Solar Thermal Receivers—A Review

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1 Introduction

The energy requirements of today's world are fulfilled by the combustion of fossil fuels, which is not only limited and emits hazardous waste and environmental pollution. It is polluting the environment and causing climate change. To combat this, scientists are trying to phase out all fossil fuels in favour of natural resources such as light, water, and other non-traditional alternative sources. Such non-traditional renewable technologies have the opportunities to resolve energy crises. Renewable energy sources like biofuels [1–9], wind energy [10], and solar energy accounts for a sizable portion of non-traditional energy sources [11].

The tradition of regular use of solar power dates back to 1455 BC, but the comprehensive operation of this form of energy has yet to be achieved. The energy absorbed from the earth by the sun in a single hour is larger than the amount of energy consumed in a year. After passing through a series of atmospheric layers, solar radiation that strikes the Earth's surface reaches it either directly or indirectly. Solar energy's primary issue is its unusual nature, as well as the question of how to collect and store it. Even in small parts of the world, this tradition of using solar energy in everyday life experiences has not been possible old time. In an hour, the amount of energy absorbed by the earth's surface exceeds the amount spent in a year.

Solar radiation enters the Earth's surface direct or indirect, passing through a series of layers of the atmosphere. Solar energy's main challenge is the unpredictability of its supply, as well as its capture and storage. It also disseminates solar energy in small regions around the world [12].

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Solar energy is used to switch to renewables in a variety of industries, including power generation, heating, agriculture, and industrial processes such as disinfection, refining, pasteurization, drying, cooling, and climate control, as well as distillation.

2 Solar Receivers

Solar power receivers are a specific type of heating systems that convert solar radiation into the heat capacity of the transport media. The major part of a solar-based system is a solar receiver, which collects solar energy, transforms it to the desired location, and transports that heat to a fluid passing through the collector (usually air, liquid, or oil). The solar energy received is transferred directly from fluid flowing to the warm water or air ventilating facilities, or to a heat storage reservoir, from which it could be obtained for use at nighttime and/or during overcast weather [13].

3 Receivers' Classification

3.1 Stationary Receivers

Solar energy receivers are essentially differentiated by their movement and stagnant nature, the axis of tracking, and the working temperature. In this study, researchers evaluate the solar receivers on stationary and working temperature bases. Those receivers remain fixed in place and, therefore, do not move with the sun. This classification includes three types of receivers:

1. Flat-plate receivers (FPR).
2. Static compound parabolic receivers (SCPR).
3. Evacuated tube receivers (ETR) (Table 1).

3.1.1 Flat-Plate Receivers (FPR)

Figure 1 depicts the basic flat-plate solar receiver. As sunlight strikes a blackened coated absorber surface with a high absorption coefficient via a transparent cover, a significant part of the energy is captured by the surface and transported to the transport medium throughout the fluid channels, where it is taken away for conservation or even use. FPRs have the benefits of being cheap to produce, collecting simultaneously beam and diffuse radiation, and being firmly fixed in place, requiring no sun monitoring.

The following are the primary parts of an FPR as shown in Fig. 2:

Upper Surface (Cover): Glass or other radiation-transmitting materials (one or more sheets).

Table 1 Solar energy receivers [14]

Movement	Receivers type	Receivers type	Concentration ratio (CR)	Temperature range (°C)
Stationary	Flat-plate receivers (FPR)	Flat	1.0	30–80
	Evacuated tube receivers (ETR)	Flat	1.0	50–200
	Static compound parabolic receivers (SCPR)	Tubular, Line focus	1.0–5.0	60–240
Single-axis tracking	Compound parabolic receivers (CPR)	Tubular, Line focus	5.0–15.0	60–300
	Linear Fresnel reflector (LFR)	Tubular, Line focus	10.0–40.0	60–250
	Cylindrical trough receivers (CTR)	Tubular, Line focus	15.0–50.0	60–300
	Parabolic trough receivers (PTR)	Tubular, Line focus	10.0–85.0	60–400
Two-axis tracking	Parabolic dish reflector (pdr)	Point focus	600.0–2000.0	100–1500
	Heliostat field receivers (hfr)	Point focus	300.0–1500.0	150–2000

