tower. As the heliostats cover a very large collection area of Sun radiation and have dual-axis tracking capability, and as the absorbing area of the receiver on top of the Sun tower is relatively small compared to the collection area (together forming high concentration ratio, which can be as high as 1,000), the temperature in the receiver can reach more than 1,000 °C. A typical Sun tower configuration uses steam in the receiver tank and operates at temperatures of about 500-650 °C. The main drawback of this topology is the relatively low average optical-to-thermal conversion efficiency of the field, due to the decreasing efficiency of remote heliostats. This limits the maximum energy capacity of a single Sun tower and requires the combined usage of several Sun towers sharing a single power block in order to benefit from the economies of scale of larger power blocks. Another significant drawback is that

15 the absorbing area of the receiver on top of the Sun tower is relatively small compared to the collection area (together forming high concentration ratio, which can be as high as 1,000), the temperature in the receiver can reach more than 1,000 °C. A typical Sun tower configuration uses steam in the receiver tank and operates at temperatures of about 500-650 °C. The main drawback of this topology is the relatively low average optical-to-thermal conversion efficiency of the field, due to the decreasing efficiency of remote heliostats. This limits the maximum energy capacity of a single Sun tower and requires the combined usage of several Sun towers sharing a single power block in order to benefit from the economies of scale of larger power blocks. Another significant drawback is that

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this technology is not modular, hence proving the operation of a 20MW plant, doesn't prove the operation of a 50MW plant, and debt financing of such a plant is therefore very difficult.

Figure 1C illustrates a dish technology. The dish is a dual-axis tracking
5 system, which concentrates sunlight at a ratio of more than 1,000 to the focal point of the dish. At the focal point is a receiver, containing steam or air and sometimes a turbine and a generator. In other, more common configurations, a Stirling engine is located at the focal point of the dish, which directly transfers the heat to mechanical work and then, through an embedded generator, to electricity. The main drawbacks of such systems are
10 the price of the dishes and the difficulty to employ efficient storage systems.

U.S. Patent No. 4276872, which is incorporated herein by reference in its entirety, discloses a solar system employing ground level heliostats and solar collectors, having towerless collectors and towerless reflectors that are disposed at ground level or substantially the same level, to eliminate the major expense of a collector tower, which is
15 inefficient and nonfunctional in a solar system.

U.S. Patent No. 5979438, which is incorporated herein by reference in its entirety, discloses a sunlight collecting system comprises an oval mirror directed downwardly and provided at a given elevation, and a plurality of heliostats arranged on the ground about the oval mirror, each heliostat having a concave mirror for reflecting
20 and converging sunlight L onto the oval mirror.

U.S. Patent No. 6530369, which is incorporated herein by reference in its entirety, discloses a solar energy plant comprising at least two reflectors successively arranged along an optical path of the system so that a first of the two reflectors reflects

the radiation towards a second of the two reflectors. The reflectors have such spectral characteristics as to be capable of highly reflecting the radiation in a reflection range of wavelengths and absorbing the radiation in an absorption range of wavelengths, wherein the absorption range of wavelengths of the first reflector substantially includes the
5 absorption range of wavelengths of the second reflector.

U.S. Patent No. 4137897, which is incorporated herein by reference in its entirety, discloses a reflector array that provides for the collection and concentration of a relatively constant daily total quantity of usable energy for one or more energy receivers through use of a collector array support configuration that provides for the efficient use of
10 collector surface and land. This is accomplished by combining a plurality of collectors with a support structure wherein the collectors are carried by a terraced support surface of the structure and the reflective surfaces of the collectors lie in essentially a common sun facing plane at noon. In a preferred embodiment, the terraced support surface is a terraced East-West extending wall of an enclosure such as comprising a residential, commercial or
15 industrial building.

German Patent Document No. 1024806, which is incorporated herein by reference in its entirety, discloses a system that has a central receiver and at least one heliostat for concentrating solar radiation on the central receiver, whereby the central receiver is arranged above the heliostat and has evaporation and superheating stages with
20 radiation absorbing surfaces. Solar radiation is concentrated by the heliostat onto the radiation absorbing surfaces of the evaporator and superheater stages. An independent claim is also included for a method of solar thermal steam generation.

U.S. Patent No. 4401103, which is incorporated herein by reference in its entirety, discloses an apparatus for converting solar energy to useful energy principally for home use. The apparatus provides a complete system for receiving solar energy over a large area, e.g. 1,000 square feet; concentrating the energy; and directing the energy
5 toward a target of a few square feet at an extremely high temperature. The receiving, concentrating and transmitting apparatus consists of an array of collectors provided with mechanisms for tracking the sun. The collectors include a system of reflectors and/or lenses to first concentrate and then direct the energy toward the target. The system further includes a substantial storage chamber with means for circulating a fluid between the
10 target and the storage chamber to transfer heat from the target to the storage chamber. The system further includes means for transferring the heat from the target and/or storage system to a heat engine and electrical generator combination to create power for use on demand. Heat transferred to the engine cooling fluid is used for space heating and air conditioning.

15 U.S. Patent No. 4227513, which is incorporated herein by reference in its entirety, discloses an improvement in a solar system having one or more collectors for receiving and using radiant energy from the sun and at least one and preferably a plurality of respective reflector means for reflecting the radiant energy onto the collectors. The improvement is characterized by having each reflector in the form of a heliostat that can
20 be moved to maximize the radiant energy reflected onto its collector, driving motor for so moving each heliostat; firmly anchored support structure carrying each heliostat; and sensor connected by suitable controls with each drive motor for so moving each heliostat; the respective sensor being mounted on the same support structure as the heliostat and

aligned in a straight line from the heliostat to its collector. With this construction, the sensor does not require an expensive and firmly anchored separate support structure to prevent receiving small surface movements different from those received by the heliostat.

U.S. Patent No. 4106481, which is incorporated herein by reference in its
5 entirety, discloses an apparatus for recovering solar energy, comprising a plurality of fluid-warming-up tubes, which extend in parallel and side-by-side relationship in one plane. Each tube has two associated plane reflective surfaces which enclose a fixed angle
10 alpha ' in the order of 30 Deg - 40 Deg. The reflective surfaces are arranged to be pivoted and moved transversely to said plane so that their bisector plane containing the centerline of the respective tube can be maintained directed at the sun without reflective surfaces
associated with successive tubes overshadowing each other.

German Patent Document No. 3003962, which is incorporated herein by reference in its entirety, discloses a solar energy plant with directly heated heat storage.

WIPO Publication No. 2008/022409, which is incorporated herein by
15 reference in its entirety, discloses solar energy collector systems comprising an elevated linear receiver extending generally in an East-West direction, a polar reflector field located on the polar side of the receiver, and an equatorial reflector field located on the equatorial side of the receiver. Each reflector field comprises reflectors positioned in
20 parallel rows which extend generally in the East-West direction. The reflectors in each field are arranged and positioned to reflect incident solar radiation to the receiver during diurnal East-West processing of the sun and pivotally driven to maintain reflection of the incident solar radiation to the receiver during cyclic yearly North-South processing of the

sun. Inter-row spacings of the reflectors on opposite sides of the receiver may be asymmetrical.

BRIEF SUMMARY

5 Embodiments of the present invention provide a solar energy collecting system comprising: a plurality of thermal receivers arranged to heat a thermal fluid by absorbing solar radiation reflected thereupon, the thermal receivers interconnected via an insulated tube arranged to hold the heated thermal fluid and conserve its heat, the interconnection being in a specified geometric configuration; a plurality of optical
10 elements arranged to intercept solar radiation and reflect it onto the thermal receivers, wherein the thermal receivers are associated with the optical elements according to specified temporal and spatial parameters; and a plurality of stands, each arranged to support one of the corresponding optical elements in a specified position, wherein the specified geometric configuration of the thermal receivers, the specified temporal and
15 spatial parameters of the optical elements, and the specified position are selected such as to optimize the interception of the solar radiation and the heating of the thermal receivers in respect to predefined specifications, and wherein the thermal receivers, optical elements and stands are modularly configurable to maximize the interception and absorption of the solar radiation.

20 Embodiments of the present invention provide a method of collecting solar energy, comprising: positioning and interconnecting a plurality of thermal receivers in a specified geometric configuration; mounting the thermal receivers on a plurality of stands in specified heights; and positioning a plurality of optical elements such as to intercept

solar radiation and to direct the intercepted solar radiation onto the thermal receivers, wherein the thermal receivers comprise a thermal fluid and are arranged to heat the thermal fluid upon absorbing the directed solar radiation, wherein the directing is carried out in respect to specified temporal and spatial parameters, and wherein the specified
5 geometric configuration, the specified heights and the positioning of the optical elements are modularly configurable to maximize the interception and absorption of the solar radiation.

