Introduction to Solar Thermal Engineering

Definition of Energy and Power

Property that must be transferred to an object to perform work on, or to heat the object is known as energy. Energy per unit time is known as power.

Types of Energy

- Static (stored for later use, Potential)
- Chemical, Elastic, Nuclear, Gravitational
- Dynamic (Transit, Kinetic)
- Thermal, Mechanical, Electrical, Magnetic
- Stage of Transformation
- Primary, Secondary, Tertiary
- Tradability
- Commercial, Non-commercial
- Regenerability
- Renewable, Non-renewable
- Source-wise

Hydro, Solar, Wind, Tidal, Geothermal, Nuclear, Fossil fuel

Units of Energy and Power

Units of Energy

- 1 Joule (J) = 1 Newton-meter
- 1 Calorie = 4.184 Joule
- 1 BTU = 1.055 kJ
- 1 kWh = 3600 kJ = 3410 BTU
- 1 toe = 41.868 GJ = 11.63 MWh
- Units of Power
- 1 Watt = 1 Joule/Sec = 1 VA
- 1 hp = 745.7 Watt

Needs for Energy

- Domestic (cooking, heating, cooling, ventilation, air-conditioning, entertainment)
- Agriculture (land preparation, irrigation, fertiliser, pesticide, storage)
- Industry (extraction, transformation, supply)
- Services (health, sanitation, water supply, education, construction, transportation)

Energy-Environment Linkage

- Global warming (CO_2, CH_4)
- Acid rain (So_x and No_x)
- Ozone layer depletion (CFCs)
- Local and global level pollution
- Displacement, Biodiversity loss, Flood (large hydro)
- Oil spill and marine health
- Poor human health (smoke from cooking)

The Two Types of Solar Energy, Photovoltaic and Thermal

Photovoltaic technology directly converts sunlight into electricity. Solar thermal technology harnesses its heat. These different technologies both tap the Sun's energy, locally and in large-scale solar farms. A photovoltaic (PV) cell, commonly called a solar cell, is a non mechanical device that converts sunlight directly into electricity. Some PV cells can convert artificial light into Photons carry solar energy

Sunlight is composed of photons, or particles of solar energy. These photons contain varying amounts of energy that correspond to the different wavelengths of the solar spectrum.

Solar thermal power systems use concentrated solar energy

Solar thermal power (electricity) generation systems collect and concentrate sunlight to produce the high temperature heat needed to generate electricity. All solar thermal power systems have solar energy collectors with two main components: *reflectors* (mirrors) that capture and focus sunlight onto a *receiver*. In most types of systems, a heat-transfer fluid is heated and circulated in the receiver and used to produce steam. The steam is converted into mechanical energy in a turbine, which powers a generator to produce electricity. Solar thermal power systems have tracking systems that keep sunlight focused onto the receiver throughout the day as the sun changes position in the sky.

Solar thermal power systems may also have a thermal energy storage system component that allows the solar collector system to heat an energy storage system during the day, and the heat from the storage system is used to produce electricity in the evening or during cloudy weather. Solar thermal power plants may also be hybrid systems that use other fuels (usually natural gas) to supplement energy from the sun during periods of low solar radiation.

Types of concentrating solar thermal power plants

There are three main types of concentrating solar thermal power systems:

- Linear concentrating systems, which include parabolic troughs and linear Fresnel reflectors
- Solar power towers
- Solar dish/engine systems
- Linear concentrating systems

Linear concentrating systems collect the sun's energy using long, rectangular, curved (U-shaped) mirrors. The mirrors focus sunlight onto receivers (tubes) that run the length of the mirrors. The concentrated sunlight heats a fluid flowing through the tubes. The fluid is sent to a heat exchanger to boil water in a conventional steam-turbine generator to produce electricity. There are two major types of linear concentrator systems: parabolic trough systems, where receiver tubes are positioned along the focal line of each parabolic mirror, and linear Fresnel reflector systems, where one receiver tube is positioned above several mirrors to allow the mirrors greater mobility in tracking the sun.

A linear concentrating collector power plant has a large number, or *field*, of collectors in parallel rows that are typically aligned in a north-south orientation to maximize solar energy collection. This configuration enables the mirrors to track the sun from east to west during the day and concentrate sunlight continuously onto the receiver tubes.

Parabolic trough power plant

Parabolic troughs

A parabolic trough collector has a long parabolic-shaped reflector that focuses the sun's rays on a receiver pipe located at the focus of the parabola. The collector tilts with the sun to keep sunlight focused on the receiver as the sun moves from east to west during the day.

Because of its parabolic shape, a trough can focus the sunlight from 30 times to 100 times its normal intensity (concentration ratio) on the receiver pipe, located along the focal line of the trough, achieving operating temperatures higher than 750°F.

Parabolic trough linear concentrating systems are used in the longest operating solar thermal power facility in the world, the Solar Energy Generating System (SEGS). The facility, with nine separate plants, is located in the Mojave Desert in California. The first plant in the system, SEGS I, operated from 1984 to 2015, and the second, SEGS II, operated from 1985 to 2015. The last plant built, SEGS IX, with a electricity generation capacity of 92 megawatts (MW), began operation in 1990. The seven currently operating SEGS III-IX plants have a combined electricity generation capacity of nearly 357 MW, making them one of the largest solar thermal electric power facilities in the world.

In addition to the SEGS, many other parabolic trough solar power projects operate in the United States and around the world. The three largest projects in the United States after SEGS are

Mojave Solar Project: a 280 MW project in Barstow, California

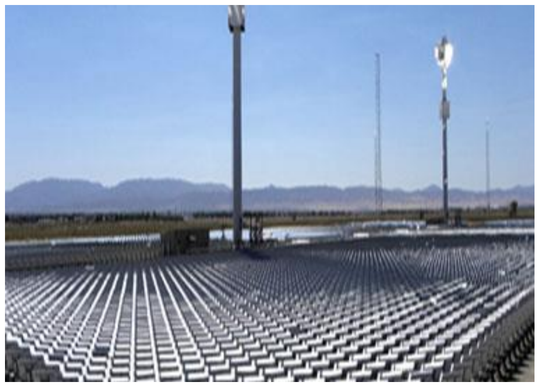
Solana Generating Station: a 280 MW project in Gila Bend, Arizona

Genesis Solar Energy Project: a 250 MW project in Blythe, California

Linear Fresnel reflectors

Linear Fresnel reflector (LFR) systems are similar to parabolic trough systems in that mirrors (reflectors) concentrate sunlight onto a receiver located above the mirrors. These reflectors use the Fresnel lens effect, which allows for a concentrating mirror with a large aperture and short focal length. These systems are capable of concentrating the sun's energy to approximately 30 times its normal intensity. The only operating linear Fresnel reflector system in the United States is a compact linear Fresnel reflector (CLFR)—also referred to as a concentrating linear Fresnel reflector—a type of LFR technology that has multiple absorbers within the vicinity of the mirrors. Multiple receivers allow the mirrors to change their inclination to minimize how much they block adjacent reflectors' access to sunlight. This positioning improves system efficiency and reduces material requirements and costs.

Solar power tower



Solar power towers

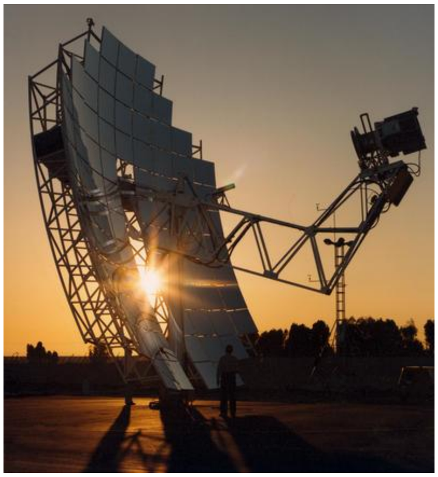
A solar power tower system uses a large field of flat, sun-tracking mirrors called heliostats to reflect and concentrate sunlight onto a receiver on the top of a tower. Sunlight can be concentrated as much as 1,500 times. Some power towers use water as the heat-transfer fluid. Advanced designs are experimenting with molten nitrate salt because of its superior heat transfer and energy storage capabilities. The thermal energy-storage capability allows the system to produce electricity during cloudy weather or at night.

The U.S. Department of Energy, along with several electric utilities, built and operated the first demonstration solar power tower near Barstow, California, during the 1980s and 1990s. Three solar power tower projects now operate in the United States:

Ivanpah Solar Power Facility: a 392 MW three-tower project with generation capacities of 126 MW, 133 MW, and 133 MW located in Ivanpah Dry Lake, California

Crescent Dunes Solar Energy Project: a 110 MW one-tower project located in Nevada

Sierra Sun Tower: a 5 MW two-tower project located in the Mojave Desert in Southern California



Solar dish/engine systems use a mirrored dish similar to a very large satellite dish. To reduce costs, the mirrored dish is usually composed of many smaller flat mirrors formed into a dish shape. The dish-shaped surface directs and concentrates sunlight onto a thermal receiver, which absorbs and collects the heat and transfers it to an engine generator. The most common type of heat engine used in dish/engine systems is the Sterling engine. This system uses the fluid heated by the receiver to move pistons and create mechanical power. The mechanical power runs a generator or alternator to produce electricity.

Solar dish/engine systems always point straight at the sun and concentrate the solar energy at the focal point of the dish. A solar dish's concentration ratio is much higher than linear concentrating systems, and it has a working fluid temperature higher than 1,380°F. The power-generating equipment used with a solar dish can be mounted at the focal point of the dish, making it well suited for remote locations, or the energy may be collected from a number of installations and converted into electricity at a central point. The U.S. Army is developing a 1.5 MW system at the Tooele Army Depot in Utah with 429 Sterling engine solar dishes. The system is scheduled to be fully operational in 2017.

