1. Introduction

The thermodynamic cycles used for solar thermal power generation can be broadly classified as low, medium and high temperature cycles. Low temperature cycles work at maximum temperatures of about 100°C, medium temperature cycles work at maximum temperatures up to 400°C, while high temperature cycles work at temperatures above 400°C. Low temperature systems use fiat-plate collectors or solar ponds for collecting solar energy. Recently, systems working on the solar chimney concept have been suggested. Medium temperature systems use the line focussing parabolic collector technology. High temperature systems use either parabolic dish collectors or central receivers located at the top of towers. In this paper, the technologies and systems developed thus far and their approximate costs are described.

2. Low temperature systems

A diagram of a typical low temperature system using flat-plate collectors and working on a Rankine cycle is shown in figure 1. The energy of the sun is collected by water flowing through the array of fiat-plate collectors. In order to get the maximum possible temperature, booster mirrors which reflect radiation on to the fiat-plate collectors are sometimes used. The hot water at-temperatures close to 100°C is stored in a well insulated thermal storage tank. From here it flows through a vapour generator through which the working fluid of the Rankine cycle is also passed. The working fluid has a low boiling point.

Consequently, vapour at about 90°C and a pressure of a few atmospheres leaves the vapour generator. This vapour then executes a regular Rankine cycle by flowing through a prime mover, a condenser and a liquid pump. The working fluids normally used are organic fluids like methyl chloride and toluene, and refrigerants like R-11, R-113 and R-114. It has to be noted that the overall efficiency of this system is rather low, because the temperature difference between the vapour leaving the generator and the condensed liquid leaving the condenser is small. For the cycle shown in figure 1, the temperature difference is only 55°C. This leads to a Rankine cycle efficiency of 7 to 8%. The efficiency of the collector system is of the order of 25%. Hence an overall efficiency of only about 2% is obtained.

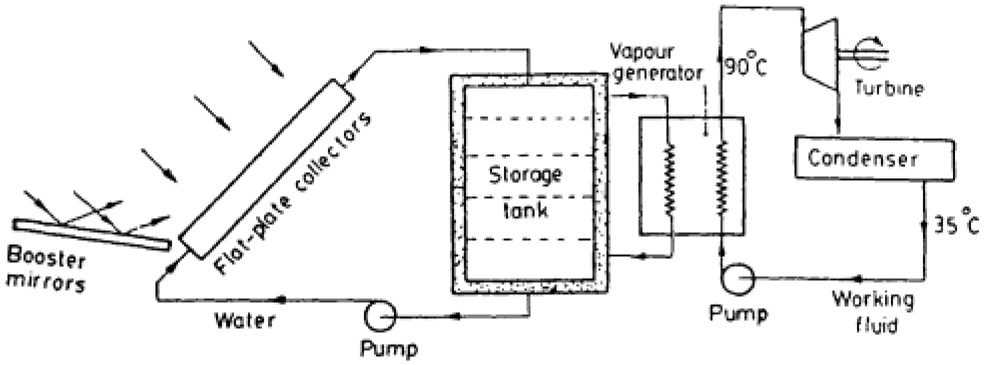


Fig. 1. Low temperature power generation cycles using flat-plate collectors.

Plants of this type of French design having generation capacities up to about 50 kW were installed in many parts of the world, particularly Africa, in the seventies. A 10 kW plant was also installed at the Indian Institute of Technology Madras in 1979-80 under an Indo-German collaboration agreement. However, such plants have been found to be very costly because of the large collector areas involved. Typically, the installed cost is about Rs. 300000 per kW for 6 to 8 h of daily operation, the main component of cost being the collectors. Because of the low efficiency and high cost, this technology is now obsolete.

In order to reduce the cost, solar ponds have been used instead of flat-plate collectors. The first two solar pond power plants having capacities of 6 kW and 150 kW were constructed in Israel about 15 years ago. These were followed in 1984 by the Bet Ha-Arava power plant, the largest in the world with an area of 250000 m 2 and a capacity of 5 MWe. The working of these plants has firmly established the technical viability of solar pond power plants. However they also do not appear to be economically attractive inspite of being less costly than plants using flat-plate collector systems.

Recently the concept of a solar chimney power plant has been suggested. In such a plant, a tall central chimney is surrounded at its base by a circular green-house consisting of a transparent cover supported a few metres above the ground by a metal frame (figure 2). Sunlight passing through the transparent cover causes the air trapped in the green-house to heat up. A convection system is set up in which this air is drawn up through the central chimney turning a turbine located near the base of the chimney. The hot air is continuously replenished by flesh air drawn in at the periphery of the green-house.

The only solar chimney power plant built so far is a 50 kW pilot plant in Spain. It has a 200 m high chimney with a constant diameter of 10.3 m. The solar collector area extends to a radius of 126m from the chimney with the glazing being 2m above the ground. The turbine, housed at the base of the chimney, has four 5 m long blades and rotates at 1500rpm to produce an output of 50kW. Although the energy conversion efficiency of such plants is low (of the order of 1%), it is claimed that there will be considerable reduction in cost with scale-up and that a large size 1000 MW plant may cost only $1000 per kW.

A large 200 MW plant is currently being planned to be built in Jaisalmer, Rajasthan. The chimney for this plant will be 1000m in height and will he built in stages, some power being generated at each stage.

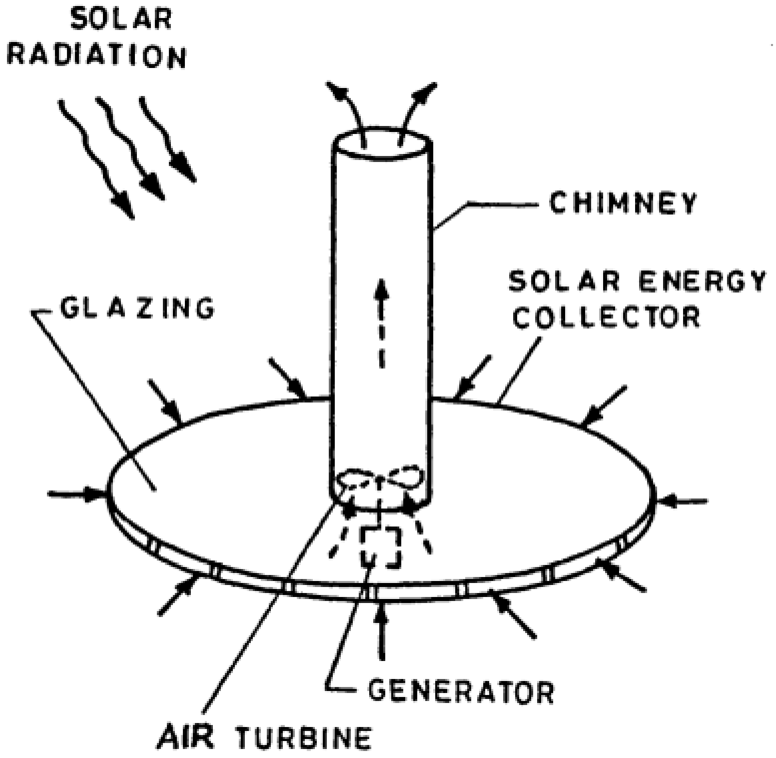


Fig. 2. Solar chimney power plant.

