IEA SHC-Task 33 and SolarPACES-Task IV: Solar Heat for Industrial Processes

Process Heat Collectors

State of the Art within Task 33/IV

Edited by Werner Weiss, AEE INTEC, Austria
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Table of Contents

1 Introduction

Approximately 128 GW_{th}, the equivalent of 183 million square meters, of solar thermal collectors were installed by the year 2006 worldwide (Weiss et al., 2008). Until now, the widespread use of solar thermal applications has focused almost exclusively on swimming pools and residential domestic hot water preparation and space heating.
The use of solar energy in commercial and industrial companies is currently insignificant compared to those mentioned above. Solar applications in industrial processes have only occurred on a relatively small scale and been mostly experimental in nature.
However, if one compares the energy consumption of the industrial, transportation, household and service sectors then one can see that the industrial sector has the highest energy consumption in OECD countries at approximately 30%.
Just one third of this energy demand is related to electricity, but two thirds are related to heat.
The major share of the heat, which is needed in commercial and industrial companies for production, processes and heating production halls, is below 250°C. The low temperature level (< 80°C) is consistent with the temperature level, that can easily be reached with solar thermal collectors already on the market.

Process Heat Collector Developments

For applications requiring temperatures up to 250°C there is limited experience and suitable collectors are still needed. Therefore, for these applications the development of high performance solar collectors and system components is necessary.
One of the objectives of Task 33/IV was to develop, improve and optimise solar thermal collectors for the temperature level from 80°C to 250°C.
The collectors investigated, in co-operation with industry, were double glazed flat plate collectors with anti-reflection coated glazing, stationary CPC collectors, evacuated tube collectors, small parabolic trough collectors, linear concentrating Fresnel collectors, and a concentrating collector with a stationary reflector.
In these activities, the investigation of materials suitable for medium temperature collectors was important, and so appropriate durability tests were applied to specific materials and components to allow the prediction of service lifetime and to generate proposals for international standards.
This report gives an overview and some background information on the present state of process heat collector development carried out in the framework of the IEA SHC Task 33/SolarPACES IV on Solar Heat for Industrial Processes.

2 Collector Description

2.1 Advanced Flat-plate Collectors

By **Stefan Heß** and **Matthias Rommel**, Fraunhofer ISE, Germany

2.1.1 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.

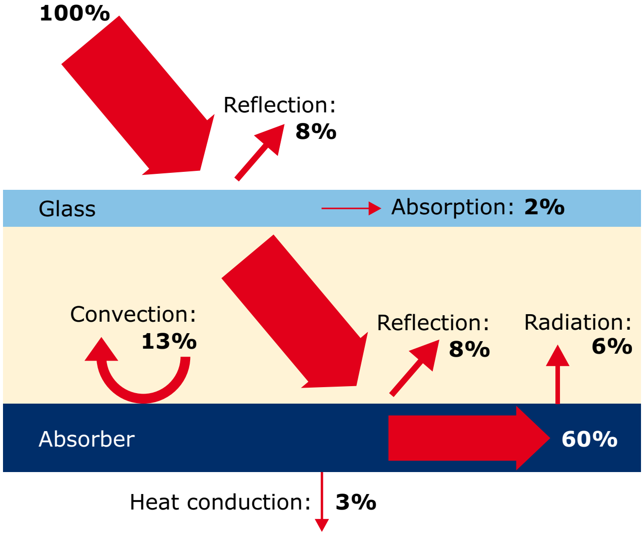


Fig. 1 Main losses of a basic flat-plate collector during angular operation (based on [2])

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.

2.1.1.1 Optical losses

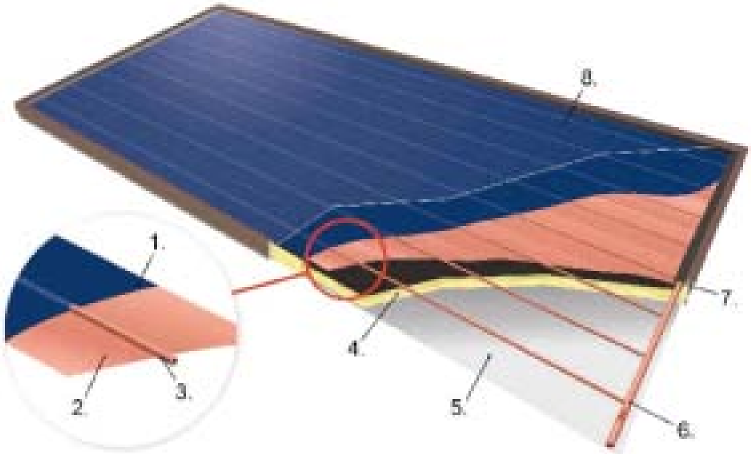
High quality covers of low-iron solar glass have a transmission of 90% for solar radiation (normal irradiation). If an anti-reflective coating is used the transmission can be increased to 93 - 96%. Usually about 1 - 2% is absorbed in the glass plane and the rest is lost due to reflection. The coating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

2.1.1.2 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.

2.1.2 Description of the Construction Principle

Fig. 2 *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:

2.1.2.1 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.

2.1.2.2 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.

2.1.2.3 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.

2.1.2.4 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.

2.1.3 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.

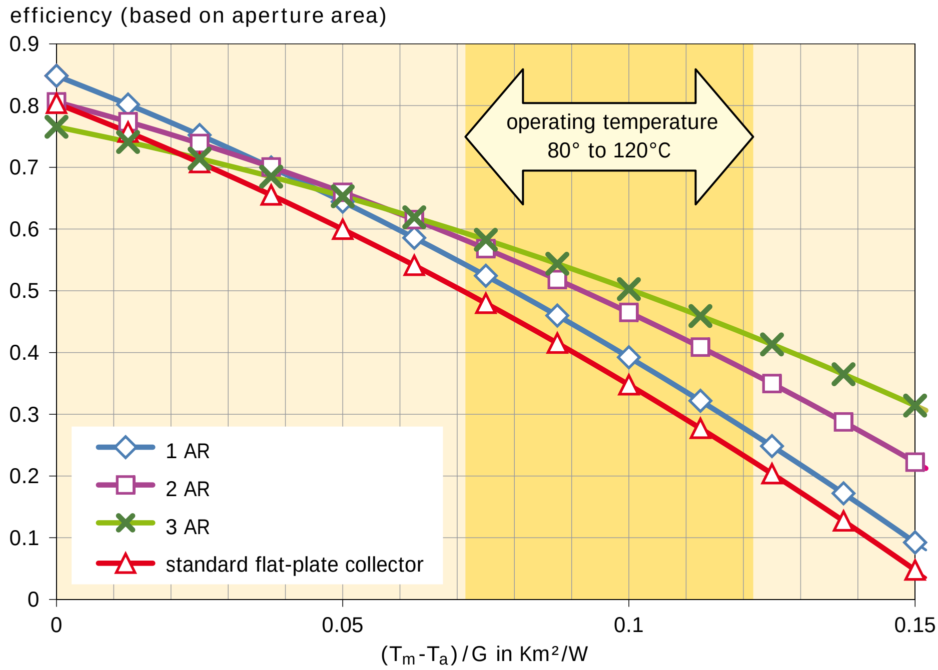


Fig. 3 Efficiency curves of a single, double and triple glazed AR collector in comparison with a standard flat-plate collector with normal solar glass [1]