These, additional, and/or other aspects and/or advantages of the present invention are: set forth in the detailed description which follows; possibly inferable from
10 the detailed description; and/or learnable by practice of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more readily understood from the detailed description of embodiments thereof made in conjunction with the accompanying
15 drawings of which:

Figure 2 is a high level schematic block diagram of a solar energy collecting system, according to some embodiments of the invention;

Figure 3 is a schematic illustration of a solar energy collecting system, according to some embodiments of the invention such as of shape A of Figure 2;

20 Figure 4 is a schematic illustration of an exemplary, illustrative embodiment of one option for implementing a field layout such as that of dashed oval B of Figure 2, according to the present invention;

Figure 5 is a schematic illustration of an exemplary, illustrative embodiment of another option for implementing a field layout such as that of dashed oval B of Figure 2, according to the present invention;

Figure 6 is a schematic illustration of an exemplary, illustrative embodiment of a
5 secondary optics sharing the construction of a heliostat in a preceding row of receivers in order to beam down the reflected solar radiation toward the receiver, according to the present invention;

Figure 7 is a schematic illustration of an exemplary, illustrative embodiment of a beaming down implementation, according to the present invention;

10 Figure 8 is a schematic illustration of an exemplary, illustrative embodiment of a Cassegrain or Newtonian etc. reflector configuration for beaming down solar rays, according to the present invention;

Figure 9 is a schematic illustration of an exemplary, illustrative embodiment of a primary optical element such as a heliostat, connected by a mechanical moving arm, to a stand
15 shared with a receiver, according to the present invention;

Figure 10 is a schematic illustration of an exemplary, illustrative embodiment of a configuration to reduce shading and blocking by neighboring heliostats, and optical losses caused by the cosine effect due to the North-South movement of the Sun, according to the present invention;

20 Figure 11 is a schematic illustration of an exemplary, illustrative embodiment of a second configuration to overcome optical losses caused by the cosine effect due to the East-West or North-South movement of the Sun, according to the present invention;

Figure 12 is a high level schematic flowchart illustrating a method of collecting solar energy, according to some embodiments of the invention;

Figure 13 is a high level schematic block diagram illustrating the modularity of configuration of the solar energy collecting system, according to some embodiments of

5 the invention; and

Figure 14 is a graph illustrating a modeled comparison of energetic output under similar environmental conditions by a trough system and by the solar energy collecting system, according to some embodiments of the invention.

10 DETAILED DESCRIPTION

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is applicable to other embodiments or of
15 being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

For a better understanding of the invention, the usages of the following terms in the present disclosure are defined in a non-limiting manner:

20 The term "optical element" as used herein in this application, is defined as an optical device which directs the solar rays that hit it, which can be, but is not limited to, one or a set of lenses, or mirrors, or diffraction gratings.

The term "primary optical element" as used herein in this application, is defined as an optical device which directs the solar rays, which are coming from the sun, that hit it, which can be, but is not limited to one or a set of lenses, or diffraction gratings, or mirrors, sometimes called heliostats, that receive directly the sun rays and focus them
5 or direct them either directly or through a secondary optical element toward the receiver.

The term "secondary optical element" as used herein in this application, is defined as one or a set of lenses or mirrors, or diffraction gratings, that receives solar rays from a primary optical element and directs and/or focuses them onto a receiver or onto a third stage optical element.

10 The term "third stage optical element" as used herein in this application, is defined as one or a set of lenses or mirrors, or diffraction gratings, that receives solar rays from secondary optics and directs and/or focuses them onto a receiver.

The term "heliostat" as used herein in this application, is defined as a device arranged to track the sun and reflect the solar radiation onto a specified device.

15 The terms "receiver" and "thermal receiver" as used herein in this application, are defined as a container of thermal fluid that absorbs solar energy in order to heat the thermal fluid inside.

The term "absorber" as used herein in this application, is defined as a subsystem part of the receiver tank which is responsible for absorbing the solar energy
20 and converting it into heat.

The term "stand" as used herein in this application, is defined as any apparatus for supporting receivers and/or optical elements, such as towers, poles or other constructions.

The term "dual-axis stand" as used herein in this application, is defined as a stand of optics that can be moved in two axes mostly providing yaw and pitch movements.

The term "three-axis stand" as used herein in this application, is defined as a
5 stand of optics that can move in three axes and provides yaw, pitch and elevation movements.

The term "shared stand" as used herein in this application, is defined as a dual-axis or a three-axis stand of both primary optical element and a receiver or a shared stand of the primary and secondary optical elements.

10 The term "tower" as used herein in this application, is defined as a construction of any material that stands on ground and holds parts of the system.

The term "insulated tube" as used herein in this application, is defined as a tube that is designed to transfer thermal fluid and to hold the thermal energy of the fluid inside it, the side walls of which are designed to have minimal radiation and minimal heat
15 conductivity.

The term "thermal loop" as used herein in this application, is defined as a section of the solar field as illustrated in the phantom rectangle C in Figure 2. The heat transfer fluid enters this section at some minimum temperature which increases gradually when passing each receiver until leaving toward the power block, optionally via a storage
20 element, at its maximum temperature. A number of thermal loops might be connected in parallel in order to create the full solar field. Figure 2 illustrates a solar field comprising of two thermal loops.

The term "local thermal storage element" as used herein in this application, is defined as a thermal storage element, which can be, but is not limited to, two tank storage, PCM (phase changed material), concrete or a combination of storage technologies. The local thermal storage element is located at the end of each thermal loop
5 before the collection of the hot thermal fluid toward the power block.

The term "central thermal storage element" as used herein in this application, is defined as a thermal storage element, which can be but is not limited to, two tank, PCM, concrete or a combination of storage technologies. The central thermal storage element is located at the collection point of all the thermal loops and before transferring
10 the heat transfer fluid to the power block.

Figure 2 is a high level schematic block diagram of a solar energy collecting system, according to some embodiments of the invention. The solar energy collecting system comprises a plurality of thermal receivers **14** also termed receivers **14** hereafter, arranged to heat a thermal fluid (not shown) by absorbing solar radiation reflected thereupon. Thermal receivers **14** are interconnected via an insulated tube **16** arranged to
15 hold the heated thermal fluid and conserve its heat. The interconnection is in a specified geometric configuration, exemplified by a field layout **100**.

The solar energy collecting system further comprises a plurality of optical elements **12** arranged to intercept solar radiation and reflect it onto thermal receivers **14**,
20 wherein optical elements **12** are associated with thermal receivers **14** according to specified temporal and spatial parameters, exemplified in field layout **100** and relating to the specified geometric configuration of optical elements **12** and of thermal receivers **14**, and solar motion and radiation parameters as they change throughout the day and year.

Optical elements **12** may be supported by stands (not shown in Figure 2) in specified positions and heights.

According to some embodiments of the invention, the specified geometric configuration of thermal receivers **14**, the specified temporal and spatial parameters (e.g.,
5 temporally variable yaw and pitch as well as height, orientation and horizontal position) of optical elements **12**, and the specified position of the stands are selected such as to optimize the interception of the solar radiation and the heating of thermal receivers **12** in respect to predefined specifications. According to some embodiments of the invention, thermal receivers **12**, optical elements **14** and the stands are modularly configurable to
10 maximize the interception and absorption of the solar radiation.

According to some embodiments of the invention, the solar energy collecting system may further comprise at least one thermal storage element **36** connected to the insulated tube and arranged to store the heated thermal fluid. The specified geometric configuration may comprise parallel subsets of serially connected thermal receivers **12**, as
15 exemplified by field layout **100**. Each subset may be associated with at least one thermal storage element **36**. According to some embodiments of the invention, the solar field may comprise a large number of parallel subsets, thus enhancing the modularity of the system and its production potential.

Figure 2 is a schematic illustration of an exemplary, illustrative embodiment
20 of field layout **100** of a solar thermal power plant using a concentrated solar power technology, according to some embodiments of the present invention, upon which dashed shape A, dashed oval B, phantom rectangle C, and dashed rectangle D are marked. Field layout **100** includes primary optical elements **12**, which are grouped into mini-fields such

as in the dashed rectangle D. Each mini-field is a single receiver **14** with the corresponding optical elements. In the example illustration of the present figure the number of corresponding primary optical elements **12** is 3, as depicted in the dashed rectangle D. Each of the primary optical elements **12**, which is supported by a stand (**20**)

5 (not shown at the present illustration), such as a dual-axis stand or a three-axis stand, and which can be a heliostat or a dish, focuses the solar radiation and directs the focused solar rays **24** toward a receiver **14**. The receivers **14** are interconnected by means of one or more thermally insulated tubes **16**, containing heat transfer fluid (HTF). The receivers **14** can share the construction with the primary optical element **12** in order to save structural

10 elements. Each thermal loop of receivers **14** is connected by thermally insulated tubes **16**. The temperature of the heat transfer fluid increases gradually along the loop when passing each receiver **14**, thus the fluid temperature in the first receivers **14** is relatively low while the fluid temperature in the last receiver **14** is the highest and can even exceed 550 °C. In order to reduce system costs, cheaper receivers can be used at the beginning of

15 the loop, where the temperature is relatively low, compared to the more sophisticated ones used at the end of the loop, where the temperature is at its maximum. At the end of the loop, the thermal fluid can transfer heat to a local thermal storage element **36** instead of running directly through a connecting thermally insulated tube **16** toward the power block. The other more common option is to collect first the heat transfer fluid from all the

20 loops (optionally also implementing local thermal storage elements in each loop) and then direct it toward the central thermal storage element **38**. From the central thermal storage element **38**, the heat is transferred usually by steam toward the power block. The

dashed shape A refers to a typical segment containing primary optical elements **12**, receivers **14**, and a connecting thermally insulated tube **16**.

