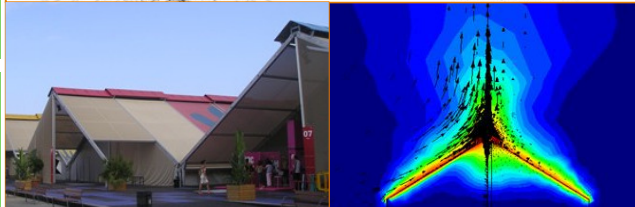
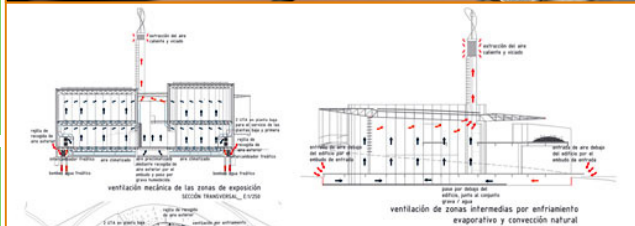


TECNOLOGÍAS DE MEDIA TEMPERATURA IEA TASK 33

- **Daniel González i Castellví**
- *Santiago de Chile, 23 de septiembre de 2011*

AIGUASOL



Cooperativa fundada en 1.999 por dos doctores investigadores de la UPC. Actualmente formada por 20 personas altamente cualificadas (2 Doctores, 9 ingenieros, 2 físicos, 1 arquitecta y 6 en administración y ventas) dedicados exclusivamente a tareas de ingeniería energética, con oficinas en Barcelona, San Sebastián i Santiago.

EDIFICACIÓN: tareas de investigación, desarrollo, estudios y proyectos relacionados con los aspectos energéticos, pasivos y activos en edificios o barrios.

INDUSTRIA: optimización y integración de procesos, mejora de eficiencia de maquinaria, introducción de renovables.

GENERACIÓN: desarrollo y diseño relacionado con sistemas solares termoeléctricos, aspectos avanzados de sistemas fotovoltaicos y diseño y optimización de sistemas energéticos o medidas de eficiencia para empresas de servicios energéticos (ESCO)

SOFTWARE: desarrollo y comercialización de software específico para sistemas energéticos, especialmente sistemas solares, como TRNSYS, TRANSOL, TRNFLOW...

Experiencia de AIGUASOL



Desarrollo HIPERTINOX

Desarrollo LFC (fm) CCSTAR

Desarrollo LFC AIRA



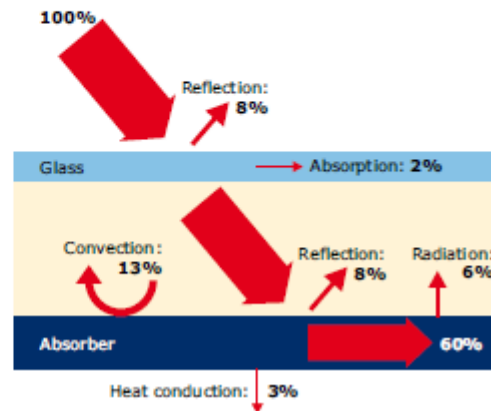
Advanced FPC

Operating Principle

Flat-plate collectors use both beam and diffuse solar radiation, do not require tracking of the sun, and are low-maintenance, inexpensive and mechanically simple.

Solar radiation enters the collector through the transparent cover and reaches the absorber. Here the absorbed radiation is converted to thermal energy. A good thermal conductivity is needed to transfer the collected heat from the absorber sheet to the absorber pipes where the heat is finally transferred to the fluid. Usually a water/glycol mixture with anticorrosion additives is used as the heat carrying fluid. The fluid also protects the collector from frost damage.

Main losses of a basic flat-plate collector during angular operation (based on [2])



To improve standard flat-plate collectors some of the main losses need to be reduced. These losses can be classified in optical and thermal losses. The thermal losses rapidly increase with higher temperatures, while the optical losses are constant.

