

## A REVIEW PAPER ON SOLAR THERMAL COLLECTOR FOR VARIOUS APPLICATIONS

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### **Abstract**

In this Paper, a review of the various types of solar energy collectors and their applications is presented. In the beginning, breakdown of various ecological problems linked with the consumption of conventional sources of energy are presented and the benefits offered by renewable energy systems are outlined. An introduction to the uses of solar energy is given followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish collectors

### **Introduction**

One of the most widely accepted definitions of sustainable development is: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. There are many factors that can help to achieve sustainable development. Today, one of the main factors that must be considered is energy and one of the most important issues is the requirement for a supply of energy that is fully sustainable. Such a supply in the long-term should be readily available at reasonable cost, be sustainable and be able to be utilized for all the required tasks without causing negative societal impacts. This is why there is a close connection between renewable sources of energy and sustainable development.

There are many alternative energy sources which can be used instead of fossil fuels. The decision as to what type of energy source should be utilized must, in each case, be made on the basis of economic, environmental and safety considerations. Because of the desirable

environmental and safety aspects it is widely believed that solar energy should be utilized instead of other alternative energy forms, even when the costs involved are slightly higher. The greatest advantage of solar

energy as compared with other forms of energy is that it is clean and can be supplied without any environmental pollution. The objective of this paper is to present the various types of collectors used to harness solar energy, their thermal analysis and performance, and a review of applications.

### **I. SOLAR COLLECTORS**

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. A large number of solar collectors are available in the market. In this section a review of the various types of collectors currently available will be presented.

This includes FPC, ETC, and concentrating collectors.

### 1. STATIONARY COLLECTORS

Solar energy collectors are basically distinguished by their motion, i.e. stationary, single axis tracking and two-axes tracking, and the operating temperature. Initially, the stationary solar collectors were examined. These collectors are permanently fixed in position and do not track the sun. Three types of collectors fall in this category:

#### FLAT PLATE COLLECTORS

Where temperatures below 90°C are adequate, flat plate collectors are particularly convenient. Flat plates can absorb both direct and diffuse solar radiation. It consists of transparent cover, tubes, fins or channels are integral with the collector absorber plate, which carry the water. Standard insulating materials such as fiber glass or styro-foam are used for this purpose. A flat-plate collector is installed at a fixed position facing the sun at an optimum inclination to the horizontal depending on the latitude of the location. Water heating is its major application which can be used for different purposes like domestic use (cleaning of utensils, clothes and bathing), industrial use (coloring, heating of secondary fluid), etc. As shown in Figure, a flat plate collector consists of five components as follows:

**Cover plate:** Its work is to entrap short-wave solar radiation falling on it by transmitting and converting them into long wave radiations. For the long wave radiations, it works as an opaque surface. Glazing is done on it, to increase its efficiency. Toughened glass and transparent plastic covers are used as cover plate.

**Absorber plate:** Its work is to absorb all the solar radiation falling on it and transmitting it to the tubes. It is mainly made up of Copper (Cu). Selective coating of black chrome, nickel black, copper oxide, etc., is being done on it to increase its efficiency.

**Flow tubes:** Its work is to transmit the energy taken from absorber plate to the fluid flowing through it. It is also made up of Copper (Cu). These are connected to

the storage tank where hot water is being kept, through header pipes.

**Insulation:** Its work is to stop transmission of the heat energy through the bottom and side surfaces. Mainly made up of glass wool, Rockwool and so on.