The suggested topology enables the usage of a proven thermal flow regime as in a trough topology (such as in Figure 1a), but it alleviates its main disadvantages, namely the single-axis tracking reflectors, the low concentration ratio and the increased heat loss (due to the large surface area of the receiver). According to the present invention, the system consists of both dual-axis tracking primary optical elements and receivers, the absorption area of which is small relative to their volume, thus allowing the heat transfer fluid to be heated to a higher temperature. Moreover, the receiver design in this topology is simpler and requires less maintenance than that of the receivers used in current trough technology. When using water/steam as the heat transfer fluid, the receiver can be designed to include a water/steam separator and save the external water/steam separator needed in the trough for direct steam generation.

The benefits of the suggested topology can be demonstrated in comparison to the central receiver topology (tower) (Figure 1b) as well. The primary optical elements share the same benefit of dual-axis tracking, as the reflectors of the tower topology. The receivers have the ability to maintain a higher operating temperature than in the trough, as in the central receiver topology. However, the disadvantages of the tower are alleviated in the suggested topology. While in the tower the optical-to-thermal efficiency of the reflectors decreases with the distance of the reflecting element from the tower (because of worse cosine factor and increased atmospheric losses), in the suggested topology the optical to thermal efficiency is the same for each mini-field of primary optical elements. The discrete receivers allow usage of different types of receivers along the thermal loop,

eliminating the necessity of using expensive receivers in the pre-heating segment at the beginning of the loop, where temperature (and therefore heat loss) is low. In the suggested topology the field is modular and the number of different types of primary optical elements is much smaller than in a single-tower topology, where almost each row
5 requires a different set of reflectors. The modularity feature significantly simplifies the financing of such plants. The suggested topology consists of repetitive elements while the central receiver topology (single tower) requires unique expensive elements such as the costly tower and the complex central receiver. The modularity provides for easier plant maintenance and upgrades, as well as for better redundancy; the usage of repetitive
10 similar sets of elements ensures improved manufacturability and significant cost reduction. Another benefit of the modularity is the possible usage of distributed thermal storage elements as well.

Figure 3 is a schematic illustration of a solar energy collecting system, according to some embodiments of the invention. Figure 3 illustrates an option for
15 implementing a field layout, such as that of dashed shape A of Figure 2. Each primary optical element **12** focuses the solar rays **22**, and directs the focused solar rays **24** toward a corresponding receiver **14** while the heat transfer fluid flows along the connecting (thermally insulated) tube **16** and between the receivers **14**. Receiver **14** can be located on a shared structure **21** with a primary optical element **12**. Each receiver **14** has an inlet **26**,
20 for high pressure low temperature fluid and an outlet **28**, for low pressure high temperature fluid. The receivers **14** may comprise a water steam separator.

Optical elements **12** may comprise an intercepting set of optical elements **12** arranged to intercept solar radiation and direct it (**22**) upon a heating set of optical

elements **12** arranged to heat the thermal receiver by focusing (**24**) the intercepted radiation thereupon.

According to some embodiments of the invention, as exemplified in Figure 3, the specified geometric configuration may comprise positioning at least some of thermal receivers **12** on at least some of stands **20**. Optical element **12** on a common stand **20** with thermal receiver **14** may be arranged to reflect solar radiation (**22**) upon another optical element **12** and not directly on thermal receiver **14** mounted on the same stand **20**.

According to some embodiments of the invention, stands **20** may comprise washing devices arranged to regularly wash optical elements **12**.

Figure 4 is a schematic illustration of an exemplary, illustrative embodiment of one option for implementing a field layout such as that of dashed oval B, according to the present invention.

Each primary optical element **12** focuses the solar rays **22**, and directs the focused solar rays **24** toward corresponding receiver **14** while the heat transfer fluid flows along the connecting tube **16** and between the receivers **14**. Receiver **14** can be located on small towers **18**, poles or stands. Each receiver **14** has an inlet **26**, for high pressure low temperature fluid and an outlet **28**, for low pressure high temperature fluid.

The receiver **14** may comprise a water steam separator. Optical elements **12** may comprise heliostats arranged to follow the sun and reflect the intercepted radiation upon thermal receivers (receivers) **14**. Optical elements **12** may be arranged on at least some of stands **20**, **21** to concentrate solar radiation.

The heights of stands **20** supporting receivers **14** may be adjusted in relation to the geometric configuration of receivers **14** and in relation to the specified temporal

and spatial parameters governing the association of receivers **14** with optical elements **12**. The specified geometric configuration may comprise positioning at least some of thermal receivers **14** on at least some of stands **20**, **21**. Figure 5 is a schematic illustration of an exemplary, illustrative embodiment of another option for implementing a field layout
5 such as that of dashed oval B of Figure 2, according to the present invention.

According to this option the receivers **14** are located close to the ground while the solar rays **22** are beamed down by a secondary (moving or stationary) optical element **32**, or even by using a third stage moving optical system, (not shown in the present illustration).

10 The primary optical elements **12** direct the solar rays **22** toward the secondary optical elements. The secondary optical element **32** is located behind or in front of the primary optical elements **12**, depending on the direction of the solar rays **22**.

Figure 6 is a schematic illustration of an exemplary, illustrative embodiment of a secondary optics sharing the construction of a heliostat in a preceding row of receivers in order to beam down the reflected solar radiation toward the receiver **14**,
15 according to the present invention.

Figure 7 is a schematic illustration of an exemplary, illustrative embodiment of a beaming down implementation, according to the present invention.

The secondary optical element **32** is located on top of a corresponding tower
20 **18** and the receiver **14** is located on the ground. In this case the secondary optical element could be moving or stationary.

Figure 8 is a schematic illustration of an exemplary, illustrative embodiment of a Cassegrain or Newtonian etc. reflector **34** configuration for beaming down solar rays, according to the present invention.

Figure 9 is a schematic illustration of an exemplary, illustrative embodiment
5 of a primary optical element **12** such as a heliostat, connected by a mechanical moving arm **29**, to a stand **21** shared with a receiver, according to the present invention.

Primary optical element **12** directs the solar rays **22** either directly to a receiver **14** or through a secondary moving or stationary optical element **32**. The receiver **14** might also be located on the ground.

10 According to some embodiments of the invention, the specified temporal and spatial parameters may be derived from the specified geometric configuration in respect to the sun's daily and annual movement, as demonstrated in the following figures **10** and **11**.

Figure 10 is a schematic illustration of an exemplary, illustrative embodiment
15 of a configuration to overcome optical losses caused by the cosine effect due to the North-South movement of the Sun, according to the present invention. The illustration shows two positions of the Sun at different times of the year and of the day, as well as two different corresponding positions of height and spatial angles of primary optical element **12**.

20 The vertical movement of primary optical element **12**, which is in this case carried upon a three-axis stand, reduces the cosine losses due to North-South Sun movement and blocking and shading losses caused by neighboring heliostats and structures.

Figure 11 is a schematic illustration of an exemplary, illustrative embodiment of a second configuration to overcome optical losses caused by the cosine effect due to the East-West or North-East movement of the Sun, according to the present invention.

A primary optical element **12** focuses the sun rays **22** to a different receiver **14** (possibly via heating optical elements) depending on the Sun's location in the sky, reducing the cosine losses and providing improved optical efficiency. A dedicated algorithm, implemented as part of the management system of the power plant, selects target receivers **14** for the various primary optical elements **12** along the day. Changing the yaw, pitch, height and horizontal position of optical elements **12**, as well as their associations with receivers **14**, during the day and along the year, may contribute to lessen losses due to shading and blocking of optical elements **12** by other optical elements **12**.

According to some embodiments of the invention, receivers **14** may be optimized in respect to their operating temperature, in dependence of their position in the whole array. Optimization parameters generally comprise maximizing absorption and minimizing emission.

Advantageously gradual and stepwise warming of the thermal liquid combines the advantages of a solar tower and a solar trough while avoiding their disadvantages. Gradual and stepwise warming avoids temperature extremity (in respect to the tower) and allows a more controlled and adaptable heating process. It also avoids losses associated with receivers with a large surface, such as the trough's long tube for thermal fluid. In addition, the stepwise heating allows a high degree of modularity that creates high construction and heat storage flexibility.

Figure 12 is a high level schematic flowchart illustrating a method of collecting solar energy, according to some embodiments of the invention. The method comprises the following stages: positioning and interconnecting a plurality of thermal receivers in a specified geometric configuration (stage **100**); mounting the thermal receivers on a plurality of stands in specified heights (stage **110**); and positioning a plurality of optical elements such as to intercept solar radiation and to direct the intercepted solar radiation onto the thermal receivers (stage **120**). The thermal receivers comprise a thermal fluid and are arranged to heat the thermal fluid upon absorbing the directed solar radiation. The directing is carried out in respect to specified temporal and spatial parameters. The specified geometric configuration, the specified heights and the positioning of the optical elements are modularly configurable to maximize the interception and absorption of the solar radiation. The specified temporal and spatial parameters may comprise an association of the thermal receivers with the optical elements, temporally variable yaw, pitch, height and angular orientation of the optical elements and may be determined in respect to the sun's daily and annual movement. Modular configuration may relate to factors illustrated in Figure 13. The method may further comprise connecting the thermal receivers to at least one thermal storage element (stage **130**), such as to effectively store and transport the generated heat.