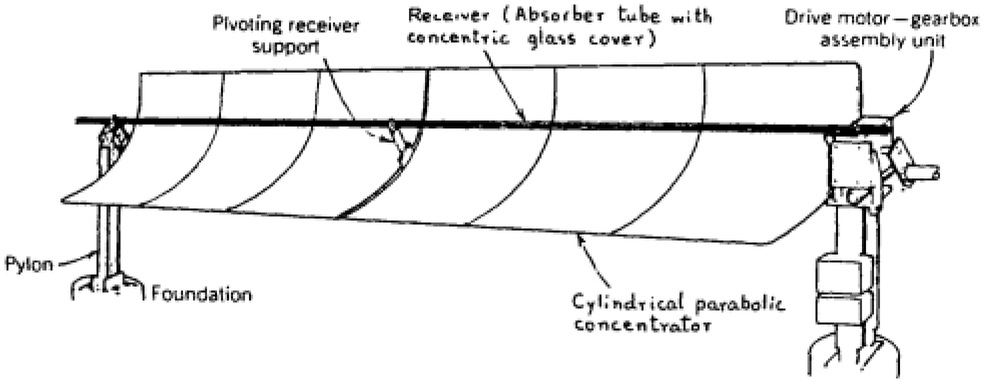


Fig. 3. Cylindrical parabolic concentrating collector.

3. Medium temperature systems

Among solar thermal-electric power plants, those operating on medium temperature cycles and using line focussing parabolic collectors (figure 3) at a temperature of about 400°C have proved to be the most cost effective and successful so far. A schematic diagram of a typical plant is shown in figure 4. The first commercial plant of this type having a capacity of 14 MW was set up in 1984. Since then, six plants of 30 MW

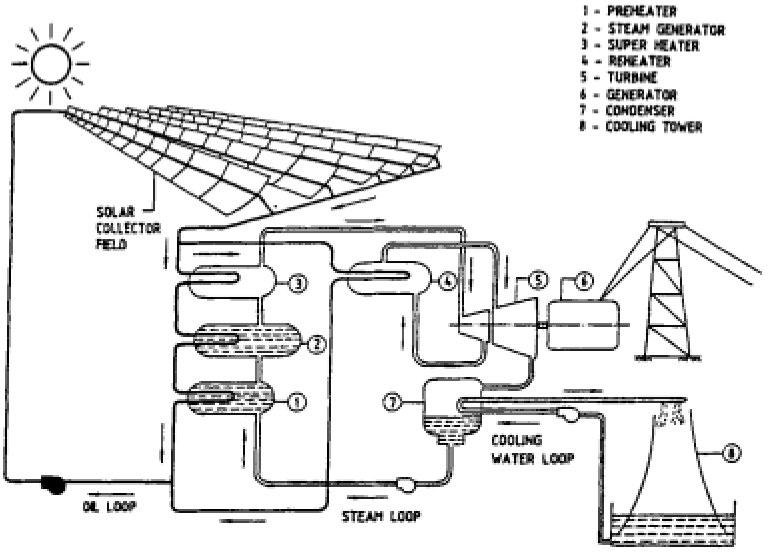


Fig. 4. Medium temperature power generation cycle using parabolic concentrating collectors

capacity each, followed by two plants of 80 MW each have been installed and commissioned. All these plants have been set up by LUZ International in California, which has a total installed capacity of 354 MW. The collector array for the 80 MW plant has an area of 464340 m 2. The cylindrical parabolic collectors used have their axes oriented north-south. The absorber tube used is made of steel and has a specially developed selective surface. It is surrounded by a glass cover with a vacuum. The collectors heat a synthetic oil to a temperature 0f,400°C with a collector efficiency of about 0-7 for beam radiation. The synthetic oil is used for generating super-heated high pressure steam which executes a Rankine Cycle with an efficiency of 38%. The plant generally produces electricity for about 8 h a day and is coupled with natural gas for continuous operation. The installed cost of this type of plant has reduced over the years because of the increasing installed capacity. The latest 80 MW plant is reported to have cost $.2900 per kW. The current generating cost is about 8 cents per kWh.

The following are some details of the collector modules used in the 80 MW power plant.

Aperture	5-76m
Length	95.2m
Reflecting surface	224 curved mirror glass panels
Reflectivity	0.94
Glass cover transmissivity	0-965
Vacuum in annular space	10-4torr
Absorber tube O. D.	0.070 m
Tube surface absorptivity	0.97
Tube surface emissivity	0-15
Optical efficiency	0-772
Peak collection efficiency	0.68 (based on beam radiation)
Annual collection efficiency	0.53 (based on beam radiation)

The above data give some idea of the international state-of-the-art in line focussing cylindrical parabolic collector technology. It may be worth noting that such collectors are not yet being made commercially in India. However considerable expertise has been developed in constructing a number of prototypes in many research institutions.

The Indian experience with power generation using the line focussing parabolic collector technology has unfortunately been restricted so far only to a small 50 kW capacity experimental plant installed at the Solar Energy Centre of the Ministry of Non-Conventional Energy Sources. However, plans are underway for setting up a 35 MW plant near Jodhpur. A detailed project report covering specifications of equipment and cost estimates has been prepared.