**Enclosure:** Its work is to support the above-mentioned components and is made up of iron sheet, wood.

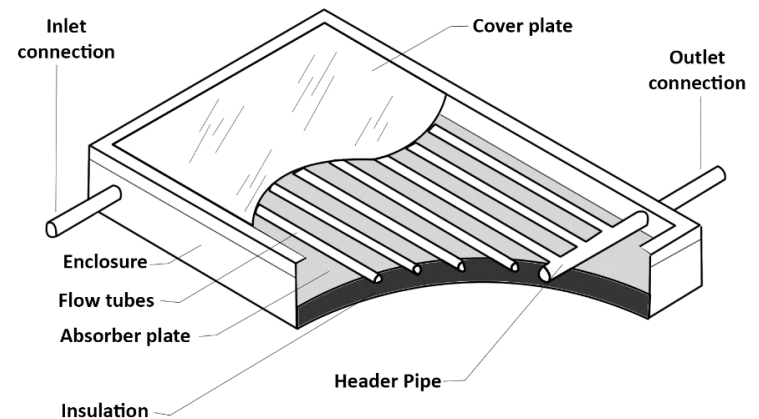


Fig . Flat Plate Collector

#### CONCENTRATING TYPE SOLAR THERMAL COLLECTORS

Concentrated solar power systems generate solar power by using mirrors to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Flat Plate Collectors are unable to provide carrier fluids at temperatures adequately elevated to be efficient, for central power generation and lots of industrial heat requirements.

Solar Concentrator increases the amount of incident energy on the receiver surface as compared to that on the concentrator aperture. The increase is achieved by the use of reflecting or refracting surfaces, the increases in achieved which focuses on the incident radiation onto a suitable receiver. If both the concentrating surface & the absorber surface are still, the concentrating surface is not capable of redirecting the sun rays on the absorber during the sunlight because of the apparent motion of the sun. To make the sun rays always focusing on to the receiver, the sun has to be followed by the concentrating system. And for that a tracking mechanism is also required for some applications.

Therefore, the Solar Concentrators generally consist of

components like:

- A Focusing Device (Concentrator)
- Receiver
- A Tracking Device (to continuously Follow the sun)

Due to the changes in the way that to track the sun and focus light, several types of concentrators make different temperatures and in the same way different thermodynamic efficiencies.

Types of Solar Concentrating systems:

- Parabolic trough
- Solar Power Tower
- Fresnel Reflectors
- Paraboloidal dishes

### PARABOLIC TROUGH

Paraboloidal troughs are the devices that have a “u” type letter shape. The Troughs concentrate sunlight onto a receiver tube that is situated next to the focal line of the trough. Sometimes to reduce heat loss, the receiver tube is enveloped by the transparent glass tube. Positioned straight above the middle of the parabolic mirror and filled with a working fluid is a receiver tube. During the daylight hours the concentrator follows the sun by tracking along a single axis. Trough systems are the most developed Concentrated Solar Power technology. The Solar Energy Generating Systems plants in California(SEGS), the world's first commercial parabolic trough plant is shown in figure below



Fig Parabolic Trough Collector

### SOLAR POWER TOWER

A solar power tower consists of an array of dual-axis tracking reflectors or heliostats that concentrate sunlight on a central receiver atop a tower, the receiver contains a HTF(Heat Transfer Fluid), which consist of water-steam or molten salt. The working fluid in the receiver is heated to 500 to 1000 °C and then used as a heat source for a power generation or energy storage system. A Computer keeps the mirror aligned so that the reflected rays of the sun are always aimed at the receiver. Main advantage of the solar tower is that the reflectors can be adjusted instead of the whole tower. Solar Power-tower development is less advanced than the trough systems, but they offer higher efficiency and better energy storage capability.



Fig . Solar Power Tower

### PARABOLOIDAL DISHES

Dish systems are same as troughs, exploit the geometric properties of a parabola, but as a three-dimensional paraboloid as shown in figure shown below. The reflected direct beam radiation is concentrated to a point focus receiver and in Concentrated Solar Trough systems can heat this to operating temperatures of over 1,000°C, similar to tower systems.

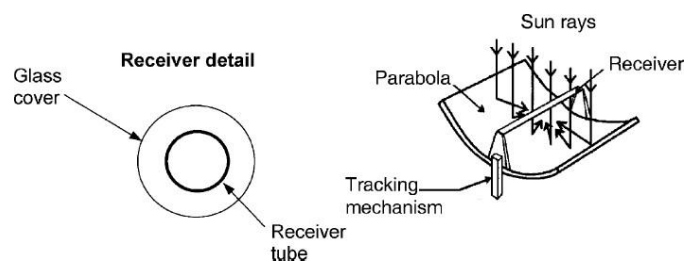
Dish systems offer the highest potential solar conversion efficiencies of all the Concentrated Solar Power technologies, because they always facing their full aperture directly towards the sun and avoid the cosine loss effect that the other approaches experience. They are, however, the least commercially mature. Dishes up to 25 m diameter have been demonstrated. As well as

thermal conversion, CPV conversion on dishes is well established, it is also applied or added with ‘micro dishes’ with diameters of just several centimeters.



