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Solar Collectors – Design and Applications

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Abstract:

After water and food, probably energy is one of the most important requirements. Even for processing of food or water purification, energy is essential. World energy consumption is expected to increase by 71% from 2003 to 2030 according to the "International Energy Outlook 2006", a publication of the Energy Information Administration. Dr. Anil Kakodakar (Chairman, DAE) had described the figures for growth of India by 2050 during his lecture in one of the conference. Growth of India is expected to be high (about 7%) compared to the Universal growth rates. So such growth increases the energy requirements for various industrial scale productions. As economic growth rate is increases, per capita income increases and it also increases the per capita consumption of energy. In short, all activities leading to higher growth rate requires lots of energy. But as per the current scenario, demand for energy is very high compared to the production of energy through various sources. If we look at the available resources to produce electricity, coal and petroleum based power plants stood first. But as the crude oil prices increases and environmental pollution related laws are becoming more and more stringent, people are looking for alternative sources for electricity generation. Looking at the various options, we must have to accept that solar energy is the best solution as it is freely available in large quantity and also most environmental friendly if utilize directly or with proper design for various applications.

Solar energy is already being used for water heating, cooking and electricity generation through PV (photo-voltaic) cell. But range of applications is very limited right now. With proper and user friendly design, use of solar water heaters and solar cookers can be increased and at the same time other applications like water purifier, water treatment, drying of various solid and food materials, steam and power generation can be developed. This work compiles various papers and patent available for use of solar energy. This work also discussed various aspects of better designs and utilization of solar energy more efficiently. Experimental work was carried out for various applications. New solar equipments with user-friendly design show better efficiency and higher performance in various applications.

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ABSTRACT

Solar Energy is a prominent source of renewable energy. In near future the demand of energy is going to be so gigantic that our conventional energy sources would not be able to fulfill it and we will be forced to develop alternative energy sources. This is where solar energy is going to play a major role. Even today we can develop solar collectors for the remote places where the supply of energy is impossible otherwise.

Solar energy can be harvested either by using photo voltaic cells or by direct concentration for heating purpose which is done using Solar Collectors. There are different kinds of solar collectors i.e. plane, line focus and point focus. Point collectors can be obtained using a paraboloidal surface. Conventional point collectors are obtained by using a horizontal cut on a paraboloidal surface. In this case the point of concentration is located in the path of incident radiation and also it is required to be moved continuously along with the trough. Another approach for point focus is using a lateral cut also known as Scheffler Collector. The advantages of using a lateral cut are that it makes our focus stationary and located at a distant position. A detailed design of Scheffler Collector along with the application of the collected energy is mentioned in the report.

INTRODUCTION

Man lives today in a time of exhaustion of the planet's natural resources and at the same time in which returns to nature the non-recyclable trash of diverse products. Among these, the prominent materials, more aggressive and abundant are such as synthetic, metals (including heavy ones), plastics, and chemicals. The conscientious awakening that something very serious has to be done is unquestionable and irreversible.

Nowadays we think a lot in using clean energy sources like solar, wind, from hydrogen, and electric energy forms, among others. The preoccupation in developing alternative energy forms has its basis not only as an environmental issue, but also as a search for economic alternatives is also fundamental.

Solar energy and the use of solar energy to supply solar power is gradually increasing in popularity and infiltrating many areas of daily life. This is particularly true of solar heating, which many people are turning to because the resources used to supply heat to our homes, oil and natural gas, are only available in limited quantities and those quantities are dwindling rapidly, and, as a result, becoming much more expensive. This has resulted in heating bills going through the roof, forcing people to look to alternative energy sources for their heating needs, such as solar heating[1].

Another major concern for many is the pollution caused by the burning of oil and natural gas to supply our heating needs, along with that caused by the burning of oil and natural gas to supply the electricity needed to run such things as water and space heating[2].

Solar heating represents a great way to help reduce expenses and pollution, so let's take a closer look at this increasingly popular phenomenon.

We get energy from the sun in 2 ways, light and heat and we humans have been taking advantage of this amazing source of energy to provide us with heat and light for our homes and everyday needs. The sun provides over six thousand times more energy in one hour than the whole earth's population uses in an entire year.

Nowadays, we've developed sophisticated means (houses or rooms designed to capture the sun's energy for heating and lighting) and equipment to help us take advantage of this massive over-abundance of energy. One of these pieces of equipment is the solar collector.

Is there an Energy Problem?