4. High temperature systems

Two concepts have been tried with high temperature systems. These are the parabolic dish concept and the central receiver concept. Parabolic dish collector system In the parabolic dish concept (figure 5) the concentrator tracks the sun by rotating about two axes and the sun's rays are brought to a point focus. A fluid flowing through a receiver at the focus is heated and this heat used to drive a prime mover. Typically Stirling engines have been favoured as the prime movers and systems having efficiencies upto 30% and generating power in the range of 8 to 50 kW have been developed. The Indian experience

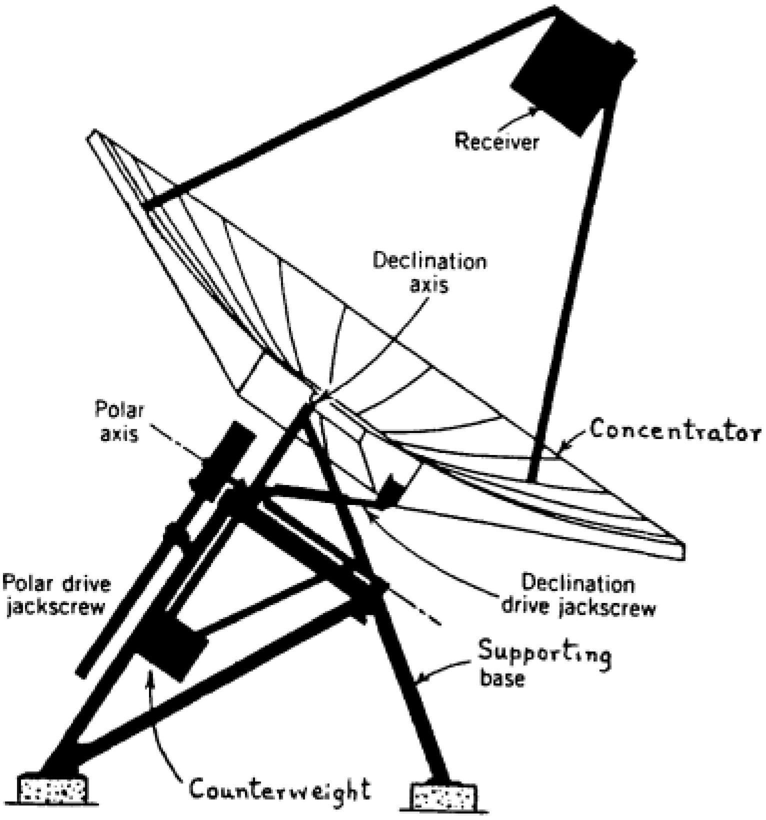


Fig. 5. Parabolic concentrating collector.

with this type of system has been restricted to a small experimental 20 kW power station near Hyderabad. Four parabolic dish collector modules were used to generate steam which ran a steam engine. Because of limitations on the size of the concentrator, parabolic dish systems can be expected to generate power in kilowatts rather than megawatts. Thus they can be expected to meet the local power needs of Communities, particularly in rural areas. Some commercial designs of parabolic dish collector systems have been developed abroad in the last ten years for electric power production. A 7.5 m diameter stretched metal membrane concentrator has been developed by a German firm. The membrane is a stainless steel sheet (0.23 mm thick) fixed on both sides of a circular ring. The two membranes are deformed plastically to a parabolic shape by applying a water load and a partial vacuum, the vacuum being maintained during operation of the concentrator. The front membrane is covered with thin glass mirrors having a reflectivity of 0"90 and an area of 42 m z. The concentrator is suspended at two points in a polar mounting and tracks the sun by rotating daily about a vertical axis and seasonally about a horizontal axis. The focal length is 5m.

A cavity-type receiver having a diameter of 0-2 m is kept at the focus. About 27 kW of energy is absorbed in the receiver if the incident beam radiation is 800 W/m 2. A Stirling engine located at the focus converts this thermal input to 8 kW with an energy conversion efficiency of 0"3. More recently, the same firm has built two 17 m diameter dishes of the same design generating 50 kW each. These are in operation in Saudi Arabia. Dish/Stirling engine systems have also been built by other manufacturers.

As stated earlier, it is generally felt that parabolic dish systems are best suited for applications which utilize solar energy directly at the focus of each collector. However in USA, a 5 MW power plant utilizing the steam generated by seven hundred dishes has been erected. Each dish consists of a reflecting array of twenty four 1.5 m diameter mirrors having an area of 42 m-'. The mirrors are made of reflective polymeric film fixed on circular aluminium frames and subjected to a continuously applied vacuum. The receiver is an insulated cylindrical cavity about 0.9 m long and 0"6m diameter and contains a molten salt. Pipes carrying water/steam pass through the salt bath. Thus the solar energy is first absorbed by the molten salt and then transferred to the water/steam, the salt bath acting as a storage which takes care of small variations in solar radiation.

Out of the total number of seven hundred dishes, six hundred are used to obtain saturated steam at 275°C, while the remaining one hundred dishes are used to superheat the steam to 400°C. The steam is used to run two turbine-generator sets-one a main set of 3-68 MW and the other, a peaking set of 1-24 MW.

5.Central receiver power plant

In central receiver power plants; solar radiation reflected from arrays of large mirrors (called heliostats) is concentrated on a receiver situated at the top of a supporting tower. A fluid flowing through the receiver absorbs the concentrated radiation and transports it to the ground where it is used to operate a Rankine power cycle. A schematic diagram showing the main components of a central receiver power plant in which water is

