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(54) **LOW CONCENTRATION SOLAR COLLECTOR SYSTEM**

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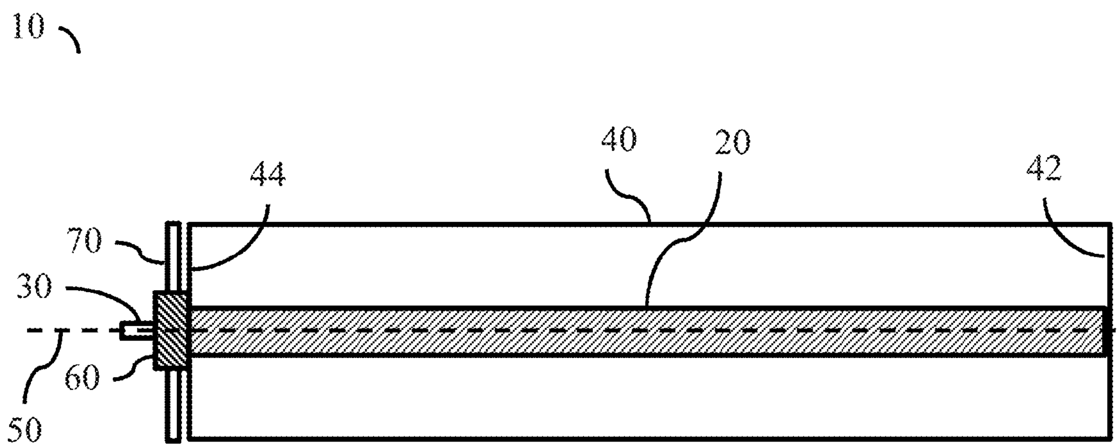
(57) **ABSTRACT**

A device and system for providing low concentration solar collection is disclosed. The device comprises a reflective parabolic trough, an evacuated tube collector, and a geared element for enabling the trough to utilize one-axis solar tracking. The system utilizes arrays of the solar collection devices, connected to a motor or actuator, to synchronize the tracking of each of the solar collection devices in the array. The heated fluid in each solar collection device is then transferred to a fluid flowing in a fluid transfer tube, where the fluid can be transported to a storage system for future power generation.