- A significant fraction is reflected or absorbed by our atmosphere
- Most of the energy falls on inaccessible locations
- Energy is needed to power the planet
- Solar energy is diffuse so equipment to collect it is large and expensive.

What Is A Solar Collector and How Does It Work?

A solar collector's job is to capture the to be transferred to its intended destination)[4].

Solar collector covers can be made from virtually any clear material, but glass is the one most commonly used. But, not just any old glass – the glass for collectors is scratch resistant and almost unbreakable. It allows sunlight to pass into the collector, where it strikes a dark surface and is converted into heat, which is trapped inside the collector courtesy of the glass cover.

Absorber plates are metal containers or sheets that contain water or dark-coloured bricks or rocks.

In order to prevent the heat produced by a collector from escaping (heat is naturally drawn to colder temperatures) insulation is used.

To make the air or liquid heated by a collector available for use, it is moved via the use of vents, air tubes (ducts) and fans to heat the house (in the case of air), or via tubes, pipes and pumps in the case of water to be used in space or water heating equipment.

If pumps and/or fans are involved in the movement of heat to the house, this is known as "active solar"; a system involving no pumps or fans is referred to as "passive solar".

This form of energy can be produced cleanly and virtually free by solar energy collectors. Solar collectors are basically heat exchangers and they can be classified into two groups:
Flat plate and concentrating collectors.

The fiat plate collectors use both beam and diffuse radiation and are usually designed to deliver energy at moderate temperatures in the 100°C range and do not require tracking of the sun[1][2].
Concentrating collectors provide energy at temperatures higher than those of fiat plate collectors. They re-direct solar radiation passing through an aperture into an absorber and usually require tracking of the sun. In such energy conversion systems, the working fluid is usually a liquid (plain water), vapour (ammonia) or gas (air)[3]. In recent years, black liquids have been used as the working fluid in place of water and transparent glass tubing is used instead of black coated copper tubing as the receiver.

APPLICATIONS OF SOLAR ENERGY IN CHEMICAL ENGINEERING PROCESSES

2.1 A continuous adsorption refrigeration system driven by parabolic trough solar collector[5]

In recent years, considerable attention has been paid to adsorption refrigeration systems, which are regarded as environmentally friendly alternatives to conventional vapour compression refrigeration systems, since they can use refrigerants that do not contribute to ozone layer depletion and global warming. In addition, the adsorption systems have the benefits of simpler control, no vibration and lower operation costs, if compared with mechanical vapour compression systems and, in comparison with the absorption systems, they do not need a solution pump or rectifier for the refrigerant, do not present corrosion problems due to the working pairs normally used, they are less sensitive to shocks and to the installation position and they could be operated with no-moving parts.

2.2 Solar Food Processing[4]

Solar food processing is an innovative and multi-faceted technique capable of addressing various problems faced by people in the developing world. The implementation of technologies for food processing and conservation using solar energy can indirectly help to reduce poverty, improve health conditions, create sustainable local economic opportunities, and limit environmental damage by promoting the use of clean and renewable energy sources. The International Solar Energy Society (ISES) has identified a need to raise awareness in the field of solar food processing and the wide range of RE applications for small-scale production. We experienced that potential users have to see the technology in operation and test (taste) the products. By placing a product in the local market the technology becomes much more interesting than targeting only private households. In Namibia we observed that private households became interested after they have seen solar stoves regularly used to produce bread, cake and peanuts for the local market.

2.3 Multistage Evaporators[4]

One of the promising options is to make more extensive use of the renewable sources of energy derived from the Sun. Solar energy can be used both directly & indirectly. It can be used directly in a variety of thermal applications like heating water or air, drying, distillation and cooking. The heated fluids can in turn be used for applications like power generation or refrigeration. A second way in which solar energy can be used directly is through the photovoltaic effect in which it is converted to electrical energy.

Solar water distillation is a technology with a very long history and installations were built over 2000 years ago, although to produce salt rather than drinking water. Documented use of solar stills began in the sixteenth century. An early large-scale solar still was built in 1872 to supply a mining community in Chile with drinking water. Mass production occurred for the first time during the Second World War when 200,000 inflatable plastic stills were made to be kept in life-crafts for the US Navy.

