Recent Patents in Solar Energy Collectors and Applications

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Abstract: Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The solar collector is the major component of any solar system. There are basically two types of solar collectors: non-concentrating or stationary and concentrating. The latter require some kind of tracking mechanism so as to allow the collector to follow the apparent movement of the sun with certain accuracy. This paper reviews various recent patents in both types of collectors, tracking mechanisms and various applications. The patents reviewed concern a period extending from the years 2002 up to date. The patents included in this review refer mainly to solar collectors which include flat plate, parabolic troughs and central receiver collectors, whereas a number of patents concern the development of mechanisms for tracking the sun. The applications concern mainly integrated collector storage, water heating systems, solar desalination, absorption cooling, air conditioning and refrigeration. The list of patents reviewed is by no means complete or extensive it shows however the extent of the subjects covered in patents in this area during the last four years. The paper concludes with a description of the future developments expected in the subjects covered.

Keywords: Flat plate collectors, parabolic trough collectors, central receiver systems, solar tracking mechanism, solar water heating, solar cooling, solar desalination.

1. INTRODUCTION

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days.

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and for absorbing solar radiation whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. Solar energy collectors are basically distinguished by their motion, i.e., stationary, single axis tracking and two-exes tracking, and by their operating temperature. A large number of solar collectors are available in the market. A comprehensive list is shown in Table 1 [1].

In this section a review of the various types of collectors currently available will be presented. This includes stationary (non-concentrating) and concentrating collectors.

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1.1. Stationary Collectors

These collectors are permanently fixed in position and do not track the sun. Three types of collectors fall in this category:

- Flat plate collectors (FPC)
- Stationary compound parabolic collectors (CPC)
- Evacuated tube collectors (ETC)

1.1.1. Flat-plate Collectors (FPC)

A typical flat-plate solar collector is shown in Fig. (**1**). When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes [1].

The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect).

Flat plate collectors (FPC) are by far the most used type of collector. Flat-plate collectors are usually employed for low temperature applications up to 80°C. Flat plate collectors are permanently fixed in position and require no tracking of the sun. The collectors should be oriented

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Table 1. Solar Energy Collectors

Motion	Collector type	Absorber shape	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat plate collector (FPC)	Flat	1	30-80
	Evacuated tube collector (ETC)	Flat	1	50-200
	Compound parabolic collector (CPC)	Tubular	1-5	60-200
Single-axis tracking			5-15	80-300
	Linear Fresnel reflector (LFR)	Tubular	10-40	80-250
	Parabolic trough collector (PTC)	Tubular	15-45	80-300
	Cylindrical trough collector (CTC)	Tubular	10-50	80-300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100-1000	100-500
	Heliostat field collector (HFC)	Point	100-1500	150-2000

Note: Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.

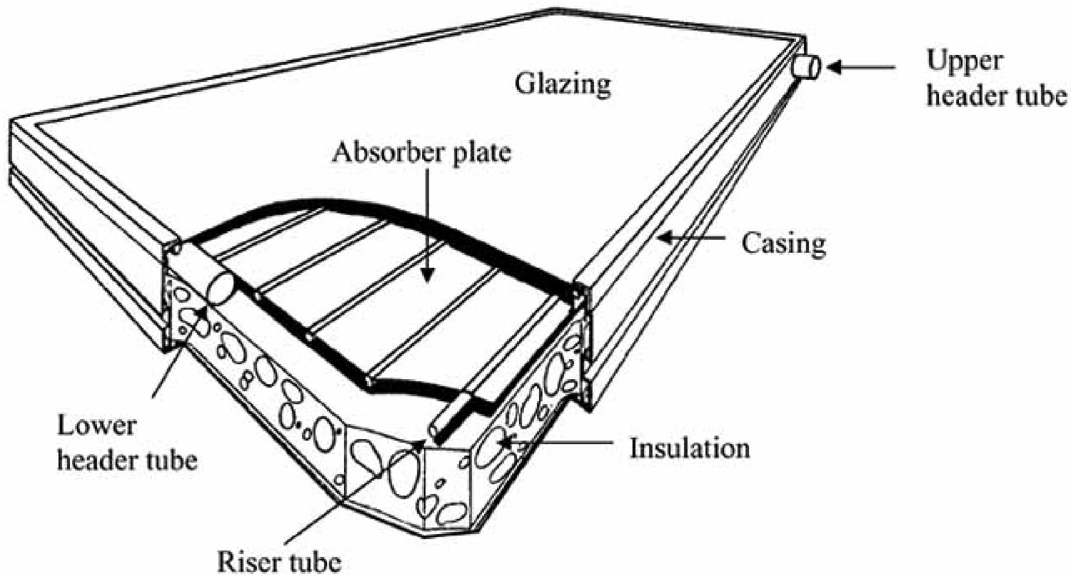

Fig. (1). Flat-plate collector detail.

directly towards the equator, facing south in the northern hemisphere and north in the southern. Flat-plate collectors have been built in a wide variety of designs and from many different materials. They have been used to heat fluids such as water, water plus antifreeze additive, or air. The collector should also have a long effective life, despite the adverse effects of the sun's ultraviolet radiation, corrosion and clogging because of acidity, alkalinity or hardness of the heat transfer fluid, freezing of water, or deposition of dust or moisture on the glazing.

1.1.2. Compound Parabolic Collectors (CPC)

Compound parabolic collectors (CPC) have the capability of reflecting to the absorber all of the incident radiation within wide limits. The necessity of moving the concentrator to accommodate the changing solar orientation can be reduced by using a trough with two sections of a parabola facing each other, as shown in Fig. (**2**).

Compound parabolic concentrators, can accept incoming radiation over a relatively wide range of angles. By using multiple internal reflections, any radiation that is entering the aperture, within the collector acceptance angle, finds its way to the absorber surface located at the bottom of the collector. The absorber can be cylindrical as shown in Fig. (**2**) or flat. In the CPC shown in Fig. (**2**) the lower portion of the reflector (BC and CD) is circular while the upper portions (AB and DE) are parabolic. As the upper part of a CPC contribute little to the radiation reaching the absorber, they are usually truncated thus forming a shorter version of the CPC, which is also cheaper. CPC's are usually covered with glass to avoid dust and other materials from entering the collector and thus reducing the reflectivity of its walls [1].