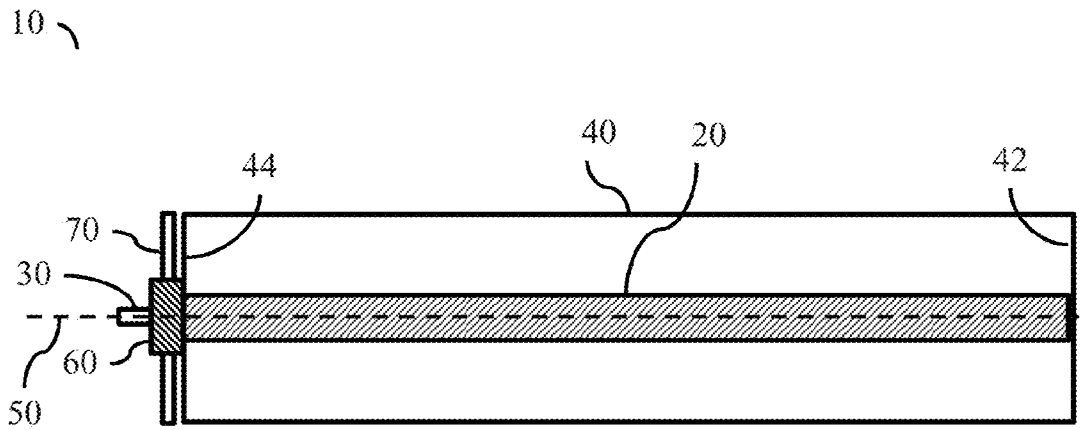


FIG. 1A

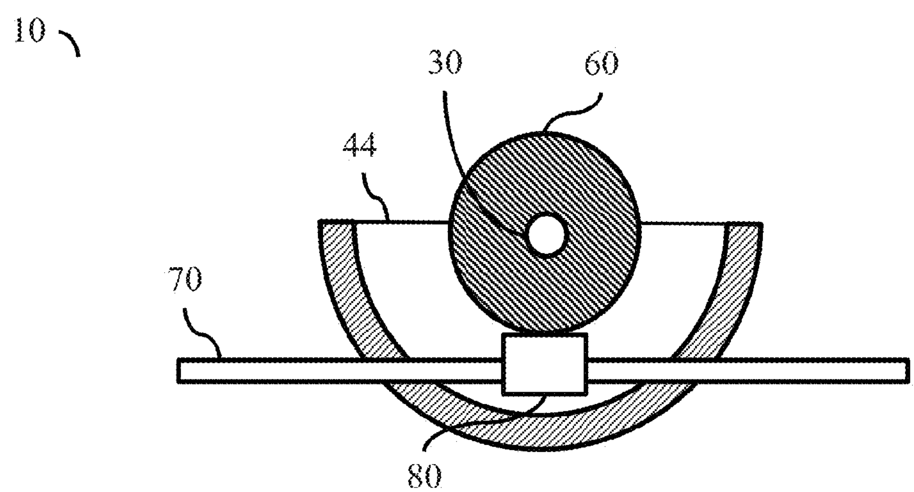


FIG. 1B

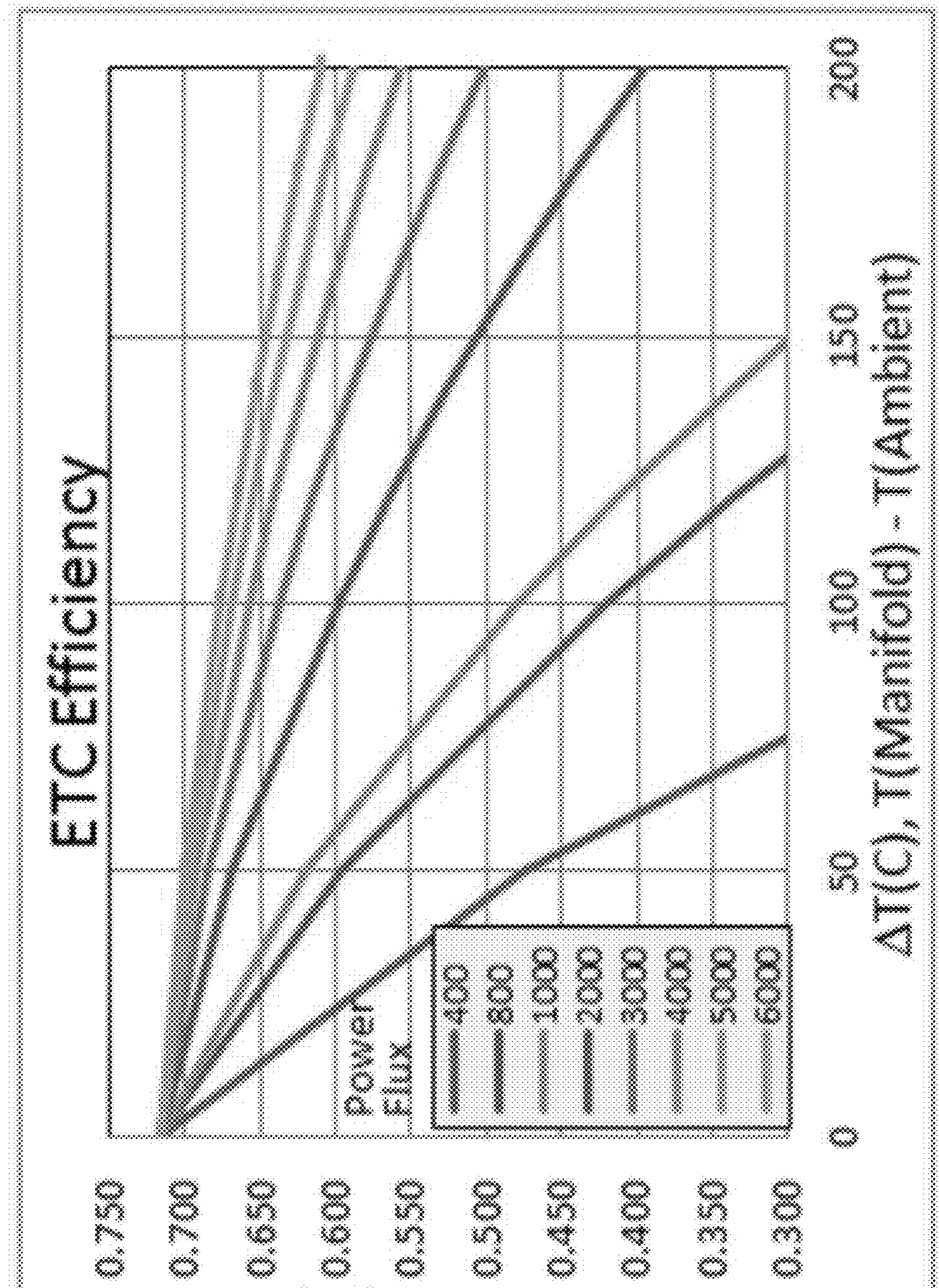

ETC Efficiency
Efficiency, η
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0
50
100
150
200
ΔT(C), T(Manifold) - T(Ambient)
Power Flux
400
800
1000
2000
3000
4000
5000
6000