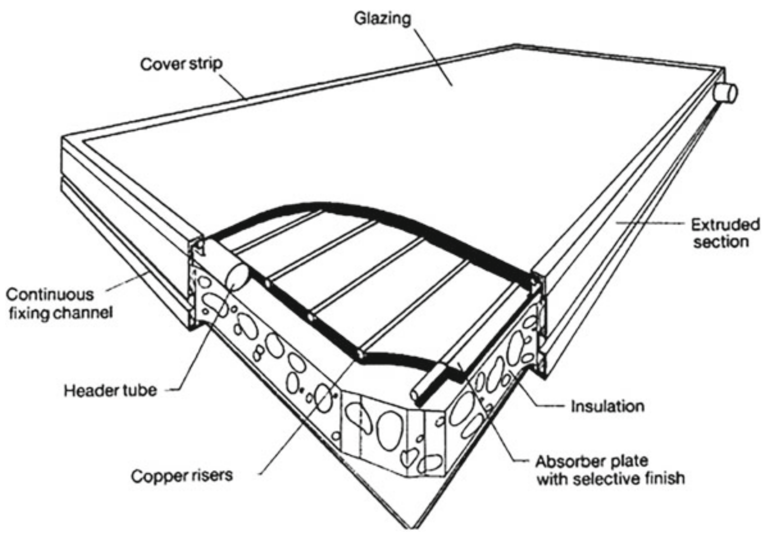

Fig. 1 Schematic view of a flat-plate receiver [15]

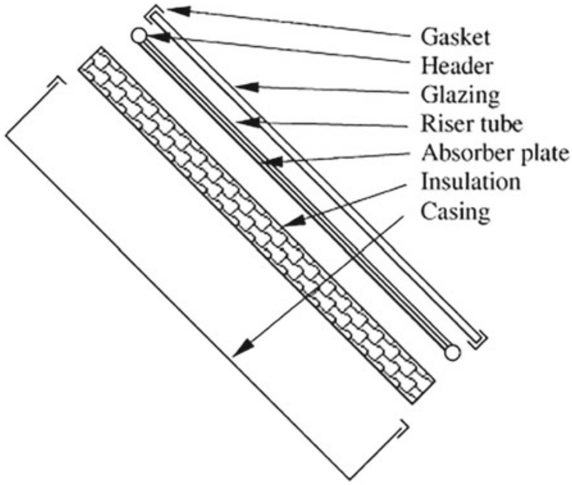

Fig. 2 Section view of an FPR with major components [15]

Fluid tunnels for heat dissipation: Heat transfer fluid is carried or directed from the source to the drain via tubing, fins, or channels.

Absorber surface: Absorber surface is a type of surface that is used to absorb water. Coils, fins, or channels are connected to flat, corrugated, or grooved surfaces.

The encoded fixing shown in Fig. 2 is a common attaching technique. A high-absorber and low-emittance coating is commonly applied to the plate.

Pipe Channels: To provide passage for working fluid.

Insulation: To reduce the thermal loss from the bottom and sides of the receivers.

Container: The enclosure covers and defends the foregoing elements from dirt, humidity, and other foreign matter.

3.1.2 Static Compound Parabolic Receivers (SCPR)

Static compound parabolic receivers (SCPRs) are receivers that do not require imaging. These also can reflect all incident radiation to the absorber in certain limits. Winston emphasized their possibilities as solar energy receivers. Using a trough with two parts of a paraboloid approaching each other, shown in Fig. 3 [16], reduces the need to move the concentrator to accept changing solar orientation. Compound parabolic receivers are capable of accepting incident radiation from a broad range of angles. The radiation approaching the aperture inside the receiver acceptance angle makes its way to the absorber tube at the base of the receiver due to various internal reflections [17]. The absorber can be configured in several ways. It can be a linear, cylindrical, rectangular, bifacial, wedge, or flattened. There are two main types of CPR receivers: symmetric and asymmetric.