These collectors are more useful as linear or trough-type concentrators. The orientation of a CPC collector is related to its acceptance angle, [θ_c, in Fig. (**2**)]. Also depending on

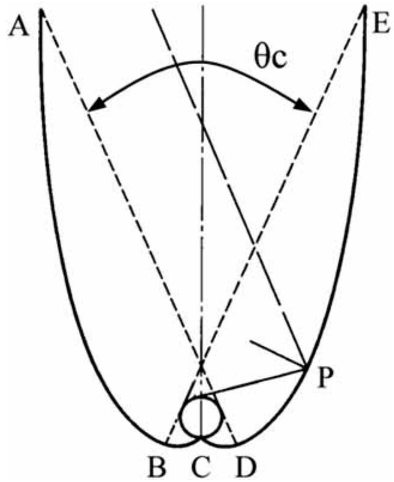

Fig. (2). Schematic diagram of a CPC collector.

the collector acceptance angle, the collector can be stationary or tracking. A CPC concentrator can be orientated with its long axis along either the north-south or the east-west direction and its aperture is tilted directly towards the equator at an angle equal to the local latitude. When orientated along the north-south direction the collector must track the sun by turning its axis so as to face the sun continuously. As the acceptance angle of the concentrator along its long axis is wide, seasonal tilt adjustment is not necessary. It can also be stationary but radiation will only be received during the hours when the sun is within the collector acceptance angle. When the concentrator is orientated with its long axis along the east-west direction, with a little seasonal adjustment in tilt angle the collector is able to catch the sun's rays effectively through its wide acceptance angle along its long axis.

Two basic types of CPC collectors have been designed; the symmetric and the asymmetric. These usually employ two main types of absorbers; fin type with pipe and tubular absorbers.

1.1.3. Evacuated Tube Collectors (ETC)

Evacuated heat pipe solar collectors (tubes) consist of a heat pipe inside a vacuum-sealed tube, as shown in Fig. (**3**). Evacuated tube collectors have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures (~150°C). Both direct and diffuse radiation can be collected [1].

Evacuated tube collectors use liquid-vapor phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate). Protruding from the top of the tube is a metal tip attached to the sealed pipe (condenser). The heat pipe contains a small amount of fluid (e.g. methanol) that undergoes an evaporating-condensing cycle. In this cycle, solar heat evaporates the liquid, and the vapor travels to the heat sink region where it condenses and releases its latent heat. The condensed fluid return back to the solar collector and the process is repeated. When these tubes are mounted, the metal tips up, into a heat exchanger (manifold) as shown in Fig. (**3**). Water, or glycol, flows through the manifold and picks up the heat from the tubes. Because no evaporation or condensation above the phase-change temperature is possible, the heat pipe offers inherent protection from freezing and overheating. This self-limiting temperature control is a unique feature of the evacuated heat pipe collector.

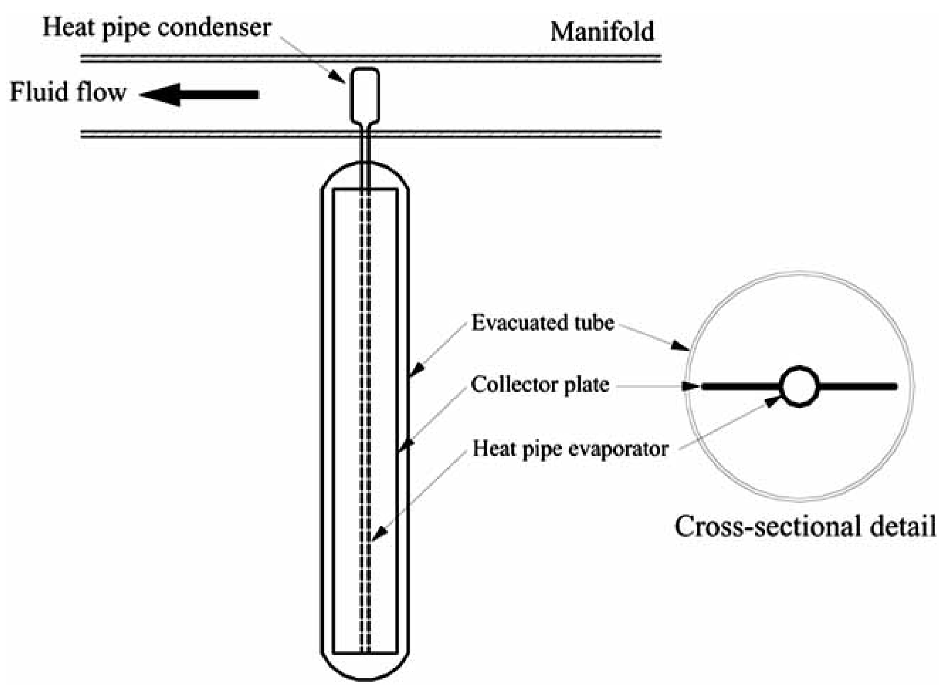

Fig. (3). Schematic diagram of an evacuated tube collector.

A large number of variations of the absorber shape of evacuated tube collectors are on the market. One design presented recently is an all-glass evacuated tube collector, which may be an important step to cost reduction and increase of lifetime.

Another type of collector developed recently is the integrated compound parabolic collector (ICPC). This is an evacuated tube collector in which at the bottom part of the glass tube a reflective material is fixed. The collector combines the vacuum insulation and non-imaging stationary concentration into a single unit. For high temperature applications, a tracking ICPC may be used [1].

1.2. Sun Tracking Concentrating Collectors

Energy delivery temperatures can be increased by decreasing the area from which the heat losses occur. Temperatures far above those attainable by flat-plate collectors can be reached if a large amount of solar radiation is concentrated on a relatively small collection area. This is done by interposing an optical device between the source of radiation and the energy absorbing surface.