LIQUID FLAT PLATE COLLECTOR: The main component of flat plate collector is 1.Transparent cover 2.absorber plate 3. Insulation

1. **Transparent cover:** The cover plate through which the solar energy must be transmitted is extremely important to the function of the collector. The purpose of the cover plates are

I.to transmit as much solar energy as possible to the absorber plate.

ii. To minimize heat loss from the absorber plate to the environment

iii. To shield the absorber plate from direct exposure to weathering

Iv.to receive as much of the solar energy as possible for the longest period of time each day. Tempered glass of 5mm is used as cover plate in order to reduce the heat lost by re-radiation from the absorber plate transparent cover is provided. This exhibits the characteristics of a high value of absorptivity for incoming solar radiation and a low value of emissivity for outgoing re-radiation. As a result the collector efficiency is improved.

v. **Tempered glass** is the most common cover material for collectors because of its proven durability and because it is not affected by ultraviolet radiation from the sun. It is properly mounted on to a flat –plate collector, is highly resistance to breakage both from thermal cycling and from natural events. It is also effective in reducing radiated heat loss because it is opaque to the longer wavelength infra-red radiation re-emitted by the hot absorber plate.

2. Absorber plate: The collector absorber plate should have high thermal conductivity, adequate tensile and compressive strength and good corrosion resistance. The absorber plate is flat aluminium sheet of 3mm in order to reduce the corrosion and leakage problem. As it is black painted, it absorbs the incoming sun light which is fixed to glass plate.

3. Insulation: The glass wool is provided for reducing side and bottom losses.

The collector is tilted according to the latitude of the location. As the Bhubaneswar latitude is 20.2961^{o}N, 85.8245^{o}E, so it is tilted with an angle 20^0 and facing due south.The flat plate collectors forms the heat of any solar energy collection system designed for operation in the low temperature range, from ambient to 60 or the medium temperature, form ambient to 100. A well engineered flat plate collector is delivers heat at a relatively low cost for a long duration. The flat plat collectors are basically a heat exchanger which transfer the radiant energy of the incident sunlight to the sensible heat of a working fluid-liquid or air. The term ‘flat plate’ is slightly misleading in the sense that the surface may not be truly flat-it may be combination of flat, grooved or of other shapes as the absorbing surface, with some kind of heat removal device like tubes or channels. Flat plate collectors are used to convert at much solar radiation as possible into heat at the highest attainable temperature with the lowest possible investment in material and labour.

Flat plate collectors have the following advantage over other types of solar energy collectors:

(i) Absorb direct, diffuse and reflected components o solar radiation,

(ii) Are fixed in tilt and orientation and thus, there is no needed of tracking the Sun,

(iii) Are easy to make and are low in cost,

(iv) Have comparatively low maintenance cost and Long lie, and

(v) Operate at comparatively high efficiency.

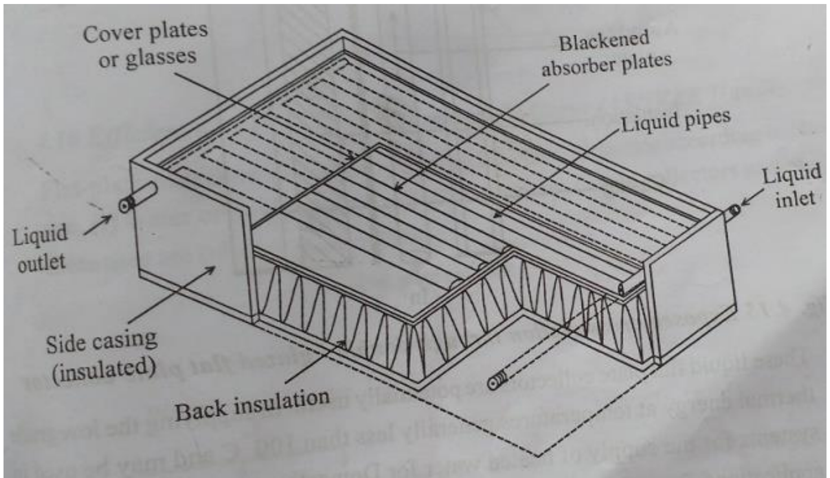


Fig. 4.14 A typical liquid flat plate collector

(i) Glazing, this may be one or more sheets of glass or other diathermanous (radiation transmitting) material

(ii) Tubes, fins or passages for conducting or directing the heat transfer fluid from the inlet to the outlet.

(iii) Absorber plate which may be flat, corrugated or grooved with tubes fins or passages attached to it.

(iv) Header or manifolds, to admit and discharge the fluid.

Concentrating Collectors

For applications such as air conditioning, central power generation, and numerous industrial heat requirements, flat plate collectors generally cannot provide carrier fluids at temperatures sufficiently elevated to be effective. They may be used as first-stage heat input devices; the temperature of the carrier fluid is then boosted by other conventional heating means. Alternatively, more complex and expensive concentrating collectors can be used. These are devices that optically reflect and focus incident solar energy onto a small receiving area. As a result of this concentration, the intensity of the solar energy is magnified, and the temperatures that can be achieved at the receiver (called the "target") can approach several hundred or even several thousand degrees Celsius. The concentrators must move to track the sun if they are to perform effectively.

- Concentrating, or focusing, collectors intercept direct radiation over a large area and focus it onto a small absorber area. These collectors can provide high temperatures more efficiently than flat-plate collectors, since the absorption surface area is much smaller. However, diffused sky radiation cannot be focused onto the absorber. Most concentrating collectors require mechanical equipment that constantly orients the collectors toward the sun and keeps the absorber at the point of focus. Therefore; there are many types of concentrating collectors.
- **Types of concentrating collectors**
- There are four basic types of concentrating collectors:

- Parabolic trough system
- Parabolic dish
- Power tower
- Stationary concentrating collectors

Parabolic trough system

Parabolic troughs are devices that are shaped like the letter “u”. The troughs concentrate sunlight onto a receiver tube that is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss

Their shapes are like letter “u” as shown figure 3.1.1 below.

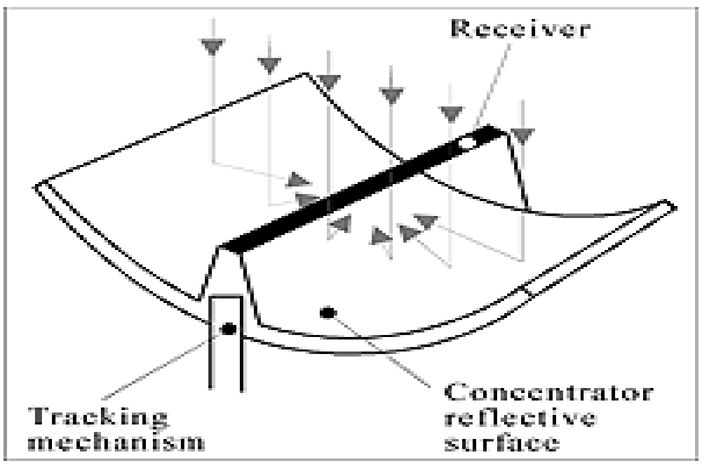


Figure .Crossection of parabolic trough.

The parabolic trough sytem is shown in the figure below

Figure . Parabolic trough system .

Parabolic troughs often use single-axis or dual-axis tracking.

The below figure shows one axis tracking parabolic trough with axis oriented E-W.

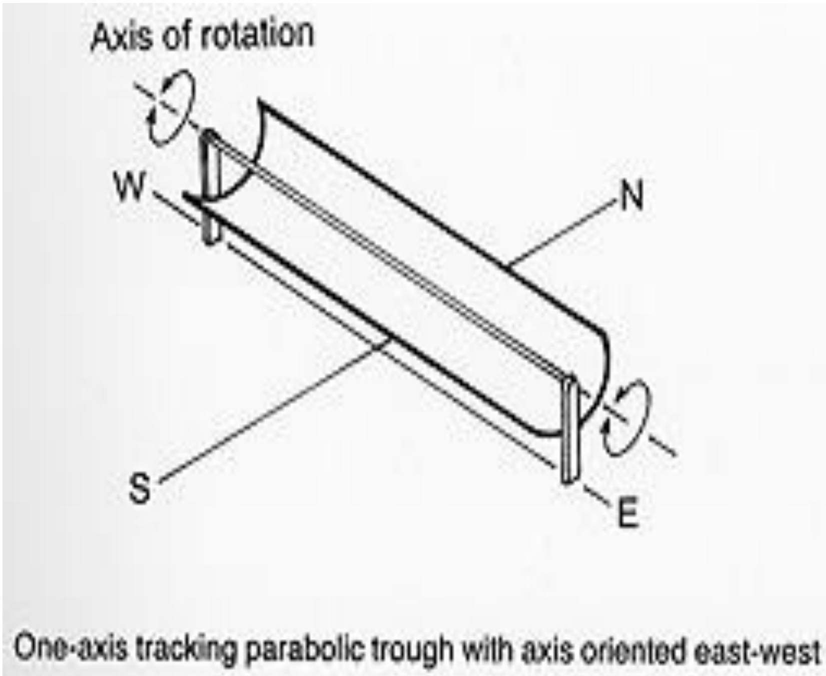


Figure . One Axis Tracking Parabolic Trough with Axis Oriented E-W .

The below figure shows two axis tracking concentrator.

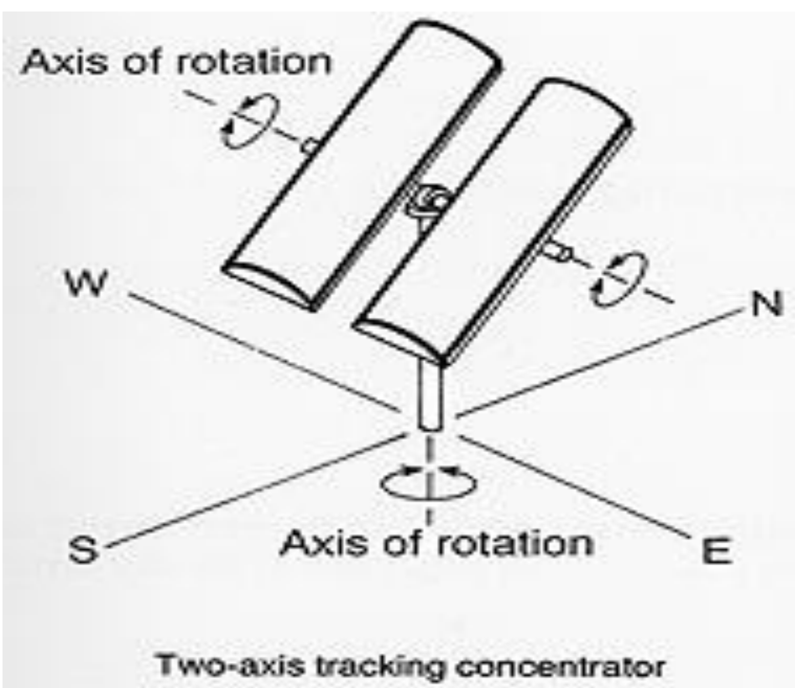


Figure . Two Axis Tracking Concentrator .