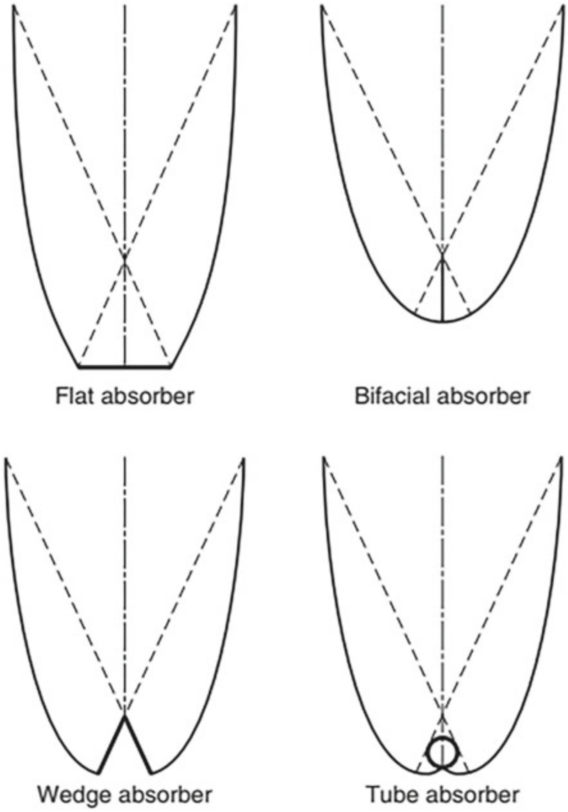

Fig. 3 Different types of CPR available

3.1.3 Evacuated Tube Receivers (ETR)

General flat-plate receivers (FPR) were originally designed to be used in bright days and in hot climates. When weather conditions are unfavourable, such as colder, cloudy, rainy, and windy days, their advantages are reduced significantly. Also, weathering factors such as precipitation and humidity cause serious materials to deteriorate prematurely, resulting in decreased quality and efficiency and also become the cause of system failure [15].

Solar receivers (pipes) with evacuated heat piping function differently than most other receivers available on the marketplace. As seen in Fig. 4, such solar receivers consist of a heat pipe in a vacuum-sealed container. As shown in Fig. 5, several tubing is linked to the same section in the setup.

The conjunction of a particular surface, as well as an efficient convection silencer in evacuated tube receivers, has demonstrated significant performance at the high-temperature range. The receivers can run at higher temperatures compared to FPRs because the vacuum boundary decreases losses due to convection and conduction heat transfer. These accumulate both beam and diffuse radiation, similar FPRs, as