In concentrating collectors solar energy is optically concentrated before being transferred into heat. Concentration can be obtained by reflection or refraction of solar radiation by the use of mirrors or lenses. The reflected or refracted light is concentrated in a focal zone, thus increasing the energy flux in the receiving target [1].

Many designs have been considered for concentrating collectors. Concentrators can be reflectors or refractors, can be cylindrical or parabolic and can be continuous or segmented. Receivers can be convex, flat, cylindrical or concave and can be covered with glazing or uncovered. Concentration ratios, i.e., the ratio of aperture to absorber areas, can vary over several orders of magnitude, from as low as unity to high values of the order of 10,000. Increased ratios mean increased temperatures at which energy can be delivered but consequently these collectors have increased requirements for precision in optical quality and positioning of the optical system.

The collectors falling in this category are:

1. Parabolic trough collector (PTC)
2. Linear Fresnel reflector (LFR)
3. Parabolic dish reflector (PDR) and
4. Heliostat field collector (HFC) or central receiver system

Because of the apparent movement of the sun across the sky, conventional concentrating collectors must follow the sun's daily motion. There are two methods by which the sun's motion can be readily tracked. The first is the altazimuth method which requires the tracking device to turn in both altitude and azimuth, i.e., when performed properly, this method enables the concentrator to follow the sun exactly. Paraboloidal solar collectors generally use this system. The second one is the one-axis tracking in which the collector tracks the sun in only one direction either from east to west or from north to south. Parabolic trough collectors generally use this system.

A tracking mechanism must be reliable and able to follow the sun with a certain degree of accuracy, return the collector to its original position at the end of the day or during the night, and also track during periods of intermittent cloud cover. Additionally, tracking mechanisms are used for the protection of collectors, i.e., they turn the collector out of focus to protect it from the hazardous environmental and working conditions, like wind gust, overheating and failure of the thermal fluid flow mechanism.

Various forms of tracking mechanisms, varying from complex to very simple, have been proposed. They can be divided into two broad categories, namely; mechanical and electrical / electronic systems. The electronic systems generally exhibit improved reliability and tracking accuracy. Recent patents of tracking mechanisms are given in section 3.

1.2.1. Parabolic Trough Collectors (PTC)

Parabolic trough collectors are made by bending a sheet of reflective material into a parabolic shape. A metal black tube, covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver as shown in Fig. (**4**). When the parabola is pointed towards the sun, parallel rays incident on the reflector are reflected onto the receiver tube. It is sufficient to use a single axis tracking of the sun and thus long collector modules are produced. The collector can be orientated in an east-west direction, tracking the sun from north to south, or orientated in a north-south direction and tracking the sun from east to west. The advantages of the former tracking mode is that very little collector adjustment is required during the day and the full aperture always faces the sun at noon time but the collector performance during the early and late hours of the day is greatly reduced due to large incidence angles (cosine loss). North-south orientated troughs have their highest cosine loss at noon and the lowest in the mornings and afternoons when the sun is due east or due west [1].

Parabolic trough collectors (PTC) can effectively produce heat at temperatures between 50°C and 400°C for solar thermal electricity generation or process heat applications. Parabolic trough technology is the most advanced of the solar thermal technologies because of considerable experience with the systems and the development of a small commercial industry to produce and market these systems. Parabolic trough collectors are built in modules that are supported from the ground by simple pedestals at either end.

The receiver of a parabolic trough is linear. Usually a tube is placed along the focal line to form an external surface receiver as shown in Fig. (**4**). The size of the tube, and therefore the concentration ratio, is determined by the size of the reflected sun image and the manufacturing tolerances of the trough. The surface of the receiver is typically plated with selective coating that has a high absorptance for solar radiation but a low emittance for thermal radiation loss.

A glass cover tube is usually placed around the receiver tube to reduce the convective heat loss from the receiver, thereby further reducing the heat loss coefficient. A disadvantage of the glass cover tube is that the reflected light from the concentrator must pass through the glass to reach the absorber, adding a transmittance loss of about 0.9, when

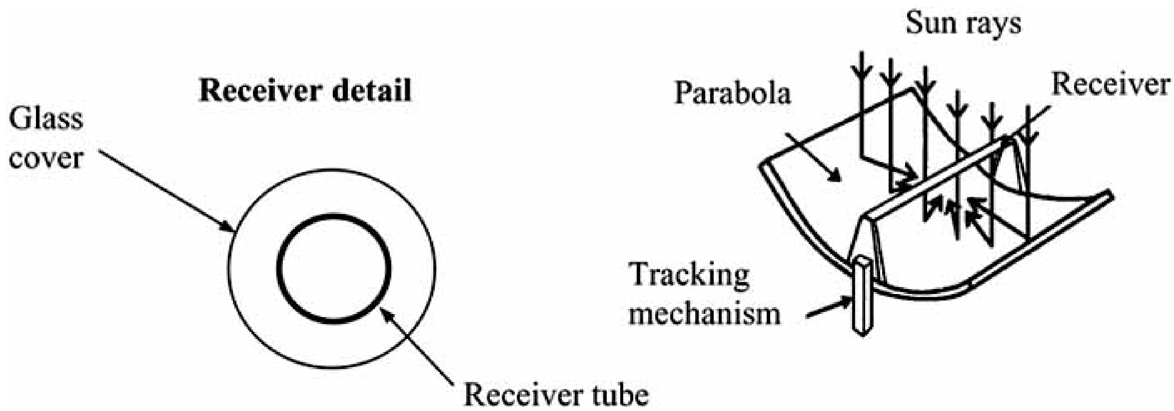

Fig. (4). Schematic diagram of a parabolic trough collector.

the glass is clean. The glass envelope usually has an anti-reflective coating to improve transmissivity. One way to further reduce convective heat loss from the receiver tube and thereby increase the performance of the collector, particularly for high temperature applications, is to evacuate the space between the glass cover tube and the receiver [1].