Temperatures at the receiver can reach 400 °C and produce steam for generating electricity. In California, multi-megawatt power plants were built using parabolic troughs combined with gas turbines. Parabolic trough combined with gas turbines is figurebelow.

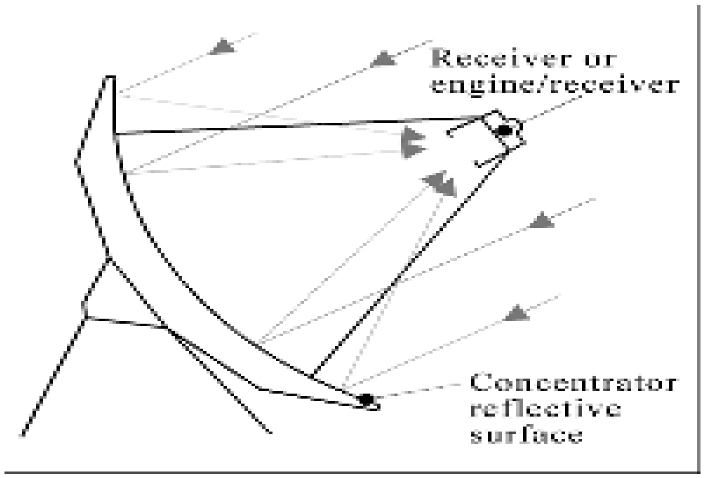
Figure .Parabolic trough combined with gas turbines .

Cost projections for trough technology are higher than those for power towers and dish/engine systems due in large part to the lower solar concentration and hence lower temperatures and efficiency.However with long operating experience, continued technology improvements, and operating and maintenance cost reductions, troughs are the least expensive, most reliable solar thermal power production technology for near-term

Parabolic dish systems

A parabolic dish collector is similar in appearance to a large satellite dish, but has mirror-like reflectors and an absorber at the focal point. It uses a dual axis sun tracker.

The below figure shows crossection of parabolic dish.



The Parabolic dish collector is shown in the below figure .

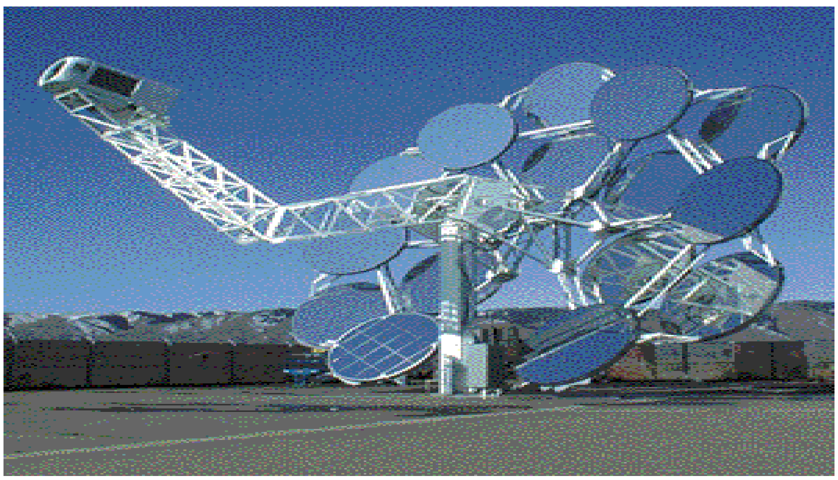


Figure shows Parabolic dish collector with a mirror-like reflectors and an absorber at the focal point

A parabolic dish system uses a computer to track the sun and concentrate the sun's rays onto a receiver located at the focal point in front of the dish. In some systems, a heat engine, such as a Stirling engine, is linked to the receiver to generate electricity. Parabolic dish systems can reach 1000 °C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity in the small-power capacity range.

Solar dish stirling engine

Engines currently under consideration include Sterling and Brayton cycle engines. Several prototype dish/engine systems, ranging in size from 7 to 25 kW have been deployed in various locations in the USA. High optical efficiency and low start up losses make dish/engine systems the most efficient of all solar technologies. A Sterling engine/parabolic dish system holds the world's record for converting sunlight into electricity. In 1984, a 29% net efficiency was measured at Rancho Mirage, California.

Power tower system

A heliostat uses a field of dual axis sun trackers that direct solar energy to a large absorber located on a tower. To date the only application for the heliostat collector is power generation in a system called the power tower.

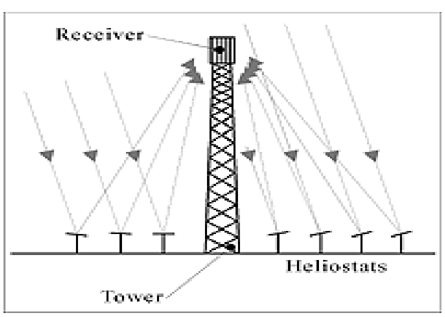


Figure shows Power tower system **Figure shows Heliostats .**

A power tower has a field of large mirrors that follow the sun's path across the sky. The mirrors concentrate sunlight onto a receiver on top of a high tower. A computer keeps the mirrors aligned so the reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000°C can be reached. High-pressure steam is generated to produce electricity.

The power tower system with heliostats is shown in the figure below.

Figure shows Power tower system with heliostats .

Stationary concentrating solar collectors

Stationary concentrating collectors use compound parabolic reflectors and flat reflectors for directing solar energy to an accompanying absorber or aperture through a wide acceptance angle. The wide acceptance angle for these reflectors eliminates the need for a sun tracker. This class of collector includes parabolic trough flat plate collectors, flat plate collectors with parabolic boosting reflectors, and solar cooker. Development of the first two collectors has been done in Sweden. Solar cookers are used throughout the world, especially in the developing countries.

Working principles of concentrating collectors

Unlike solar (photovoltaic) cells, which use light to produce electricity, concentrating solar power systems generate electricity with heat. Concentrating solar collectors use mirrors and lenses to concentrate and focus sunlight onto a thermal receiver, similar to a boiler tube. The receiver absorbs and converts sunlight into heat. The heat is then transported to a steam generator or engine where it is converted into electricity. There are three main types of concentrating solar power systems: parabolic troughs, dish/engine systems, and central receiver systems.

These technologies can be used to generate electricity for a variety of applications, ranging from remote power systems as small as a few kilowatts (kW) up to grid connected applications of 200-350 megawatts (MW) or more. A concentrating solar power system that produces 350 MW of electricity displaces the energy equivalent of 2.3 million barrels of oil.

Trough Systems

These solar collectors use mirrored parabolic troughs to focus the sun's energy to a fluid-carrying receiver tube located at the focal point of a parabolic ally curved trough reflector [5].It is shown in the figure

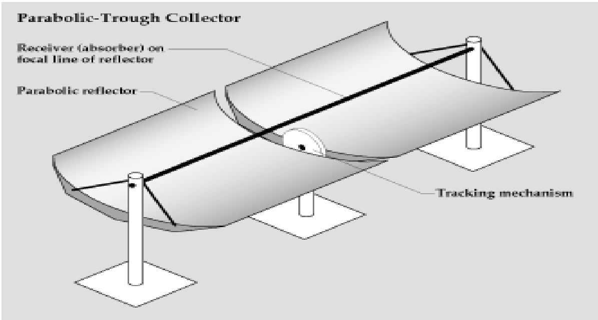


Figure 4.1.1 Parabolic trough with mirrored parabolic troughs [10].

The energy from the sun sent to the tube heats oil flowing through the tube, and the heat energy is then used to generate electricity in a conventional steam generator. Many troughs placed in parallel rows are called a "collector field." The troughs in the field are all aligned along a north south axis so they can track the sun from east to west during the day, ensuring that the sun is continuously focused on the receiver pipes. Individual trough systems currently can generate about 80 MW of electricity.

Trough designs can incorporate thermal storage-setting aside the heat transfer fluid in its hot phase allowing for electricity generation several hours into the evening. Currently, all parabolic trough plants are "hybrids," meaning they use fossil fuels to supplement the solar output during periods of low solar radiation. Typically, a natural gas-fired heat or a gas steam boiler/reheater is used. Troughs also can be integrated with existing coal-fired plants.

Dish Systems

Dish systems use dish-shaped parabolic mirrors as reflectors to concentrate and focus the sun's rays onto a receiver, which is mounted above the dish at the dish center. A dish/engine system is a standalone unit composed primarily of a collector, a receiver, and an engine. It works by collecting and concentrating the sun's energy with a dish shaped surface onto a receiver that absorbs the energy and transfers it to the engine. The engine then converts that energy to heat. The heat is then converted to mechanical power, in a manner similar to conventional engines, by compressing the working fluid when it is cold, heating the compressed working fluid, and then expanding it through a turbine or with a piston to produce mechanical power. An electric generator or alternator converts the mechanical power into electrical power.

Each dish produces 5 to 50 kW of electricity and can be used independently or linked together to increase generating capacity. A 250-kW plant composed of ten 25-kW dish/engine systems requires less than an acre of land. Dish/engine systems are not commercially available yet, although ongoing demonstrations indicate good potential. Individual dish/engine systems currently can generate about 25 kW of electricity. More capacity is possible by connecting dishes together. These systems can be combined with natural gas, and the resulting hybrid provides continuous power generation.