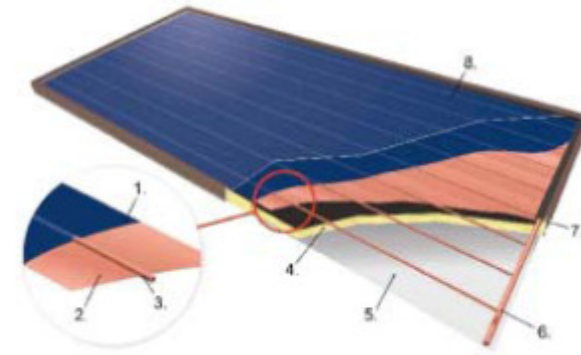
Optical losses

High quality covers of low-iron solar glass have a transmission of 90% for solar radiation (normal irradiation). If an anti-reflective coating is used the transmission can be increased to 93 - 96%. Usually about 1 - 2% is absorbed in the glass plane and the rest is lost due to reflection. The coating of the absorber can reach absorption coefficients of 95%. The optical losses grow with increasing angles of the incident sunlight.

Thermal losses

The main thermal losses at the front are caused by convection. The circulating air between absorber and cover transports the absorbed heat to the glazing. After heat conduction through the cover there is again convective loss because of the air that flows around the collector. The hot absorber also radiates infrared radiation to the cover, from where the heat is transferred to the environment. The IR-emittance of a selective absorber can reach down to 5%. At the backside, thermal losses occur at the insulation. The heat conduction there depends on the used material and can be kept low by using thermal insulation of adequate thickness. For a single glazed flat-plate collector with a selective coated absorber only about 1/7 of the total heat losses occur at the rear side.

Basic flat-plate collector for applications up to 80°C [1]



1. Selective Coating
2. Absorber
3. Tube
4. Insulation
5. Rear panel
6. Manifold
7. Frame
8. Transparent cover

Advanced flat-plate collectors differ little from standard flat-plate collectors. The main elements are:

Transparent cover

To assure high transmittance and high durability, covers of low iron, tempered solar glass with anti-reflective coating are used. If a second or third transparent cover is used, they are made of anti-reflective coated glass or Teflon films. Key factors are high transmissivity, high temperature stability, and low heat expansion.

Absorber

The most common material for sheet and absorber pipes is copper, however sheets of aluminium are also used due to their lower costs. For corrosive applications, stainless steel is a possible material. The state-of-the-art is a selective coating on the sheet to reduce the thermal losses due to infrared radiation.

The absorber pipe work should be designed to ensure high heat transfer. With regard to stagnation, the hydraulic absorber should be designed to allow a fluid emptying behaviour when steam occurs under stagnation conditions.

Insulation

Due to the high temperatures mineral wool or rock wool is often used as insulation material to reduce the thermal losses on the backside of the absorber. In some configurations additional polyurethane plates are used between the insulation mat and the rear panel of the collector.

Casing

The casing ensures stability and protects the absorber and the insulation against environmental impacts. It often consists of aluminium, steel, wood or synthetic material.

The frame parts can be brazed, riveted or glued. Some frames are formed as a tray so that a connection is not needed between the side plates and rear panel.

Current Stage of Development

With standard flat-plate collectors operation temperatures up to 80°C can be reached.

Because of its high heat losses, the basic flat-plate collector has to be improved to economically cover the lower medium temperature level up to 150°C.