1.2.2. Linear Fresnel Reflector (LFR)

Linear Fresnel reflector (LFR) technology relies on an array of linear mirror strips which concentrate light on to a fixed receiver mounted on a linear tower. The LFR field can be imagined as a broken-up parabolic trough reflector as shown in Fig. (**5**), but unlike parabolic troughs, it doesn't have to be of parabolic shape, large absorbers can be constructed and the absorber does not have to move. A representation of an element of an LFR collector field is shown in Fig. (**6**). The greatest advantage of this type of system is that it uses flat or elastically curved reflectors which are cheaper compared to parabolic glass reflectors. Additionally these are mounted close to the ground, thus minimizing structural requirements [1].

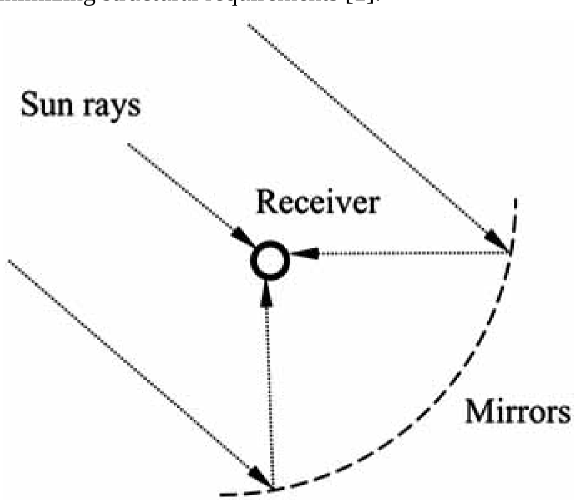

Fig. (5). Schematic diagram of a Fresnel type parabolic trough collector.

One difficulty with the LFR technology is that avoidance of shading and blocking between adjacent reflectors leads to increased spacing between reflectors. Blocking can be reduced by increasing the height of the absorber towers, but this increases cost. Alternatively, compact linear Fresnel reflector (CLFR) technology can be used. The classical LFR system has only one receiver, and there is no choice about the direction and orientation of a given reflector. However, in large systems, in the MW class, there will be many towers in the system and the individual reflectors reflect solar radiation to two towers as shown in Fig. (**7**). This provides the means for much more densely packed arrays, because patterns of alternating reflector orientation can be such that closely packed reflectors can be positioned without shading and blocking. The arrangement minimizes beam blocking by adjacent reflectors and allows high reflector densities and low tower heights to be used. Close spacing of reflectors also reduces land usage. The avoidance of large reflector spacing and tower heights is an important cost issue when the cost of ground preparation, array substructure cost, tower structure cost, steam line thermal losses and steam line cost are considered [1].

1.2.3. Parabolic Dish Reflector (PDR)

A parabolic dish reflector, shown schematically in Fig. (**8**), is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must track fully the sun to reflect the beam into the thermal receiver.

The receiver absorbs the radiant solar energy, converting it into thermal energy in a circulating fluid. The thermal energy can then either be converted into electricity using an engine-generator coupled directly to the receiver, or it can be transported through pipes to a central power-conversion system. Parabolic-dish systems can achieve temperatures in excess of 1,500°C. Because the receivers are distributed throughout a collector field, like parabolic troughs, parabolic dishes are often called distributed-receiver systems. Parabolic dishes have several important advantages [1]:

- Because they are always pointing the sun, they are the most efficient of all collector systems

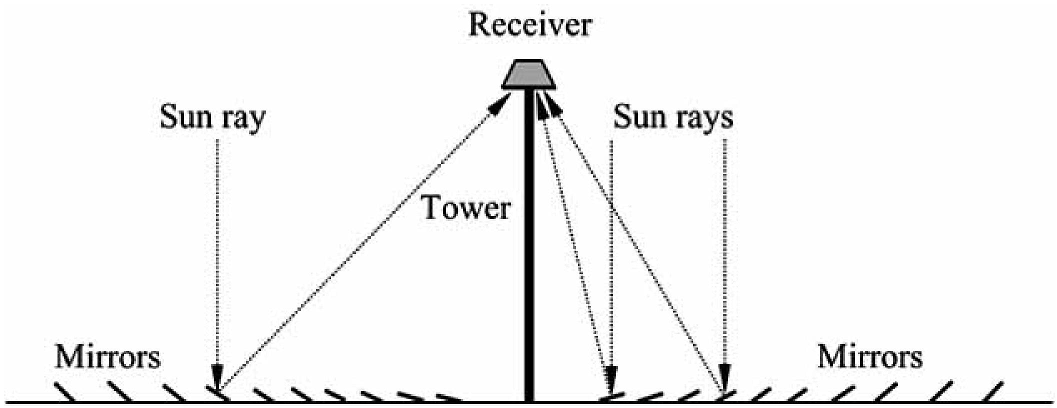

Fig. (6). Schematic diagram of a downward facing receiver illuminated from an LFR field.

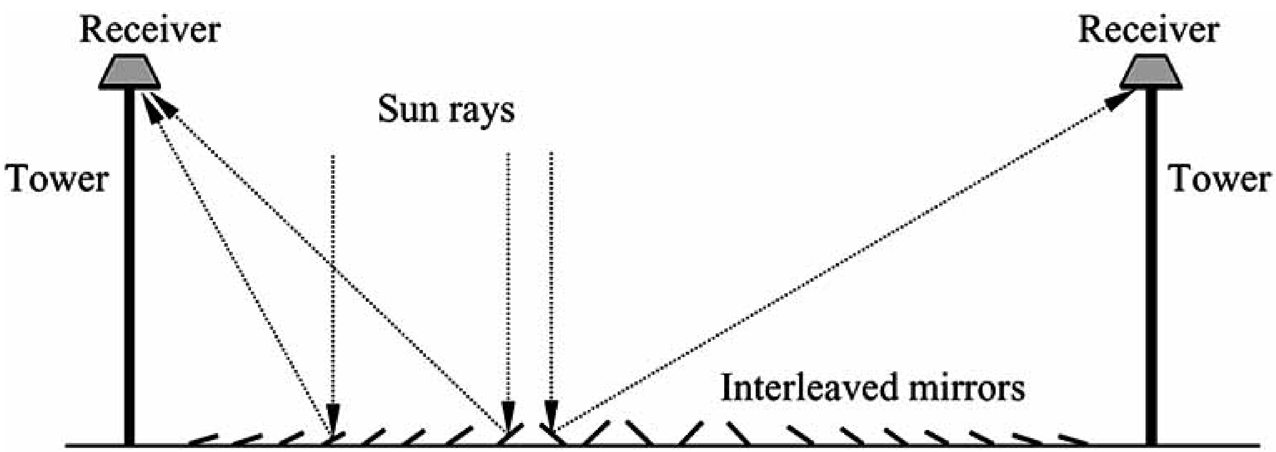

Fig. (7). Schematic diagram showing interleaving of mirrors in a CLFR with reduced shading between mirrors.