Figure shows Combination of parabolic dish system

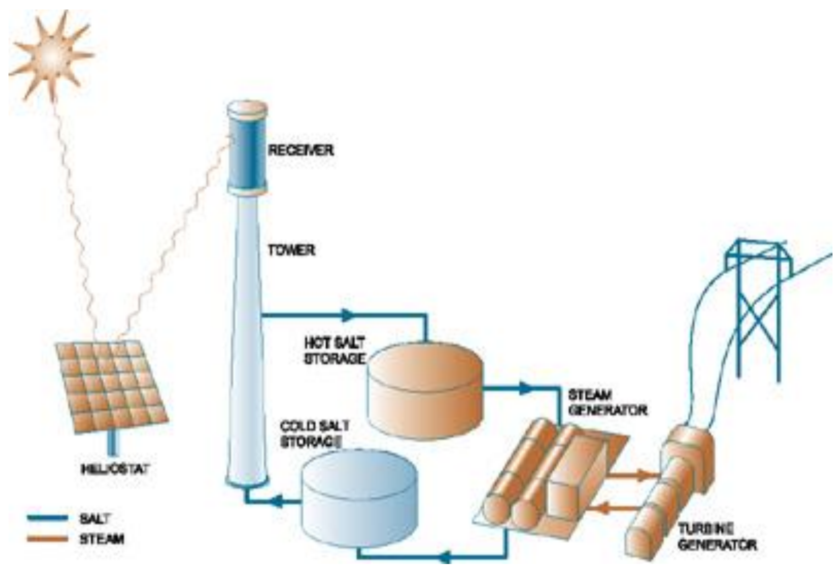


Figure shows The process of molten salt storage

Technology Comparison

Towers and troughs are best suited for large, grid-connected power projects in the 30-200 MW size, whereas, dish/engine systems are modular and can be used in single dish applications or grouped in dish farms to create larger multi-megawatt projects. Parabolic trough plants are the most mature solar power technology available today and the technology most likely to be used for near-term deployments. Power towers, with low cost and efficient thermal storage, promise to offer dispatch able, high capacity factor, solar-only power plants in the near future. The modular nature of dishes will allow them to be used in smaller, high-value applications. Towers and dishes offer the opportunity to achieve higher solar-to-electric efficiencies and lower cost than parabolic trough plants, but uncertainty remains as to whether these technologies can achieve the necessary capital cost reductions and availability improvements. Parabolic troughs are currently a proven technology primarily waiting for an opportunity to be developed. Power towers require the operability and maintainability of the molten-salt technology to be demonstrated and the development of low cost heliostats. Dish/engine systems require the development of at least one commercial engine and the development of a low cost concentrator.

Calculations

Heat from a solar collector may be used to drive a heat engine operating in a cycle to produce work. A heat engine may be used for such applications as water pumping and generating electricity.

The thermal output Q_{out} of a concentrating collector operating at temperature T is given by

$Q_{out} = F'[\textit{gamma}.A_{in}q_{in} - U.A_{rec}(T - T_a)]$,

A_{in} : the area of the incident solar radiation (m^2).

A_{rec} : the area of the receiver (m^2)

gamma:optical efficiency

q_{in} : the incident solar irradiation (W/m^2)

T_a :the ambient temperature (°C)

U :the heat loss coefficient (W/m^2K)

F’ :collector efficiency factor

The quantity A_{in}/A_{rec} is called the **concentration ratio**.

High concentration ratios are obtained by making A_{in} the area of a system of mirrors designed to concentrate the solar radiation received onto a small receiver of area A_{rec}. Heat losses from the receiver are reduced by the smaller size of the receiver. Consequently, high concentration ratios give high collector temperatures. The stagnation temperature T_{max} is given by:

$\textit{gamma}.A_{in}q_{in} = U.A_{rec}(T_{max} - T_a)$.

For example, if the optical efficiency is *gamma* = 0.8, the incident solar irradiation is q_{in} = $800W/m^2$, the ambient temperature is T_a = 30°C, and the heat loss coefficient is U = $10W/m^2K$, then a concentration ratio A_{in}/A_{rec} = 1 (no concentration) gives T_{max} = 94°C, and a concentration ratio A_{in}/A_{rec} = 10 gives T_{max} = 670°C.

The collector efficiency $\textit{eta}_c$ at operating temperature T is

$\textit{eta}_c=Q_{out}/A_{in}q_{in} = F'[\textit{gamma}-U.A_{rec}(T - T_a)/A_{in}q_{in}]$

$= F'\textit{gamma}(T_{max} - T)/(T_{max} - T_a)$.

The available mechanical power from the thermal power output of the collector that would be obtained using a Carnot cycle is $Q_{out}(1 - T_a/T)$, where the temperatures are absolute temperatures.

where T_{max} depends on the design of the collector and on the solar radiation input q_{in}. Now, given F', *gamma*, eta_2, T_a, and T_{max}, we can find the maximum efficiency obtainable, and the optimum operating temperature T_{opt} from the condition d(*eta*)/dT = 0. This occurs at the optimum temperature

$T_{opt} = [T_{max} T_a]$,

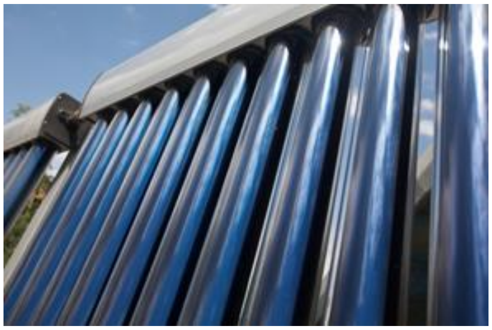
and the maximum efficiency is obtained by putting

$T = T_{opt}$ in the equation

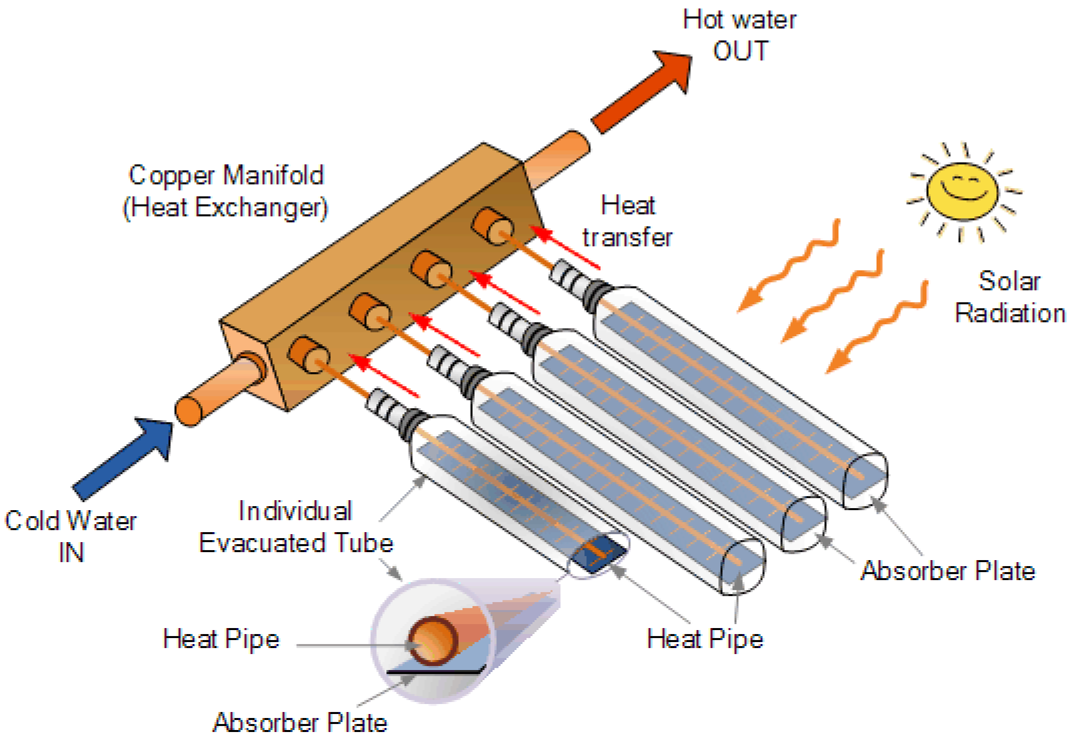
$eta = eta_c . eta_1$.

Evacuated Tube Collector

The **Evacuated tube collector** consists of a number of rows of parallel transparent glass tubes connected to a header pipe and which are used in place of the blackened heat absorbing plate we saw in the previous flat plate collector. These glass tubes are cylindrical in shape. Therefore, the angle of the sunlight is always perpendicular to the heat absorbing tubes which enables these collectors to perform well even when sunlight is low such as when it is early in the morning or late in the afternoon, or when shaded by clouds. Evacuated tube collectors are particularly useful in areas with cold, cloudy wintry weathers.



Unlike flat panel collectors, evacuated tube collectors do not heat the water directly within the tubes. Instead, air is removed or evacuated from the space between the two tubes, forming a vacuum (hence the name **evacuated tubes**). This vacuum acts as an insulator reducing any heat loss significantly to the surrounding atmosphere either through convection or radiation making the collector much more efficient than the internal insulating that flat plate collectors have to offer. With the assistance of this vacuum, evacuated tube collector generally produce higher fluid temperatures than they're flat plate counterparts so may become very hot in summer.



Inside the each glass tube, a flat or curved aluminum or copper fin is attached to a metal heat pipe running through the inner tube. The fin is covered with a selective coating that transfers heat to the fluid that is circulating through the pipe. This sealed copper heat pipe transfers the solar heat via convection of its internal heat transfer fluid to a "hot bulb" that indirectly heats a copper manifold within the header tank. These copper pipes are all connected to a common manifold which is then connected to a storage tank, thus heating the hot water during the day. The hot water can then be used at night or the next day due to the insulating properties of the tank.

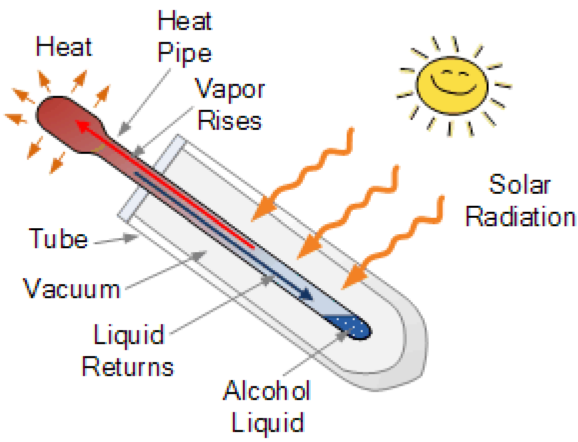
The insulation properties of the vacuum are so good that while the inner tube may be as high as 150^{o}C, the outer tube is cooler to touch. This means that evacuated tube water heaters can perform well and can heat water to fairly high temperatures even in cold weather when flat plate collectors perform poorly due to heat loss.