Fig Paraboloidal Dish

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 (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.



#### A. Linear Fresnel Reflector

### FRESNEL REFLECTOR

To concentrate sunlight onto tubes or receiver to which working fluid is passed, flat mirror strips are placed called as Fresnel reflectors made of many thin strips. Better than a parabolic reflector, flat mirror gives more reflective surface while the amount of space is still same so as to capture more of the obtainable sunlight. They are also of lesser cost than parabolic reflectors. Fresnel reflectors can be used in a variety of size concentrated solar Power systems.

Fresnel reflectors are sometimes regarded as a technology with a worse than other methods. Instead of others higher output rating, this model is used because of its cost efficiency. Some new models of Fresnel Reflectors with Ray Tracing capabilities have initially proved to yield higher output than the standard version of Fresnel reflector.

applications up to 400°C could be obtained with parabolic through collectors (PTCs). PTCs can effectively produce heat at temperatures between 50°C and 400°C [10].

PTCs are made by bending a sheet of reflective

LFR technology relies on an array of linear mirror strips which concentrate light on to a fixed receiver mounted on a linear tower [11]. The LFR field can be imagined as a broken- up parabolic trough reflector, but unlike parabolic troughs, it does not 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. 5.

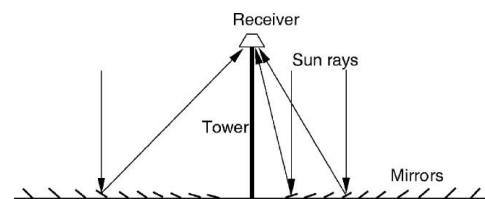


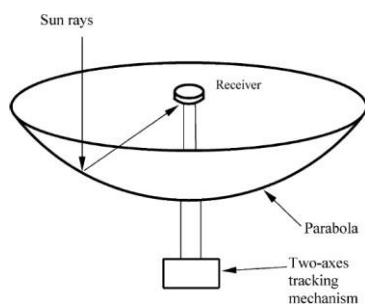
Fig. . Schematic diagram of a downward facing receiver illuminated from an LFR field

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.

### B. Parabolic Dish Collector

A parabolic dish reflector, shown schematically in Fig. 6, 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 1500°C. Because the receivers are distributed throughout a collector field, like parabolic troughs, parabolic dishes are often called distributed-receiver systems.

## II. SOLAR COLLECTOR APPLICATIONS

### Fig. . Schematic of a parabolic dish collector.

Solar collectors have been used in a variety of applications. These are described in this section. In Table the most important technologies in use are listed together with the type of collector that can be used in each case.

#### A. Solar water heating systems

The main part of a SWH is the solar collector array that absorbs solar radiation and converts it into heat. This heat is then absorbed by a heat transfer fluid (water, non-freezing liquid, or air) that passes

through the collector. This heat can then be stored or used directly [12]. In solar water heating systems, potable water can either be heated directly in the collector (direct systems) or indirectly by a heat transfer fluid that is heated in the collector, passes through a heat exchanger to transfer its heat to the domestic or service water (indirect systems) [13]. The heat transfer fluid is transported either naturally (passive systems) or by forced circulation (active systems). Natural circulation occurs by natural convection (thermosyphoning) [14], whereas for the forced circulation systems pumps or fans are used.

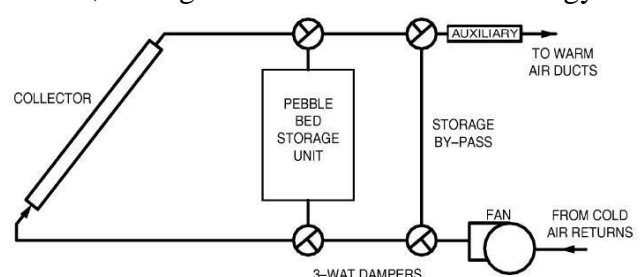
Five types of solar energy systems can be used to heat domestic and service hot water: thermosyphon, ICS, direct circulation, indirect, and air. The first two are called passive systems as no pump is employed, whereas the others are called active systems because a pump or fan is employed in order to circulate the fluid.