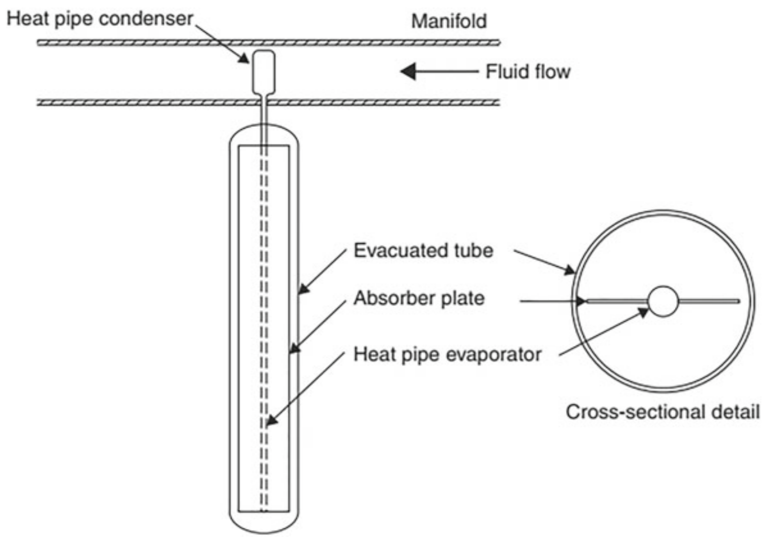

Fig. 4 Schematic diagram of an evacuated tube receiver

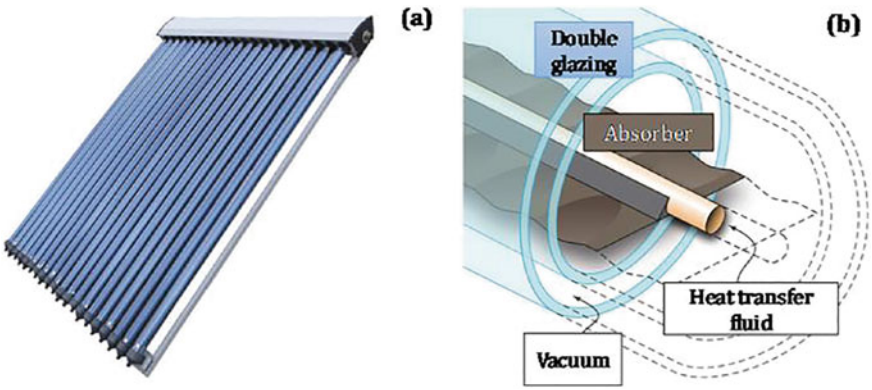

Fig. 5 **a** Evacuated tube collectors; **b** representation of a concentric tube [18]

they are more efficient at a low incident angle. This makes ETRs a productivity edge over FPRs over the course of a day.

3.2 Sun-Tracking Concentrating Receivers

The temperature of the energy distribution system can be raised by reducing the area where heat is lost. If a significant amount of solar energy is focussed on a limited collection area, temperatures far exceeding the achievable by FPRs can be attained. This is accomplished by placing an optical device between both the radiation source and also the energy-absorbing face. Concentrating receivers have a few benefits over traditional flat-plate receivers [19].

For concentrating receivers, a variety of concepts were already proposed. Concentrators may be reflectors or refractors, cylindrical or parabolic, continual or partitioned, and rectangular or curvatures. Convex, smooth, curved, or contoured receivers may be shielded with glass or left exposed. Concentration ratios, or the proportion of aperture to absorption zones, may range from marginally above unity to levels on the scale of 10,000. Higher ratios result in higher temperatures where the energy can be supplied, but this also means that these receivers need more accuracy in optical quality and optical system orientation [15].

Solar energy is optically focussed in focussing receivers before being converted to heat. Solar radiation may be reflected or refracted using mirrors or lenses to achieve concentration. The energy density in the receiving target is increased as the reflected or refracted sunlight is concentrated in a focal zone. Based on whether the picture of the sun is aimed at the receiver, concentrating receivers can be categorized as non-imaging or imaging receiver [20].

The CPR is a receiver that belongs to the very first category, while all other concentrators are imaging receiver.

1. The Parabolic Trough Concentrator (PTC).
2. The Linear Fresnel Reflector (LFR).
3. Parabolic Dish Reflector (PDR).
4. Heliostat Field Receiver (HFR).
5. Fixed Focus Elliptical Scheffler Reflector.
6. The Solar Tower.

3.2.1 The Parabolic Trough Solar Concentrator

Scholars constructed several parabolic troughs concentrators and used tracking mechanisms to monitor the sun. The sun monitor layer (or reflective surface) is used to direct the solar radiation to the central-focus point of the reflector. Scholars used glass, copper, or aluminium solar concentrator trough's focal point to absorb the reflecting solar radiation. The working fluid, primarily water, consumes the latent and sensible heat radiation which allows the fluid to flow through the system [13]. A high-performance solar receiver is needed to deliver high temperatures in high efficiency and maximum reliability. With parabolic through receivers (PTRs), systems with light support frame and moderate technology for process heat operations up to 400 °C could be achieved. PTRs can efficiently generate heat at temperatures ranging from 50 to 400 °C. Sheets of reflective material are bent into a parabolic shape to create PTRs. Along the focal axis of the receiver, a metallic black tube is mounted, which is covered with a glass tube to minimize heat losses Fig. 6.