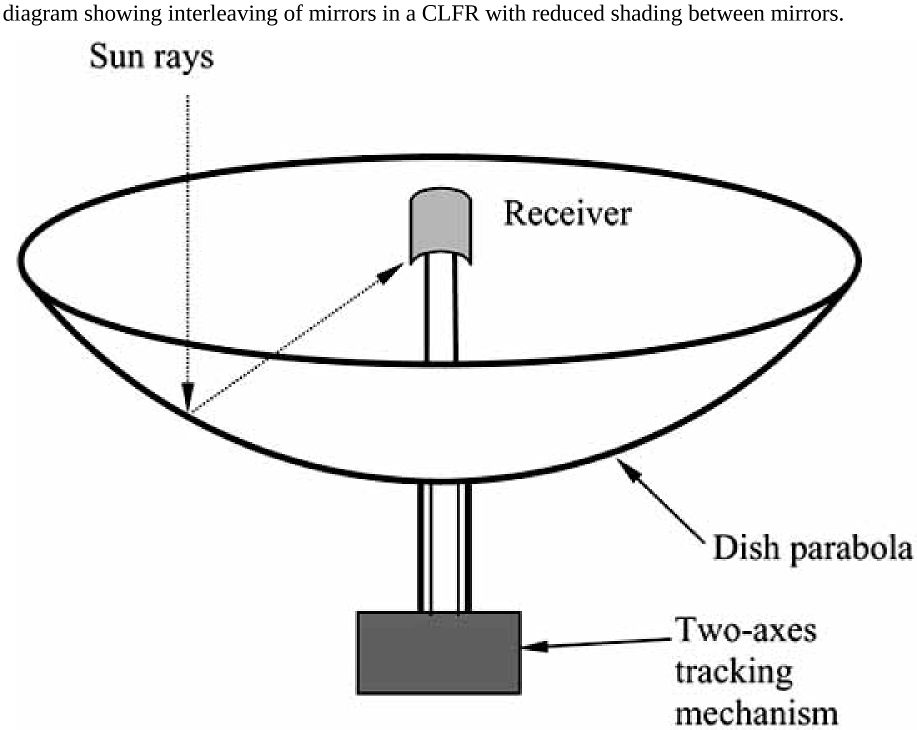

Fig. (8). Schematic diagram of a parabolic dish collector.

- They typically have concentration ratio in the range of 600 to 2,000, and thus are highly efficient thermal-energy absorption and power conversion systems, and
- They have modular collector and receiver units that can either function independently or as part of a larger system of dishes.

The main use of this type of concentrator is for parabolic dish engines. A parabolic dish-engine system is an electric generator that uses sunlight instead of crude oil or coal to produce electricity. The major parts of a system are the solar dish concentrator and the power conversion unit.

Parabolic-dish systems that generate electricity from a central power converter collect the absorbed sunlight from individual receivers and deliver it via a heat-transfer fluid to the power-conversion system. The need to circulate heat-transfer fluid throughout the collector field raises design issues such as piping layout, pumping requirements, and thermal losses [1].

Systems that employ small generators at the focal point of each dish provide energy in the form of electricity rather than as heated fluid. The power conversion unit includes the thermal receiver and the heat engine. The thermal receiver absorbs the concentrated beam of solar energy, converts it to heat, and transfers the heat to the heat engine. A thermal receiver can be a bank of tubes with a heat transfer medium circulating through it. The heat transfer medium usually employed as the working fluid for an engine is hydrogen or helium. Alternate thermal receivers are heat pipes wherein the boiling and condensing of an intermediate fluid is used to transfer the heat to the engine. The heat engine system takes the heat from the thermal receiver and uses it to produce electricity. The engine-generators have several components; a receiver to absorb the concentrated sunlight to heat the working fluid of the engine, which then converts the thermal energy into mechanical work; an alternator attached to the engine to convert the work into electricity, a waste-heat exhaust system to vent excess heat to the atmosphere, and a control system to match the engine's operation to the available solar energy. The distributed parabolic dish system lacks thermal storage capabilities, but can be hybridised to run on fossil fuel during periods without sunshine. The Stirling engine is the most common type of heat engine used in dish-engine systems [1].

1.2.4. Heliostat Field Collector (HFC)

For extremely high inputs of radiant energy, a multiplicity of flat mirrors, or heliostats, using altazimuth mounts, can be used to reflect their incident direct solar radiation onto a common target as shown in Fig. (**9**). This is called the heliostat field or central receiver collector. By using slightly concave mirror segments on the heliostats, large amounts of thermal energy can be directed into the cavity of a steam generator to produce steam at high temperature and pressure.

The concentrated heat energy absorbed by the receiver is transferred to a circulating fluid that can be stored and later used to produce power. Central receivers have several advantages [1]:

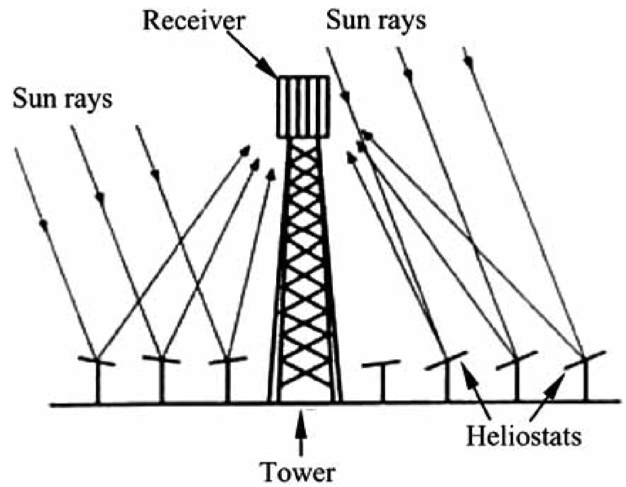

Fig. (9). Schematic diagram of heliostat field collector.