However, the downside is that they can be a lot more expensive compared to standard flat plate collectors or solar batch collectors. Evacuated tube solar collectors are well suited to commercial and industrial hot water heating applications and can be an effective alternative to flat plate collectors for domestic space heating, especially in areas where it is often cloudy.

Evacuated tube collectors are overall more modern and more efficient compared to the standard flat plate collectors as they can extract the heat out of the air on a humid, dull overcast days and do not need direct sunlight to operate. Due to the vacuum inside the glass tube, the total efficiency in all areas is higher and there is a better performance even when the sun is not at an optimum angle. For these types of solar hot water panels, the configuration of the vacuum tube is what's really important. There are a few different vacuum tube configurations, single wall tube, double wall tube, direct flow or heat pipe, and these differences can determine how the fluid is circulated around the solar hot water panel.

Heat Pipe Evacuated Tube Collectors

In heat pipe evacuated tube collectors, a sealed heat pipe, usually made of copper to increase the collectors efficiency in cold temperatures, is attached to a heat absorbing reflector plate within the vacuum sealed tube. The hollow copper heat pipe within the tube is evacuated of air but contains a small quantity of a low pressure alcohol/water liquid plus some additional additives to prevent corrosion or oxidation.



his vacuum enables the liquid to vaporize at very lower temperatures than it would normally at atmospheric pressure. When sunlight in the form of solar radiation hits the surface of the absorber plate inside the tube, the liquid in the heat pipe quickly turns into a hot vapour type gas due to presence of the vacuum. As this gas vapour is now lighter, it rises up to the top portion of the pipe heating it up to a very high temperature.

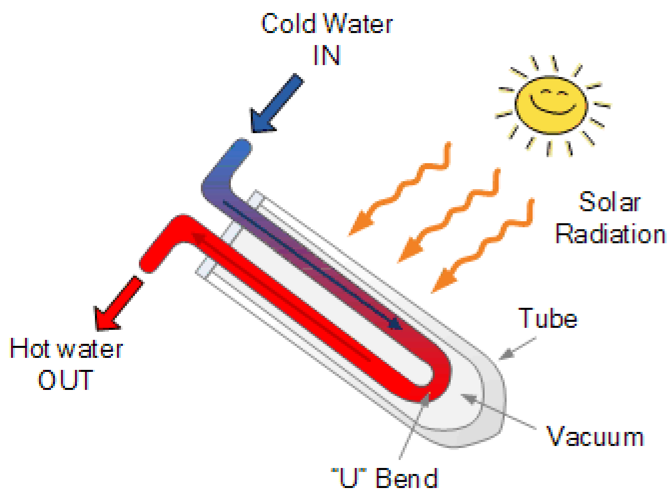
The top part of the heat pipe, and therefore the evacuated tube is connected to a copper heat exchanger called the “manifold”. When the hot vapours still inside the sealed heat tube enters the manifold, the heat energy of the vapour is transferred to the water or glycol fluid flowing through the connecting manifold. As the hot vapour looses energy and cools, it condenses back from a gas to a liquid flowing back down the heat pipe to be reheated.

The heat pipe and therefore the evacuated tube collectors must be mounted in such a way as to have a minimum tilt angle (around 30^{o}) in order for the internal liquid of the heat pipe to return back down to the hot absorber plate at the bottom of the tube. This process of converting a liquid into a gas and back into a liquid again continues inside the sealed heat pipe as long as the sun shines.

The main advantage of **Heat Pipe Evacuated Tube Collectors** is that there is a “dry” connection between the absorber plate and the manifold making installation much easier than with direct flow collectors. Also, in the event an evacuated tube cracking or breaking and the vacuum become lost the individual tube can be exchanged without emptying or dismantling the entire system. This flexibility makes heat pipe evacuated tube solar hot water collectors ideal for closed loop solar designs as the modular assembly allows for easy installation and ability to easily expand by adding as many tubes as you want.

Direct Flow Evacuated Tube Collector

Direct flow evacuated tube collectors also known as "U" pipe collectors, are different from the previous ones in that they have two heat pipes running through the centre of the tube. One pipe acts as the flow pipe while the other acts as the return pipe. Both pipes are connected together at the bottom of the tube with a "U-bend", hence the name. The heat absorbing reflective plate acts like a dividing strip which separates the flow and the return pipes through the solar collector tubes. The absorber plate and the heat transfer tube are also vacuum sealed inside a glass tube providing exceptional insulation properties.



The hollow heat pipes and the flat or curved reflector plate are made out of copper with a selective coating to increase the collectors overall efficiency. This particular evacuated tube configuration is similar in operation to the flat plate collectors, with the exception of the vacuum provided by the outer tube.

Since the heat transfer fluid flows into and out of each tube, direct flow evacuated tube collectors are not as flexible as the heat pipe types. If a tube cracks or breaks it can not be easily replaced. The system will require draining as there is a "wet" connection between the tube and manifold.

Many solar industry professionals believe that direct flow evacuated tube designs are more energy efficient than heat pipe designs, because with direct flow, there isn't a heat exchange between fluids. Also, in an all-glass direct flow construction the two heat tubes are placed one inside the other so the fluid being heated passes down the middle of the inner tube and then back up through the outer absorber tube.

Direct flow evacuated tubes can collect both direct and diffuse radiation and do not require solar tracking. However, various reflector shapes placed behind the tubes are sometimes used to usefully collect some of the solar energy, which may otherwise be lost, thus providing a small amount of solar concentration.

Other Considerations when using Evacuated Tube Collectors

Due to the sealed vacuum within their design, evacuated tube collectors can get very hot, exceeding the boiling point of water during the hot summer months. These high temperatures can cause significant issues in an existing domestic solar hot water system such as overheating and cracking of the evacuated glass tubes.

To help prevent this from happening in hot summer climates, bypass valves and large heat exchangers are used to “dump” the excess heat as well as mixer valves which mix regular (cool) water with the hot water, to ensure the temperature and pressure levels never exceed a preset limit.

Also, heat pipe collectors should never be exposed to direct sunlight without a heat transfer fluid flowing through the heat exchanger. Doing so will cause the empty heat exchanger to become extremely hot and which may crack due to the sudden shock once cold water begins to flow through it.

Even though evacuated tube collectors are capable of heating water to +50 degrees Celsius in the winter, the outer glass tube of an evacuated tube does not heat up like a normal flat plate solar collectors when in use. This is due to the inherent insulation properties of the vacuum inside the tube which prevents the outer heat tube from being cooled by the outside ambient temperature which can be well below freezing.

Thus in the colder winter months, these types of collectors can not melt away the large quantity of snow that falls on them at any one time which means clearing the snow and ice from the glass tubes daily can be a problem without breaking them.

Even if it is very snowy or very cold, enough sunlight will get through to keep the tubes well above freezing and still be able to preheat the water which can then be heated further by a standard electrical immersion heater or gas burner reducing the costs of heating the water in winter.

Evacuated Tube Collectors are a very efficient way of heating much of your hot water use just using the power of the sun. They can achieve high very temperatures but are more fragile than other types of solar collectors and are much more expensive to install. They can be used in either an active open-loop (without heat exchanger) or an active closed-loop (with heat exchanger) solar hot water system but a pump is required to circulate the heat transfer fluid from collector to storage in order to stop it from overheating.

SOLAR DRYER

People traditionally dry fruits or vegetables in open, often in unhygienic conditions. It results in poor price realization from the market. Application of solar drying technology has the potential for higher value addition of such products.

Solar Drying Technology

The first requirement is the transfer of heat to the surface of the moist material, (a) by conduction from heated surface in contact with the material, convection i.e . absorption of heat by the material supplied the energy necessary for vaporization of water from it. The drying of a product simply by circulating relatively dry air around it, is known as the adiabatic drying. The heat required for vaporizing the moisture is supplied by the air to the solid material, thereby reducing the air temperature while increasing its relative humidity. Air leaving the dryer is almost saturated, nearly at the wet bulb temperature of the incoming air. Hence drying involves both heat transfer and mass transfer. In convective drying the heat required for evaporating moisture from the drying product is supplied by air. The total heat=Qconduction+Qconvection+Qradiation

Q **conduction**=-kAdt/dx, where k=Thermal conductivity of the material in W/mK

A=Surface area of heat flow in m2

dt=temperature difference in 0C

dx=Thickness of the material in m

Q=heat transfer due to conduction in watt

Q **convection**=hA (Ts-Ta), Where h=coefficient of convective heat transfer in W/m2 0C Q **radiation**=FA (Ts4- Ta4) where F=1 for black body, =stefen's Boltzmann constant

Moisture content and its measurement

The moisture content of a substance is expressed in percentage by weight on wet basis and dry basis. For percentage wet basis is m=Wm/Wm+WdX100

Moisture content for dry basis M= Wm/WdX100

The drying process depends upon Psychometric condition.