The method may further comprise washing the optical elements regularly and automatically (stage **140**).

Figure 13 is a high level schematic block diagram illustrating the modularity of configuration of the solar energy collecting system, according to some embodiments of

the invention. The modular adaptation of the solar energy collecting system **200** may express itself in positioning the receivers **210** and in positioning the optical elements **250**.

Positioning the receivers **210** comprises positioning and configuring loops of serially connected receivers **230**, which are set in parallel rows **220**. The arrangement of the receivers determines the steps in which the thermal fluid is heated. Positioning the loops **230** may comprise determining the number of receivers per loop **232**, receiver sizes **234**, receiver positions **236**, receiver heights **238** and receiver specifications, e.g., relating to the designated working temperatures. Positioning the parallel rows **220** may comprise configuring the row in respect to the thermal storage elements **222** and to geographical considerations **224**.

Positioning the optical elements **250** may comprise selecting reflectors (e.g., third stage optical elements) **262**, interceptors (e.g., primary optical elements) **264** and intermediate optical elements (e.g., secondary optical elements) **266** such as to efficiently direct solar radiation upon the receivers. Further, positioning the optical elements **250** may comprise configuring the daily motion **272** and the yearly motion **274** of the optical elements in respect to the sun's motions (e.g., see Figures 10 and 11) and locations of the receivers, as optical elements and receivers may be variably and temporally dependently coupled **276**. Finally, the heights of the elements may be determined **278** in relation to the receivers and terrain related factors.

Figure 14 is a graph illustrating a modeled comparison of energetic output under similar environmental conditions by a trough system and by the solar energy collecting system, according to some embodiments of the invention. Figure 14 shows a consistent

advantage to the proposed system over the whole year, with an enhanced efficiency during wintertime.

In the above description, an embodiment is an example or implementation of the inventions. The various appearances of "one embodiment," "an embodiment" or
5 "some embodiments" do not necessarily all refer to the same embodiments.

Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single
10 embodiment.

Reference in the specification to "some embodiments", "an embodiment", "one embodiment" or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments, of the inventions.

15 It is to be understood that the phraseology and terminology employed herein is not to be construed as limiting and are for descriptive purpose only.

The principles and uses of the teachings of the present invention may be better understood with reference to the accompanying description, figures and examples.

It is to be understood that the details set forth herein do not construe a
20 limitation to an application of the invention.

Furthermore, it is to be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in embodiments other than the ones outlined in the description above.

It is to be understood that the terms “including”, “comprising”, “consisting” and grammatical variants thereof do not preclude the addition of one or more components, features, steps, or integers or groups thereof and that the terms are to be construed as specifying components, features, steps or integers.

5 If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

It is to be understood that where the claims or specification refer to "a" or "an" element, such reference is not to be construed that there is only one of that element.

10 It is to be understood that where the specification states that a component, feature, structure, or characteristic "may", "might", "can" or "could" be included, that particular component, feature, structure, or characteristic is not required to be included.

15 Where applicable, although state diagrams, flow diagrams or both may be used to describe embodiments, the invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described.

Methods of the present invention may be implemented by performing or completing manually, automatically, or a combination thereof, selected steps or tasks.

20 The term "method" may refer to manners, means, techniques and procedures for accomplishing a given task including, but not limited to, those manners, means, techniques and procedures either known to, or readily developed from known manners, means, techniques and procedures by practitioners of the art to which the invention belongs.

The descriptions, examples, methods and materials presented in the claims and the specification are not to be construed as limiting but rather as illustrative only.

Meanings of technical and scientific terms used herein are to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless
5 otherwise defined.

The present invention may be implemented in the testing or practice with methods and materials equivalent or similar to those described herein.

Any publications, including patents, patent applications and articles, referenced or mentioned in this specification are herein incorporated in their entirety into
10 the specification, to the same extent as if each individual publication was specifically and individually indicated to be incorporated herein. In addition, citation or identification of any reference in the description of some embodiments of the invention shall not be construed as an admission that such reference is available as prior art to the present invention.

15 While the invention has been described with respect to a limited number of embodiments, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of some of the preferred embodiments. Other possible variations, modifications, and applications are also within the scope of the invention. Accordingly, the scope of the invention should not be limited by what has thus far been
20 described, but by the appended claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A solar energy collecting system comprising:

5 a plurality of thermal receivers arranged to heat a thermal fluid by absorbing solar radiation directed thereupon, the thermal receivers interconnected via an insulated tube arranged to hold the heated thermal fluid and conserve its heat, the interconnection being in a specified geometric configuration;

a plurality of optical elements arranged to intercept solar radiation and direct it
10 onto the thermal receivers, wherein the thermal receivers are associated with the optical elements according to specified temporal and spatial parameters; and

a plurality of stands, each arranged to support a corresponding one of the optical elements in a specified position,

wherein the specified geometric configuration of the thermal receivers, the
15 specified temporal and spatial parameters of the optical elements, and the specified position are selected such as to optimize the interception of the solar radiation and the heating of the thermal receivers in respect to predefined specifications, and

wherein the thermal receivers, optical elements and stands are modularly configurable to maximize the interception and absorption of the solar radiation.

20 2. The solar energy collecting system of claim 1, wherein the plurality of optical elements comprises a plurality of heliostats.

3. The solar energy collecting system of claim 1, wherein the plurality of optical elements comprise an intercepting set of optical elements arranged to intercept solar

radiation and direct it upon a heating set of optical elements arranged to heat the thermal receiver by directing the intercepted radiation thereupon.

4. The solar energy collecting system of claim 1, wherein the plurality of optical elements comprise an intercepting set of optical elements arranged to intercept solar radiation and direct it upon an intermediate set of optical elements arranged to receive the intercepted solar radiation from the intercepting set and direct it upon a heating set of optical elements arranged to heat the thermal receiver by directing the directed radiation thereupon.

5. The solar energy collecting system of claim 1, further comprising at least one thermal storage element connected to the insulated tube and arranged to store the heated thermal fluid.

6. The solar energy collecting system of claim 1, wherein the specified geometric configuration comprises parallel subsets of serially connected thermal receivers.

7. The solar energy collecting system of claim 6, wherein each subset is associated with at least one thermal storage element.

8. The solar energy collecting system of claim 1, wherein the specified geometric configuration comprises positioning at least some of the thermal receivers on at least some of the stands.

9. The solar energy collecting system of claim 1, wherein at least one of the optical elements is arranged to concentrate the solar radiation.

10. The solar energy collecting system of claim 1, wherein the specified temporal and spatial parameters are derived from the specified geometric configuration in respect to the sun's daily and annual movement.

11. The solar energy collecting system of claim 10, wherein the specified temporal and spatial parameters comprise the association of the thermal receivers with the optical elements.

12. The solar energy collecting system of claim 10, wherein the specified temporal and spatial parameters comprise temporally variable yaw, pitch and height of the optical elements.

10 13. A method of collecting solar energy, comprising:
positioning and interconnecting a plurality of thermal receivers in a specified geometric configuration;

mounting the thermal receivers on a plurality of stands in specified heights;

and

15 positioning a plurality of optical elements such as to intercept solar radiation and to direct the intercepted solar radiation onto the thermal receivers,

wherein the thermal receivers comprise a thermal fluid and are arranged to heat the thermal fluid upon absorbing the directed solar radiation,

20 wherein the directing is carried out in respect to specified temporal and spatial parameters, and

wherein the specified geometric configuration, the specified heights and the positioning of the optical elements are modularly configurable to maximize the interception and absorption of the solar radiation.

14. The method of claim 13, further comprising connecting the thermal receivers to at least one thermal storage element.
15. The method of claim 13, wherein the specified geometric configuration comprises parallel subsets of serially connected thermal receivers.
- 5 16. The method of claim 13, wherein the specified geometric configuration comprises positioning at least some of the thermal receivers on at least some of the stands.
17. The method of claim 13, wherein the specified temporal and spatial parameters are derived from the specified geometric configuration in respect to the
10 sun's daily and annual movement.
18. The method of claim 17, wherein the specified temporal and spatial parameters comprise an association of the thermal receivers with the optical elements.
19. The method of claim 17, wherein the specified temporal and spatial parameters comprise temporally variable yaw, pitch and height of the optical
15 elements.
20. The method of claim 13, further comprising washing the optical elements regularly and automatically.