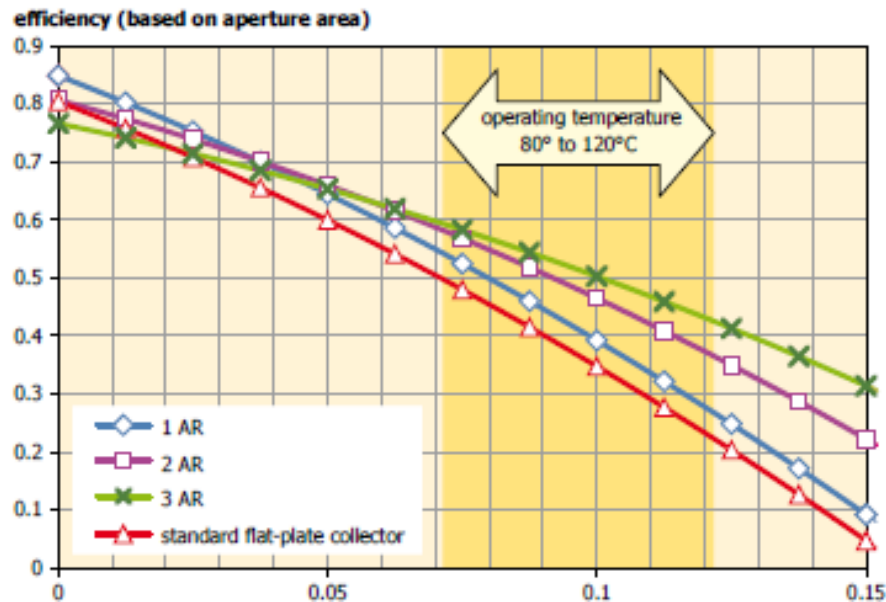
For applications in the temperature range of 80 to 120°C, in particular, there exist a number of possibilities to improve flat-plate collectors so that they can be suitable for those applications. In order to achieve this, it is necessary to reduce the collector heat losses mainly on the front side of the collector, but without sacrificing too much of the optical performance at the same time.

Improvements include:

- hermetically sealed collectors with inert gas fillings;
- double covered flat-plate collectors;
- vacuum flat-plate collectors; and
- combinations of the above mentioned.

As an example, **Figure 3** shows estimated efficiency curves of single, double and triple glazed flat-plate collectors when anti-reflection glazing ('AR-glass') is used.

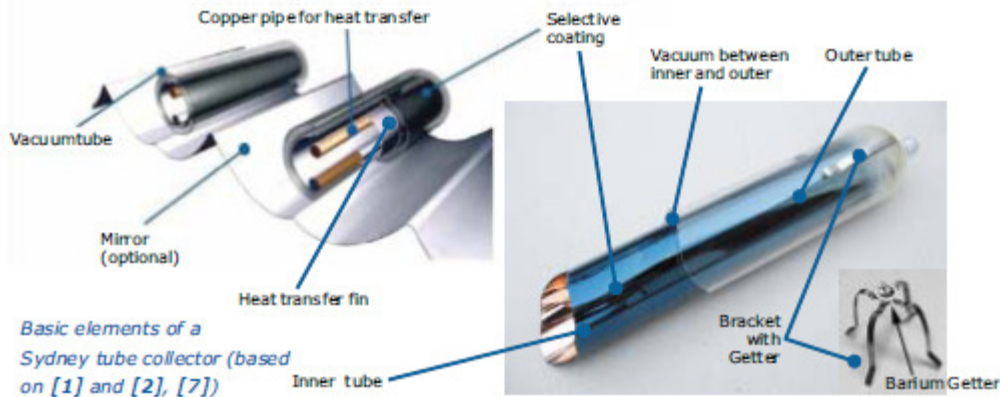
Efficiency curves of a single, double and triple glazed AR collector in comparison with a standard flat-plate collector with normal solar glass [1]



Advanced FPC

Description of Construction and Operating Principles

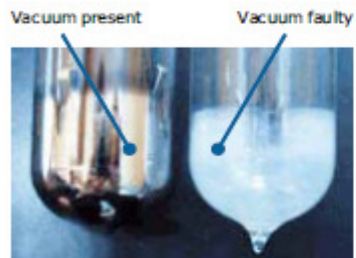
There are several types of evacuated tubes in use for solar collectors. The Sydney tube (also: "twin-glass tube" or "thermos flask tube") shown in **Figure 4** is a popular collector type.



The different types of evacuated tube collectors have similar technical attributes:

- A collector consists of a row of parallel glass tubes.
- A vacuum ($< 10^{-2}$ Pa) inside every single tube extremely reduces conduction losses and eliminates convection losses.
- The form of the glass is always a tube to withstand the stress of the vacuum.
- The upper end of the tubes is connected to a header pipe.