As illustrated above, there is great potential for improvement in flat-plate collectors if the standard solar glass is replaced by AR-glass. This improvement is independent of the operating temperature (see comparison of standard flat-plate collector to 1AR collector in **Figure 3**.).
It is also interesting to note that with respect to the double glazing, the 2AR collector reaches the same η_0-value as the standard flat-plate collector. Therefore, the complete efficiency curve of the 2AR-collector is above the standard flat-plate collector. For higher operating temperatures the advantage of 2AR collectors is especially promising. At $\Delta T/G=0.1$ (K m²)/W the efficiency of the 2AR collector in **Figure 3** is better than the standard flat-plate collector by more than 33% (relative).
These results on the estimated efficiency curves have been verified by experiments and measured efficiency curves by Fraunhofer ISE.
Double glazed flat-plate collectors with inert gas filling (SCHÜCO) as well as vacuum flat-plate collectors (Thermosolar) are already available on the market.

2.1.4 Applications

In general, for all applications needing solar process heat at levels up to 120°C, advanced flat plate collectors have economical benefits compared to concentrating solar systems. This is especially the case for climates with a high proportion of diffuse radiation. Suitable processes are:

Process	Temperature [°C]
Drying	30 - 90
Washing	40 - 80
Cooking	95 - 105
Thermal treatment	40 - 60

Because the basic construction of a standard flat-plate collector can often be used for advanced flat-plate collectors they can be produced at reasonable costs. This also makes them predestined for solar air conditioning and for solar cooling applications. Single effect absorption chillers (optimum temperature around 100°C) as well as adsorption chillers could be equipped with advanced flat-plate collectors **[3]**. However, the obtainable temperatures are too low for their use in double effect absorption chillers.

2.1.5 References

[1] Rommel, Matthias: *Medium Temperature Collectors for Solar Process Heat up to 250°C*. Estec 2005

[2] Wagner & Co. (Hrsg.): *So baue ich eine Solaranlage. Technik, Planung und Montage.* Cölbe: Wagner & Co Solartechnik GmbH, 1995

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2.2 Evacuated Tube Collectors

By **Stefan Heß** and **Matthias Rommel**, Fraunhofer ISE, Germany

2.2.1 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.

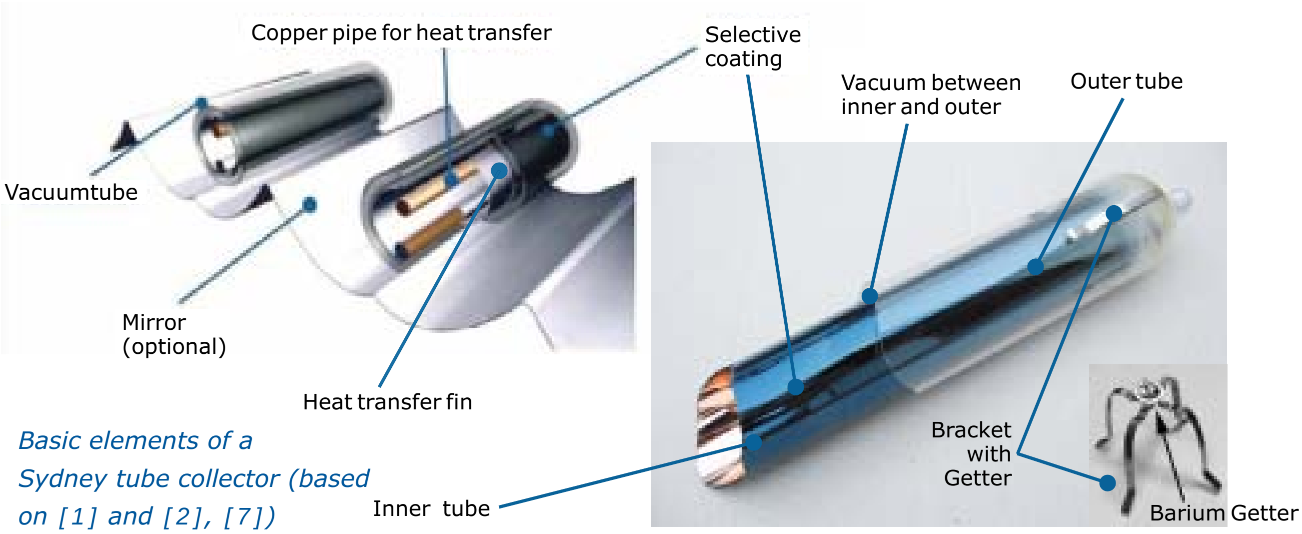

Fig. 4 *Basic elements of a Sydney tube collector (based on [1] and [2], [7])*

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**).

Fig. 5 *Error-Indication based on [1], [7]*

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.

2.2.1.1 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.

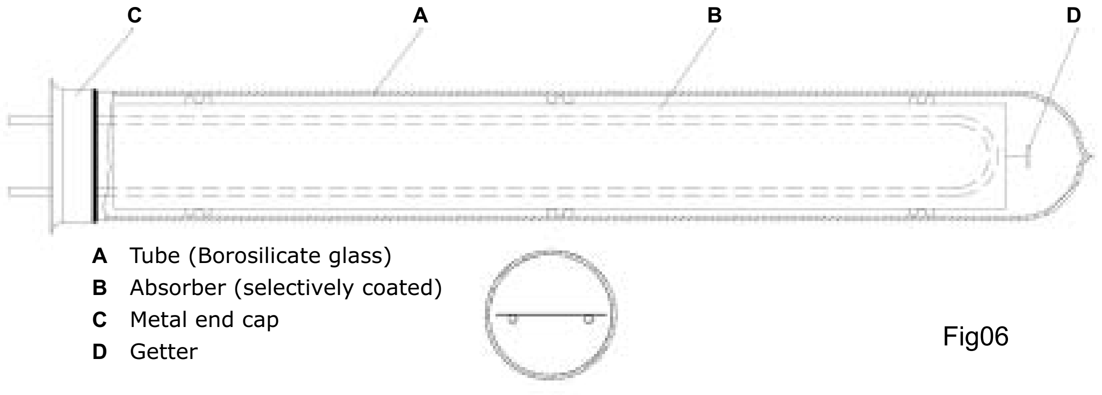

Fig. 6: Sectional drawing of a direct flow pipe with flat absorber and u-tube (based on [3])

The tubes are divided by configuration of the fluid pipes. The traditional type is a collector with **separated tubes for fluid inlet and fluid outlet** (indicated in **Figure 6**).
Besides this type, collectors with **concentric inlet and outlet pipes** are also manufactured (see **Figure 7**). This means, that only the fluid outlet pipe is connected to the absorber. The pipe for fluid inlet is located inside the outlet pipe. The fluid flows back between the outer surface of the inner pipe and the inner surface of the outer pipe. The advantage of this construction is rotational symmetry. This offers the possibility to optionally orientate the absorber by rotating the whole tube. In this way, any desired tilt angle can be achieved even if the collector is mounted horizontally. The efficiency of direct-flow single glass tubes is quite high, but they require a good glass to metal seal that withstands the different heat expansion rates of those materials.