(i) Energy required raising the product temperature up to drying air temperature in the form of sensible heat. E1=MCpdt where E1=Energy in kCal, M=Quantity of product, Cp=Specific heat of product, dt=temperature rise
(ii)Latent heat of vaporization for removal of moisture E2=M'L Where M'=Quantity of moisture to be removed, kg, L= latent heat of vaporization in kJ/kg

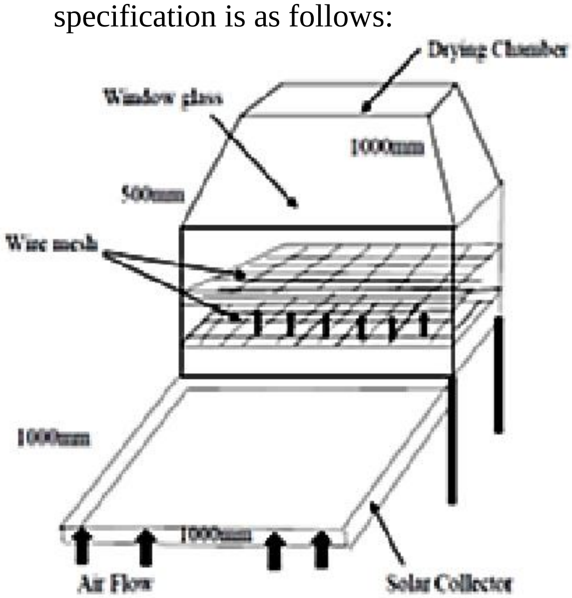
(iii). Losses which depends upon various factors like thermal insulation, material construction, area in contact of drying air. Therefore, total energy needed= E1+ E2+ Losses

Fabrication and Material

The solar collector made of Aluminum is covered by glass and surrounded by an insulating material i.e. glass wool. The solar collector supplies heated air which passes on to the fruit kept at the stainless steel trays. The outlet temperature of air delivered by solar collector increases therefore the relative humidity reduces and moisture carrying capacity of air increases, and accordingly the performance of the dryer increases. The dry and warm air absorbs moisture from food, become saturated moisture in the air. The saturated air is withdrawn from the drying chamber by the exhaust fans.

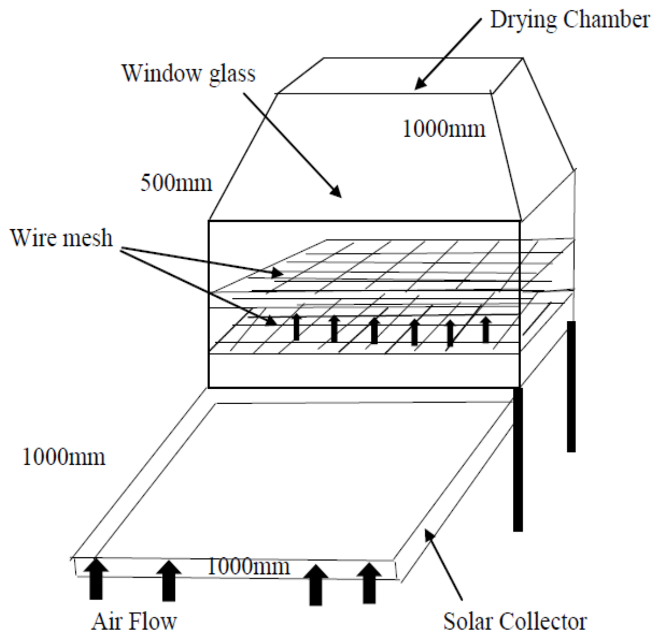
The dryer has been fabricated using aluminum sheets, steel angle and bars. The exhaust fan is fixed on the top of the drying chamber to withdraw the saturated air. Trays are stainless steel wire meshed for proper airflow and placed inside the dryer at equal space. To keep the trays, the angle bars are fixed on the side frame of the dryer. The collector is tilted at 20°angle according to the latitude of the location and facing due south. The collector is fixed with glass plate (5 mm), absorbing plate (3mm aluminum sheet) and glass wool (75mm). The collector having 1.28X1.28m is fixed with the drying chamber.

COLLECTOR: The component of flat plate collectoris1.Glass Transparent Cover2. Aluminum alloy absorber plate 3. Glass Wool Insulation. The Bhubaneswar latitude is 20.2961°N, 85.8245°E, so it is tilted with an angle 20° and facing due south so that more amount of sun radiation will incident on collector. The dryer has 20kg/day drying capacity for mangoes. This dryer contains aluminum sheet and aluminum wire mesh as trays. The thermal design specification is as follows:



The main component of the dryer is the solar collector, which is covered by glass and surrounded by glass wool which acts as an insulator. The heated air passes through the solar collector and passes on to the food kept at the trays.

Collector consists of transparent cover made up of glass 5mm, absorber plate made up of corrugated aluminium sheet 3mm and insulating material made up of glass wool 75mm. In order to reduce the heat lost by re-radiation from the absorber plate transparent cover is provided. This exhibits the characteristics of a high value of absorptivity for incoming solar radiation and a low value of emissivity for outgoing re-radiation. As a result the collector efficiency is improved. The absorber plate is corrugated aluminum sheet in order to reduce the corrosion and leakage problem. The glass wool is provided for reducing side and bottom losses. The exhaust fan which is powered by PV panel is used to exhaust out the moisture air from the drying chamber.



Development of Solar Drying

Solar drying is very important application of solar energy. Solar dryers use air collectors to collect solar energy. Solar dryers are used primarily by the agricultural industry. The purpose of drying an agricultural product is to reduce its moisture content to a level that prevents its deterioration. In drying, two processes take place: one is a heat transfer to the product using energy from the heating source, and the other is a mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air. Traditionally, farmers used the open-to-the-sun or natural drying technique, which achieves drying by using solar radiation, ambient temperature, relative humidity of ambient air and natural wind. In this method, the crop is placed on the ground or concrete floors, which can reach higher temperatures in open sun, and left there for a number of days to dry. Capacity wise, and despite the very rudimentary nature of the process, natural drying remains the most common method of solar drying. This is because the energy requirements, which come from solar radiation and the air enthalpy, are readily available in the ambient environment and no capital investment in equipment is required. The process, however, has some serious limitations. The most obvious ones are that the crops suffer the undesirable effects of dust, dirt, atmospheric pollution, and insect and rodent attacks. Because of these limitations, the quality of the resulting product can be degraded, sometimes beyond edibility. All these disadvantages can be eliminated by using a solar dryer.

The purpose of a dryer is to supply more heat to the product than that available naturally under ambient conditions, thus increasing sufficiently the vapours pressure of the crop moisture. Therefore, moisture migration from the crop is improved. The dryer also significantly decreases the relative humidity of the drying air and by doing so, its moisture-carrying capability increases, thus ensuring sufficient low equilibrium moisture content.

Types of Solar Dryer

All drying systems can be classified according to their according to their temperature range i.e. high temperature range dryer and low temperature range dryer. If the fossils source is the heating sources for drying propose then that is called high temperature dryer. If the heating source is the solar energy that is called low temperature dryer. To classify the various types of solar dryer it is necessary to simplify the complex construction and various modes of operation on the basic principle. Solar dryer can be classified as

- Modes of air movement
- Exposure to insulation
- Direction of air flow
- Arrangement of the dryer
- Status of solar radiation

Solar dryers can be classified primarily according to their heating modes and the manner in which the solar heat is utilized. These can be classified as

1. Active solar energy drying system (most types of which are termed hybrid solar dryer)

2. Passive solar energy drying system (conventionally termed natural-circulation solar drying system)

These are three sub classes of either the active or passive solar drying system a) Integral type solar dryer b) Distributed type solar dryer c) mixed mode solar dryer (Fig. 2.1).

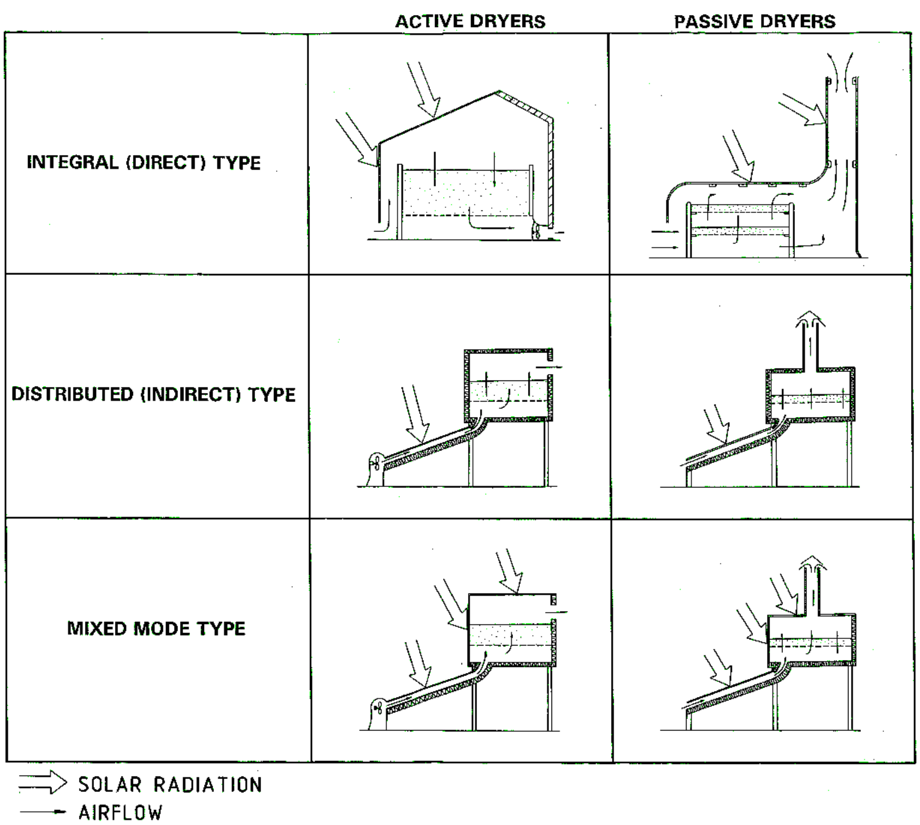


Figure shows Types of solar dryers

Natural convection is used on the diminution of the specific weight of the air due to heating and vapour uptake. The difference in specific weight between the drying air and the ambient air promotes a vertical air flow. Natural convection dryer therefore can be used independent from electricity supply. However, the air flow in this type of dryer is not sufficient to penetrate higher crop bulks. Furthermore the air flow comes to a standstill during night and adverse weather conditions. The risk of product deterioration and enzymatic reaction is high. Furthermore, the mode of drying can be differentiated into direct and indirect, depending whether the product is directly exposed to solar radiation or dried in the shade. In direct mode, the product itself serves as absorber, i.e. the heat transfer is affected not only by convection but also by radiation .Therefore, the surface area of the product being dried has to be maximized by spreading the crop in thin layer. To obtain uniform final moisture content, the crop has to be turned frequently.

Passive Solar Dryer

Passive solar dryers are also called natural circulation or natural convection systems. They are generally of a size appropriate for on-farm use. They can be either direct (e.g. tent and box dryer) or indirect (e.g. cabinet dryer). Natural-circulation solar dryers depend for their operation entirely on solar-energy. In such systems, solar-heated air is circulated through the crop by buoyancy forces or as a result of wind pressure, acting either singly or in combination.