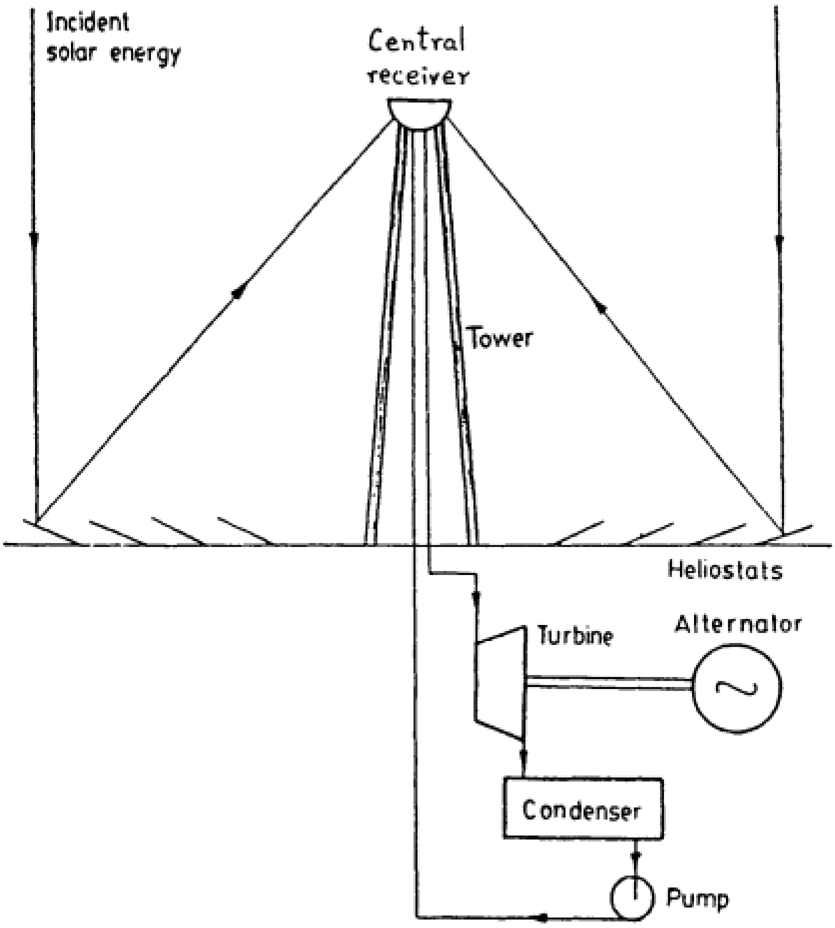
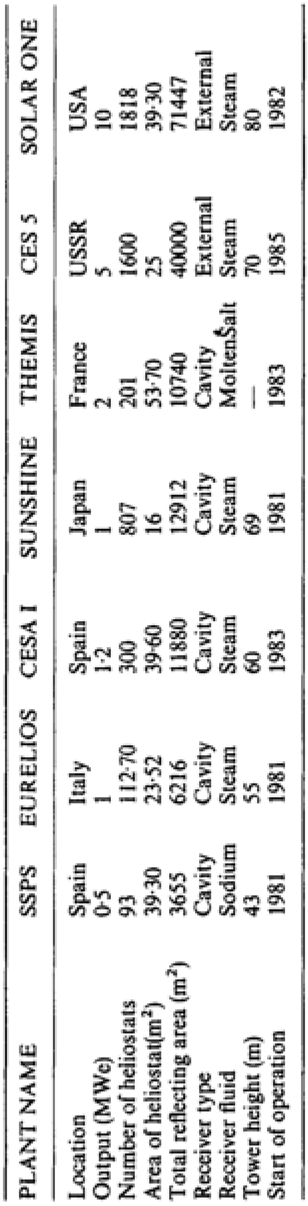


Fig. 6. Central receiver power plant.

Converted into steam in the receiver itself is shown in figure 6. Alternatively, the receiver is used to heat a liquid metal or a molten salt and this fluid is passed through a heat exchanger in which steam for the power cycle is generated. The idea of building such a plant was first suggested by scientists in the Soviet Union. Based on their calculations, they indicated the possibility of erecting an installation in the sunny regions of the USSR to produce 11 to 13 t of steam per hour at 30 atm and 400°C. The optical system was calculated to consist of 1293 mirrors of 3 × 5 m. These heliostats were proposed to be mounted on carriages which moved on rails in arcs around the tower.

A number of small pilot plants were built in Italy in the period 1965 to 1967. In one of these 50 kW of energy was collected. After a break of a few years, the design of central receiver collector systems again attracted attention in the eighties and seven plants ranging in capacity from 0"5 to 10 MW were built. These are listed in table 1 along with some technical specifications. These include the number and the size of the heliostats, the receiver type, the receiver fluid and the height of the central supporting tower.

Table 1. Solar central receiver power plants



PLANT NAME	SSPS	EURELIOS	CESA I	SUNSHINE	THEMIS	CES 5	SOLAR ONE
Location	Spain	Italy	Spain	Japan	France	USSR	USA
Output (MWe)	0·5	1	1·2	1	2	5	10
Number of heliostats	93	112·70	300	807	201	1600	1818
Area of heliostat(m^2)	39·30	23·52	39·60	16	53·70	25	39·30
Total reflecting area (m^2)	3655	6216	11880	12912	10740	40000	71447
Receiver type	Cavity	Cavity	Cavity	Cavity	Cavity	External	External
Receiver fluid	Sodium	Steam	Steam	Steam	MoltenSalt	Steam	Steam
Tower height (m)	43	55	60	69	—	70	80
Start of operation	1981	1981	1983	1981	1983	1985	1982

Although all the central receiver plants have been operated successfully, the available data indicate that the construction cost was very high. For example, the largest plant, Solar One, at Barstow, California cost approximately $14, 000 per kW. However, costs are likely to reduce with more operational experience, improved design and scale-up. The two major components requiring considerable development are the heliostats and the receiver. These will now be discussed.

The heliostats form an array of circular arcs around the central tower. They intercept, reflect and concentrate the solar radiation onto the receiver. The array is served by a tracking control system which continuously focusses beam radiation towards the receiver during collection. In addition, when solar radiation is not being collected, the control system orients the heliostats in a safe direction so that the receiver is not damaged.

As stated earlier, the 10MWe plant at Barstow was the largest of the pilot plants built. It was operated for six years from 1982 to 1988. The plant had a field of 1818 heliostats positioned all round a central tower of height 80 m. Each heliostat was an assembly of 12 slightly concave glass mirrors mounted on a support structure and geared drive that could be controlled for azimuth as well as elevation. The total reflective area of each heliostat was 39-3 m 2. A rear view sketch is shown in figure 7.