FIG. 2

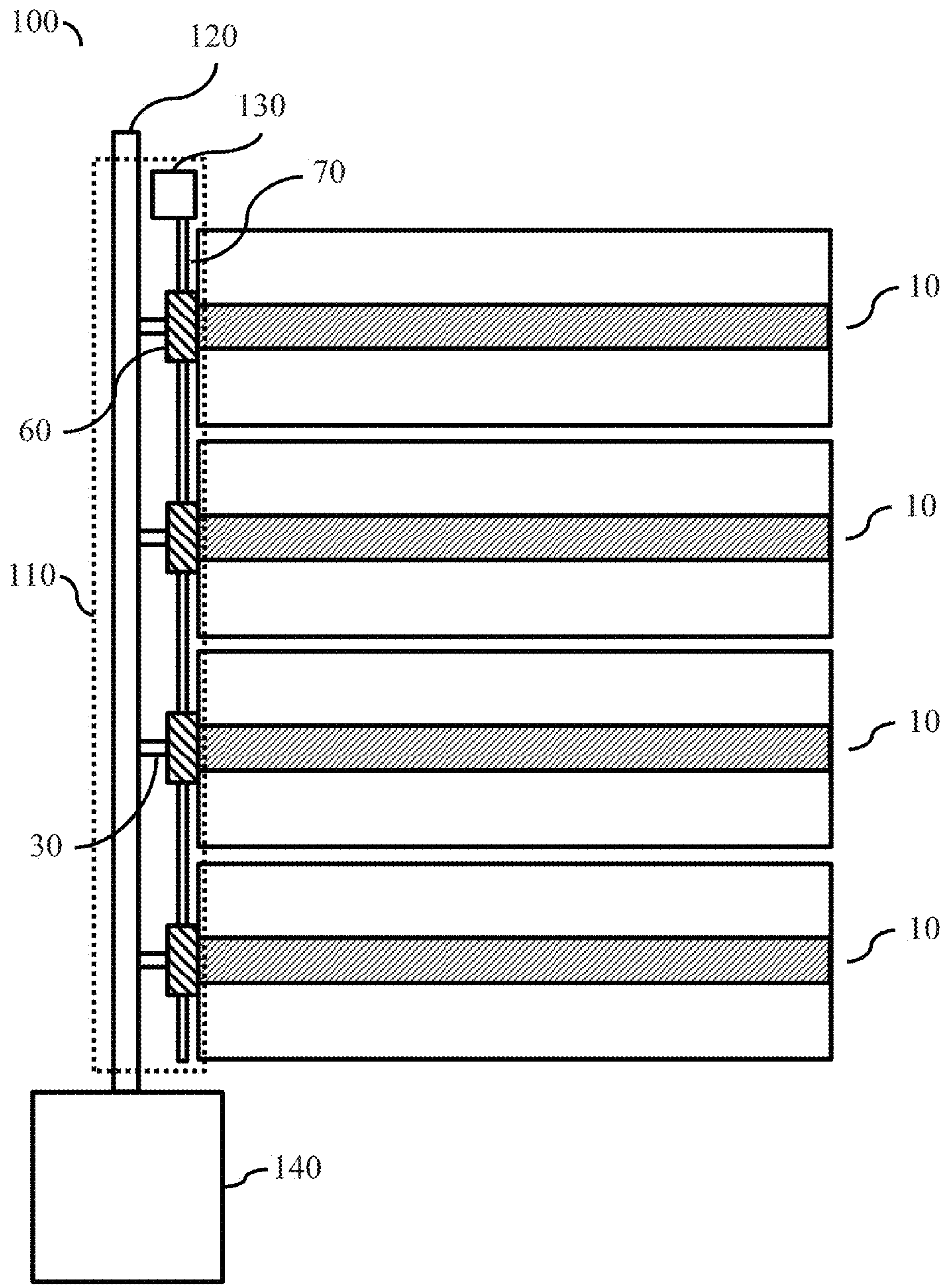


FIG. 3

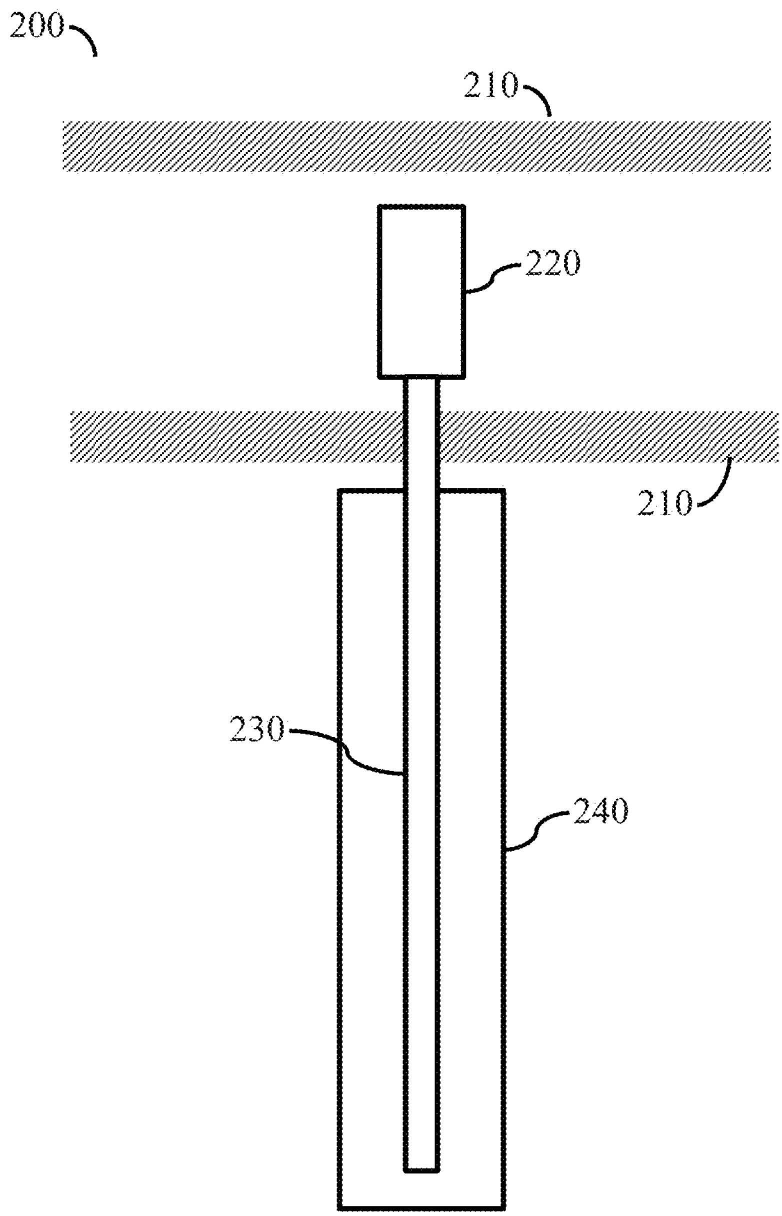


FIG. 4

LOW CONCENTRATION SOLAR COLLECTOR SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of U.S. Patent Application No. 62/356,126, filed Jun. 29, 2016, which is hereby incorporated in its entirety by reference.

BACKGROUND

[0002] Solar energy can be captured in a variety of ways, the most commonly recognized way being through the use of photovoltaics in solar panels, where the sun's energy is converted to electrical energy. However, a solar thermal collector is a device for capturing solar radiation, collecting heat by absorbing sunlight, and transferring that heat to some means for storing the heat, typically involving a heat transfer fluid.

[0003] As used in the industry, the term "solar collector" refers to a variety of actual device types, including but not limited to solar hot water panels, solar parabolic troughs, solar towers, or solar air heaters. Simple collectors are typically used in residential and commercial buildings for space heating. Concentrated solar power plants usually use the more complex collectors to generate electricity by heating a fluid to drive a turbine connected to an electrical generator.

[0004] Solar collectors are either non-concentrating or concentrating. In the non-concentrating type, the collector area (i.e., the area that intercepts the solar radiation) is the same as the absorber area (i.e., the area absorbing the radiation). In these types the whole solar panel absorbs light. Concentrating collectors have a bigger interceptor than absorber. Flat-plate and evacuated-tube solar collectors are used to collect heat for space heating, domestic hot water or cooling with an absorption chiller.

[0005] However, solar collectors, if used, have generally focused on domestic power generation, to provide power to thousands of households. These systems cost millions of dollars, and maximize concentration by using hundreds or thousands of mirrors to focus on a tower receiver to heat unique fluids, such as molten salts, to extremely high temperatures, often upwards of 500 degrees C. Little effort has been spent on developing small scale, affordable systems that do not generate or require such unique fluids to be kept at high temperature. Thus, an inexpensive, low-concentration solar collector system is desirable.