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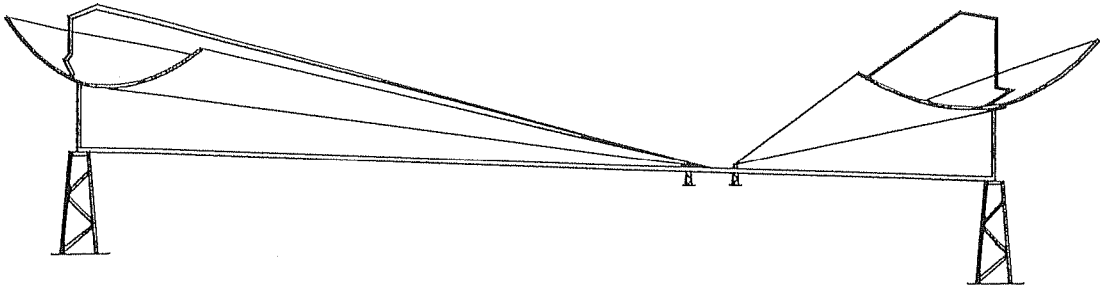


Fig. 1a PRIOR ART

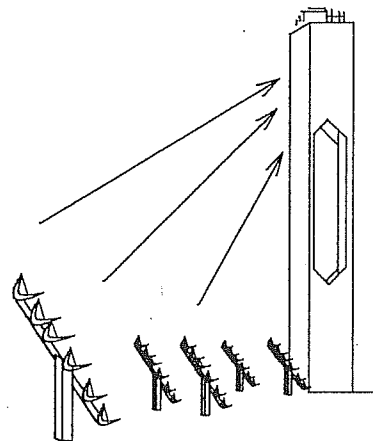


Fig. 1b PRIOR ART

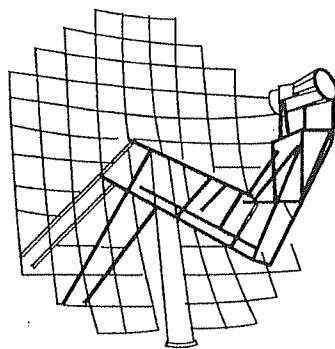


Fig. 1c PRIOR ART

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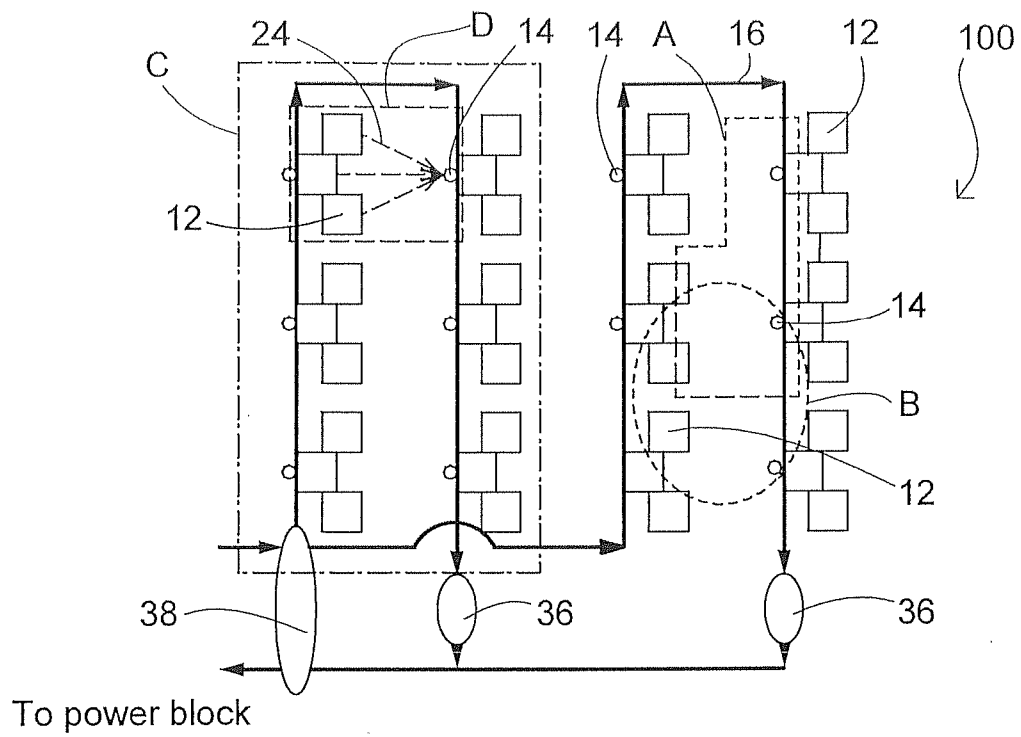


Fig. 2

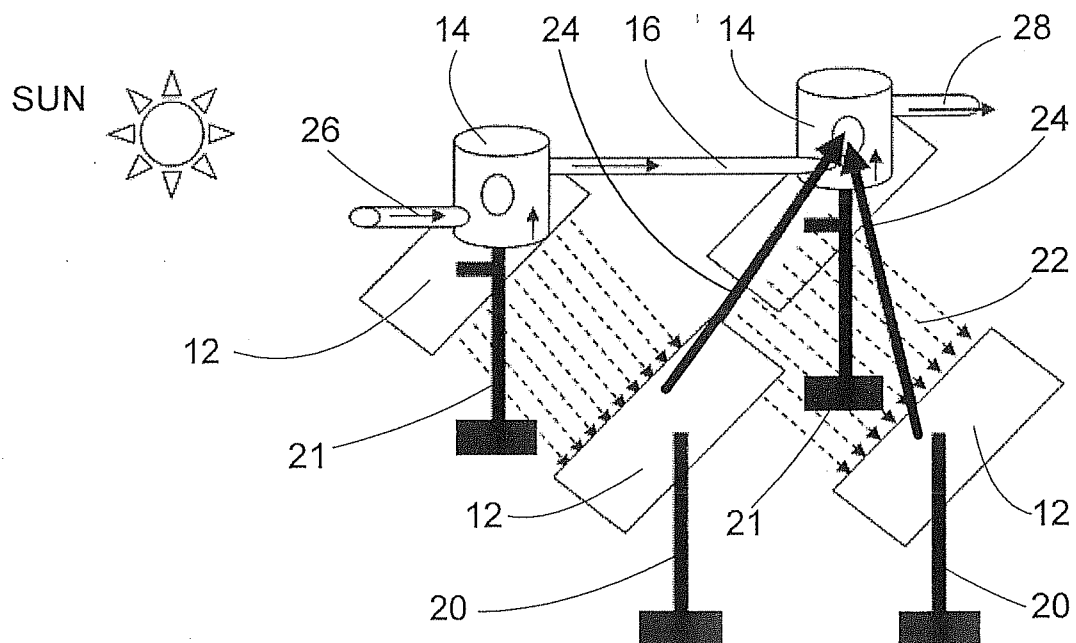


Fig. 3

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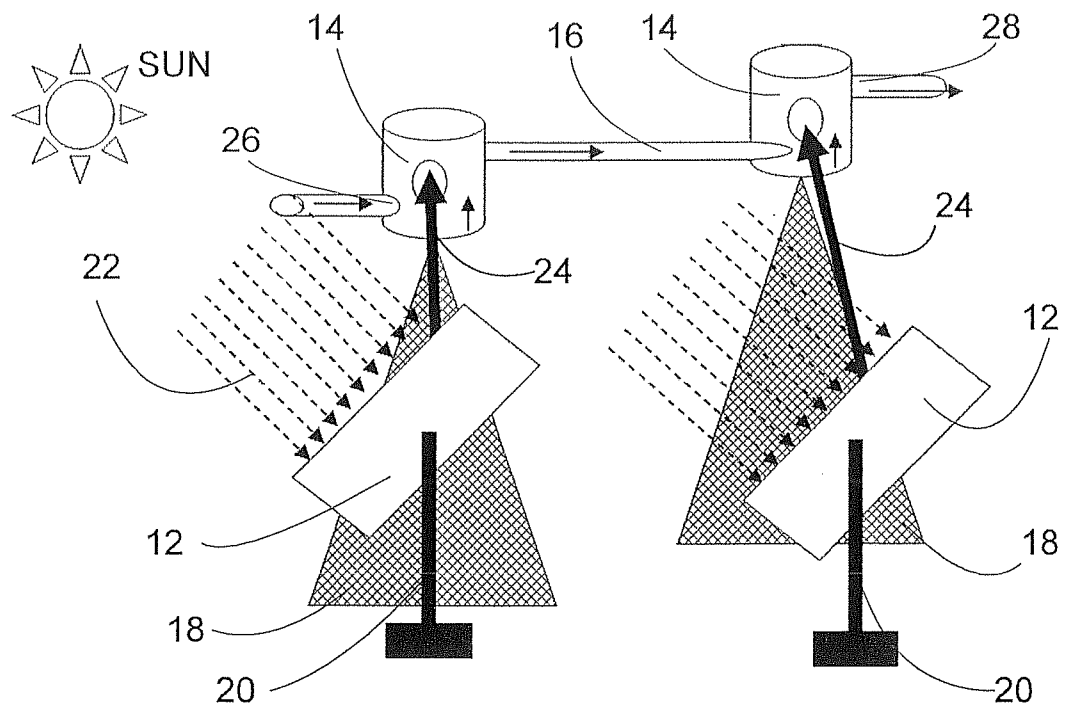