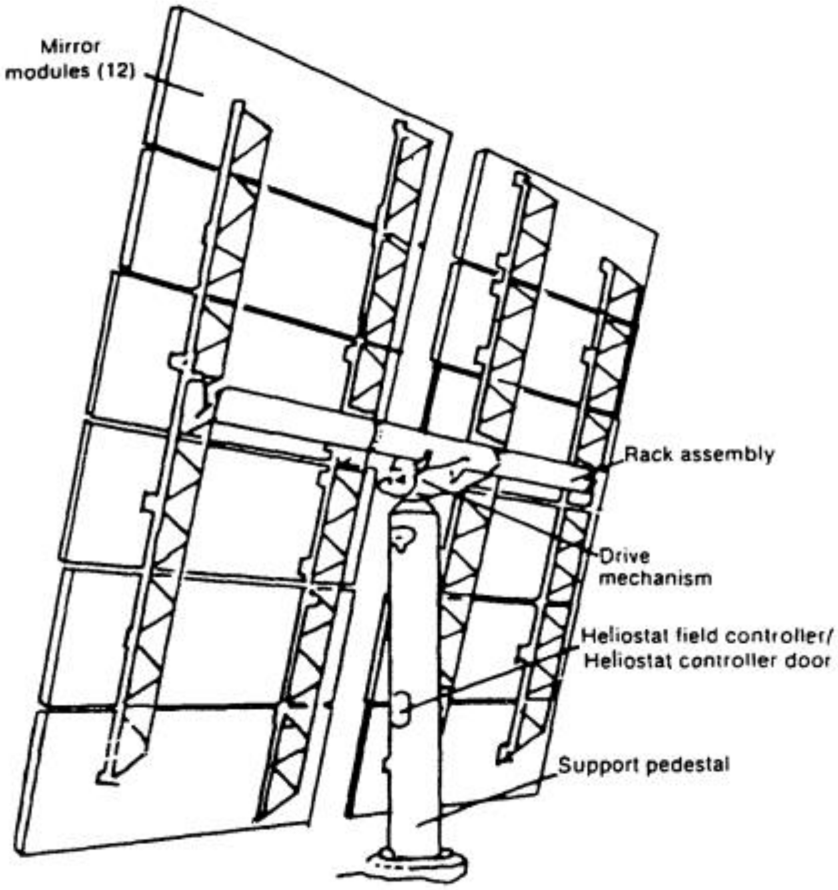


Fig. 7. A heliostat.

The 12 mirror panels in each heliostat were 1 x 3 m in size and were made from 3 mm low iron float glass. When clean, the heliostats had an average reflectivity of 0-903. However exposure to the environment caused them to become dirty, thereby reducing the average reflectivity to 0"82. A goal of 0-92 has been set for future heliostat arrays. In order to achieve this goal along with reduced cost and weight, a. number of new concepts are being tried. For example, larger size glass-mirror heliostats having areas of 150m 2 and reflectivity values up to 0-94 have been built. Also a new type of cost effective heliostat using a stretched membrane has been developed. In this heliostat, the reflector is a silvered polymer film laminated to a thin metal foil which is stretched over a large-diameter metal ring. The reflectivity of this surface has been measured to be 0"92. Because of its simplicity and light weight, a stretched-membrane heliostat could be about 3 0 o less costly than a glass-mirror design.

The receiver is the most complex part of the collection system. The main factor influencing its design is its ability to accept the large and variable heat flux which results from the concentration of the solar radiation by the heliostats. This flux has to be transferred to the receiver fluid. The value of the heat flux can range from 100 to 1000 kW/m 2 and this results in high temperatures, high thermal gradients and high stresses in the receiver. The value depends on the concentration ratio and varies with the season and the day. It also varies over the surface of the receiver. For these reasons, attention has to be given to the absorber shape, the heat transfer fluid, the arrangement of tubes to carry the fluid and the materials of construction.

There are two types of receiver designs: the external type and the cavity type (figure 8). The external receiver is usually cylindrical in shape. The solar flux is directed onto the outer surface of the cylinder consisting of a number of panels and is absorbed by the receiver fluid flowing through closely spaced tubes fixed on the inner side. On the other hand, in a cavity receiver, the solar flux enters through a small aperture in an insulated enclosure. The cavity contains a suitable tube configuration through which the receiver fluid flows. The geometry of the cavity is such that it maximises the absorption of the entering radiation, minimizes heat losses by convection and radiation to the ambient and at the same time accommodates the heat exchanger that transfers the radiant energy to the receiver fluid. Both types of receivers have their advantages and disadvantages. The external type has a very wide acceptance angle, while the cavity

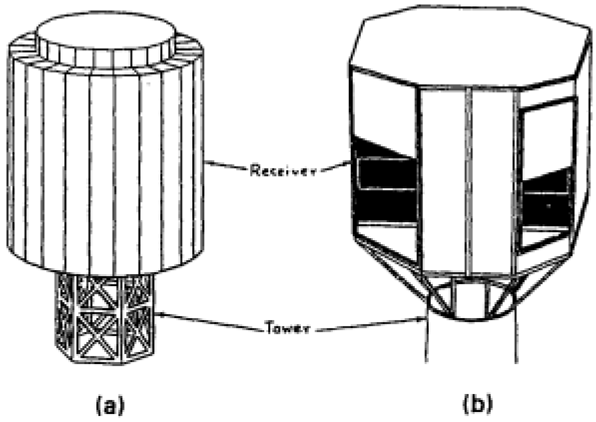


Fig. 8. Receivers (a) External type, (b) Cavity type with four apertures.

type has a small acceptance angle. On the other hand, the cavity type traps the solar flux more effectively and consequently has a higher efficiency than the external type. The 10 MW plant at Barstow had an external type of receiver in which water was heated directly and converted to superheated steam. The receiver was a cylinder, 7 m in diameter and 13"5 m in height, made up of 24 vertical panels painted black. Incoloy 800 tubes (0-6 cm I. D., 1"25 cm O. D.) were fixed on the inside. The receiver was located on a tower 80m high and produced steam at 102 bar and 510°C. The receiver had an annual efficiency of 0-69, which was rather low. In order to achieve higher efficiencies, it is planned that the next design will use a molten salt as the heat transfer fluid instead of water/steam. With a molten salt, the receiver can operate with higher incident solar fluxes. Consequently the size of the receiver would be reduced resulting in smaller thermal losses. In addition, the molten salt would be essentially at atmospheric pressure, thereby permitting the use of thinner walled tubes in the receiver. An annual efficiency goal of 0.90 has been set for this design.

6. Fresnel

Concentrated solar power systems have until recently focused on bulk electricity production, with the main focus on solar towers and trough type collectors. Recent developments have focused on smaller units to supplement thermal power stations and to provide heat for industrial processes. Collectors based on the linear Fresnel reflector design are leading the pack.

There is a gap in the market between non-concentrating rooftop collectors used for solar heating and large scale systems used for bulk electricity generation. This gap is being filled by systems which use linear instead of circular focusing. Two main systems are the solar trough and the linear Fresnel (LFR) based collector. Although the trough based system has proven itself over many years of operation in different applications, the Fresnel system is emerging as an alternative with several advantages.