- They collect solar energy optically and transfer it to a single receiver, thus minimizing thermal-energy transport requirements,
- They typically achieve concentration ratios of 300 to 1,500 and so are highly efficient both in collecting energy and in converting it to electricity,
- They can conveniently store thermal energy, and
- They are quite large (generally more than 10 MW) and thus benefit from economies of scale.

Each heliostat at a central-receiver facility has a reflective surface between 50-150m^2. The heliostats collect and concentrate sunlight onto the receiver, which absorbs the concentrated sunlight, transferring its energy to a heat-transfer fluid. The heat-transport system, which consists primarily of pipes, pumps, and valves, directs the transfer fluid in a closed loop between the receiver, storage, and power-conversion systems. A thermal-storage system typically stores the collected energy as sensible heat for later delivery to the power-conversion system. The storage system also decouples the collection of solar energy from its conversion to electricity. The power-conversion system consists of a steam generator, turbine generator, and support equipment, which convert the thermal energy into electricity and supply it to the utility grid. After energy collection by the solar system, the conversion of thermal energy to electricity has many similarities with the conventional fossil-fuelled thermal power plants.

The average solar flux impinging on the receiver has values between 200 and 1,000 kW/m^2. This high flux allows working at relatively high temperatures of more than 1,500°C and to integrate thermal energy in more efficient cycles. Central receiver systems can easily integrate in fossil-fuelled plants for hybrid operation in a wide variety of options and have the potential to operate more than half the hours of each year at nominal power using thermal energy storage.

There are three general configurations for the collector and receiver systems. In the first, heliostats completely surround the receiver tower, and the receiver, which is cylindrical, has an exterior heat-transfer surface. In the second, the heliostats are located north of the receiver tower (in the northern hemisphere), and the receiver has an enclosed heat-transfer surface. In the third, the heliostats are located north of the receiver tower, and the receiver, which is a vertical plane, has a north-facing heat-transfer surface [1].

The heat-transfer fluid may either be water/steam, liquid sodium, or molten nitrate salt (sodium nitrate/potassium nitrate) whereas the thermal-storage medium may be oil mixed with crushed rock, molten nitrate salt, or liquid sodium.

The following section reviews some of the latest patents in solar energy collectors. This is followed by a review of recent tracking mechanism patents and finally patents on various applications are presented. Table **2** shows the number of patents included in each category.

Table 2. Number of Patents Reviewed

Category	Number of patents included
Solar energy collectors	7
Tracking mechanisms	3
Collector applications	9

2. RECENT PATENTS OF SOLAR COLLECTORS

The first patent included in this review concerns an alterable solar collector [2]. A solar collector of a solar water heating system comprises a conduit formed by two circular cross-sectioned manifolds running parallel with each other. The manifolds are able to rotate vertically about the central line of the manifolds. The manifolds have:

(I). a number of T-shaped members

(II). a number of seal means connecting the T-shaped members together in a watertight way

(III). at least one heat insulating means covering outside of the T-shaped members and the seal means, and

(IV). at least one cover means supporting and protecting the heat insulating means, as well as the T - shaped members and the seal means inside the heat insulating means.

The solar collector also comprises a number of solar absorbers perpendicularly positioned along the conduit and connected to the side holes of the T-shaped members of the manifolds of the conduit, at least one bottom support means at each side of the conduit holding the low ends of the solar absorbers to keep them in position and at least two connection means riding on a roof on which the solar collector is installed to connect the bottom support means to the manifolds.

Another patent in stationary collectors concern a heliothermic flat plate collector module [3]. The heliothermic flat plate collector module comprises a sheet metal panel, whose rear face lies opposite to the face exposed to solar radiation. It is covered by a bonded grid-type arrangement of capillary tubes, positioned at a distance one below the other, permitting the passage of a liquid medium, in addition to connections for admitting and evacuating the liquid to and from the grid-type arrangement. The capillary tubes are attached to the rear face of the sheet metal panel by means of a coating that encases the capillary tubes, or an accumulation of thermally sprayed metal particles, which adhere to the rear face of the sheet metal panel and to the surface of the capillary tubes.

The first invention relating to concentrating collectors concerns a parabolic trough collector, whose supporting structure is configured as a dual-shell torsion box, which increases the rigidity of the collector [4].

The objective of a second patent in this area is to provide a tubular cover for a parabolic trough collector for helping accumulation of sun radiation more than a conventional receiver tube and having an uptake factor of the best capability [5]. In the case that the absorption tube is provided in the tubular cover, the tubular cover of the parabolic trough collector has four structure elements at which sunlight is focused, at the absorption tube provided in the tubular cover.

Another invention on parabolic trough collectors concerns a collector which includes a single-axis parabolic mirror and a receiver tube arranged at the focal point (F) of the parabolic mirror [6]. The receiver tube includes an absorber tube and an outer tubular glass jacket around it. To compensate for focusing errors in the parabolic collector and thus to reduce associated geometric optical losses, the tubular jacket is provided by four structural elements, which focus the sunlight on the absorber tube arranged in the tubular jacket by reflection and/or refraction. The receiver tube is preferably arranged relative to the parabolic mirror, so that its center is displaced from the focal point (F) in the direction of the mirror by a distance equal to half the spacing between the tubular jacket and the absorber tube.

In another patent, the parabolic trough collector has a receiver formed by several single absorber tubes [7]. The single absorber tubes are supported by absorber tube supports and surrounded by a glass tube. Because of different expansion behavior of the absorber tube and the glass tube during collector operation flexible unions are foreseen between absorber tube and glass tube. In order to use the radiation coming to the non active-area where the absorber tube supports and the flexible unions are located, a mirror collar is installed. The mirror collar is able to reflect the solar radiation, which is coming from different directions, to the active absorber part of the single absorber tubes even when the sun incident angle is changing.