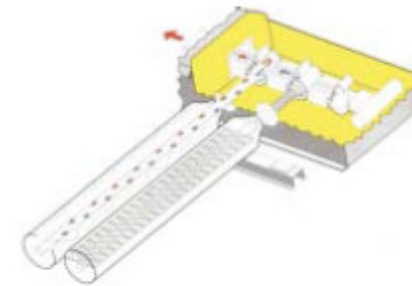
The getter is another component evacuated tubes have in common. It is used to maintain the vacuum inside. During the manufacturing of most evacuated tubes the getter is inductively exposed to high temperatures. This causes the bottom of the evacuated tube to be coated with a pure layer of barium. This barium layer eliminates any CO , CO_2 , N_2 , O_2 , H_2O and H_2 out-gassed from the evacuated tube during storage and operation. The barium layer also provides a clear visual indicator of the vacuum status. The silver coloured barium layer will turn white if the vacuum is ever lost. This makes it easy to determine whether or not a tube is in good condition (see **Figure 5**).



Evacuated tube collectors can be classified in two main groups:

- **Direct flow tubes:** the fluid of the solar loop is also circulated through the piping of the absorber.
- **Heat pipe tubes:** the absorbed heat is transferred by using the heat pipe principle without direct contact to the heat transfer fluid of the solar loop.

Heat Pipe Evacuated Tube Collectors



Principle of a heat pipe [5]

The main difference between a heat pipe tube and a direct flow tube is that the heat carrier fluid inside of the copper heat pipe is not connected to the solar loop. In this case there are two different ways of connection.

The "dry" connection is shown in **Figure 8**. Here the heat has to be transferred from the condenser through the material of the header tube. This way the installation and removal of the tubes is much easier than with direct flow pipes brazed to the header. On the other hand, heat-conductive paste often has to be used and thus requiring that the pipes be installed professionally.

In the case of a "wet" connection, the fluid of the solar loop directly flows around the condenser of the heat pipes. In this case, no heat-conductive paste is needed but the exchange of tubes is more difficult.

Direct Flow Evacuated Tube Collectors

If a single evacuated glass tube is used the whole interior is evacuated. For this configuration the flat or curved absorber as well as fluid inlet and fluid outlet pipes are inside of the vacuum. The absorber is coated with a selective surface. Single evacuated tubes often have diameters between 70 and 100 mm.