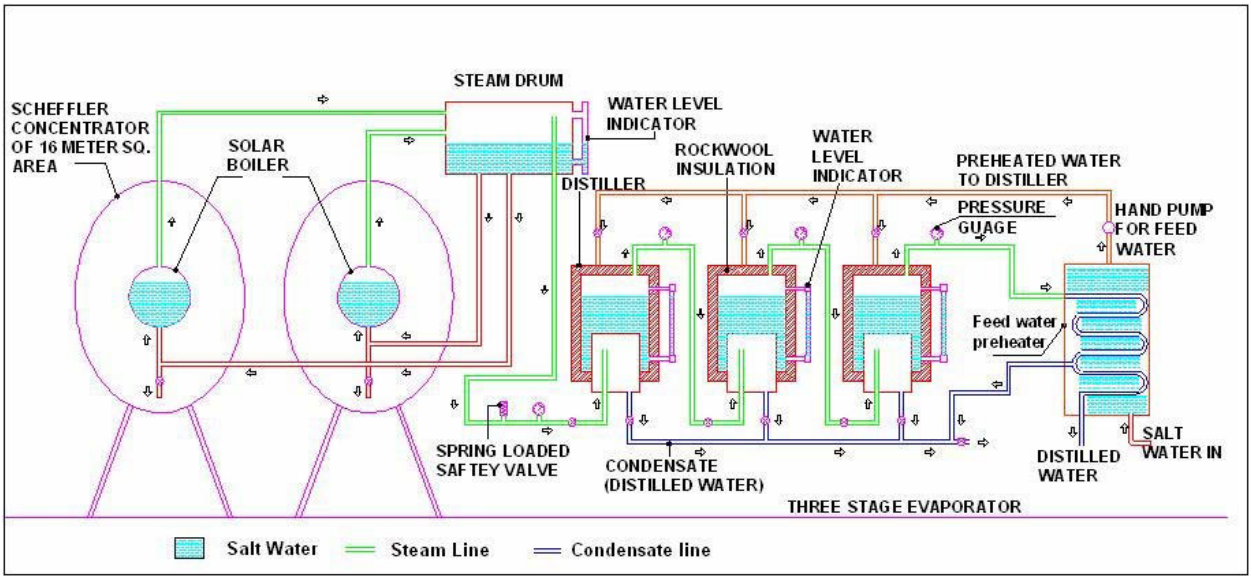


Fig: 2.1 Schematic layout of Multistage evaporators with Scheffler concentrators

2.4 CSP(Concentrating Solar Power) plants[6]

Both world total final energy consumption and world CO2 emissions have doubled in the last 35 years. The limited supply of fossil hydrocarbon resources and the negative impact of CO2 emissions on the global environment dictate increased usage of renewable energy resources. CSP is the most likely candidate for providing the majority of this renewable energy, because it is amongst the most cost-effective renewable electricity technologies and can make a substantial contribution towards international commitments to reduce the increase in the level of greenhouse gases and their contribution to climate change. Furthermore, many countries are exploring various sources of renewable energy to reduce their dependence on foreign imports to meet their energy requirements. As solar energy is the most abundant and geographically widespread resource, it offers advantages over other energy resources. To emphasize the magnitude of the solar resource, an illustrative calculation is useful. Even under the assumption that only 1% of the land area in the world with enough solar radiation were used for CSP plants, the potential annual electricity generation would still be higher than total world electricity production in the year 2009, and regarding environmental benefits, each square meter of solar field is enough to avoid the annual emissions of 200–300 kg of CO2.

2.5 Domestic hot water and space heating [6]

One of the most widespread applications of solar thermal energy is hot water production. According to an IEA report for 2008, solar thermal collector capacity in operation worldwide was about 127.8 GWth (182.5 millions m2), most of it domestic, both for DHW (kitchen, shower, laundry and sanitation facilities) and space heating. Israel is the country with the oldest solar legislation, in force since 1980. The law’s success has made it largely superfluous. Today, more than 90% of Israel’s solar thermal market is voluntary, retrofitted in existing buildings or systems larger than required by law. Currently, a number of countries are promoting solar water heating systems. A clear example is Spain, where current legislation included in the building code requires that all new or remodelled DHW installations and covered swimming-pool heating have to have a solar system to supply a certain amount of the energy demanded. Another example is Portugal, where the new Portuguese building code includes a requirement for solar thermal installations, which must be a minimum of 1 m2 per person, or some other form of renewable energy providing a similar energy saving.

The temperatures at which energy is required by these applications are below 100 degC. Therefore, conventional solar collectors with suitable efficiencies could be employed. However, when a large amount of hot water is demanded, a large collection area, which sometimes becomes excessive, must be installed. In this case, Parabolic Trough Collectors might be of interest, because they supply thermal energy at higher temperatures than those required by the load and, therefore, higher demands can be covered by mixing the hot solar fluid with another cooler.