#### B. Solar Space Heating and Cooling

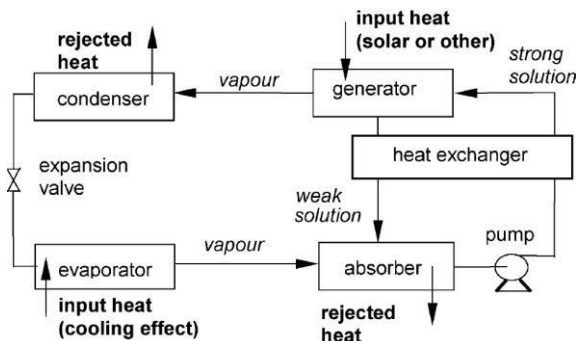
The components and subsystems of solar collectors are employed for solar heating and cooling systems. There are again two principal categories of such systems, passive and active. The fluid used for heating and cooling is generally air and the collectors used for space heating are also called solar air heaters [15,16].

The term passive system is applied to buildings that include as integral part of the building elements, that admit, absorb, store and release solar energy and thus reduce the needs for auxiliary energy for comfort heating. As no solar collectors are employed in the passive systems in this paper, only active systems are considered.

Active solar space systems use collectors to heat a fluid, storage units to store solar energy until



needed, and distribution equipment to provide the solar energy to the heated spaces in a controlled manner. A complete system includes additionally pumps or fans for transferring the energy to storage or to the load which require a continuous availability of non-renewable energy, generally in the form of electricity [17].



Solar cooling of buildings is an attractive idea as the cooling loads and availability of solar radiation are in phase. Additionally, the combination of solar cooling and heating greatly improves the use factors of collectors compared to heating alone. Solar air conditioning can be accomplished by three types of systems: absorption cycles, adsorption (desiccant) cycles and solar mechanical processes.

### C. Solar refrigeration

Solar cooling can be considered for two related processes: to provide refrigeration for food and medicine preservation and to provide comfort cooling. Solar refrigeration systems usually operate at intermittent cycles and produce much lower temperatures (ice) than in air conditioning. When the same cycles are used in space cooling they operate on continuous cycles. The cycles employed for solar refrigeration are the absorption and adsorption [18]. During the cooling portion of the cycles, the refrigerant is evaporated and reabsorbed. In these systems the absorber and generator are separate vessels. The generator can be integral part of the collector, with refrigerant absorbent solution in the tubes of the collector circulated by a combination of a thermosyphon and a vapour lift pump [19].

There are many options available which enable the integration of solar energy into the process of ‘cold’ production. Solar refrigeration can be accomplished by using either a thermal energy source supplied from a solar collector or electricity supplied from photovoltaics. This can be achieved by using either thermal adsorption or absorption units or conventional refrigeration equipment powered from photovoltaics. Solar refrigeration is employed mainly to cool vaccine stores in areas with no mains electricity and for solar space cooling.

Photovoltaic refrigeration, although uses standard refrigeration equipment which is an advantage, has not achieved widespread use because of the low efficiency and high cost of the photovoltaic cells.

Fig. 8 Schematic of Solar refrigeration system.

### D. Solar Desalination

About 97% of the earth’s water is salt water in the oceans; 3% of all fresh water is in ground water, lakes and rivers, which supply most of human and animal needs. Water is essential to life. The importance of supplying potable water can hardly be overstressed. Man has been dependent on rivers, lakes and underground water reservoirs for fresh water requirements in domestic life, agriculture and industry. However, rapid industrial growth and the population explosion all over the world have resulted in a large escalation of demand for fresh water. Added to this is the problem of pollution of rivers and lakes by industrial wastes and the large amounts of sewage discharged. The only nearly inexhaustible sources of water are the oceans. Their main drawback, however, is their high salinity. It would be attractive to tackle the water-shortage problem with desalination of this water.