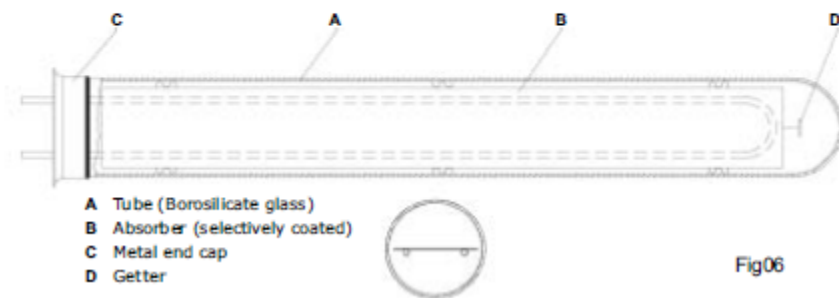


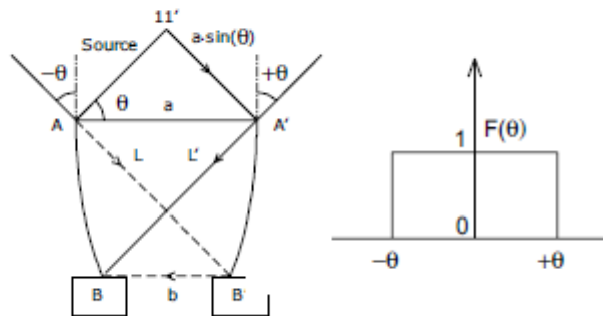
Fig06

CPC

Description of the Construction and Operating Principles

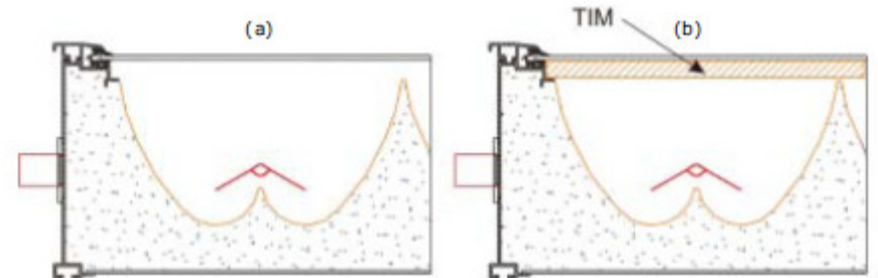
Ideal CPC concentrators can concentrate isotropic radiation incident on an aperture "a" within a solid angle θ with the normal to this aperture without losses. The minimal possible aperture "b" onto which the radiation can be delivered is shown in **Figure 9**. A full CPC, as shown in **Figure 9**, can achieve the maximum concentration C_{max} within the angle θ .

Aperture
 (left): CPC concentrator in 2D for a flat absorber parallel to a flat entrance aperture
 (right): Acceptance angle function of a 2D-CPC of an half acceptance angle θ



The maximum concentration ratio is given in equation (1). Equation (2) expresses the general ratio.

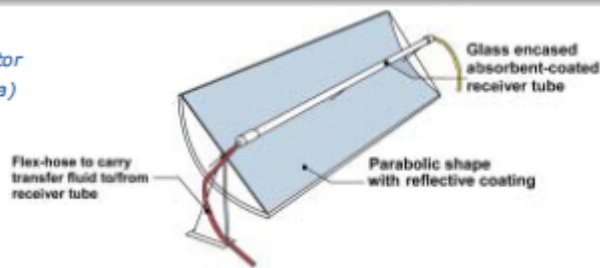
$$C_{max} = \frac{1}{\sin(\theta)} \quad (1) \quad C = \frac{a}{b} \quad (2)$$



(a): Cross section of a CPC with $C = 1.5$
 (b): Collector of (a) with transparent insulation material

PTC

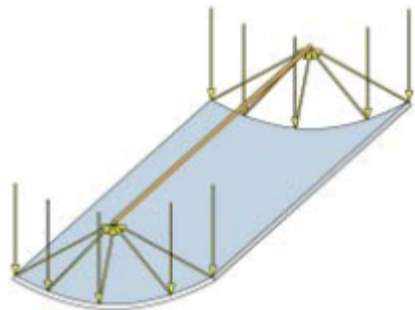
Sketch of a parabolic trough collector
(picture source: AEE INTEC, Austria)



Parabolic troughs are collectors designed to reach temperatures over 100°C and up to 450°C and still maintain high collector efficiency by having a large solar energy collecting area (aperture area) but a small surface where the heat is lost to the environment (absorber surface). Although different definitions are used, in this paper the concentration ratio refers to the ratio of the aperture area and the absorber surface (the surface that is hot and dissipates heat to the environment). The concentration ratio determines the temperature up to which the heat transfer fluid can be heated in the collector [3].

Operating Principle

The reflecting surface of parabolic trough collectors, also called linear imaging concentrators, has a parabolic cross section. The curve of a parabola is such that light travelling parallel to the axis of a parabolic mirror will be reflected to a single focal point from any place along the curve. Because the sun is so far away, all solar light coming directly (i. e., excluding diffuse) is essentially parallel so if the parabola is facing the sun, the sunlight is concentrated at the focal point. A parabolic trough extends the parabolic shape to three dimensions along a single direction, creating a focal line along which the absorber tube is run [4].

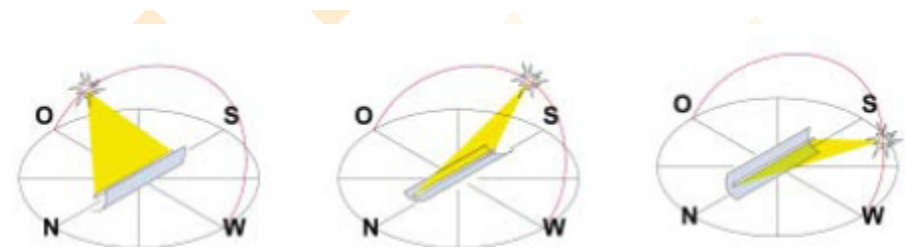


Parallel sun rays being concentrated onto the focal line of the collector
(picture source: AEE INTEC, Austria)

Parabolic trough collectors—like other solar concentrating systems—have to track the sun. The troughs are normally designed to track the sun along one axis oriented in the north-south or east-west direction. As parabolic troughs use only direct radiation, cloudy skies become a more critical factor than when using flat-plate collectors, which can use diffuse sunlight. Periodic maintenance for cleaning mirrors also is essential to assure an adequate parabolic trough field performance.