SUMMARY OF THE INVENTION

[0006] The present invention is drawn to a low-concentration solar collection device and system. Disclosed is a solar collector device that utilizes a reflective parabolic trough capable of one-axis solar tracking, to concentrate solar energy in an evacuated tube collector. Among the many possibilities considered, the device may advantageously utilize a parabolic trough composed of polycarbonate, and may be twin walled. It is contemplated that the device may also utilize a sleeve bearing, which may be composed of ultra-high molecular weight (UHMW) polyethylene, and the device may come in a variety of lengths, including between 1.5 and 3 meters long. It is also contemplated that the parabolic trough may advantageously be designed to have a concentration between about 3 and about 20. It is further contemplated that the devices may be incorporated into arrays, such as an array of 20 to 30 solar collectors, and these arrays may be, for example, 5 to 7 meters in width. It is contemplated that these devices and arrays may utilize a variety of means for the one-axis tracking, but may advantageously utilize an actuator connected to a shaft with teeth on one surface, the teeth meshing with the geared element of each of the solar collector devices, a motor connected to a gear, the gear connected to a chain or belt, the chain or belt connected to the geared element of each of the solar collector devices, or a motor connected to a shaft, the shaft connected to a plurality of worm gears, each worm gear meshed with the geared element of one of the solar collector devices.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1**A is a top-down depiction of one embodiment of a solar collector.

[0008] FIG. **1**B is an end view of one embodiment of a solar collector.

[0009] FIG. **2** is a graph illustrating a representative uptake diagram.