LFR plant is highly modular, ranging from a few hundred kW to several MW in size, and offers the lowest land occupancy compared to other CSP technologies. Parabolic troughs represent the optimal solution for achievable concentration ratio and achievable energy yield per aperture area and, hence, the best overall plant efficiency in line-focussing mirror systems. For that reason CSP development efforts have concentrated on parabolic trough geometry.

Nevertheless, in the last decade LFR systems have aroused an increasing interest. The main reason for this is the search for cheaper solar field solutions. The considerable economic advantages of Fresnel collectors are principally related to their constructive simplicity. In addition, Fresnel solar fields permit higher land use efficiency than any other type of solar fields. These advantages can offset the lower solar-to-heat efficiency, and LFR power plants represent an interesting alternative to parabolic trough power plants.

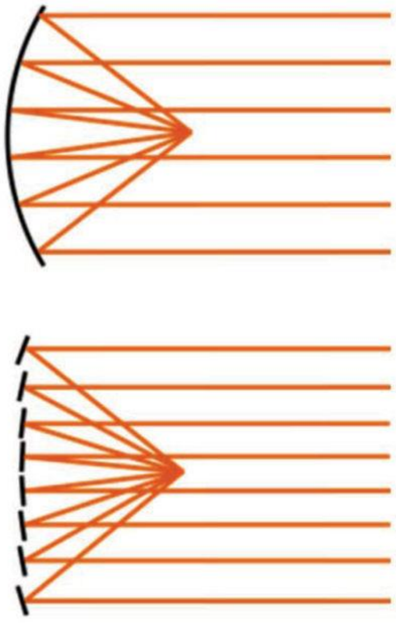


Fig. 9: Principle of Fresnel mirror system

The main advantage of LFR systems is that their simple design of flat or flexibly bent mirrors and fixed receivers requires lower investment costs and offers a wide range of configurations. Originally designed for low and medium power applications, LFRs are now being designed for higher temperatures which facilitate direct steam generation (DSG) which can be used efficiently in the industrial or power generation sector.

Fresnel systems can be configured to operate over a wide range of temperatures, from 200 to 500°C, although systems with temperatures as high as 550°C are under development. Applications range from industrial process heat, distributed power generation using the organic Rankin cycle to steam turbine systems.

Developments in energy efficiency in both industry and power generation have focused attention on medium and high temperature solar thermal systems. LFRs have great potential in southern Africa due to the low cost and high percentage of local manufacture inherent in the technology.

Principle

The linear Fresnel reflector technology receives its name from the Fresnel lens, which was developed by the French physicist Augustin-Jean Fresnel for lighthouses in the 18th century. The principle of this lens is the breaking of the continuous surface of a standard lens into a set of surfaces with discontinuities between them. This allows a substantial reduction in thickness (and thus weight and volume) of the lens, at the expense of reducing the imaging quality of the lens. Where the purpose is to focus a source of light this impact on the image quality is not of major importance.

The principle of dividing an optical element into segments which have the same (or a very similar) optical effect as the original optical element can also be applied to mirrors. It is possible to divide a parabolic mirror into annular segments, forming a circular Fresnel mirror which focuses the light that arrives in rays parallel to the optical axis onto the focal point of the parabolic mirror.

In an analogous way, a linear Fresnel mirror can be constructed substituting a parabolic trough by linear segments that focus the radiation that arrives in a plane parallel to the symmetry plane of the parabolic trough onto the focal line of the parabolic trough. A LFR has a similar effect to a parabolic trough, when considering the concentration of the radiation in a focal line i.e. a LFR behaves like a parabolic trough with the same focal length and the same aperture.

Fresnel mirror system

The mirrors focus the sun onto a receiver which contains the heat transfer medium which could be water, oil or even molten salt in some designs. The heat transfer medium used will depend on the operating temperature of the system. The main difference between the two systems lies in the way that the sun's rays are tracked, and this is what gives rise to the cheaper cost of Fresnel.

In the trough system the whole structure rotates about an axis coincident with the focal point of the trough. This means that the mirrors and the collector are connected mechanically, requiring bearings through which the collector tube must pass. In the Fresnel system the individual mirrors rotate to track the sun. There is no mechanical connection between the mirrors and the collector.

Separation of the mirrors and the receiver allows high temperature heat transfer mediums to be used, and also a much wider scope in the design of the receiver. The Fresnel system also allows individual control of each mirror, effectively changing the configuration of the reflector to optimise its function.

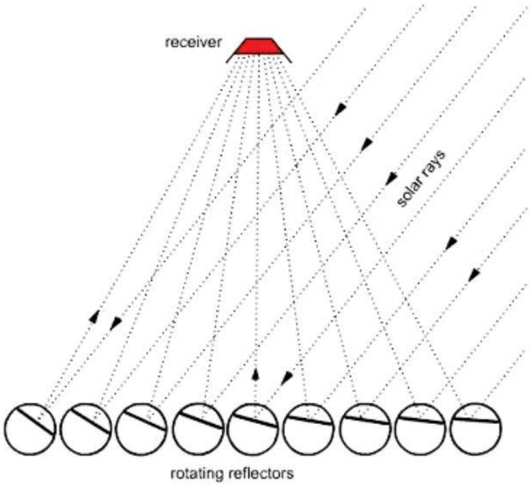


Fig. 10: Mirror tracking with Fresnel system

Supplementary heat or steam generation for power plants

Fresnel mirrors are being considered as a means to supplement heat in thermal power stations. Parts of the cycle such as preheating of the boiler feed water use low to medium temperature heat sources, and solar thermal systems can provide this heat. Typical applications are to substitute the bleed steam used for preheating boiler feedwater as shown.