Desalination can be achieved by using a number of techniques. These may be classified into the following categories:

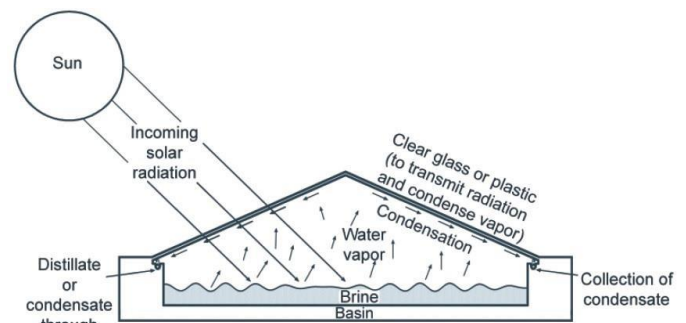
- a. phase-change or thermal processes; and
- b. membrane or single-phase processes.

Solar energy can be used for sea-water desalination either by producing the thermal energy required to drive the phase change processes or by producing electricity required to drive the membrane processes. Solar desalination systems are thus classified into two categories, i.e. direct and indirect collection systems [20]. As their name implies, direct collection systems use solar energy to produce distillate directly in the solar collector, whereas in indirect collection systems, two sub-systems are employed (one for solar energy collection and one for desalination) [21]. Conventional desalination systems are similar to solar systems since the same type of equipment is applied. The prime difference is that in the former, either a conventional boiler is used to provide the required heat or mains electricity is used to provide the required electric power, whereas in the latter, solar energy is applied.

A representative example of direct printing press at the Paris Exposition. The idea is to use concentrating collectors to produce and supply steam to heat engines.

The basic process for conversion of solar to mechanical energy is shown schematically in Fig.10. The process of conversion of solar to mechanical and electrical energy by thermal means is fundamentally similar to the traditional thermal processes [23]. These systems differ from the ones considered so far as these operate at much higher temperatures. Energy is collected by concentrating collectors, stored (if appropriate), and used to operate a heat engine. The main problem of these systems is that the efficiency of the collector is reduced as its operating temperature increases, whereas the efficiency of the heat engine increases as its operating temperature increases. The maximum operating temperature of

collection systems is the conventional solar still,



which uses the greenhouse effect to evaporate salty water. It consists of a basin, in which a constant amount of seawater is enclosed in a v-shaped glass envelope [22]. The sun's rays pass through the glass roof and are absorbed by the blackened bottom of the basin. As the water is heated, its vapour pressure is increased. The resultant water vapour is condensed on the underside of the roof and runs down into the troughs, which conduct the distilled water to the reservoir.

#### E. Solar thermal Power Systems

Conversion of solar to mechanical and electrical energy has been the objective of experiments for more than a century, starting from 1872 when Mouchot exhibited a steam-powered

stationary collectors is low relative to desirable input temperatures of heat engines, therefore concentrating collectors are used exclusively for such applications [23].

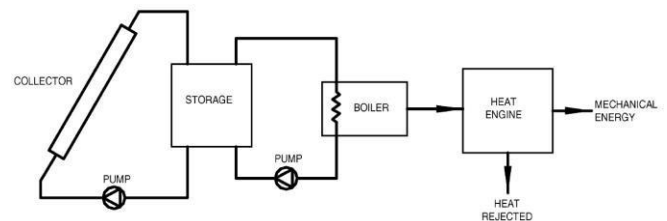


Fig. 10 Schematic of a solar-thermal conversion system.

## CONCLUSIONS

Several of the most common types of solar collectors are presented in this paper. The various types of collectors described include flat-plate, compound parabolic, evacuated tube, parabolic

trough, Fresnel lens and parabolic dish type collector. Additionally, typical applications are described in order to show to the reader the extent of their applicability. These include water heating, space heating and cooling, refrigeration, industrial process heat, desalination, thermal power systems, solar furnaces and chemistry applications. It should be noted that the applications of solar energy collectors are not limited to the above areas. There are many other applications which are not described here either because they are not fully developed or are not matured yet. The application areas described in this paper show that solar energy collectors can be used in a wide variety of systems, could provide significant environmental and financial benefits, and should be used whenever possible.

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