A high concentration central receiver system and a method which provides improved reflectors and a unique heat removal system is presented in [8]. The central receiver has a number of interconnected reflectors coupled to a tower structure at a predetermined height above ground for reflecting solar radiation. A number of concentrators are disposed between the reflectors and the ground such that the concentrators receive reflective solar radiation from the reflectors. The central receiver system further includes a heat removal system for removing heat from the reflectors and an area immediately adjacent the concentrators. Each reflector includes a mirror, a facet and an adhesive compound. The adhesive compound is disposed between the mirror and the facet such that the mirror is fixed to the facet under a compressive stress.

Patents which deal with tracking mechanisms are reviewed in the next section.

3. RECENT PATENTS OF TRACKING MECHANISMS

As seen in section 1, tracking mechanisms are required in concentrating collectors for following the trajectory of the sun in the sky with certain accuracy. In fact, the concentrating collector performance depends on the effectiveness of the tracking mechanism as any large deviations will focus solar radiation away from the receiver.

The first invention in this category, concerns a solar tracking mechanism utilized in connection with a solar energy collection system [9]. The collection system includes a light reflective shell shaped to focus solar radiation on a radiation absorbing segment of a tube which carries a heat transfer fluid. The shell is pivotally mounted on a support frame. An actuator mounted between the support frame and the shell is able to rotate the shell. A solar sensor is mounted deep within a sighting tube which is fixed to the shell such that a line of sight through the sighting tube is at least parallel to the optical axis of the shell. The solar sensor generates a sensor signal which is used as a control input to an actuator control system. End limit switches generate a limit stop signals when the shell reaches maximum angular positions. The actuator control system generates fluid flows to the actuator based on the solar sensor signal and the limit stop signals. The method of tracking the sun includes the provision of a solar cell array, which activates the solar collection system when solar radiation illuminating the array exceeds a predetermined threshold. This provides a solar sensor shielded from the solar radiation except for direct, aligned radiation, pivotally rotating the shell westward based upon the solar sensor signal, stopping the shell at a maximum angular positions, and rotating the shell westward if the shell does not reach the maximum westward angular orientation during a predetermined daylight time period. The solar energy collection system may be further configured to include a bisected shell, which is hinged together. The shell halves can be collapsed onto each other thereby protecting the light reflective surface and the radiation absorbing segment of the tube carrying heat transfer fluid.

In another invention, the solar tracking mechanism is employed in relation with a solar energy captivation system [10]. The captivation system includes a light reflective cover, with a shape to focus solar radiation over a segment of radiation absorption from a tube that carries a heat transfer fluid. The cover is mounted by pivot over a support structure. An actuator mounted between the support structure and the cover is able to rotate around the cover. A solar sensor is mounted inside a visor tube fixed to the cover, so that the visual line through the visor tube is at least parallel to the optical axis of the cover. The solar sensor generates a sensor signal used as a control inlet for a control system of the actuator. Limiting switches generate end thrust block signals when the cover reaches maximum angular positions. The actuator control system generates fluid flows in the actuator according to the solar sensor signal and to the end thrust block signals. The sun tracking method includes also an arrangement of solar cells, actuating the solar captivation system when the solar radiation that illuminates the arrangement surpasses a predetermined threshold value. In this way the solar sensor is protected against solar radiation, except from direct radiation, aligned radiation, turning with pivot the cover to the west, according to the signal of the solar sensor, stopping the cover in maximum angular positions and turning the cover to the west if the cover does not reach the maximum angular orientation to the west, during a predetermined period of daylight. The solar energy captivation can also be configured to include a bisected cover joined by means of hinges. The cover halves can be folded one against the other to protect the light reflective surface and the radiation absorption segment of the tube that carries the heat transfer fluid.

The final invention in this category relates generally to an easy-to-assemble building structure with a mountable frame for mounting solar panels, solar water heating panels, fuel cells or any other renewable energy device and more particularly relates to a gazebo or a storage space or an overhang used for purposes of mounting solar panels [11].

The next section reviews patents related to solar collector applications.

4. RECENT PATENTS OF SOLAR COLLECTORS APPLICATIONS

The first invention in this category concerns a patent which deal with an integral storage-collector solar water-heating system [12]. The system includes a tank and two absorbers, wherein the entire system is full of water. The water circulation goes from the bottom of the tank trough a fin-tube absorber plate, which is located between a transparent cover exposed to the sun and an insulated plate. The heated water passes through a second absorber that heats it to a usage temperature and causes it to flow into the tank's space. The second absorber is created between the exposed wall of the tank, by a grid of tunnels that are grooved in a thermally insulated layer that are attached to the inside walls of the tank. The second absorber is also covered with a transparent cover. The water flow into the upper part of the tank and a thermosiphon valve prevents the back flow. After a double heating, the water is stored inside the tank and is ready for use. The system can also have an electrical heating option, a flexible turbolator in the fin-tube absorber which can be shrunk in case of freezing and flexible means inside the tank for the same purpose.

In another invention, the solar water heating plant comprises a transparent vacuum multiple glass pane, heat insulated housing, and water supply and water distributing cocks [13]. The housing is separated with a heat insulating baffle into two sections. The top section is used for heating water by solar radiation absorbed by the bottom and walls of the section. The bottom section is used for accumulating the water heated in the top section. The plant is provided with the valve which is controlled with the thermal gauge and is used for the overflowing water from the top section to the bottom section and overflow pipes that are also drain pipes. The plant also has the device with anti-evaporator to prevent condensate to be settled out on the inner side of the transparent vacuum multiple glass pane when a gap is presented between the multiple glass pane and water surface and instruments for visual monitoring of temperature and water lever in both of the sections. The housing is made of fiber glass and foam concrete. The transparent vacuum multiple glass pane, is secured to the housing by means of locks through the flexible spacer.