[0010] FIG. **3** is a top-down depiction of one embodiment of an array of solar converters.

[0011] FIG. **4** is a cross-sectional view of one embodiment of an evacuated tube collector connected to the manifold.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Before the present invention is described in further detail, it is to be understood that the invention is not limited to the particular embodiments described, as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims.

[0013] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the invention. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges is also encompassed within the invention, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the invention.

[0014] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those described herein can also be used in the practice or testing of the present invention, a limited number of the exemplary methods and materials are described herein.

[0015] It must be noted that as used herein and in the appended claims, the singular forms "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

[0016] Many methods for collecting solar heat exist. For certain purposes, flat-plate collectors are typically precluded due to low collection efficiency at target temperatures. Disclosed is a low-concentration solar collector system that utilizes evacuated tube collectors (ETC). High-concentration factors required for solar thermal electrical generation (e.g., temperatures above 400° C.) are not necessary for all applications; even moderate concentration may be beneficial in some applications.

[0017] One aspect of a system with moderate concentrating efficiencies is illustrated in FIGS. **1**A and **1**B. FIG. **1**A is a top-down view of one concentrator (**10**) of a system. The concentrator (**10**) comprises an ETC (**20**) with thermosiphoning heat pipes or a U-shaped tubes for circulation of thermal-transfer fluid (**30**), which run substantially the entire length of the ETC (**20**). The concentrator (**10**) also comprises a reflective parabolic trough (**40**), which is adapted to rotate at least partially around a central axis (**50**). The parabolic trough preferably has two end pieces (**42**, **44**) to provide, e.g., a connection to the ETC to enable rotation. A hole, or a cut-out, is made in one or both of the end pieces (**44**) through which at least the thermosiphoning heat pipes or U-shaped pipe (**30**), and typically the entire ETC (**20**) can run. Typically, sleeve bearings (not shown) will be used in the holes to allow the trough (**40**) to rotate around the ETC (**20**) smoothly and to ensure the connection between the ETC and the trough exhibits minimal wear.

[0018] In preferred embodiments, the trough (**40**) is adapted to rotate through at least a 90 degree arc over the course of normal daylight hours. The trough (**40**) as a whole, preferably via one end piece (**44**), is connected to a geared element (**60**). The geared element (**60**) allows mechanical power provided by the shaft (**70**) to control the rotation of the parabolic trough (**40**).

[0019] FIG. **1**B is an end view of a solar collector (**10**), illustrating that the geared element (**60**) could be connected to, for example, a worm gear (**80**) on a rotatable shaft (**70**). In other embodiments, the shaft itself may comprise teeth for meshing with the geared element (**60**); in these embodiments, the shaft would not rotate, but would be actuated. Alternatively, element (**70**) may not be a shaft, and may instead be a chain, and the geared element is turned by the chain.

[0020] FIG. **2** plots the efficiency of ETCs used for solar hot water as a function of solar flux and ΔT. As seen, for a temperature difference of 130-160° C., unconcentrated solar flux would produce low efficiency even for ETCs. However, a concentration factor of six results in good efficiencies even with low winter solar irradiance between 400-800 W/m^2. One embodiment of the present invention utilizes ETCs with thermosiphoning heat pipes for several reasons, including for improved reliability.

[0021] Concentration is a description of how many times more energy is directed to a collector over what would otherwise naturally reach the collector, and for any optical system, it is the ratio of the optical area to the collector area. Concentration solves the issue of low aperture to cost ratio for ETCs, which have long been used for solar distillation since the 1970s. Although ETC cost is relatively low, low ETC aperture area (e.g., 0.094 m^2 for a typical 2 m, 58 mm diameter tube) still results in high areal cost for the evacuated tube alone. Increasing the aperture area, e.g., six-fold, using a concentrating reflector will achieve both higher output temperature and reduce collection areal cost.