Tent dryers

Tent solar dryers, as shown in Fig. Below are cheap and simple to build and consist of a frame of wood poles covered with plastic sheet. Black plastic should be used on the wall facing away from the sun. The food to be dried is placed on a rack above the ground. Drying times are however not always much lower than for open-air drying (-25 %). (Probably, insufficient attention has so far been paid to utilizing natural convection.) The main purpose of the dryers may be to provide protection from dust, dirt, rain, wind or predators and they are usually used for fruit, fish, coffee or other products for which wastage is otherwise high. Tent dryers can also be taken down and stored when not in use. They have the disadvantage of being easily damaged by strong winds.

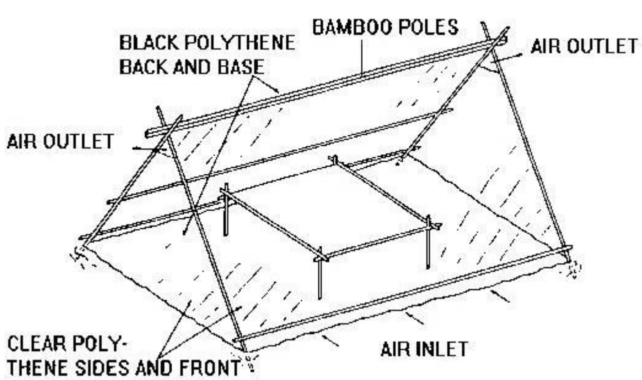


Figure shows Solar tent dryer

[Solar tent dryer]

Box dryers

The box-type solar dryer has been widely used for small scale food drying. It consists of a wooden box with a hinged transparent lid. The inside is painted black and the food supported on a mesh tray above the dryer floor. Air flows into the chamber through holes in the front and exits from vents at the top of the back wall. Brace type dryers achieve higher temperatures, and thus shorter drying times, than tent dryers. Drying temperatures in excess of about 80 °C were reported for the dryer.

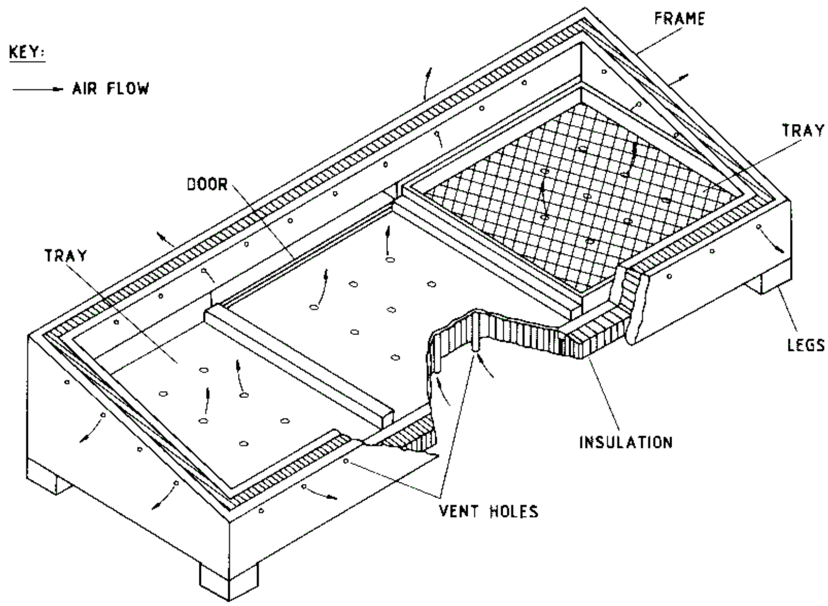


Figure shows Box dryer

Cabinet solar dryers

Here, the crop is located in trays or shelves inside a drying chamber. If the chamber is transparent, the dryer is termed an integral-type or direct solar dryer. If the chamber is opaque, the dryer is termed distributed-type or indirect solar dryer Fig. 13. Mixed-mode dryers combine the features of the integral (direct) type and the distributed (indirect) type solar dryers. Here the combined action of solar radiation incident directly on the product to be dried and pre-heated in a solar air heater furnishes the necessary heat required for the drying process.

Active solar cabinet dryers

Active solar dryers are also called forced convection or hybrid solar dryers. Optimum air flow can be provided in the dryer throughout the drying process to control temperature and moisture in wide ranges independent of the weather conditions. Furthermore the bulk depth is less restricted and the air flow rate can be controlled. Hence, the capacity and the reliability of the dryers are increased considerably compared to natural convection dryers. It is generally agreed that well designed forced-convection distributed solar dryers are more effective and more controllable than the natural-circulation types. The use of forced convection can reduce drying time by three times and decrease the required collector area by 50 %. Consequently, dryer using fans may achieve the same throughput as a natural convection dryer with a collector six times as large. Fans may be powered with utility electricity if it is available, or with a solar photovoltaic panel.

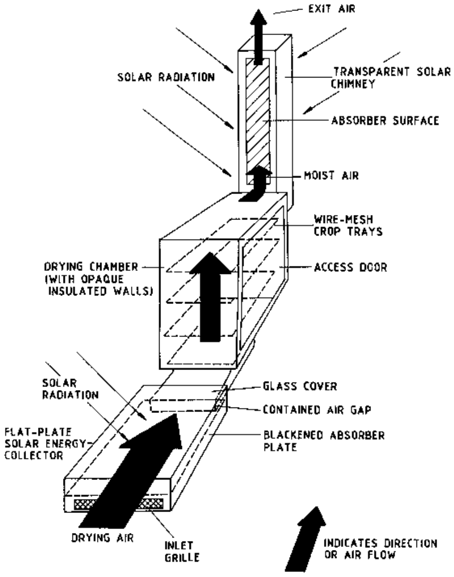


Figure shows Features of a typical distributed (indirect) mode natural convection cabinet dryer.

Almost all types of natural convection dryers can be operated by forced convection as well. In a PV-powered system, the fan is directly coupled to the solar module, working without an accumulator and load controller. Increasing solar radiation increases the module's output, thus speeding up the fan. This has the advantage of permitting a simple temperature control merely by appropriately designing the components of the PV system, thus obviating any additional control devices as long as the system is suitably dimensioned.

Figure. Shows PV-powered solar vegetable and fruit dryer

Greenhouse dryers

The idea of a greenhouse dryer is to replace the function of the solar collector by a greenhouse system. The roof and wall of this solar dryer can be made of transparent materials such as glass, fiber glass, UV stabilized plastic or polycarbonate sheets. The transparent materials are fixed on a steel frame support or pillars with bolts and nuts and rubber packing to prevent humid air or rain water leaking into the chamber other than those introduced from the inlet opening. To enhance solar radiation absorption, black surfaces should be provided within the structure. Inlet and exhaust fans are placed at proper position within the structure to ensure even distribution of the drying air. Designed properly, greenhouse dryers allow a greater degree of control over the drying process than the cabinet dryers and they are more appropriate for large scale drying.The earliest form of practically-realized natural-circulation solar greenhouse dryers reported was the Brace Research Institute glass-roof solar dryer in. The dryer consisted of two parallel rows of drying platforms (along the long side) of galvanized iron wire mesh surface laid over wooden beams. A fixed slanted glass roof over the platform allowed solar radiation over the product. The dryer, aligned lengthwise in the north-south axis, had black coated internal walls for improved absorption of solar radiation. A ridge cap made of folded zinc sheet over the roof provides an air exit vent. Shutters at the outer sides of the platforms regulated the air inlet.A simplified design of the typical greenhouse-type natural-circulation solar dryer consists of a transparent semi-cylindrical drying chamber with an attached cylindrical chimney, rising vertically out of one end, while the other end is equipped with a door for air inlet and access to the drying chamber. The chimney (designed to allow for a varying height) has a maximum possible height of 3.0 m above the chamber and a diameter of 1.64 m. The drying chamber was a modified and augmented version of a commercially-available poly- tunnel type greenhouse. The dryer operates by the action of solar-energy impinging directly on the crop within the dryer. The crop and a vertically-hung, black absorbing curtain within the chimney absorb the solar radiation and are warmed. The surrounding air is, in turn, heated. As this heated air rises and flows up the chimney to the outside of the dryer, fresh replenishing air is drawn in from the other end of the dryer. Apart from the obvious advantages of passive solar-energy dryers over the active types (for applications in rural farm locations in developing countries), the advantages of the natural- circulation solar-energy ventilated greenhouse dryer over other passive solar-energy dryer designs include its low cost and its simplicity in both on-the-site construction and operation. Its major drawback is its susceptibility to damage under high wind speeds.