Possible fields of application of small parabolic trough collectors are:

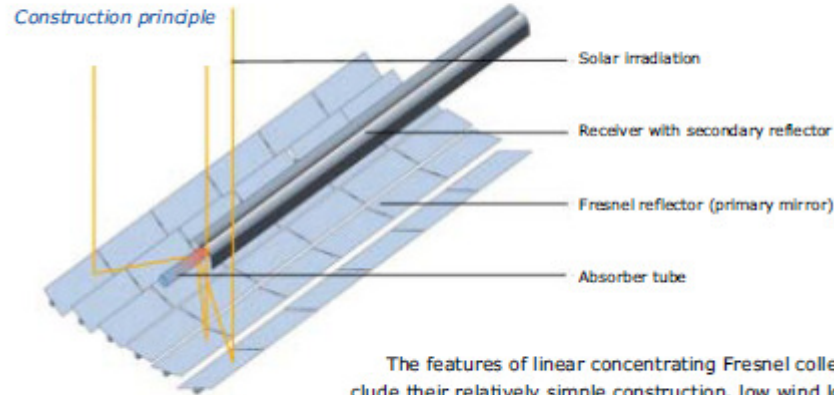
- Industrial processes where heat at a temperature higher than approximately 100°C - 130°C (depending on climate conditions) is needed [5]. They can be used to generate steam either in direct steam generation mode or using an indirectly fired steam generator. The steam can be fed into steam heat distribution networks that are used widely in industry.
- Driving absorption chillers, whether single or the most promising, double-stage machines. These last mentioned chillers have a higher efficiency than single-stage absorption chillers and due to their lower operating temperature are used for most solar cooling applications [1].



Tracking of the sun by a parabolic trough collector with the collector axis oriented north-south
(picture source: AEE INTEC, Austria)

Description of the Construction Principle

Linear concentrating Fresnel collectors use an array of uniaxially-tracked mirror strips to reflect the direct sunlight onto a stationary thermal receiver (Figure 19).



The features of linear concentrating Fresnel collectors include their relatively simple construction, low wind loads, a stationary receiver and a high ground usage. Some applications allow for the use of the shaded area underneath the collector (e. g., as parking lots).

Operating Principle

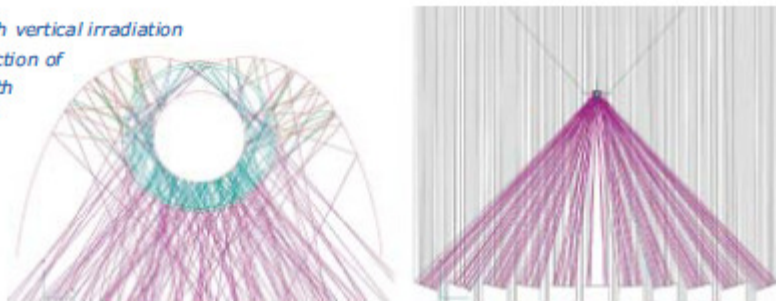
Almost flat primary mirrors are tracking the sun such that they reflect the direct sun rays to a stationary receiver. The primary mirrors can be made of flat glass because the slight curvature, which is needed for a focal length of several meters, can be applied by mechanical bending.

A common approach for the receiver is to use an absorber tube with a secondary concentrator. Figure 20 illustrates the optical principle for an absorber tube that is covered by a glass tube.

Ray tracing with vertical irradiation

(left:) cross section of the receiver with secondary concentrator.

(right:) Cross section of the whole collector.