A new type of concentric pipe configuration is the **Lenz tube** shown in **Figure 7**. The pipe for the fluid inlet is copper and the outlet pipe is glass. In addition to the rotational symmetry, no connection between glass and metal is needed to maintain the vacuum. The absorber is jammed to the outlet pipe. A graphite film between absorber and outlet pipe improves the heat transfer.
Currently the most common type is the **Sydney tube collector** shown in **Figure 4**. It consists of two glass tubes fused together. The vacuum is located between the two tubes. The outside of the inner tube is usually coated with a sputtered cylindrical selective absorber (Al-N/Al). Inside of the inner pipe, the heat is removed by copper u-tubes, which are embedded in a cylindrical (aluminium) heat transfer fin.

Because the absorber is applied completely around the tube, often a (CPC-) reflector is placed under the tube to also use the radiation that passes between the parallel mounted tubes. This radiation is reflected to the absorber. There is no permanent connection between thermos flask tube and the heat conductor or the header of the collector. This means that tubes damaged due to exceptional reasons can easily be replaced.

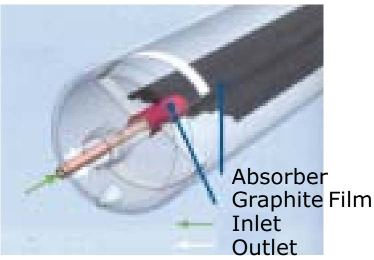

Fig. 7: Function and design of the Lenz tube [4]

2.2.1.2 Heat Pipe Evacuated Tube Collectors

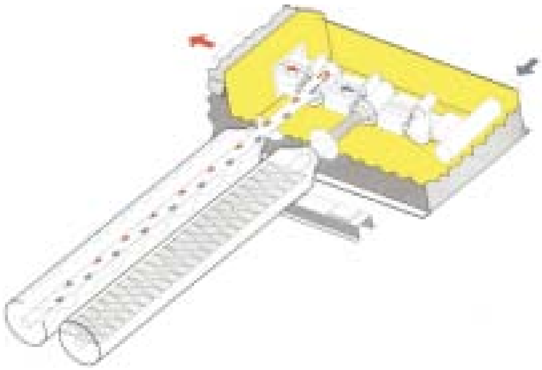

Fig. 8: Principle of a heat pipe [5]

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 flown 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.
A heat pipe is hollow with low pressure inside. The objective is not to insulate, but rather to alter the state of the liquid inside. Inside the heat pipe is a small quantity of purified water and some special additives. When the heat pipe is heated above an adjustable temperature the water vaporizes. This vapour rapidly rises to the top of the heat pipe (condenser) transferring heat. As the heat is transferred to the condenser, the vapour condenses to form a liquid and returns to the bottom of the heat pipe to once again repeat the process. The condenser has a much larger diameter than the shaft to provide a large surface over which heat can be transferred to the header. To ensure circulation, a heat pipe collector has to be tilted at a minimum angle of operation (about 20°). The quality of the heat transport also can be seriously affected if the heat pipe contains too much condensable gasses. They can form a pocket of air in the top of the heat pipe. This has the effect of moving the heat pipe's hottest point downward away from the condenser.
Frost protection is an issue for both types of collector. Outdoor temperatures lower than -10°C over a long period of time can cause freezing. To avoid this, a water/glycol mixture with anti-corrosion additives is used in the solar loop for frost protection.
The heat pipe principle offers the theoretical possibility to avoid stagnation due to the restricted maximum temperature that the heat pipe can reach. Depending on the fluid and pressure used there is a temperature at which all the fluid within the heat pipe is vaporized and inside the condenser. In this case, the fluid is less effective in heat transportation. Because of that the temperature of the solar loop should be kept under the disruption temperature of the used glycol, which means working temperatures below 170°C. The reliable handling of this effect sensitively depends on the right amount of fluid and the right pressure inside of the heat pipe. Another approach to avoid stagnation is to use a memory metal to separate the fluid inside the heat pipe from the condenser if a certain temperature is reached.
In direct flow vacuum collectors the stagnation temperature can reach 300°C so the glycol and the components of the solar loop have to be protected separately.

2.2.2 Current Stage of Development

Evacuated tubes have been used for years in Germany. In 2006, the main markets were China followed by Germany, the UK, Italy and Australia **[8]**. Because of the increasing quantity of vacuum tubes and improvements in the reflectors for solar thermal applications, vacuum collectors are becoming less expensive.

2.2.3 Applications

Currently vacuum tube collectors are a standard component of solar thermal systems working at higher temperatures. They can also be used instead of a standard flat-plate collectors to decrease the necessary collector area.

2.2.4 References

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[4] Röhrentypen im Überblick. Sonne Wind & Wärme 08/2006, S 46

[5] http://www.bbs2.de/solaranlage/anlage/bilder/rk_gross.html

[6] http://www.schott.com/solarthermal/german/products/collector/collector_tube/index.html

[7] http://www.solar-water-heater.com/product/trendsetter/basics.htm

[8] Weiss, W., Bergmann, I., Solar Heat Worldwide 2006, Gleisdorf 2008

2.3 CPC Collectors

By **Manuel Collares Pereira** (AO SOL, Portugal) and **Stefan Heß** (Fraunhofer ISE, Germany)

CPC collectors use a CPC (Compound Parabolic Concentrator) to concentrate solar radiation on an absorber. Because they are not focussing (non-imaging), they are a natural candidate to bridge the gap between the lower temperature solar application field of flat-plate collectors (T < 80°C) to the much higher temperature applications field of focussing concentrators (T > 200°C). **Flat-plate collectors** have an enormous advantage over other collector types because they collect radiation coming from all directions, and therefore, they can be stationary on any given roof and all of the diffuse radiation is available to them. However, they also have the highest heat losses since they are proportional to the very large absorber area they possess. Because of these heat losses, the efficiency of flat-plate collectors at higher working temperatures of the solar loop is decreasing. **Solar concentrators of the imaging focusing type** have a small absorber area and therefore smaller heat losses. They provide high efficiency at high working temperatures. On the other hand, they have the disadvantage of having a smaller angle of view, and therefore, require a tracking system and can not collect most of the diffuse radiation.
Collectors with CPCs can be designed so that they concentrate solar radiation by 1 - 2 factors and at the same time accept most of the diffuse radiation. Furthermore, these concentrators can be stationary or only need seasonal tilt adjustments. CPCs for process heat applications are line-concentrators with trough reflectors of different cross sectional shapes.

2.3.1 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.