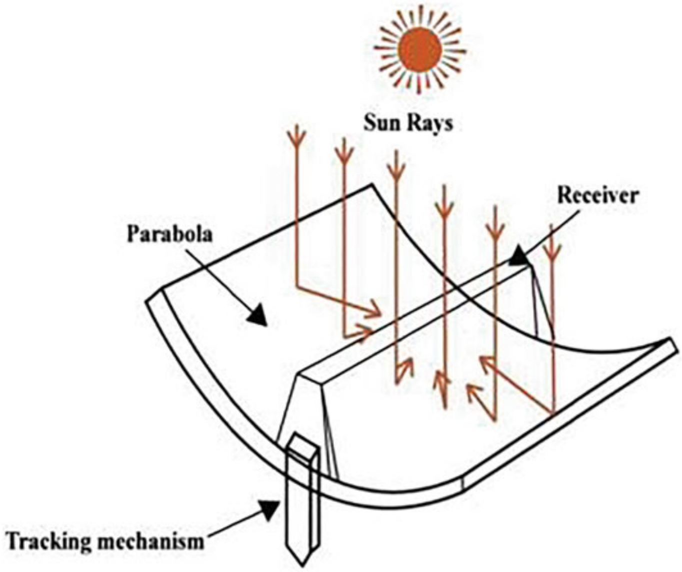

Fig. 6 Parabolic trough concentrator [21]

3.2.2 Fresnel Lens Solar Concentrator

The Fresnel lens receiver (FLR) can be seen in Fig. 8, and the linear Fresnel reflector (LFR) can be seen. The first is made out of plastic and moulded in the manner shown to concentrate suns radiation onto a point receiver, while the latter relies on arrays of linear mirror stripes to reflect sunlight over to a linear receiver. The LFR receiver looks like a broken-up parabolic dish reflector (see Fig. 3); however, unlike parabolic troughs, the individual stripes do not have to be parabolic. The stripes can also be installed on a flat piece of ground (field) to focus light on a linear stationary receiver on a tower (Fig. 7).

Fresnel lens quality characteristics such as limited length, lightweight, mass manufacturing, and cheap cost have made this profitable in the energy department [22]. The Polymethyl methacrylate (PMMA) components (a Fresnel lens modification discovered by some experts in 1928) can construct Fresnel lenses (discovered by Augustine Jean Fresnel) because of their exceptional sunlight resistance and transmissivity [23, 24]. A lens of a Fresnel concentrator comprises a flat optical segment in which it removes heavy materials as its surface comprises many concentric grooves. Because each groove is calculated by a smooth surface that reflects at the position of the regular lens due to curvature, prisms are formed [25].

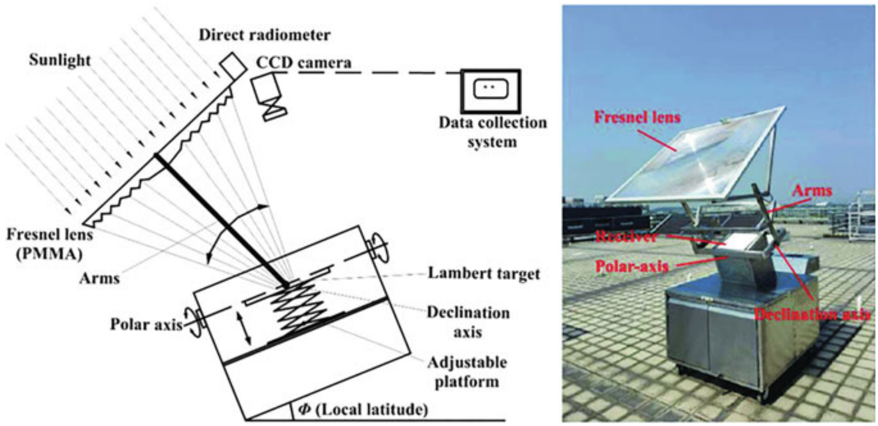

Fig. 7 Experimental setup of Fresnel lens solar concentrator [26]