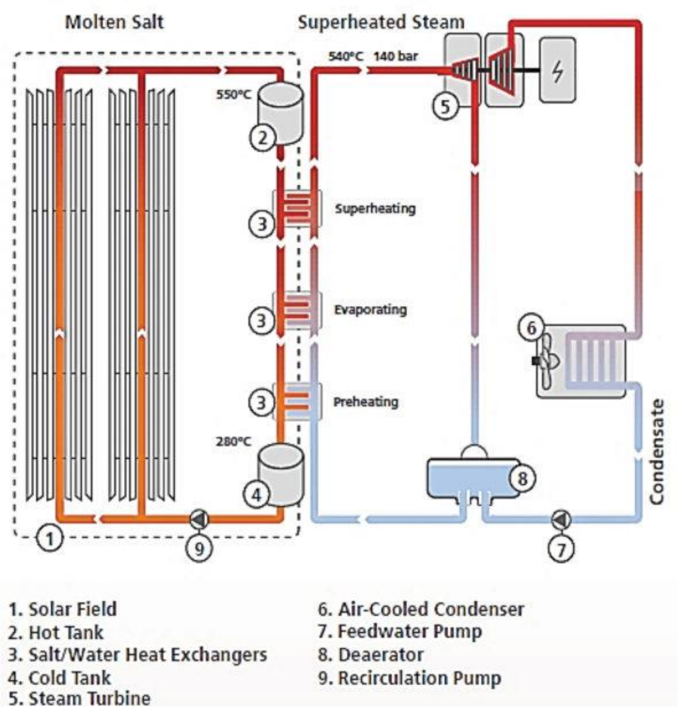


Fig. 11: High temperature CLF system using molten salt

The solar heat source is connected in parallel with the bled steam source and when available provides the heat normally used from the steam. The increased steam output then enables additional power generation from the turbine (solar boosting mode) or fuel consumption can be reduced (fuel saver mode).

More complex systems use several stages of regeneration with heat substitution at each stage. Heat may be stored for periods when the solar resource is low, or the plant may be operated in a two shift mode. Using solar power may have two effects:

Increase in the power generation capacity of the plant during periods when solar power is available.

Decrease in coal consumption with no increase in power generation.

The integration of solar thermal collectors into conventional fossil plants, or solar aided power generation (SAPG), has proven a viable solution to address the intermittency of power generation and combines the environmental benefits of solar power plants with the efficiency and reliability of fossil power plants. In SAPG technology, thermal oil can be used as solar heat carrier and no solar steam needs to be generated, therefore the pressure of solar system can be much lower than that of the solar collector using water/steam as the heat carrier. Newer developments make use of the higher heat content of solar steam directly, provided from DSG plants.

The temperature of the heat source is one of the major defining factors of a power plant – higher temperature results in higher overall power plant efficiency. With SAPG, the heat source temperature is not limited by the solar input temperature and is therefore an effective means of utilising low or medium solar heat (250°C) for power generation. However, internationally the adoption of the technology has been slow, despite it being a viable and quick means of CO2 emission reduction.

A study was conducted on a simulated SAPG power plant at Lephalale, which was based on a generic 600 MW subcritical fossil power plant with a reheater and regenerative Rankine cycle with two low pressure feedwater heaters (FWH) downstream of the deaerator and three high-pressure FWHs upstream.

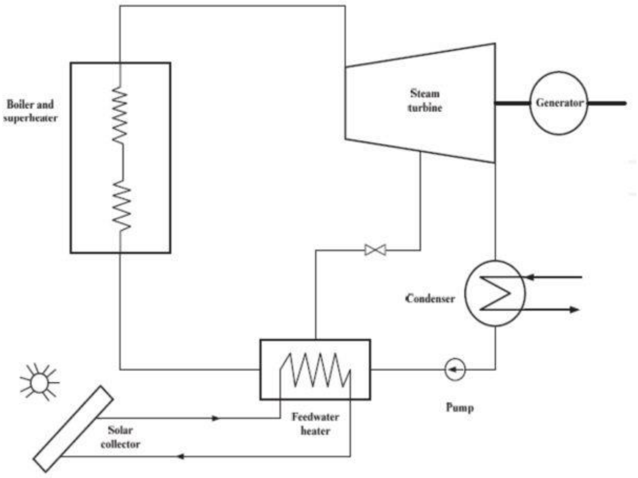


Fig. 12: Single-stage regenerative Rankine cycle with open feedwater heater

This study showed that integrating solar thermal with steam plant is approximately 1,5 times as efficient at converting solar energy to electricity as a CSP stand-alone generating plant. Therefore, a solar assisted high pressure feedwater heater system at an existing coal-fired power station is 1,8 times more cost-effective than a stand-alone CSP plant. The conversion efficiency is claimed to be of the same order as solar PV.

The Fresnel mirror solution is gaining popularity because of cost and simplicity advantages over the parabolic trough solution for SAPG systems. Costs of the Fresnel based system are estimated to be approximately 70% of the equivalent parabolic trough system.

7. Solar Pond

Pond collectors are either natural or artificial lakes, ponds or basins that act as a flat plate collector because of the different salt contents of water layers due to

stratification.

•The upper water layers of relatively low salt content are often provided with plastic covers to inhibit waves.

•This upper mixing zone of such pond collectors usually is approximately 0.5 m thick.

•The adjacent transition zone has a thickness of 1 to 2 m, and the lower storage zone is of 1.5 to 5 m thickness.

Mechanism:

•If deeper layers of a common pond or lake are heated by the sun, the heated water rises up to the surface since warm water has a lower density than cold water.

•The heat supplied by the sun is returned to the atmosphere at the water surface.

•This is why, in most cases, the mean water temperature approximately equals ambient temperature.

•In a solar pond, heat transmission to the atmosphere heat transmission to the atmosphere is prevented is prevented by the salt dissolved in deeper layers since, due to the salt, water density at the bottom of the pond is that high, that the water cannot rise to the surface, even if the sun heats up the water to temperatures that are close to the boiling point.

System components: The salt concentration of the different layers must thus increase with increasing depth

In a first phase, this ensures stable water stratification.

The upper, almost salt-less layer only acts as transparent, heat-insulating cover for the cooling, heat-storing deeper layers at the pond bottom.

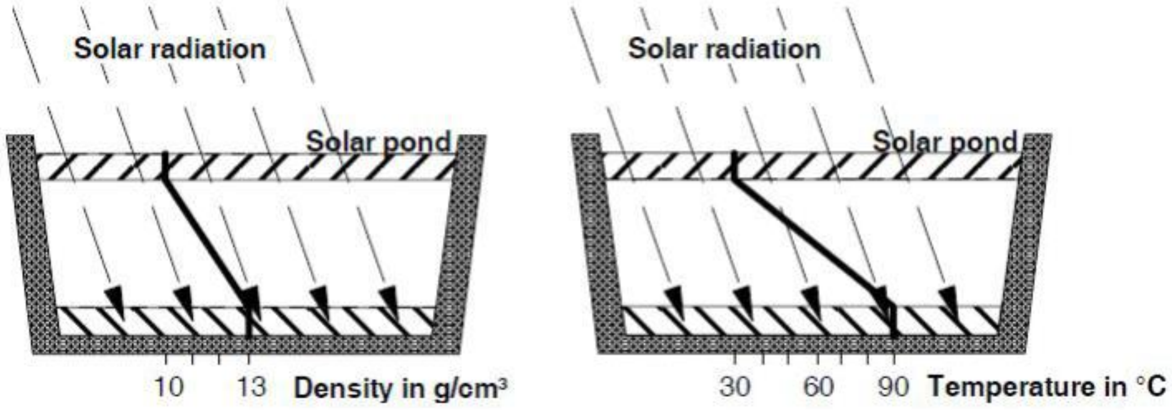


Fig.13. Constructions of solar pond

Attentions:

To ensure stable stratification of a solar pond, with increasing depth the temperature increase must not exceed density increase (i.e. salt content). This is why all relevant parameters must be continuously monitored in order to take appropriate measures (e.g. heat withdrawal, salt supply) in due time.