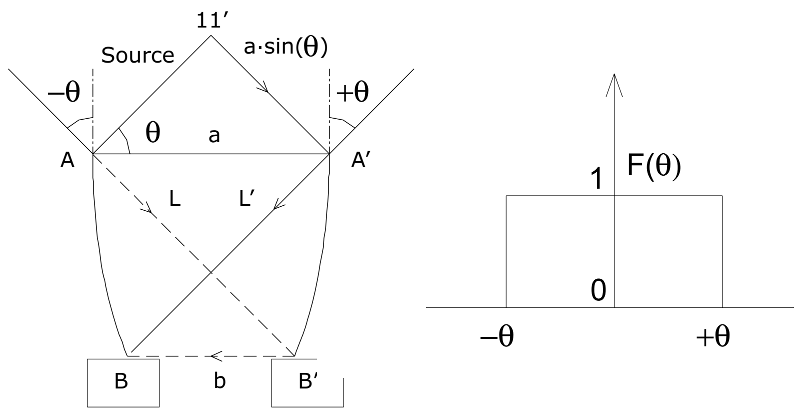

Fig. 9 Aperture (left): CPC concentrator in 2D for a flat absorber parallel to a flat entrance aperture (right): Acceptance angle function of a 2D-CPC of an half acceptance angle Θ

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

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

In **Figure 9 (left)** the aperture "a" is defined by points A and A′ and the aperture "b" by points B and B′. There is an axis of symmetry and the angle Θ is the angle that the lines AB′ and A′B make with this axis. Radiation is isotropically incident on "a" between (+Θ) to (-Θ). Mirrors formed by par-

abolic arcs with foci respectively in points B and B′ extend from A to B and from A′ to B′. The centerlines of the parabolas are pointing at the directions (+Θ) and (-Θ). The optical signature—the acceptance angle function—of a full, ideal CPC is shown in **Figure 9 (right)** for a 2D case: all radiation within the acceptance angular range is collected and all other is rejected.
However, CPC collectors are usually truncated **[1]** since the upper part of the mirrors contribute little to the overall concentration. Reduced manufacturing costs due to saved reflector material favour this option. For a truncated CPC, the acceptance angle function extends to the angle Θ_t since some of the rays previously rejected can now directly hit the absorber. It should be noted that the geometrical concentration is no longer C_{max} because the entrance aperture "a" becomes smaller while "b" keeps its width.

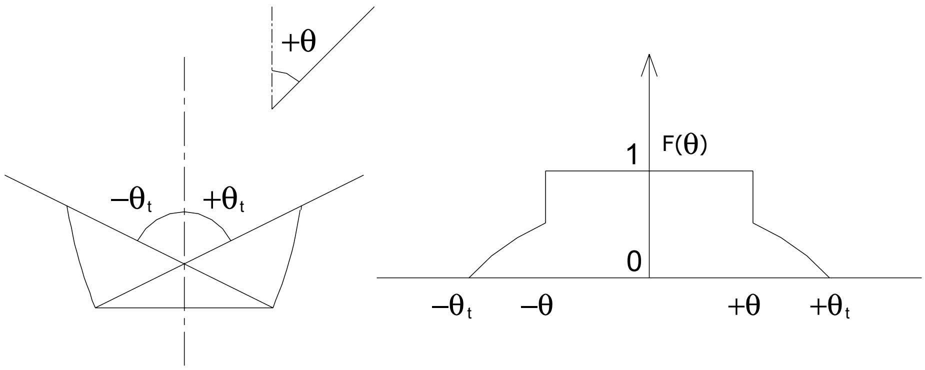

Fig. 10 (left): Comparison between full (dotted) and truncated CPC (right): Acceptance angle function of a truncated CPC with an acceptance angle Θ_t

The acceptance angle function implies that, unless the half acceptance angle is very large, the collector must be oriented from east to west. That means that the axis of cylindrical symmetry should run parallel to the east-west direction.

2.3.2 Most Suitable Application and Current Stage of Development

There are two main domains of application for the CPC-concept:

- large acceptance angle devices (low concentration);
- small acceptance angle devices (high concentration).

2.3.2.1 Low Concentration

Non-Evacuated Collectors

Low concentration is what should be used if a stationary collector (similar to a flat-plate collector) is to be developed. In fact, it can be shown that a true stationary collector requires $C_{max} < 2$ with resulting half acceptance angles of $\Theta > 30°$ **[2]**. In practice, even lower values of C are preferred. This is mainly related to two facts: the main market for solar collectors has been for domestic hot water heating where relatively low temperatures are required. And, particularly in Southern Europe, there is widespread use of thermosyphon systems which require collector orientation in a north-south direction creating a very large value for the angle Θ if a CPC is applied.

The collector shown in **Figure 11** is a specific case where the absorber is no longer flat as in **Figures 9** and **10**, but has a triangular shape. With its low value of concentration and the use of a selective absorber, the collector shown in **Figure 11** behaves like a very good flat-plate collector and achieves high performance.
If the concentration factor is increased and other means to control heat losses are added, the resulting collectors have a distinct lower heat loss factor, approaching that of evacuated tube collec-

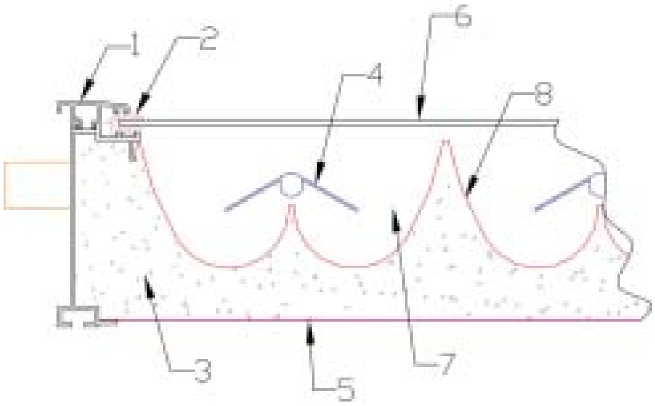

Fig. 11: Cross section of a non-evacuated CPC collector with C = 1,15 [3]

tors **[2]**. **Figure 12(a)** shows a collector with a higher concentration factor. Convection losses of the collector can be reduced, for example, by using transparent insulation materials (TIM) as shown in **Figure 12(b)**. This type of collector is expected to perform very well in promising solar applications, such as absorption cooling, desalination and industrial processes because it can deliver heat around and above 100°C. Non-evacuated CPC collectors can be manufactured at the cost of good conventional flat-plate collectors, can be mounted and used like flat-plate collectors, and demonstrate the same high level of durability.