2.6 Distillation[3]

A large part of industrial process heat lies from low to medium temperature range which can be supplied by solar energy. The promotion of decentralized agro-based industries by using innovative solar collectors can open new landmarks in rural development especially in tropical countries. Essential oils extraction from herbs through distillation process is one of the medium temperature agro-based industries. These oils are used in food, medicines, fragrances, perfumery and cosmetics. Scheffler fixed focus concentrators provide the required temperature range for solar distillation systems. The system is installed at solar campus, University of Kassel, Witzenhausen to avail fresh supply of different herbs. In the first phase of the research, several trials were made to evaluate the performance of the system. Within the beam radiations range of 700-800 Wm-2, the receiver temperatures were recorded between 300- 400°C. All kinds of herbs were processed successfully by using solar distillation system.

3.1 Plane Solar Collectors:

3.1.1 Flat Panel Collectors[1][2][3]

The flat panel collectors are boxes with a semi-transparent covering (transparent for solar radiation and opaque for infrared radiation) to take advantage of greenhouse effect. Within the box we put a radiator covered by a selective surface that absorbs solar light and heats itself. Collector's bottom and side walls are covered by thermal insulators to avoid heat loss by conduction between the radiator and walls or roof wherein the system is fixed.

Generally, flat-plate collector acts as a receptor that gathers energy from the sun and warm up a plate. The energy stored in the plate is transferred to the fluid. Usually, these collectors have a transparent cover glass or plastic taking advantage of the greenhouse effect, consisting of a series of copper tubes, which exposed to the sun absorb solar radiation and it is transmitted to the fluid passing through its interior. Its application is the production of hot water, air conditioning and heating of swimming pools.

3.1.2 Heliostat[1][2][3]

A heliostat is a device that includes a mirror which moves so as to keep reflecting sunlight toward a predetermined target despite the sun's apparent motions in the sky. The target may be a physical object or a direction in space. To do this, the reflective surface of the mirror has to be kept perpendicular to the bisector of the angle between the directions of the sun and the target as seen from the mirror. In almost all cases, the target is stationary relative to the heliostat, so the light is reflected in a fixed direction. Most modern heliostats are controlled by computers. The computer is given the latitude and longitude of the heliostat's position on the earth and the time and date. From these, using astronomical theory, it calculates the direction of the sun as seen from the mirror, e.g. its compass bearing and angle of elevation. Then, given the direction of the target, the computer calculates the direction of the required angle-bisector, and sends control signals to motors, often stepper motors, so they turn the mirror to the correct alignment. This sequence of operations is repeated frequently to keep the mirror properly oriented.

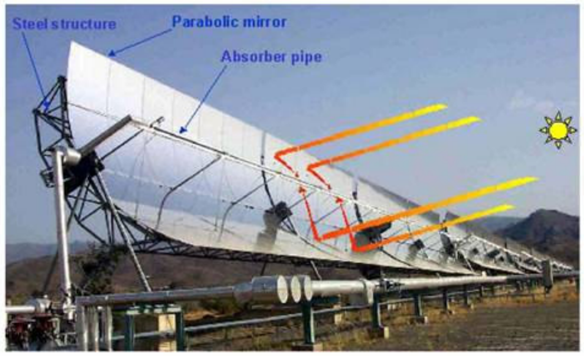
3.2 Line Focus:

3.2.1 Fresnel Reflector[3][4]

It is an array of single axis, linear solar mirrors to reflect sunlight onto a receiver tube. In that way it is similar to a solar parabolic trough system. The compact linear Fresnel solar power system, however, uses a 'parabola' made up of flat mirrors that each rotate to follow the sun, Instead of a more expensive parabolic shaped mirror, as in the solar parabolic trough system. This type of system allows the flat solar mirrors to remain near the ground, avoiding wind loads.

3.2.2 Parabolic Line Focus[1][4]

A type of concentrating solar collector that uses U-shaped troughs to concentrate sunlight onto a receiver tube, containing a working fluid such as water, which is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss. Parabolic troughs often use single-axis or dual-axis tracking. In rare instances, they may be stationary.