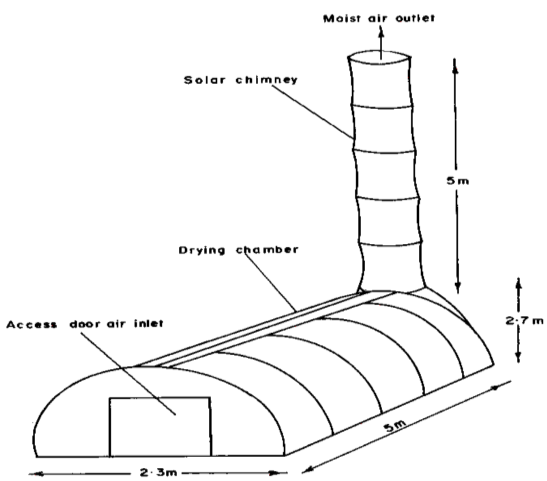


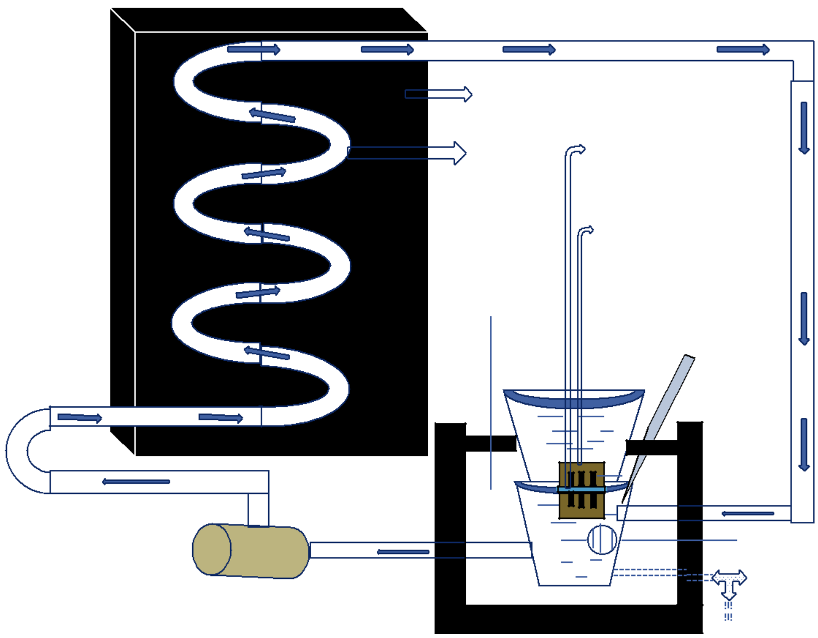
Figure. Shows Natural convection greenhouse dryer with chimney

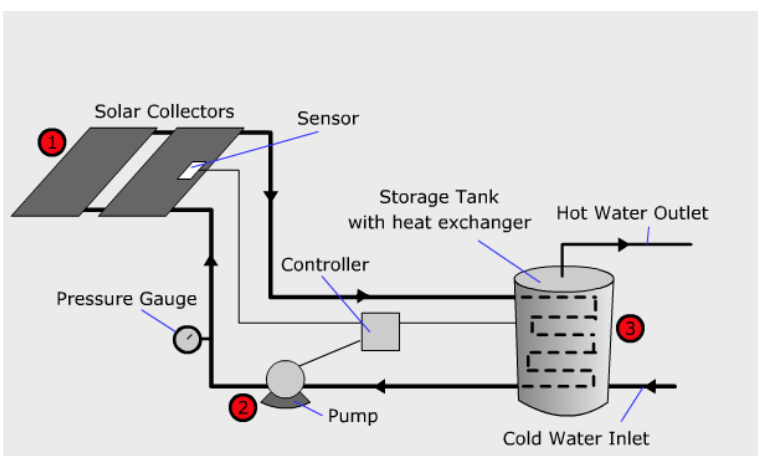
Solar water heating system

Water heating typically represents a high percentage of energy consumption in homes and businesses, in some cases 30% or more[4].Solar water heater is nothing but a device which utilizes harnessing energy from the sun to heat water. Solar water heating is a reliable and renewable energy technology used to heat water. Sunlight strikes and heats an "absorber" surface within a "solar collector" or an actual storage tank. Water flows through tubes attached to the absorber and picks up the heat from it. Most of the solar radiation is absorbed and converted to heat. Some of this absorbed heat is conducted through the pipe to the riser tubes and then through the riser tubes walls to the water. The transfer of heat to the water rises the water temperature. Some of the heat is lost to the surroundings. The heat losses should keep as low as possible. Water heating typically represents a high percentage of energy consumption in homes and businesses, in some cases 30% or more. Solar water heater is nothing but a device which utilizes harnessing energy from the sun to heat water. Solar water heating is a reliable and renewable energy technology used to heat water. Sunlight strikes and heats an “absorber” surface within a “solar collector” or an actual storage tank. Water flows through tubes attached to the absorber and picks up the heat from it. Most of the solar radiation is absorbed and converted to heat. Some of this absorbed heat is conducted through the pipe to the riser tubes and then through the riser tubes walls to the water. The transfer of heat to the water rises the water temperature. Some of the heat is lost to the surroundings. The heat losses should keep as low as possible. Water heating typically represents a high percentage of energy consumption in homes and businesses, in some cases 30% or more. Solar water heater is nothing but a device which utilizes harnessing energy from the sun to heat water. Solar water heating is a reliable and renewable energy technology used to heat water. Sunlight strikes and heats an “absorber” surface within a “solar collector” or an actual storage tank. Water flows through tubes attached to the absorber and picks up the heat from it. Most of the solar radiation is absorbed and converted to heat. Some of this absorbed heat is conducted through the pipe to the riser tubes and then through the riser tubes walls to the water. The transfer of heat to the water rises the water temperature. Some of the heat is lost to the surroundings. The heat losses should keep as low as possible. Water heating typically represents a high percentage of energy consumption in homes and businesses, in some cases 30% or more. Solar water heater is nothing but a device which utilizes harnessing energy from the sun to heat water. Solar water heating is a reliable and renewable energy technology used to heat water. Sunlight strikes and heats an “absorber” surface within a “solar collector” or an actual storage tank. Water flows through tubes attached to the absorber and picks up the heat from it. Most of the solar radiation is absorbed and converted to heat. Some of this absorbed heat is conducted through the pipe to the riser tubes and then through the riser tubes walls to the water. The transfer of heat to the water rises the water temperature. Some of the heat is lost to the surroundings. The heat losses should keep as low as possible.

Design of the solar water heater Design of the collector

Water heating for domestic purposes is a simple and effective way of utilizing solar energy. The initial cost of solar water heating system is very high without any operating cost. It is a natural solar thermal technology. In this system, incident solar radiation is converted into heat and transmitted to a transfer medium such as water. The solar energy is the most capable of the alternative energy sources. Due to increasing demand for energy and rising cost of fossil fuels (i.e., gas or oil), solar energy is considered as an attractive source of renewable energy. Solar heater is a device that uses solar energy to produce steam for domestic and industrial applications. Heating of water consumes nearly 20% of total energy consumption for an average family. Solar water heating systems are the cheapest and most easily affordable clean energy available to homeowners that may provide hot water required for a family. Solar water heaters can operate in any climate. The performance of these heaters varies depending on the availability of solar energy at that locality and more importantly on the temperature of cold water coming into the system. It can be either active or passive. A thermo siphon solar water heater relies on warm water rising, a phenomenon known as natural convection, to circulate water through the solar collector and to the storage water tank. The thermo siphon effect for solar water heating system has been employed with solar collectors as the principal heating component. These solar heating systems use either direct heating or indirect heating by the collector. In these cases, the thermo siphon induced flow is a result of the incident solar radiation, but it is also affected by the hot water removal pattern. Recently, a fuzzy model system is used to predict the outlet water temperature of a thermo siphon solar water heating system . Presently, solar and other alternative energy resources are being harnessed for various applications such as power generation, air conditioning, space heating, and domestic hot water system. Photovoltaic thermal technology (PVT) refers to the solar thermal collectors that use PV cells as an integral part of the absorber plate. This kind of system generates both thermal and electrical energy simultaneously.





Pyranometer

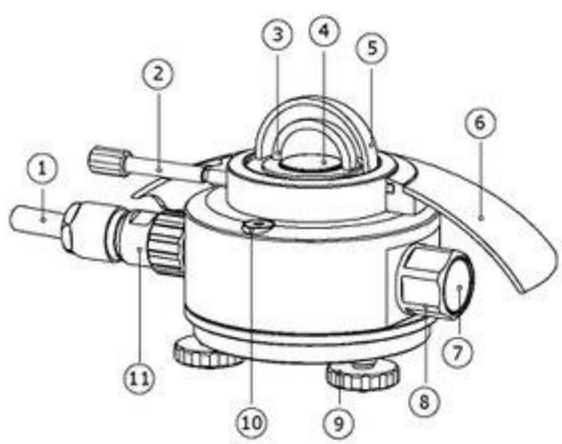
A pyranometer is a type of actinometer used for measuring solar irradiance on a planar surface and it is designed to measure the solar radiation flux density (W/m2) from the hemisphere above within a wavelength range 0.3 µm to 3 µm. A typical pyranometer does not require any power to operate. However, recent technical development includes use of electronics in pyranometers, which do require (low) external power.

Thermopile Pyranometers

A **thermopile pyranometer** is a sensor based on thermopiles designed to measure the broadband of the solar radiation flux density from a 180° field of view angle. A thermopile pyranometer thus usually measures 300 to 2800 nm with a largely flat spectral sensitivity (see the Spectral Response graph) The first generation of thermopile pyranometers had the active part of the sensor equally divided in black and white sectors. Irradiation was calculated from the differential measure between the temperature of the black sectors, exposed to the sun, and the temperature of the white sectors, sectors not exposed to the sun or better said in the shades.

In all thermopile technology, irradiation is proportional to the difference between the temperature of the sun exposed area and the temperature of the shadow area.

Design



Line drawing of a pyranometer, showing essential parts: (1) cable, (3) and (5) glass domes, (4) black detector surface, (6) sun screen, (7) desiccant indicator, (9) levelling feet, (10) bubble level, (11) connector

In order to attain the proper directional and spectral characteristics, a thermopile pyranometer is constructed with the following main components:

- A thermopile sensor with a black coating. It absorbs all solar radiation, has a flat spectrum covering the 300 to 50,000 nanometer range, and has a near-perfect cosine response.
- A glass dome. It limits the spectral response from 300 to 2,800 nanometers (cutting off the part above 2,800 nm), while preserving the 180° field of view. It also shields the thermopile sensor from convection. For first class and secondary standard pyranometers (see ISO 9060 classification of thermopile pyranometers) a second glass dome is used. This construction provides an additional "radiation shield", resulting in a better thermal equilibrium between the sensor and inner dome, compared to using a single dome. The effect of having a second dome is a strong reduction of instrument offsets.

In the modern thermopile pyranometers the active (hot) junctions of the thermopile are located beneath the black coating surface and are heated by the radiation absorbed from the black coating. The passive (cold) junctions of the thermopile are fully protected from solar radiation and in thermal contact with the pyranometer housing, which serves as a heat-sink. This prevents any alteration from yellowing or decay when measuring the temperature in the shade, thus impairing the measure of the solar irradiance.

The thermopile generates a small voltage in proportion to the temperature difference between the black coating surface and the instrument housing. This is of the order of 10 µ • VW/m^2. Typically, on a sunny day the output is around 10 mV. Each pyranometer has a unique sensitivity, unless otherwise equipped with electronics for signal calibration.