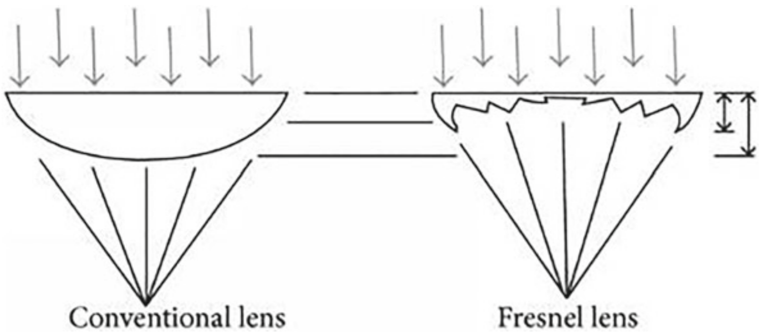

Fig. 8 Fresnel lens and normal lens [20]

3.2.3 The Solar Tower System

A large number of dual-axis tracking mirrors are mounted over a tower of solar thermal turbine power plants. These strongly angled mirrors are sometimes called heliostats; the optimal location for each of these is determined by a computer, and a motor drives them towards the sun. To guarantee the sunlight is much centred on the top of the tower, the device needs to be accurate. The absorber is situated there, and it heats this to temperatures of 1000 °C or higher. Heated air or molten salt then carries the heat energy from the absorber to a gas turbine or steam generator creates super-heated water vapour which operates a turbine and electrical generator [27]. A large number of dual-axis tracking mirrors are mounted over a tower in solar thermal power plants. Often called heliostats are those strongly angled mirrors. A machine determines the optimal location for both of these and drives them towards the sun

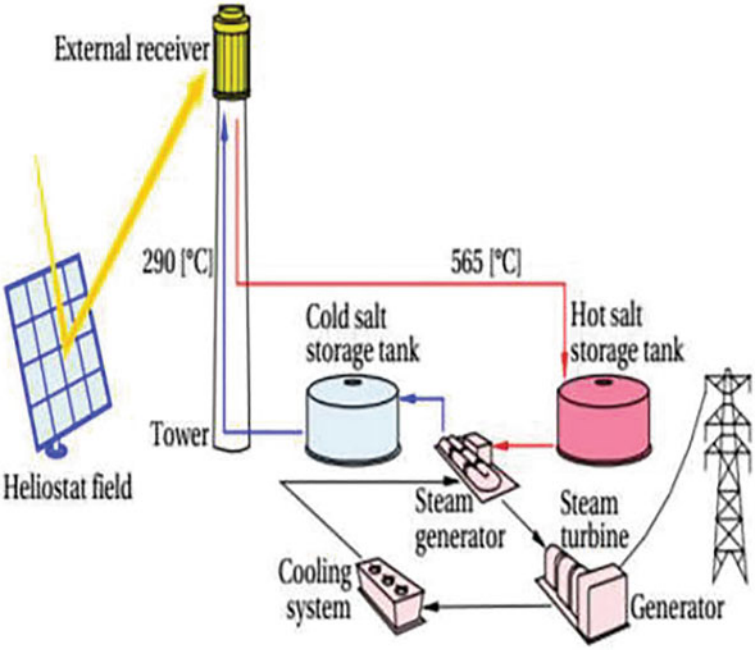

Fig. 9 Solar tower power plant [29]

with a motor drive. To guarantee the sunlight is very centred on the top of the tower, the device needs to be accurate [28] (Fig. 9).

Most of the old towers were using steam as a heat transfer agent but owing to their improved heat transfer and energy conservation capacities, newer buildings use molten salts [30]. Transferring the heat to water transforms into steam. The steam is then transferred to a traditional turbine for the generation of electric energy [31].