3.3 Point Focus:

3.3.1 Parabolic Dish (Horizontal Cut)[4]

It is the most powerful type of collector which concentrates sunlight at a single, focal point, via one or more parabolic dishes—arranged in a similar fashion to a reflecting telescope focuses starlight, or a dish antenna focuses radio waves. This geometry may be used in solar furnaces and solar power plants.

There are two key phenomena to understand in order to comprehend the design of a parabolic dish. One is that the shape of a parabola is defined such that incoming rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive. The second key is that the light rays from the sun arriving at the Earth's surface are almost completely parallel. So if dish can be aligned with its axis pointing at the sun, almost all of the incoming radiation will be reflected towards the focal point of the dish—most losses are due to imperfections in the parabolic shape and imperfect reflection.

Losses due to atmosphere between the dish and its focal point are minimal, as the dish is generally designed specifically to be small enough that this factor is insignificant on a clear, sunny day. Compare this though with some other designs, and you will see that this could be an important factor, and if the local weather is hazy, or foggy, it may reduce the efficiency of a parabolic dish significantly.

3.3.2 Parabolic Dish (Vertical Cut) / Scheffler[4]

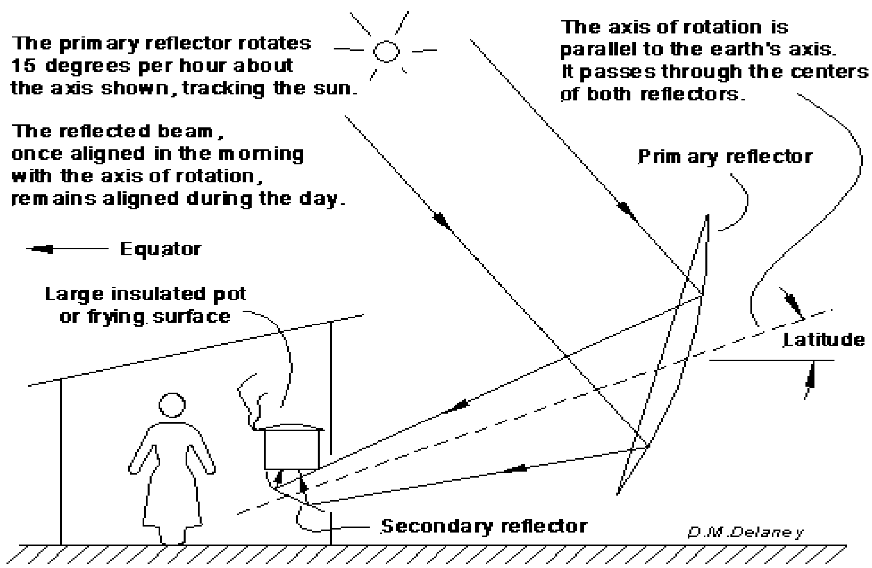
Beyond the low temperature applications, there are several fields of application of solar thermal energy at a medium and medium–high temperature level. From a number of studies on industrial heat demand, several industrial sectors have been identified with favorable conditions for the application of solar energy. The most important industrial processes using heat at a mean temperature level are: sterilizing, extraction, pasteurizing, drying, solar cooling and air conditioning, hydrolyzing, distillation and evaporation, washing and cleaning, and polymerization. The ranges of all these processes lie between 60 and 280 _C.

Several experiments were carried out to utilize the solar energy at medium temperature range using vacuum tube collectors to increase the temperature at medium–high temperature range. These vacuum tube collectors are efficient at low temperature range but not suitable for continuous processing at medium–high temperature range due to higher heat losses by increase in the amount of exposed area. Decreasing the area from which the heat losses occur can increase energy delivery temperatures. With higher a concentration ratio, there is an increase in temperature at which heat is delivered due to an increase in flux intensity and a decrease in the receiver area.

Modern parabola trough concentrators and central receiver towers are operated by high-tech computer programmed tracking systems and are used only in large-scale applications to justify the high investment costs and gross over design. The conventional paraboloidal concentrators converge all the beam radiations at the focus and are selected as the bottom part of a paraboloid parallel to the directrix. With such parabolic concentrators, not only the frequent tracking of two axes is required but also the receiver is fixed at the focal point as an integral part of the reflector. Moreover,focus lies in the path of incident beam radiations. Despite the high temperature output, such types of concentrators are rarely used for industrial applications due to frequent changes of the focus position and inadequacy of handling approach at the receiver.