Another invention relates to a solar heat pump water heater, which is characterized by the fact that it adopts a flat plate collector without cover plate and heat-insulating bottom [14]. The flat plate collector can also be used as evaporator of liquid refrigerant; its outlet is connected with air suction opening of compressor. The air exhaust opening of the compressor is connected with air inlet of condenser and the liquid outlet of condenser is connected with liquid storage device. The liquid is respectively passed through the drying filter, thermal expansion valve and connected with liquid inlet of collector/evaporator to form the closed circulating channel of refrigerant. Its condenser is placed in the heat-storage water tank and the solar radiation instrument and two temperature sensors are connected with a controller. The invention adopts the characteristic temperature to control the activation of the compressor, it can make water heater to be in optimum operation state, its energy-saving effect is obvious, its system structure is compact and its cost is low.

A freeze protection apparatus to prevent damage to solar water heating systems is presented in [15]. A temperature sensor detects the temperature of water in a solar collector of a solar water system. An electrically controlled valve controls the flow of water through the cold supply pipe. The valve is in a normally open condition when it is deactivated, and is closed when in an activated state to prevent the reverse flow of cooler water from the solar collector back into the hot water storage tank due to reverse thermosiphon. If the temperature sensor senses that the water temperature in the collector falls to a level where it may begin to freeze the controller activates the pump and deactivates the valve to supply warm water from the storage tank to the solar collector to prevent freezing from occurring. In the event of a pump or power failure the valve will be in a deactivated state (open), allowing warm water to circulate into the solar collector due to reverse thermosiphoning.

The design of a compact solar air conditioning system especially suited for tropical climates is presented in [16]. The system includes an air-cooled single-effect absorption machine driven by an array of high performance flat-plate collectors along with a thermal storage tank. The absorption machine uses lithium-bromide as a refrigerant and a water-based absorption fluid. The operation of the compact solar air conditioning system is determined by an optimal control strategy.

Another patent in this area deals with an invention which provides a water sanitizing process to be performed in a water heating system [17]. The system includes a water storage tank, a solar water heater for heating water in the storage and a supplementary water heater for heating the water. The system has a sanitation mode of operation whereby when the system determines that a predetermined heating condition is met, the water is subjected to heating by the supplementary water heater. The process includes the sanitation initiation step, i.e., it determines the time period P_w that has passed since the water last satisfied a predetermined sanitation satisfaction criterion of the system. Then it compares P_w with the predetermined maximum allowable period $P_{w,max}$. If P_w is equal to or greater than $P_{w,max}$, the system is placed in the sanitation mode of operation. It then determines whether the predetermined heating condition is met and then if it does, the water is heated by the supplementary water heater.

A drain back water heater which includes a hot water storage tank with an internal heat exchanger is presented in [18]. The heat exchanger is in the form of a cylinder closed at the top by a cap and also closed at the base. A pump draws off water from the bottom of the heat exchanger and circulates the heat transfer fluid back to the top of the heat exchanger when required. Attached to, or incorporated in the cap is a falling film distributor which serves to distribute the heat transfer fluid in a thin film around the inner wall of the heat exchanger. The heat transfer fluid can be heated in solar water heating panels. When the pump is turned off, the heat transfer fluid drains into the heat exchanger to at least partially fill the heat exchanger.

Another invention in this category, presents a solar water heating system [19]. The system includes a heat transfer fluid circuit and a heat exchanger for transferring heat from the heat transfer fluid to water, wherein the heat transfer fluid circuit includes a bypass path via which the heat transfer fluid is diverted around the heat exchanger in response to an overheating condition indication.

The final invention deals with a diffusion driven desalination apparatus [20]. The apparatus includes a structure for receiving a heated water stream and creating at least one region having a thin film of water and structure for forcing a low humidity air stream over the thin film of water, wherein water from the thin film of water evaporates and diffuses into the air stream to create a humidified air stream. A diffusion tower including at least one plenum can be used to create and transfer the humidified air stream. At least one condenser, such as a direct contact condenser, condenses the humidified air stream, wherein purified water is produced. Waste heat from a power plant can be used to provide the heated water stream and power plants can use the waste heat generated to inexpensively provide purified water.

5. CURRENT & FUTURE DEVELOPMENTS

It is obvious from the introductory part of this paper, that a great variety of collectors has been developed over the years, which can be used in a variety of applications extending from low to high temperature ones. It is apparent that some of the areas of solar systems are matured and little attention would be paid on these in the coming years. These include flat plate collectors and parabolic troughs.

The author believes that future patents would deal with various aspects of applications, possibly into areas not covered extensively so far, like for chemistry applications, which include solar reforming of low hydrocarbon fuels such as LPG and natural gas and upgrade it into a synthesis gas that can be used in gas turbines, solar gasification of biomass and the production of solar aluminium the manufacture of which is one of the most energy intensive processes. Another interesting application in this area is the solar zinc and syngas production which are both very valuable commodities. Another field of solar chemistry applications is the solar photochemistry. Solar photochemical processes make use of the spectral characteristics of the incoming solar radiation to effect selective catalytic transformations which find application in the detoxification of air and water and in the processing of fine chemical commodities.

Additionally, any new collectors that would be developed would be integrated into the process/application so the future trends in this respect are developments of patents for collectors that will be part of a process or made specifically for a particular process and collectors integrated into the building structure.

A major area of future research would also be the development of new materials for reflectors and heat absorption. The objective is to create materials with high reflectivity approaching unity and heat absorption materials with high absorptance and low emittance so as to enhance the thermal behavior of the solar energy collectors. The research in this domain is ongoing and future trends would involve the use of nanotechnology in various areas of materials science for the more efficient solar conversion, by employing nanostructured components. This extends both in solar energy collectors by producing more efficient absorbing plates and in applications, like the solar nano-photocatalytic wastewater treatment process. Nanotechnology would also be used in the near future for the more efficient solar conversion by employing nanostructured components in thin film solar cells.

ABBREVIATIONS

CLFR	=	Compact Linear Fresnel Reflector
CPC	=	Stationary Compound Parabolic Collectors
ETC	=	Evacuated Tube Collectors
FPC	=	Flat Plate Collectors
HFC	=	Heliostat Field Collector
ICPC	=	Integrated Compound Parabolic Collector
LFR	=	Linear Fresnel Reflector
PDR	=	Parabolic Dish Reflector
PTC	=	Parabolic Trough Collector

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