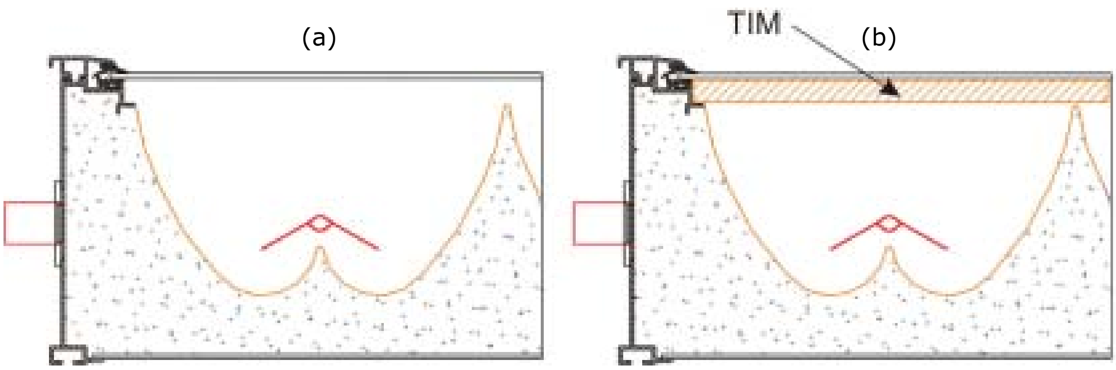

Fig. 12 (a): Cross section of a CPC with C = 1.5
(b): Collector of (a) with transparent insulation material

At the time of this report, the projects MEDESOL **[4]**, POWERSOL **[5]** and PRIME-IDEA **[6]** are under way to take non-evacuated CPC stationary collectors to the limit of their performance. They are expected to deliver useful heat with efficiencies no lower than 50% at temperatures up to 160°C. It is certainly possible to achieve this if stationary is relaxed to quasi-stationary, if two or three tilts per year would be acceptable, and concentration is allowed to take values around 3 or even higher. This is also being studied in ongoing projects.

Evacuated Tubes with CPC reflector

As shown in the **Chapter 2.2 (Evacuated Tube Collectors)**, reflectors of the CPC type are often applied behind vacuum tubes. In this case, the reflectors often take the shape of a partial involute. Evacuated tubes with CPC reflector typically show a concentration ratio of $C < 1$, since the sum of the tubular or fin perimeters is larger than the entrance aperture.

In the U.S. during the 1970s and 1980s, several evacuated tube collectors with CPC reflectors were proposed reducing by a factor of at least $C*\pi$ the number of tubes per entrance aperture area **[2]**. Today, with the better tubes and reflector materials able to withstand direct exposure to the environment perhaps this concept will be revisited as it will certainly allow delivery of energy between 150ºC and 200ºC with a fully stationary collector.

2.3.2.2 High Concentration

CPC collectors, even with modest concentration ratios around C = 20, would be hopelessly tall and therefore totally impractical. By comparison, focussing concentrators are quite compact. Nevertheless, CPC concentrators can be very useful for high concentrating collectors. Because focussing collectors like parabolic troughs are so far from the limit in concentration for their acceptance angle, it is possible to recover almost all of the difference by using second-stage concentrators which are of the ideal Non-Imaging Optics type **[7, 8, 9]**.
Some collectors on the market today use this concept **[10]**, where a second-stage CPC type concentrator further concentrates the radiation emerging from a linear primary concentrator of the Fresnel type (see **chapter on Fresnel collectors** within this booklet).

2.3.3 References

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[5] Project acronym "POWERSOL". Project full title: *"Mechanical Power Generation Based on Solar Heat Engines"*. Supported by the European Commission. Contract Nº 032344

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[7] J. M. Gordon, Harald Ries: *Tailored Edge-ray Concentrators as Ideal Second Stages for Fresnel Reflectors*, Vol. 32, Nº 13, APPLIED OPTICS 1993

[9] Welford, W. T., and Winston, R., 1989, *High Collection Nonimaging Optics*, Academic, New York.

[10] www.pse.de (Market surveys: Andreas Häberle)

2.4 Parabolic Trough Collectors

By **Dagmar Jaehnig** (AEE INTEC, Austria) and **Esther Rojas Bravo** (CIEMAT, Spain)

Parabolic trough collectors concentrate the sunlight before it strikes the absorber. Mirrored surfaces curved in a parabolic shape linearly extended into a trough shape focus sunlight on an absorber tube running the length of the trough. A heat transfer fluid is pumped through the absorber tube of the collector where the solar flux is transformed to heat.

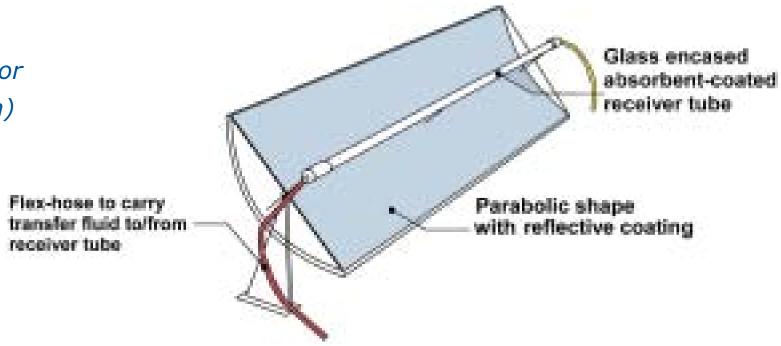


Fig. 13: Sketch of a parabolic trough collector (picture source: AEE INTEC, Austria)

Parabolic troughs are collectors designed to reach temperatures over 100ºC and up to 450ºC 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]**.

2.4.1 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]**.

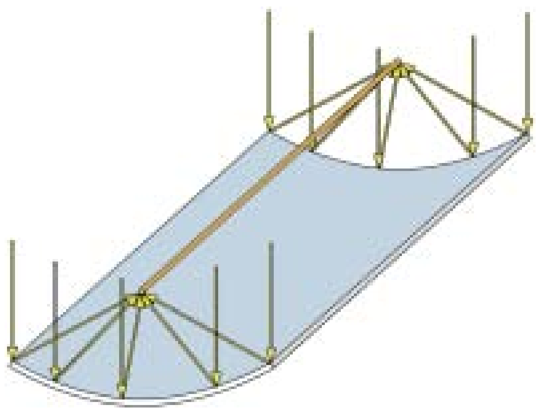


Fig. 14: Parallel sun rays being concentrated onto the focal line of the collector (picture source: AEE INTEC, Austria)

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.

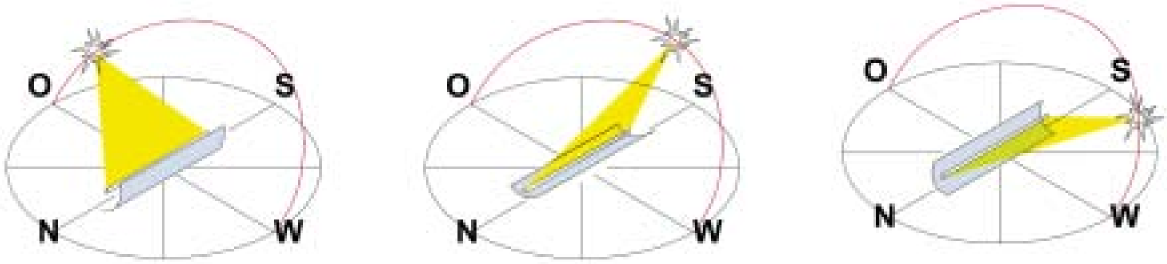


Fig. 15: Tracking of the sun by a parabolic trough collector with the collector axis oriented north-south (picture source: AEE INTEC, Austria)