Fig. 4

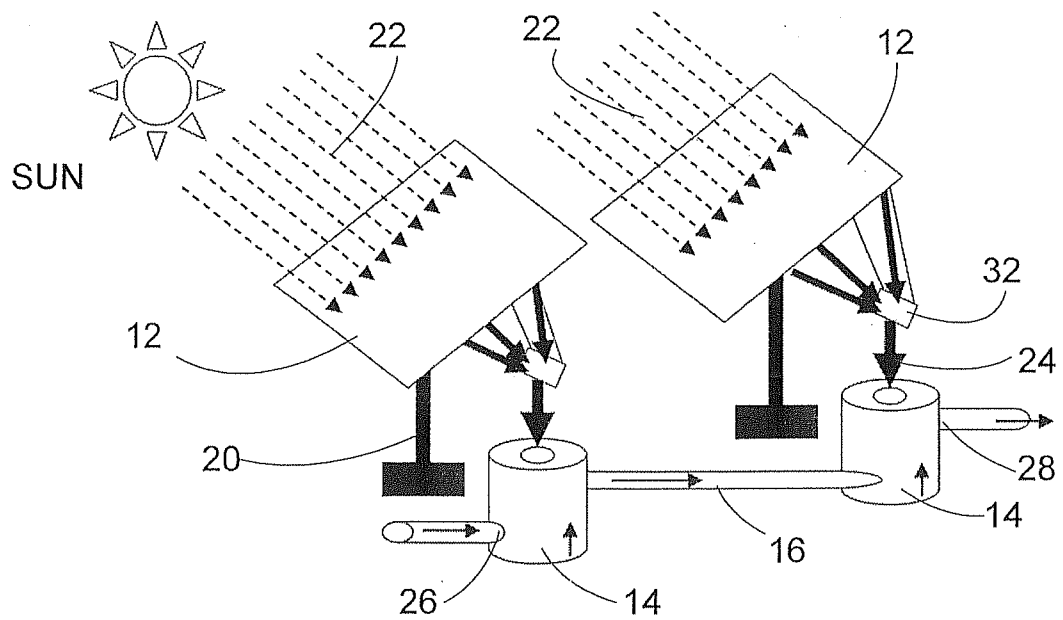


Fig. 5

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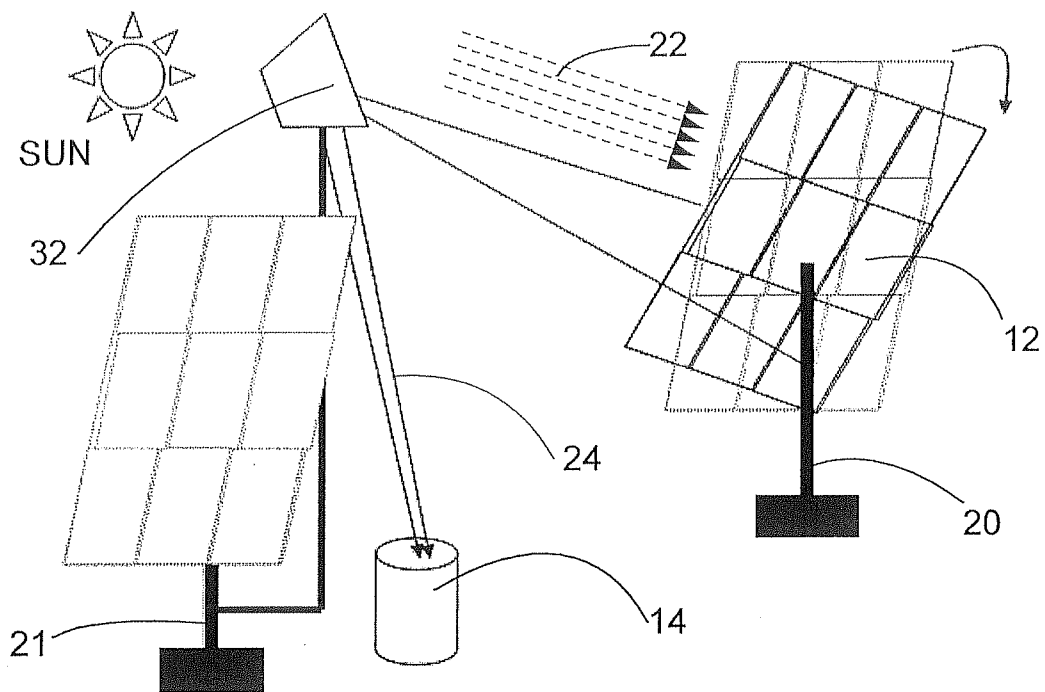