This limitation, however, is solved by the Scheffler fixed focus concentrator which not only provides simple and precise automatic tracking but also a fixed focus away from the path of incident beam radiations. This design also provides an opportunity to shift the receiver for indoor applications. The versatile reflector rotates along an axis parallel to a polar axis with an angular velocity of one revolution per day from east to west to counterbalance the effect of earth rotation. Therefore, the relative position of the Scheffler reflector with respect to the sun remains stationary and provides a fixed focus on the line of the axis of rotation. The reflector not only provides daily tracking but also a seasonal tracking device to ensure the focus remains at the same fixed point with changing solar declination. Nevertheless, there is little compromise on the aperture area as compared with the conventional parabolic concentrator, but this drawback is compensated by,

- Precise automatic tracking
- Fixed focus with respect to the earth
- Focus located at a distant location from the trough



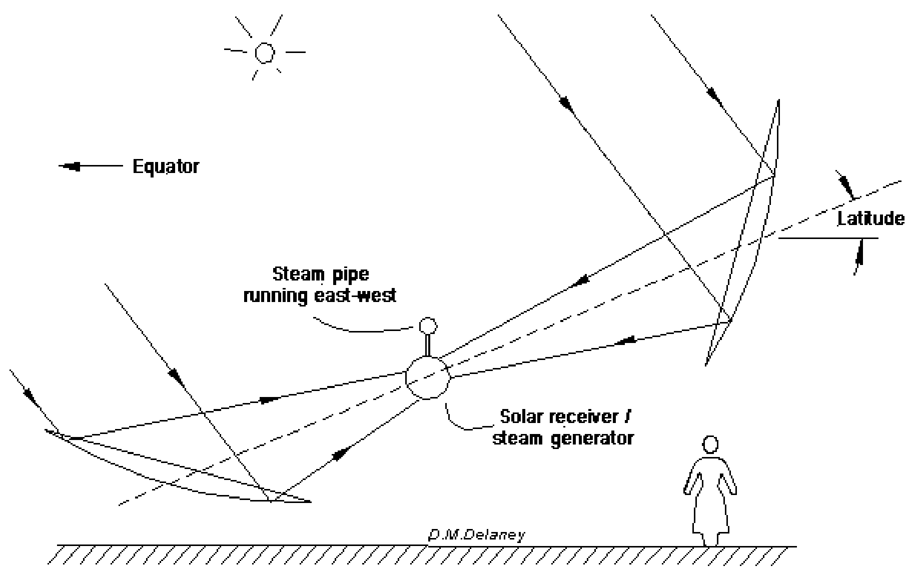
How a Scheffler reflector used for cooking keeps its focus on the cooking place as the sun moves.

Fig: 3.1

Scheffler reflector provides an extraordinary opportunity that can be used for domestic and industrial applications. The automatic tracking system with a stationary focus point has made it even more attractive for decentralized industrial applications in underdeveloped areas, where there is no electricity or fossils fuels availability. For small-scale applications, it can be used as a point source of heat, directly or indirectly by using a secondary reflector. On large-scale applications and steam generation, a number of Scheffler reflectors are arranged in the form of tandems to get a common focus point in the center. It also provides an opportunity to set the reflector in a standing position or in a laying position rotating along same axis of rotation. In addition, the balanced structure of the Scheffler reflector requires only a nominal torque to track the sun. This is done with the help of a small PV tracking system or clock work driven by gravity.

Different sizes of the Scheffler reflectors can be constructed ranging from 2 m^2 to 60 m^2. In order to obtain direct absorption of solar energy, a parabolic dish with a receiver configuration is often used. These types of reflectors can be successfully used in distillation, baking, water distillation, solar community kitchen, etc. It is observed through comparison that the two axes tracking paraboloidal dish, which always faces the sun, is the most promising design for concentrating systems justifying the use of the Scheffler concentrator for industrial process heat applications.

These concentrators are capable of delivering temperatures in the range of 300 `C[4] and are technically suitable for medium temperature applications. A focal receiver absorbs the concentrated solar radiations and transforms it into thermal energy to be used in a subsequent process. The essential feature of a receiver is to absorb the maximum amount of reflected solar energy and transfer it to the working fluid as heat, with minimum losses. About half the power of sunlight which is collected by the reflector becomes finally available in the cooking vessel. The use of solar energy for the generation of steam is now an economically attractive possibility since the payback period of such a system lies between 1.5 and 2 years.



Arrangement of Scheffler reflectors for large steam generating plants.
Solar receivers and pairs of reflectors are positioned along the steam pipe.

Fig: 3.2

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