[0022] These low cost evacuated solar thermal collection tubes coupled with 1 dimensional tracking parabolic troughs allow mid-grade heat at, for example, 150-180° C. to be collected efficiently and cheaply compared to photovoltaics. Coupled with hot water storage at moderate pressures (e.g., 10 atm, which is the same pressure home hot water heaters are designed for), thermal solar collection and storage can be made roughly an order of magnitude less expensive than solar electricity.

[0023] Therefore, solar concentrators capable of tracking are advantageous. As used herein, low concentration systems are understood to be systems in which the concentrations are greater than 1, but less than about 20. In preferred systems, the concentrations are from about 3 to about 20. For example, one embodiment uses a 14 inch parabolic trough with a 2 inch diameter collector, for a concentration of 7.

[0024] All concentrating optics balance concentration factor C with acceptance angle θ_a, where acceptance angle is the maximum angle at which incoming sunlight can be captured by a solar concentrator. The upper limit for concentration factor C is given by $C=1/\sin(\theta_a)$.

[0025] For example, in an embodiment with a concentration factor of six, the acceptance angle is 9.6°, which will not capture most of the total solar insolation for east-west tracking. This simple argument is supported by published results.

[0026] Although many configurations are envisioned for the concentrator, a parabolic trough reflector using twin walled polycarbonate sheets is preferred. Polycarbonate is a highly durable polymer used for optical discs (CD, DVDs) and as a layer in bulletproof glass. The material has a very high stiffness to weight ratio, making it increasingly popular as a construction material for roofing. Increasing popularity for construction has reduced the cost and improved the endurance to prolonged outdoor exposure.

[0027] As one example of the preferred concentrator, twin wall polycarbonate sheets were thermoformed into light (approximately 2.5 pounds each) and stiff parabolic troughs by aligning reinforcement ribs perpendicular to the trough direction. 2 m long by 0.3 m wide by 0.1 m thick troughs are stiff enough to be completely self-supporting without torque tubes or trusses, although other dimensions are also envisioned. In some embodiments, the length of the trough is between 1.5 and 3 meters in length, between 0.2 and 0.5 meters wide, and between 0.05 and 0.3 meters thick. These concentrators are designed to be hung directly to the ETCs using the ETC itself as the axle. Low friction, long-wearing ultra-high molecular weight (UHMW) polyethylene will be used for sleeve bearings. In this example, the low profile troughs do not exceed the thickness of the manifold.

[0028] Although many reflective surfaces are envisioned, preferably, a mirror film will be the reflecting surface that faces the ETC. This mirror film will preferably have been both lab and field tested for endurance to outdoor conditions and maintain a very high (>90%) reflectance for over multiple years.

[0029] In practice, arrays of solar converters are typically utilized. An array preferably comprises a plurality of the concentrators and at least one means for actuating the concentrators. In some systems, multiple arrays are deployed to power one or more devices. One preferred embodiment utilizes 28 arrays, where each array is roughly 6 m wide by 2.3 m tall by 0.15 m thick with collection aperture of 11.5 m^2. In other embodiments, the arrays are between 5 and 14 meters wide. In this embodiment, spacing between troughs permits about 60° of tracking without self-shading. These arrays preferably have low profiles and are stackable, especially for transportation purposes.

[0030] The means for actuating the concentrators varies, depending on the number of degrees of tracking that is desired. Many methods are already well known in the industry. One preferred method utilizes a 1-axis tracking mechanism integrated into a thermal manifold, typically inside the same housing. In one embodiment of this mechanism, actuation of an entire array of reflectors will be accomplished by a single electric motor coupled using a worm drive made up of steel rods and polymer gears commonly used in garage door openers. FIG. **2** depicts a top-down view of such a system (**100**). In the system (**100**), each solar concentrator (**10**) is connected to a manifold (**110**), the manifold covering the fluid transfer pipes (**120**) connected to the thermosiphoning heat pipes (**30**) of each solar collector (**10**), for transferring heat from the ETC to a fluid that is part of a fluid storage system (**140**). The fluid storage system can utilize any fluid, although preferably it stores hot water. The manifolds preferably also utilize sealed thermosiphon heat pipes (**120**) similar to those used in hot water heating for reliability. However, due to the increased thermal load, the heat pipes will typically be enlarged from, for example, ⅜" diameter to 1", with internal pressures increased to operate at higher temperatures. Thermal connections and pipe diameters inside the manifold will need similar enlargement. One embodiment is shown in FIG. **4**, where a heat pipe condenser (**220**) is connected to thermosiphoning tube (**230**) that is at least partially within the evacuated tube (**240**). The heat pipe condenser (**220**) is at least partially within the walls (**210**) of the fluid transfer pipes. As fluid flows through the fluid transfer pipes, the heat from the condenser (**220**) transfers to the fluid.