Fig. 6

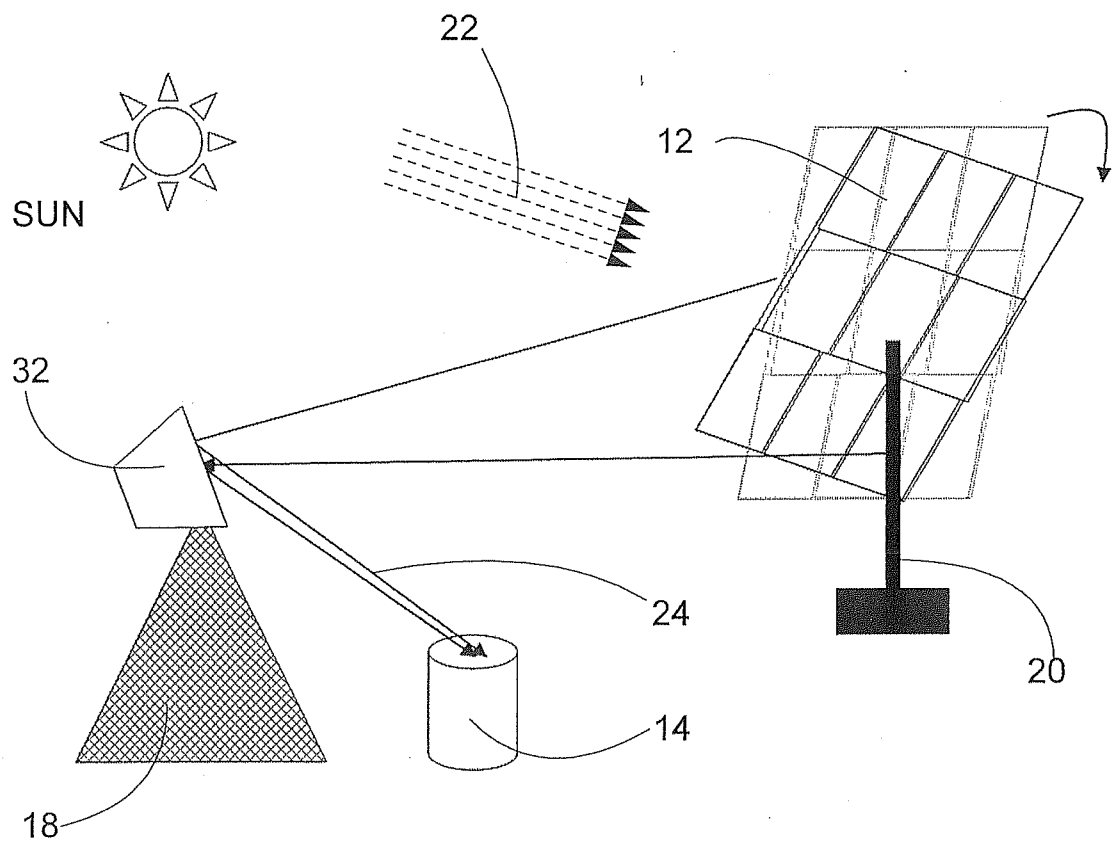


Fig. 7

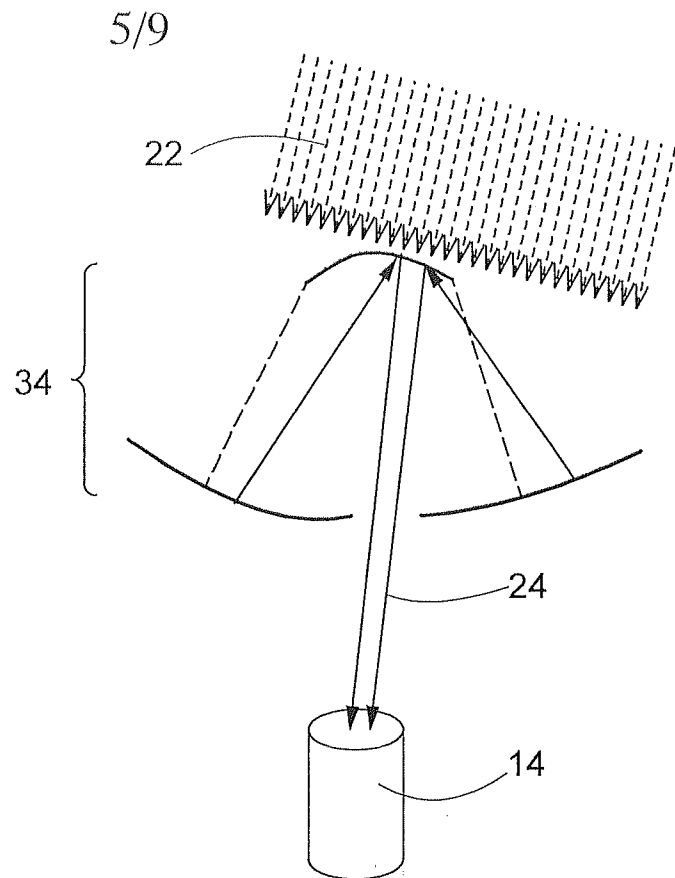


Fig. 8

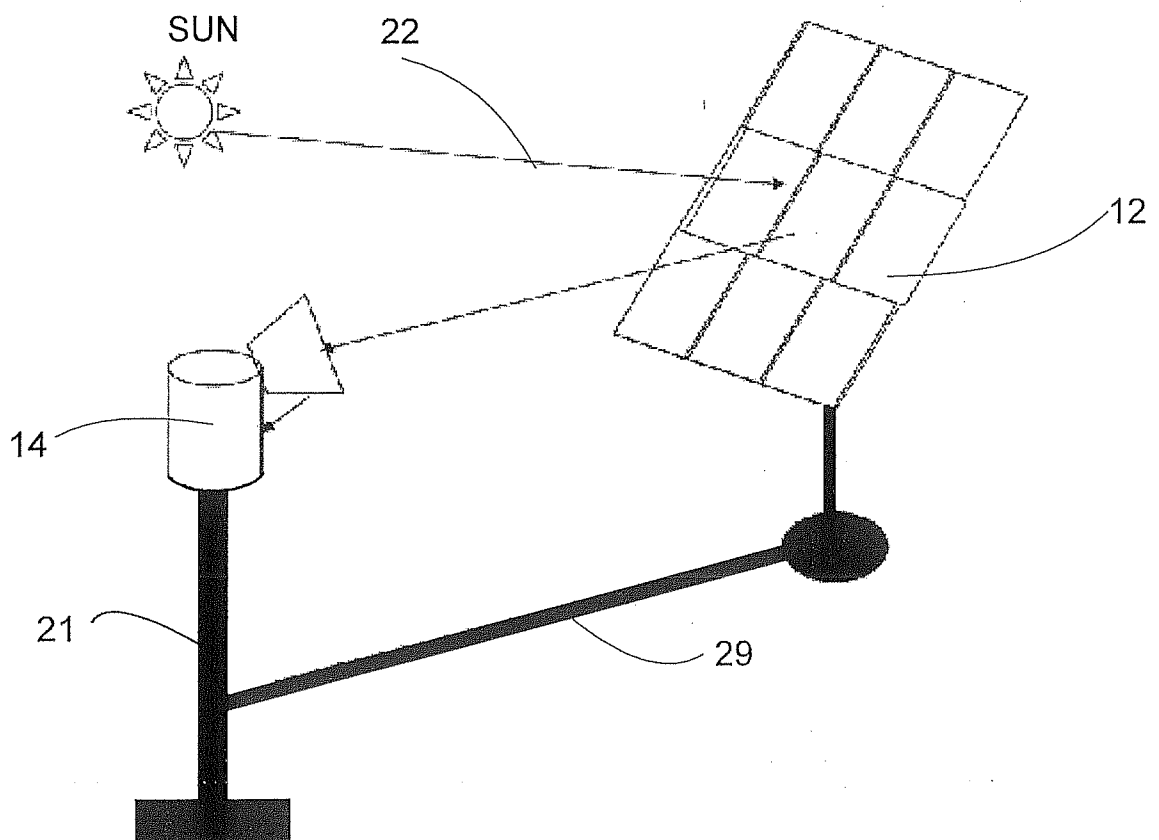


Fig. 9

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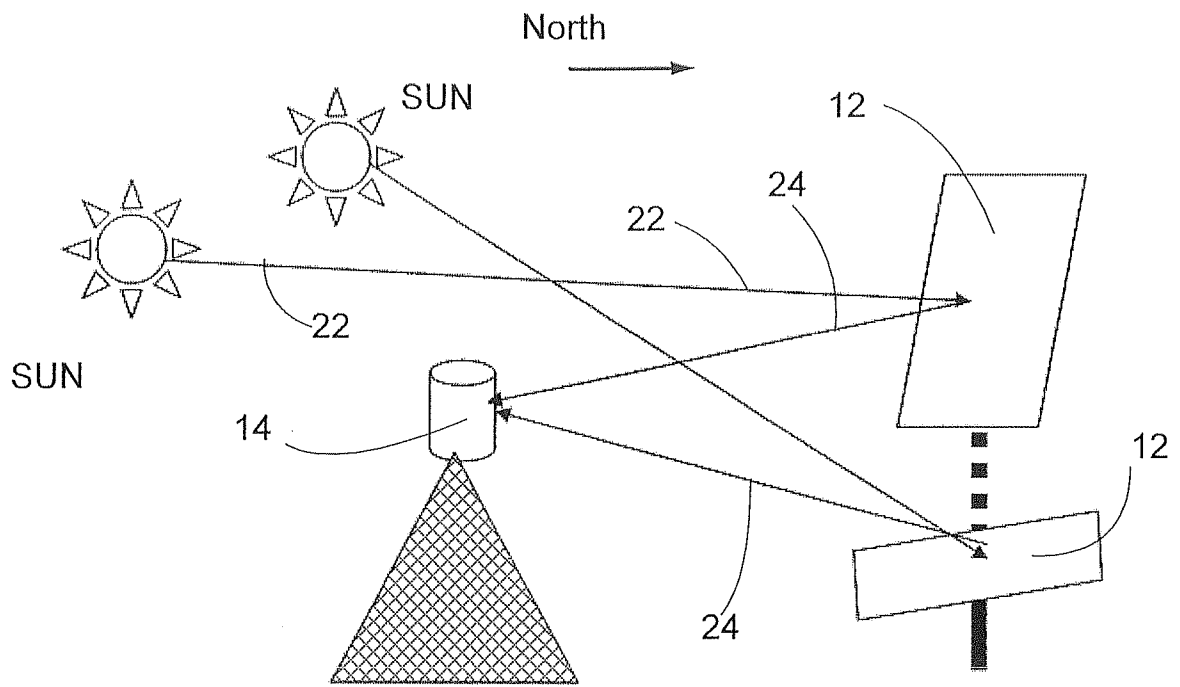


Fig. 10

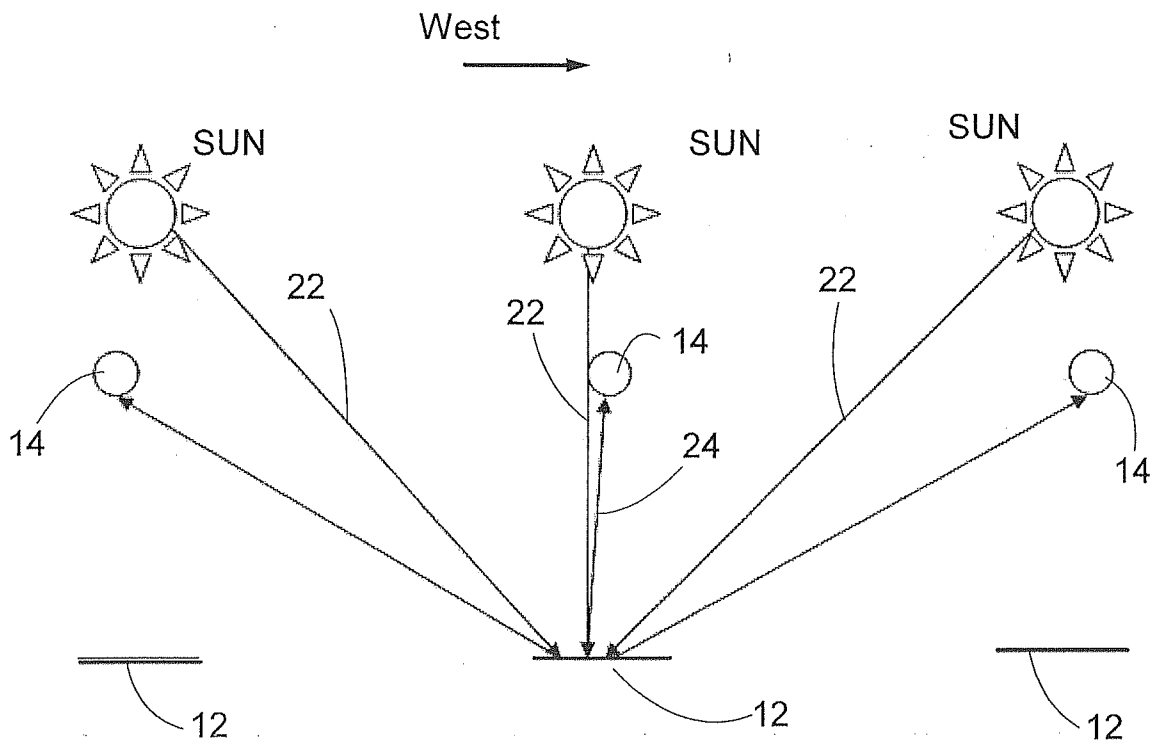


Fig. 11

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100	Positioning and interconnecting thermal receivers in a specified geometric configuration
110	Mounting the thermal receivers on stands in specified heights
120	Positioning optical elements such as to intercept solar radiation and to reflect it onto the thermal receivers
130	Connecting the thermal receivers to at least one thermal storage element
140	Washing the optical elements regularly and automatically