3.2.4 Parabolic Dish Based Solar System

A parabolic dish reflector (PDR), as can be seen in Fig. 10, is a central-focus receiver that follows the sun in 2 axes, focussing the sun's radiation onto a receiver only at the dish's point of focus. To reflect the beam into another thermal receiver, the dish system must completely follow the sun. The receiver absorbed solar radiation and converts it into thermal energy in a fluid flowing. The thermal energy can also be converted into electrical energy using a direct-coupled engine power generator or transferred to a centralized power conversion system via pipelines. Temperatures of over 1500 °C can be achieved using parabolic dish arrays. Parabolic dishes are also referred to as distributed receiver systems since these receivers remain distributed across a receiver field, similar to parabolic troughs.

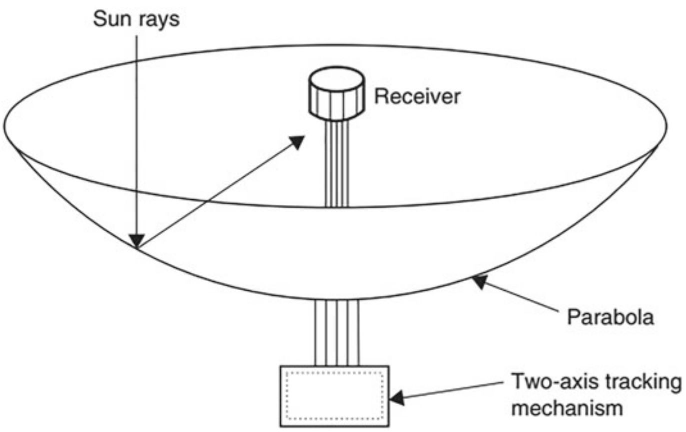

Fig. 10 Schematic diagram of parabolic dish collector

Application in Cooking

In the 1950s, Ghai developed a solar parabolic dish cooker (PDSC) at the National Physical Laboratory located in New Delhi, India [32] Since then, many researchers have proposed and analyzed various shapes and designs for concentrating solar cookers [33, 34]. A parabolic dish solar cooker consists typically of a parabolic platter-fashioned solar concentrator fitted on a suitable structural base. The cooking vessel is directly placed on a solar cooker and tracked in conjunction with the parabolic platter (Fig. 11).

3.2.5 Fixed Focus Elliptical Scheffler Reflector

A paraboloid reflector dish/mirror is a reflecting plate that is used to collect or focussing on energy such as solar radiation. It takes the shape of a circular paraboloid, a surface formed by a parabola rotating around its axis. The arriving plane light wave moves along the axis, and the parabolic reflector transforms this into a spherical wave which converges itself on focus. Parabolic reflectors gather energy from a remote point and concentrate it into a specific point of focus, eliminating the chromatic aberrations seen in more basic nearly spherical reflectors [36]. Because the reflection laws are reversible, parabolic reflectors can also be used in a parallel light ray to project the light of a source at its focus outward, as seen in car lights and searchlights.

The reflector Scheffler is titled after Wolfgang Scheffler, the developer of the device. As seen in Fig. 12, it is a main concentrating reflector that monitors the sun's motion and focuses the light on a fixed point. Because the focus would move as the dish rotates if the utilized reflector was a rigid paraboloid, the reflector is made more flexible and twists as the platter rotates [37]. The reflector will always be perfectly paraboloid. The light concentrated by the reflector heats a huge vessel that can be