[0031] The geared element (**60**) of each solar collector (**10**) is controlled by a single shaft (**70**), which may be controlled by a motor, actuator, or other device (**130**). The motor (**130**) may be controlled by, for example, a processor, a timer, light sensor. While any amount of rotation is envisioned, including 360 degree rotation capability, preferred embodiments utilize a motor adapted to rotate the parabolic trough 90 degrees, from 45 degrees east to 45 degrees west, over the course of normal daylight hours. In other preferred embodiments, the rotation angle may be limited to about 60 degrees (i.e., to minimize self-shading). In some embodiments the system rotates each trough a fixed amount every 5 minutes, for example, to minimize power consumption while still enabling solar tracking.

[0032] Thus, specific devices and systems utilizing low concentration solar collectors have been disclosed. It should be apparent, however, to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the spirit of the disclosure. Moreover, in interpreting the disclosure, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms "comprises" and "comprising" should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced.

What is claimed is:

1. A solar collector device comprising:
an evacuated tube collector having an end portion;
a low-concentration parabolic trough having an end wall and at least one reflective surface facing the evacuated tube collector, the trough connecting to the evacuated tube collector; and
a geared element connected to the end wall.

2. The solar collector device according to claim **1**, wherein the parabolic trough is comprised of polycarbonate.

3. The solar collector device according to claim **2**, wherein at least a portion of the trough is twin walled.

4. The solar collector device according to claim **1**, further comprising a sleeve bearing.

5. The solar collector device according to claim **4**, wherein the sleeve bearing is comprised of ultra-high molecular weight (UHMW) polyethylene.

6. The solar collector device according to claim **1**, wherein the parabolic trough is between 1.5 and 3 meters in length.

7. The solar collector device according to claim **1**, wherein the concentration of the system is between about 3 and about 20.

8. The solar collector device according to claim **1**, wherein the evacuated tube collector is the physical axis for the rotation of the parabolic trough.

9. A solar collection system comprising
a plurality of solar collector devices, each device comprising:
an evacuated tube collector having an end portion and at least one thermosiphoning tube;
a parabolic trough having an end wall and at least one reflective surface facing the evacuated tube collector, the trough connecting to the evacuated tube collector; and
a geared element connected to the end wall;
a means for rotating the parabolic trough of each of the solar collector devices; and
a fluid transfer tube connected to each thermosiphoning tube.

10. The solar collection system of claim **9**, wherein the means for rotating the parabolic trough and a thermal fluid manifold operably connected to the thermosiphonic tubes are both housed within a first housing.

11. The solar collection system of claim **9**, wherein the means for rotating the geared element is selected from the group consisting of:
an actuator connected to a shaft with teeth on one surface, the teeth meshing with the geared element of each of the solar collector devices,
a motor connected to a gear, the gear connected to a chain, the chain connected to the geared element of each of the solar collector devices, or
a motor connected to a shaft, the shaft connected to a plurality of worm gears, each worm gear meshed with the geared element of one of the solar collector devices.

12. The solar collection system of claim **9**, further comprising a processor adapted to control the means for rotating the parabolic trough of each of the solar collector devices.

13. The solar collection system of claim **9**, wherein the number of solar collector devices is between 10 and 50.

14. The solar collection system of claim **9**, wherein each collection system is between 5 and 14 meters wide.

* * * * *