To achieve the utmost collector efficiency, a high portion of the solar radiation must reach the absorption zone. Yet, this can only be achieved, if the top layers are of sufficient transmission capability.

Monitoring:

During the operation of a solar pond, the transmissivity, the salt content and the temperature must be regularly monitored. The timely course of these parameters must be measured from the water surface to the ground in order to determine the heat quantity that can be withdrawn from the pond or to determine the measures to maintain the respective required salt concentration and the water quality (prevention of turbidity due to particulate matter, algae or bacteria).

Heat exchangers:

Basically, there are two methods to withdraw heat from a solar pond:

The working fluid of the thermal engine flows through tube bundle heat exchangers installed within the storage zone of the solar pond, and is thereby heated up.

The hot brine can also be pumped from the storage zone by means of an pumped from the storage zone by means of an intake diffuser, subsequently be transmitted to the working fluid of the thermal engine and eventually be re-supplied to greater depths of the pond by another diffuser, once the brine has cooled down.

- The technical approach allows adjusting the position of the intake diffuser to the depth of the highest temperature. Secondly, heat losses by the pond bottom are reduced, since the cooled water is recycled to the pond near the bottom.

Thermal Engine:

To convert solar thermal energy into mechanical and afterwards in electrical energy, usually Organic Rankine Cycles (ORC) processes are applied.

These are basically steam cycles which utilize a low-boiling, generally organic, cycle fluid.

Such processes permit to provide electrical energy also at low useful temperature differences.

Plant Concepts:

•The water absorbs the incident direct and diffuse radiation, similar to the absorber of a conventional solar collector, and is heated up.

•The technically adjusted salt concentration prevents natural convection and the resulting heat loss at the surface due to evaporation, convection and radiation.

*Water can thus be withdrawn from the storage zone at the bottom at an approximate temperature of 80 – 90oC. This heat can subsequently be used for power generation by an ORC process.

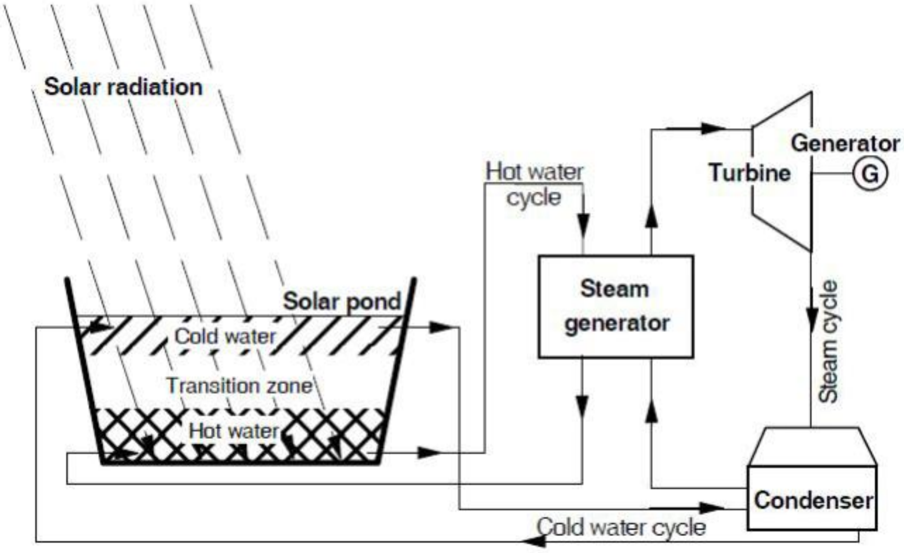


Fig.14. Plant diagram of a solar pond power plant

Solar pond power plants of electric capacities from a few ten kW up to a few MW have been built in Israel, the US (Texas), Australia (for process heat provision), among other countries.

With approximately one percent, solar thermal efficiencies are low; the mean specific capacities range from 5 to 10 W/m2 depending on radiation, salt content and maximum temperature.

For the short-term, also higher capacities can be withdrawn; however, in such a case the solar pond would cool down much faster

Applications

The heat from solar ponds can be used in a variety of different ways. First, since the heat storing abilities of solar ponds are so great they are ideal for use in heating and cooling buildings as they can maintain a fairly stable temperature. These ponds can also be used to generate electricity either by driving a thermo-electric device or some organic Rankine engine cycle - simply a turbine powered by evaporating a fluid (in this case a fluid with a lower boiling point). Finally, solar ponds can be used for desalination purposes as the low cost of this thermal energy can be used to remove the salt from water for drinking or irrigation purposes.

Benefits and Drawbacks

One benefit of using these ponds is that they have an extremely large thermal mass. Since these ponds can store heat energy very well, they can generate electricity during the day when the Sun is shining as well as at night.

Despite being a source of energy, there are numerous thermodynamic limitations as a result of the relatively low temperatures achieved in these ponds. Because of this, the solar-to-electricity conversion is fairly inefficient - generally less than 2%. As well, large amounts of fresh water are necessary to maintain the right salt concentrations all through the pond. This is an issue in places where fresh water is hard to come by, especially in desert environments. These ponds also do not work well at high latitudes as the collection surface is horizontal and cannot be tilted to collect more sunlight.

8. Conclusion

Solar thermal energy can make a real impact if it leads to large scale cost-effective electrical power generation. The survey done in this paper shows that this is far from being the case. However, impressive developments have taken place in the last decade. Medium temperature systems using line focussing parabolic collector technology have been commercialized to some extent, the central receiver concept has been tested extensively on a pilot scale, and the solar chimney concept has been proved. The last two systems also show promise for commercialization, but need a considerable amount of developmental work.