2.4.2 Description of the Construction Principle

A substructure—made out of metal profiles and/or curved glass—maintains the parabolic shape of the reflecting surface. The reflecting surface is often an aluminium sheet or a reflective coating applied directly to the curved glass section forming the parabola.
The receiver consists of an absorber tube positioned in the focal line of the parabolic trough. The absorber has a black (non-selective) or a selective coating in order to absorb as much solar radiation as possible. The metal tube (steel, stainless steel or other metals), where the heat transfer fluid flows, may be designed to act also as an absorber.
If it is not designed to be an absorber, the absorber is usually a glass tube inside which a U-shaped metal tube is placed, with both fluid inlet and outlet on the same side (similar to evacuated tube collectors as shown in **Chapter 2.2.1., Figure 4**). In other collector designs, the fluid inlet is on one side of the absorber and the outlet on the other side or a concentric pipe is used with both inlet and outlet on the same side.
In most designs, a transparent glass tube (in some cases evacuated) envelops the receiver tube to reduce heat losses. The exact design of the receiver depends on the concentration ratio and the target operating temperature of the collector. Concentration ratios, as previously defined, of parabolic troughs developed and used for collectors range from 10 to 26, and temperatures range up to 400°C. Some of the small parabolic trough collectors (up to 1.5 m aperture width) have an additional glass pane that covers the entire aperture area. This gives stability to the construction of the parabolic shape and prevents the reflecting surface from becoming dirty, but has the disadvantage of additional transmission losses.

2.4.3 Energy Balance

The so-called optical efficiency of parabolic trough collectors (efficiency if the operating temperature is equal to the ambient temperature) is always lower than that of flat-plate or evacuated tube collectors. The reason for this is that the shape of the parabola can never be perfect (due to manufacturing tolerances) and that the reflectivity of the mirrors is always less than 100%. On that score, parabolic trough collectors have a disadvantage compared to flat-plate or evacuated tube collectors at low temperatures. However, their advantage is that heat losses are reduced because of the small surface of the receiver. This advantage becomes predominant if the collector is operated at temperatures higher than approximately 100°C.

2.4.4 Most Suitable Applications

With the 354 MW_e of the SEGS plants in California, the best known application of parabolic trough collectors is for power generation **[2]**.

For these systems, troughs of roughly 6 m aperture width have been used to heat thermal oil up to 400°C. This heat is then used to generate steam for a steam turbine to generate electricity. The concentration ratio of these collectors is around 26.

Fig. 16: 180 m² aperture area of parabolic trough collectors at a hotel in Turkey (picture source: SOLITEM, Germany)

Smaller parabolic troughs, with concentration ratios between 10 and 15, can operate at temperatures between 100°C and 250°C. The aperture width of these small troughs ranges from 50 cm to 2.3 m. The advantage of these small troughs is that they are relatively lightweight and easier to handle. Some of them can even be installed on roofs.

Due to the concentrating nature of parabolic trough collectors, they are best applied in climates that have a high share of direct solar radiation. However in moderate climates, such as in Central Europe, parabolic trough collectors have the same advantage over flat-plate or evacuated tube collectors as in sunnier climates if operating temperatures are roughly above 130°C. At lower temperatures and because they cannot use the diffuse solar radiation, the overall solar energy yield is still smaller than that of an evacuated tube collector. As always, careful system design that takes into account the correct operating temperatures, load characteristics and reliable climate data is important.

Fig. 17: 860 m² of small parabolic trough collectors installed at SOLEL headquarters in Beith Shemesh, Israel (picture source: SOLEL, Israel)

Parabolic troughs can be operated in a pressurised circuit where the heat transfer medium does not evaporate in the collector field (indirect mode). They also can be operated in a direct steam generating mode. In the indirect mode, typical heat transfer media are thermal oil or water. In the direct steam generation mode, water is the best solution in regions where there is no danger of freezing. Alternative heat transfer media that provide freeze protection are currently under investigation.

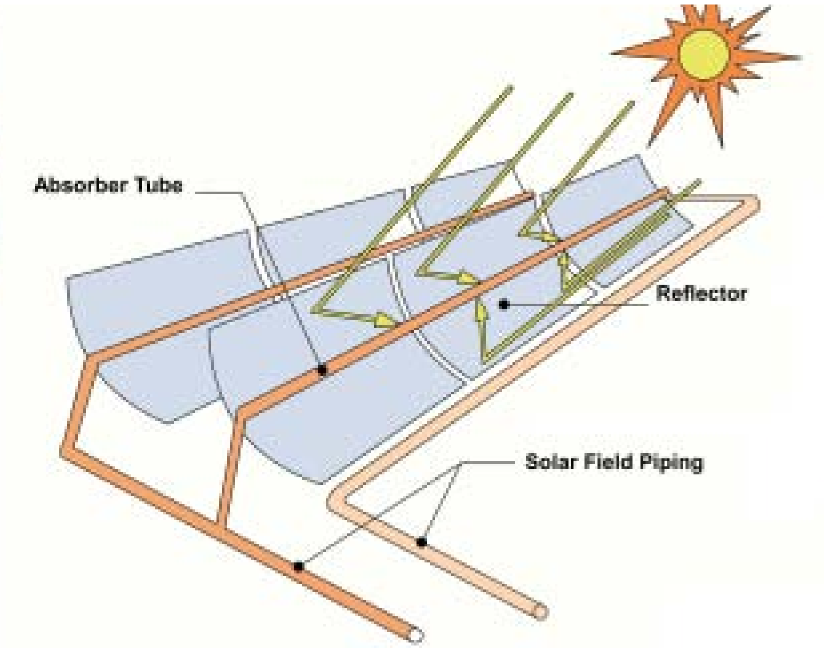


Fig. 18: Troughs can be connected in series and/or in parallel to form a larger collector array (picture source: AEE INTEC, Austria and CIEMAT, Spain)

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]**.

2.4.5 Current Stage of Development

A few large parabolic troughs designs for electricity generation have been kept on the market for many years because all the solar power plants have been on working since their opening. Small parabolic troughs were mainly developed in recent years. Most of them have been developed for a specific installation and were deserted when the installation itself was closed **[6]**. A limited number of collectors have remained on the market and a few systems demonstrating the possibilities of this type of collector are in operation.
In order to enlarge the solar thermal market to the temperature range that is characteristic for small parabolic troughs, several small-scale parabolic trough designs are currently under development. One collector from the German company SOLITEM is now on the market. For all other small parabolic trough collectors the first test results of prototype collectors are available, but they are not yet ready to enter the market. Some of them are described in more detail in this booklet (see **Chapters 3.8 to 3.12**).