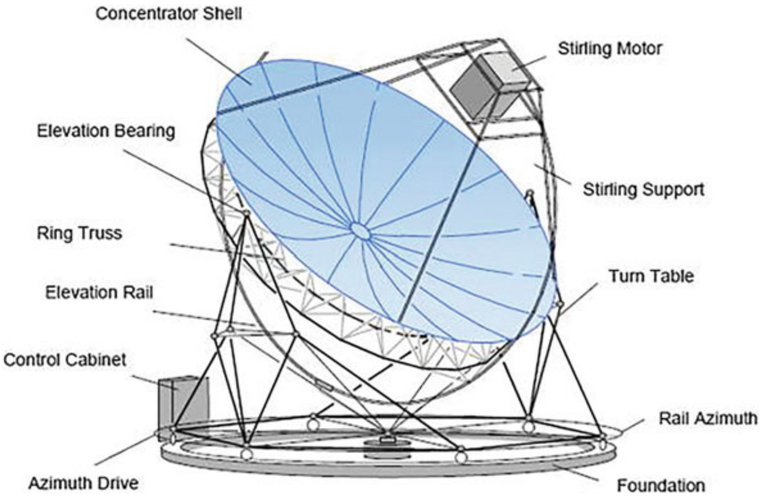

Fig. 11 Layout of a EURODISH parabolic trough system "EURODISH" TM is a Stirling solar dish system with a 10kWe capacity [35]

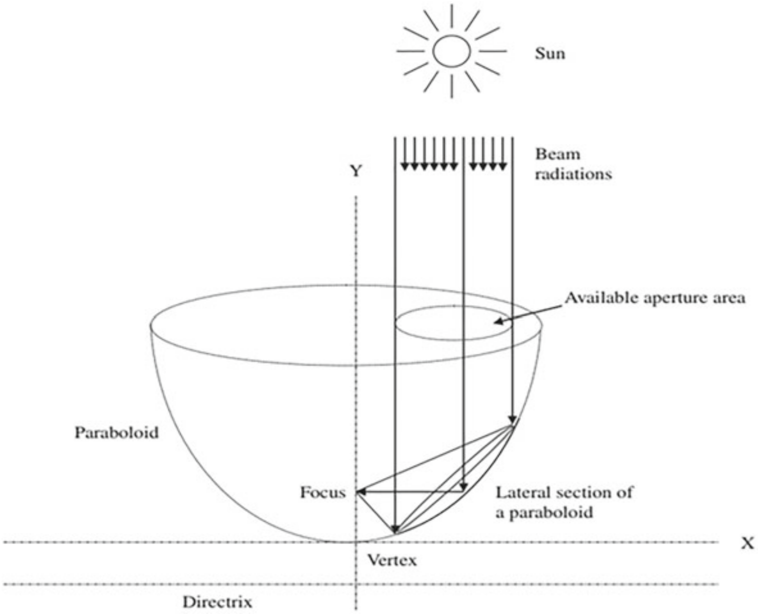

Fig. 12 Scheffler reflector section in a paraboloid shape [36]

applied for heating systems, steam generation, preparing food, including making pieces of bread, and among other things. The Scheffler reflector can be used to heat water in the home [38]. Via the use of sub-uniform solar radiation dispersed on the heated cylindrical absorber surface, Scheffler reflectors can provide efficient water heating. This has a wide spectrum of uses, including solar cooking (in which the sun is concentrated on the cooking vessel), textiles, pharmaceuticals, and so on [39].

4 Conclusion

- This paper discusses a few of the most popular kinds of solar receivers. Flat plate, compound parabolic, evacuated pipe, parabolic trough, Fresnel glass, parabolic dish, solar tower, Scheffler reflector, and parabolic mirrors field collectors are among the different types of collectors mentioned.
- The temperature of the energy delivery system can be raised by reducing the area where heat is lost. If a significant amount of solar energy is focussed on a restricted collection area, temperatures far exceeding the achievable by FPRs can be attained.
- In a concentrator receiver, the working fluid can reach higher temperatures than in an FPR with the same solar energy-collecting surface. As a result, greater thermodynamic performance can be enhanced.
- It is possible to obtain a thermal match between temperature level and tasks using a concentrator receiver. It may be necessary to operate thermionic, thermodynamic, or other high-temperature devices.
- Solar energy receivers can be used for a wide range of systems, can provide substantial economic and environmental advantages, and can be used wherever possible, as the potential applications areas outlined in this paper.
- Reflecting panels use fewer materials and have a simpler structure than FPRs. As a result, the price per unit area of the solar-collecting surfaces for a focussing receiver is lower than for an FPR.
- When compared to FPRs, concentrator systems receive little or no diffuse solar radiation, based on the concentration ratio.

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