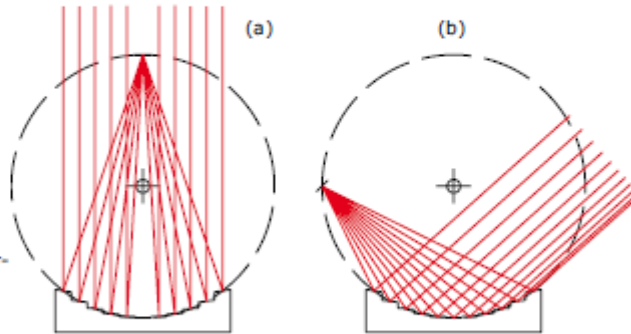


Typical concentration ratios are in the range of 25 to 40 with respect to the absorber tube surface (this corresponds to a concentration ratio of 80 to 130 with respect to the absorber diameter).

LFC (fm)

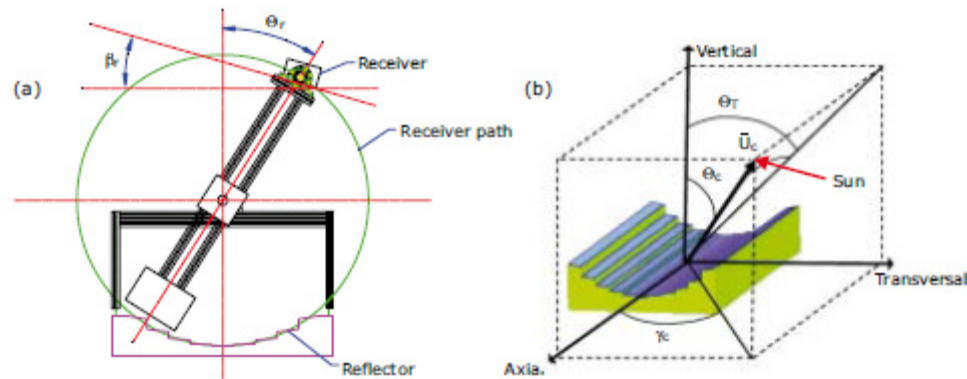
The so called Concentrating Collector with Stationary Reflector (CCStAR) is also described in the literature as a Fixed-Mirror Solar Collector (FMSC) [1]. The collector is based on a reflecting cylindrical concentrator that creates a linear focus for any sun incidence angle. The position of this linear focus follows a circular path and therefore tracking of the sun can be accomplished by moving the receiver instead of the reflector (Figure 22).

(a), (b): Operation principle



Description of the Construction Principle

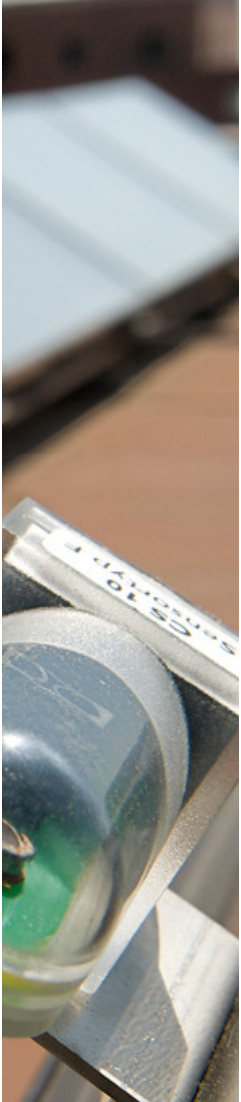
One possible implementation of the CCStAR principle of operation consists of a set of flat mirrors arranged in a Fresnel like geometry [2] according to the Figures 22a and 22b. A pair of movable arms support and guide the receiver (Figure 23a) that is always positioned on a circular path and forms an angle to the vertical plane $\theta_r = 2 \theta_s$, where θ_s is the projected transversal angle of the sun direction at any given time (Figure 23b).



(a), (b): Basic implementation

Other reflector geometries like parabolic segments could be used (Figure 24). These have the advantage of a smoother geometry, but on the other hand, the quality of the generated focus decreases as the transversal sun angle (θ_s) increases. In order to reach the highest efficiencies, the receiver should be rotated to form an angle to the aperture area of the reflector (Figure 23a).





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