2.4.6 References

[1] Henning H-M (Ed.), IEA *'Solar-Assisted Air-Conditioning in Buildings Task 25, A Handbook for Planners'*. Austria. Springer-Verlag/Wien, 2004

[2] http://www.nrel.gov/csp/troughnet/power_plant_data.html, 2007

[3] Kreith, F.; Kreider, J.F. *'Principles of Solar Engineering'* McGraw-Hill Co, 1978

[4] Rabl, A. *'Active Solar Collectors and their Applications'*. Oxford University Press, 1985

[5] Schweiger, H. et al. *'The Potential of Solar Heat in Industrial Processes. A State of the Art Review for Spain and Portugal'*. EuroSun 2000, June 2000

[6] Stine, W.B., *'Solar Industrial Process Heat Project: Final Report'*, SAND89-1968, 1989

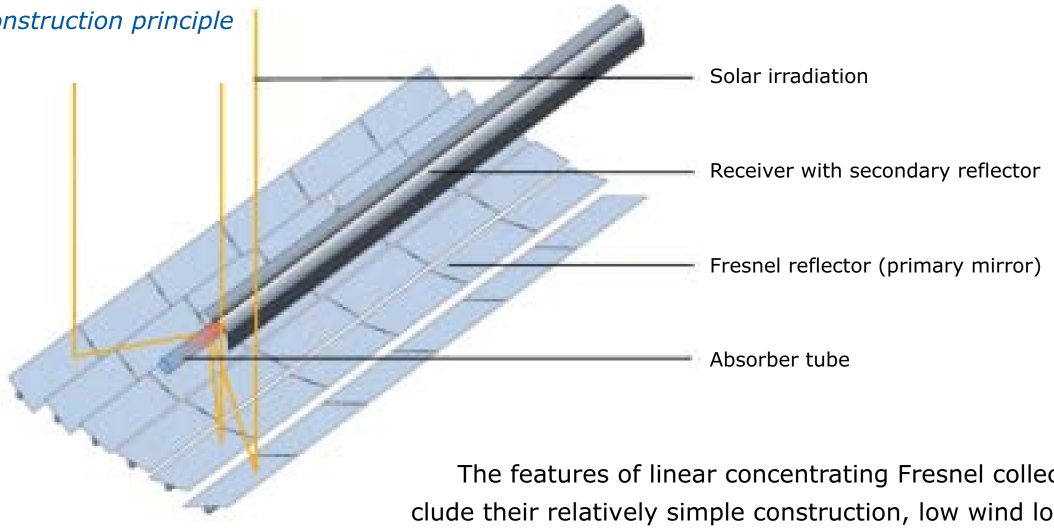
2.5 Linear Concentrating Fresnel Collectors

By **Andreas Häberle**, PSE GmbH, Germany

2.5.1 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**).

Fig. 19: Construction principle

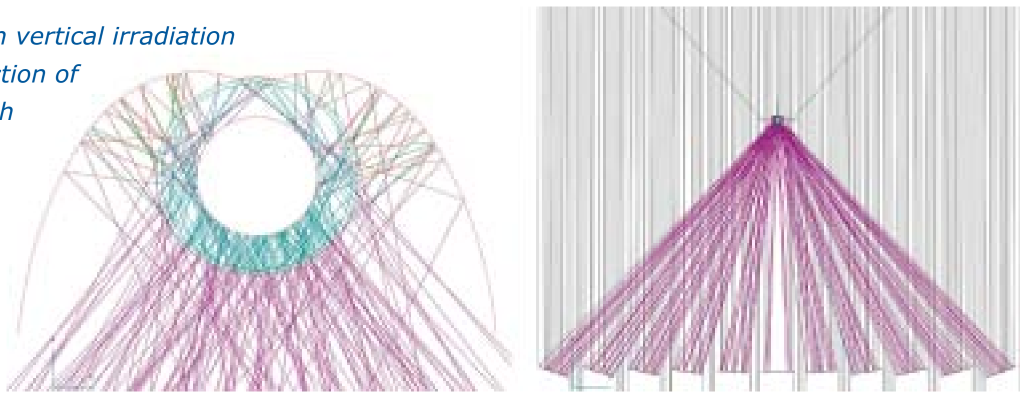


The features of linear concentrating Fresnel collectors include their relatively simple construction, low wind loads, a stationary receiver and a high ground usage. Some applications allow for the use of the shaded area underneath the collector (e. g., as parking lots).

2.5.2 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.

Fig. 20: 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).

Due to the optical concentration, the operating temperature can be as high as 400°C. It is mainly limited by material constraints of the receiver (e. g., the absorber coating). Up to around 200°C pressurised water can be used as the heat carrier. Thermal oil is used for higher operation temperatures. An interesting option is the direct generation of steam in the collector.

2.5.3 Most Suitable Application

Linear Fresnel collectors were developed for large-scale solar thermal power generation that results in thermal capacities of at least several tens and up to many hundreds of MW. Such plants are typically planned for remote areas.
When scaled down, the linear Fresnel collector meets the special boundary conditions for the generation of industrial process heat:

- The collector can be used for processes starting with a thermal capacity of around 50 kW and up to several MW.
- The collector is easy to mount on flat roofs as a result of good weight distribution and low wind resistance. It also allows very high surface coverage so that the heat can be produced close to where it is needed and to where space is not so freely available.

2.5.4 Current Stage of Development

Several industrial groups are commercially offering linear concentrating Fresnel collectors and are developing projects for solar thermal power generation.
The German company PSE AG offers a linear concentrating Fresnel collector for industrial process heat applications, which is ideally suited for rooftop installations. At this time, three systems have been installed. A prototype in Freiburg, Germany that is being used for detailed performance measurements. A second system in Bergamo, Italy that is powering a NH_3/H_2O absorption chiller (see **Figure 21**). And the latest installation, a 176 kW_p (352 m²) collector installed on a roof at the University of Seville to power a double effect H_2O/LiBr chiller. Further projects are currently being developed.

Fig. 21: PSE linear concentrating Fresnel collector in Bergamo, Italy. A demonstration system for solar cooling.

2.5.5 References

[1] Häberle et al.: *Experience with linear concentrating Fresnel collectors for process heat applications*, Solar Paces, 14th International Symposium on Concentrating Solar Power and Chemical Energy Technologies, Las Vegas, U.S.A., March 4 - 7, 2008

[2] Häberle et al.: *Linear concentrating Fresnel collector for process heat applications*, 3rd European Solar Thermal Conference—estec2007, Freiburg, Germany, June 19 - 20, 2007

2.6 Concentrating Collectors with Stationary Reflector

By **Victor Martinez Moll**, Universitat de les Illes Balears, Spain

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**).

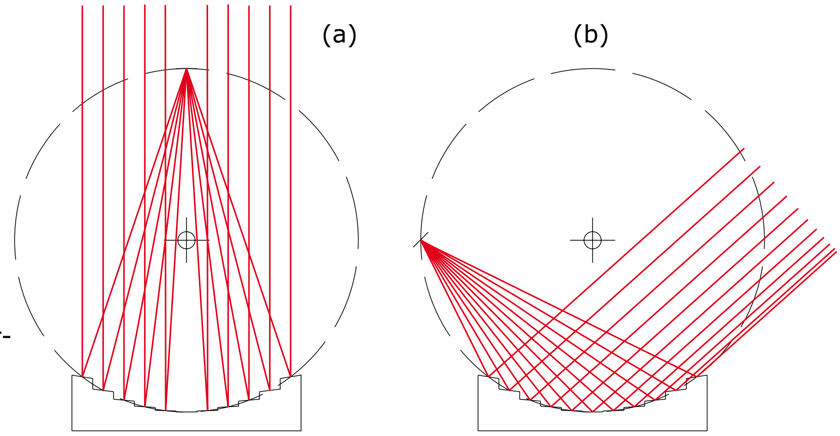


Fig. 22 (a), (b): Operation principle

2.6.1 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 $\Theta_r = 2\ \Theta_t$, where Θ_t is the projected transversal angle of the sun direction at any given time (**Figure 23b**).