Fig. 12

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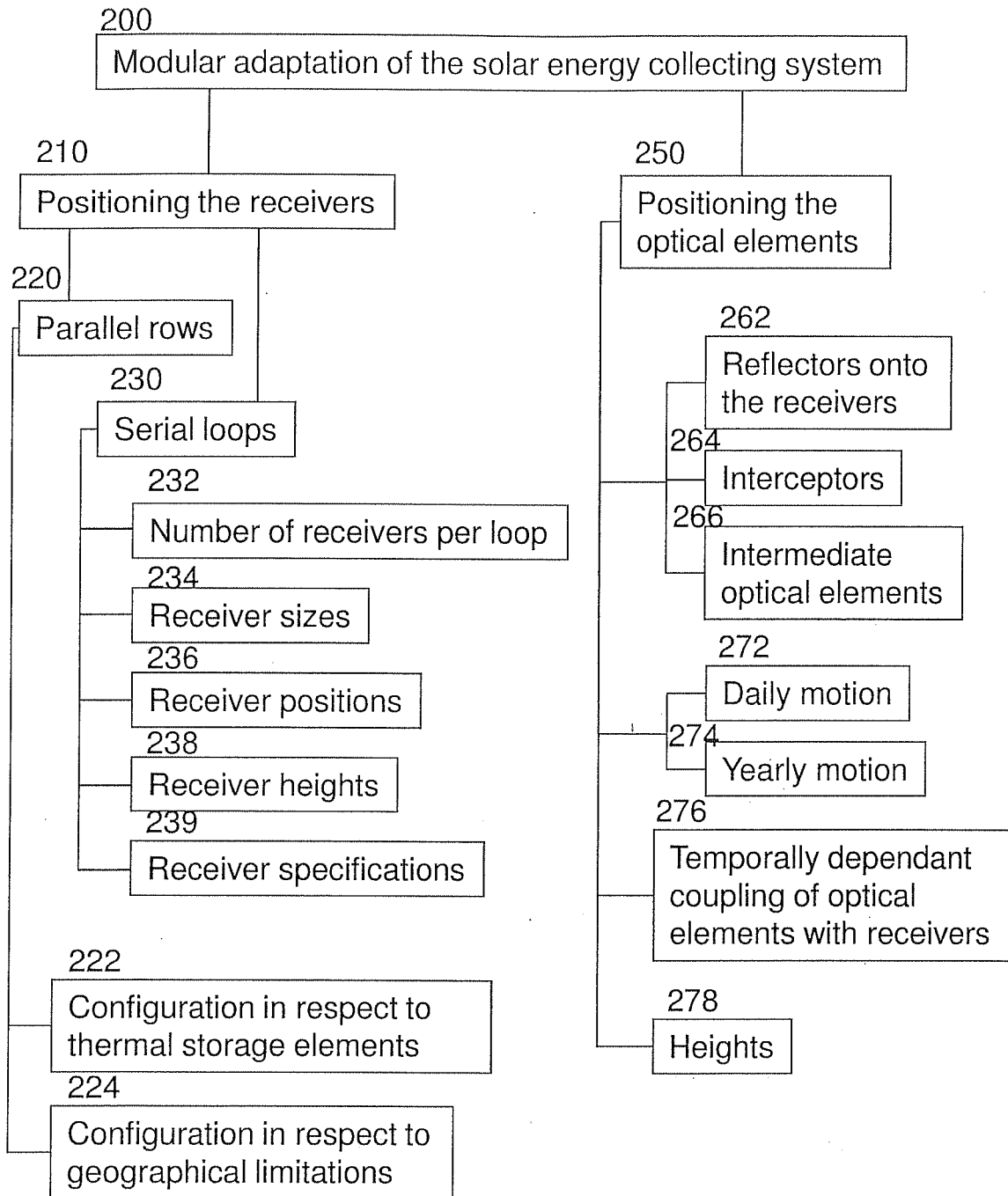


Fig. 13

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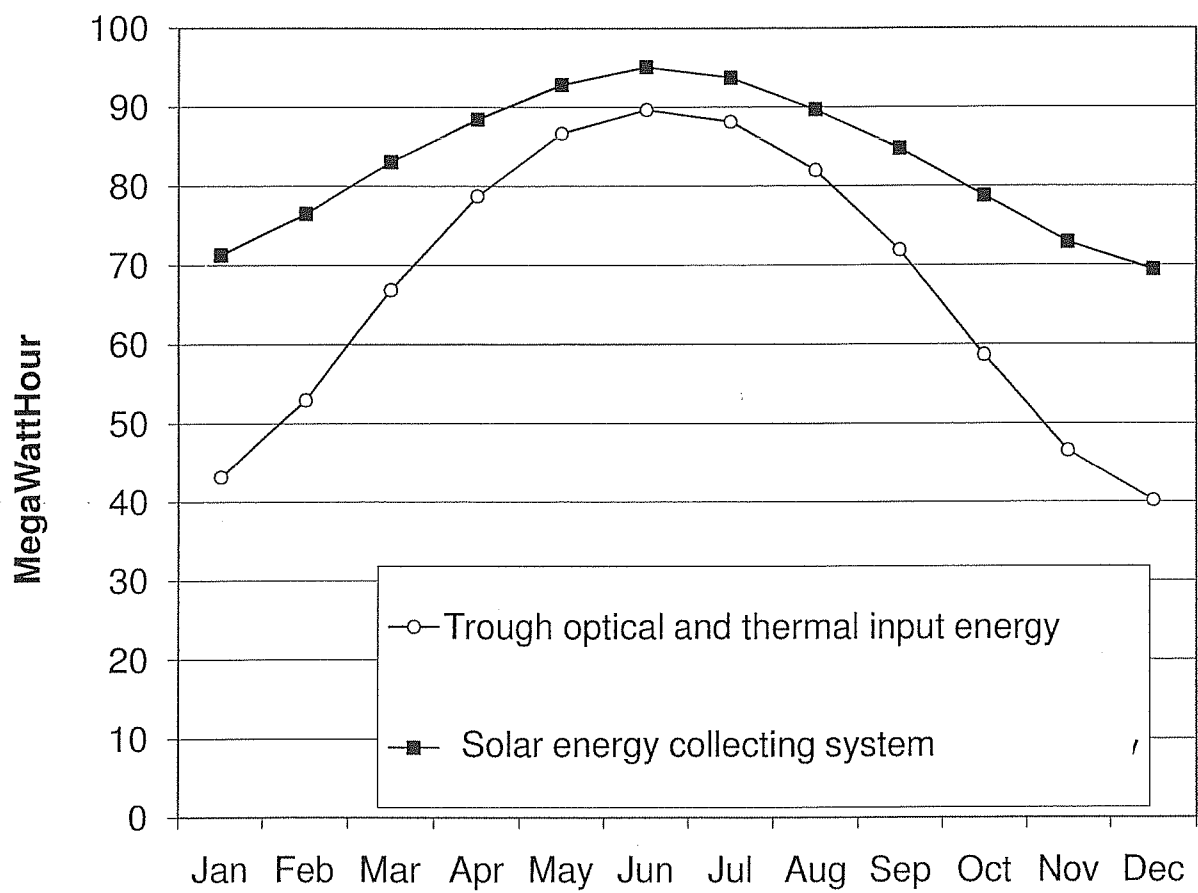


Fig. 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB 09/55944

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F24J 2/00 (2010.01)

USPC - 126/569

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

USPC - 126/569

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 126/569-571, 600, 704-713 (keyword limited - see below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PubWEST(PGPB,USPT,EPAB,JPAB), Google Scholar

Search terms used: solar, radiation, trap, collector, tube, pipe, conduit, fluid, stand, tower, heliostat, tracking, heat, thermal, storage, connect, receiver, rotate, adjustment, clean, wash, intermediate, optic, mirror, secondary, serial

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,276,872 A (BLAKE et al.) 07 July 1981 (07.07.1981) entire document, especially; col 1, ln 29-30; col 5, ln 35 - col 8 ln 46; Fig. 6	1-2, 5-20 ----- 3-4
Y	US 2008/0087276 A1 (ZHAO) 17 April 2008 (17.04.2008) entire document, especially; para [0029]	3-4
A	US 2005/0126170 A1 (LITWIN) 16 June 2005 (16.06.2005) entire document	1-20
A	US 6,530,369 B1 (YOGEV et al.) 11 March 2003 (11.03.2003) entire document	1-20



Further documents are listed in the continuation of Box C.



* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 May 2010 (24.05.2010)

Date of mailing of the international search report

15 JUN 2010

Name and mailing address of the ISA/US

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