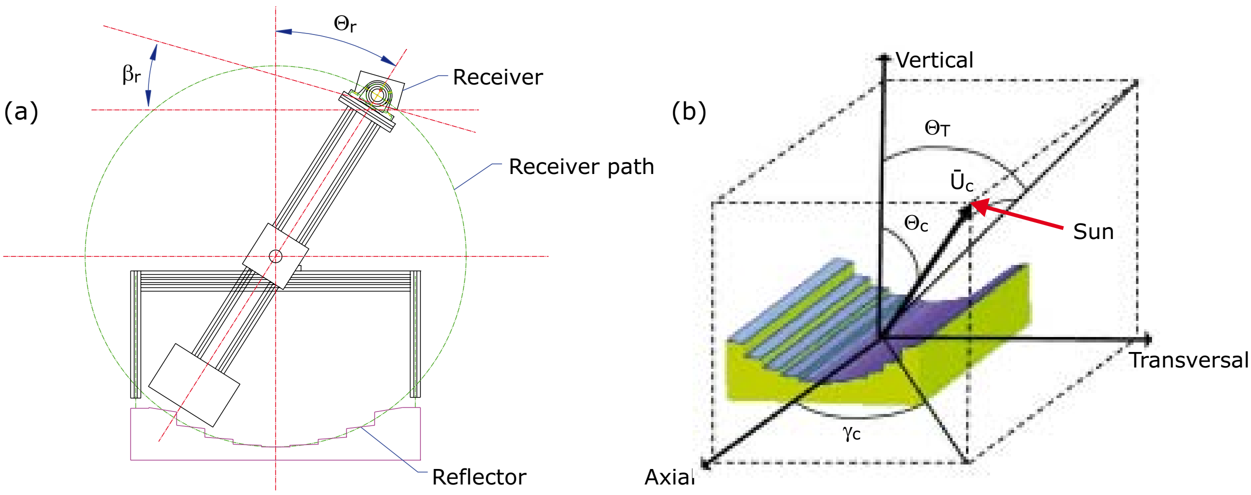


Fig. 23 (a), (b): Basic implementation

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_t) 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**).

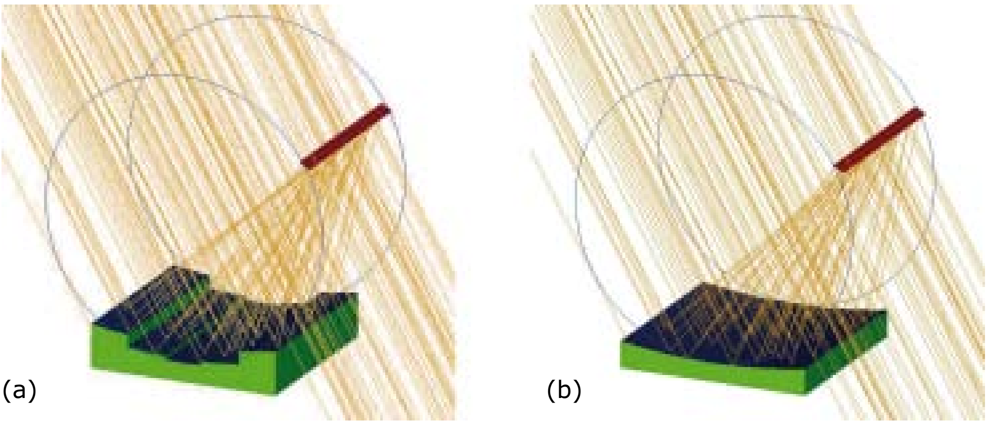


Fig. 24 *(a), (b): Curved reflectors*

2.6.2 Operating Principle

Like parabolic trough collectors, the CCStaR collector concentrates direct solar radiation in order to increase the working temperature of the heat transport fluid. Although theoretically it is possible to reach concentrations of 40 to 50 suns, the averaged optical efficiency in this range of concentration ratios falls to about 60%, and is only achievable with flat mirrors. (Therefore, the specific current development described in this booklet aims at about 15 suns. The envisaged working temperature range is from 80°C to 140°C. According to current estimations the average annual efficiency at 120°C would be between 40% to 50% referred to direct incident radiation for a latitude of 39°. The evaluation of the efficiency was done assuming a horizontal placement of the reflector). It should be noted that for CCStaR collectors there is a strong dependency of efficiency and concentration factor on the angle of incidence as can be seen in **Figure 25**: The normalized concentration factor for several geometric concentration factors is shown against the transversal incidence angle (normalized value is obtained as the ratio between the average radiation concentration and the geometric concentration ratio of the receiver).
Therefore, the optical efficiency is not an almost constant parameter as is the case for parabolic trough collectors. And thus, efficiency should be evaluated not only for a certain given location, but also for a certain given orientation of the collector. For example, placing the specific collector described in this booklet on a south facing roof with a slope of 15° could improve the efficiency of the collector more than a 10% during winter months.

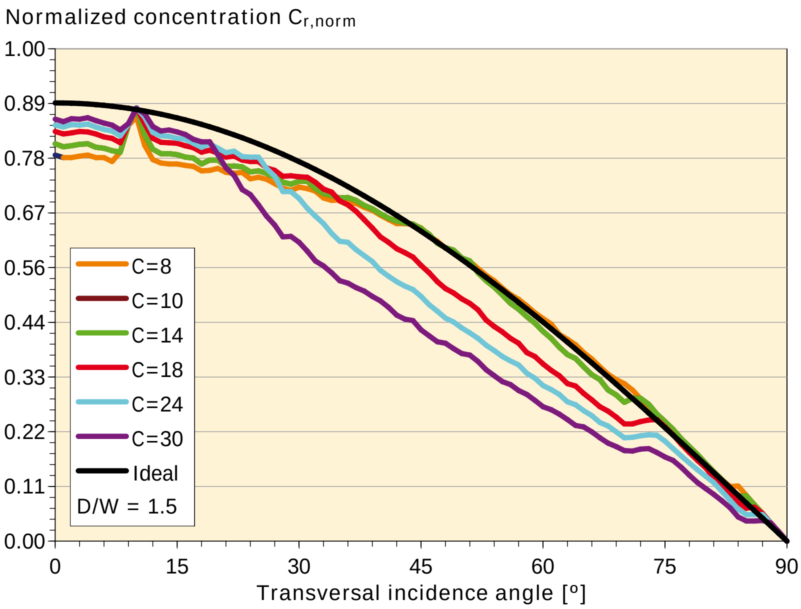


Fig. 25: *Normalized concentration factor*

2.6.3 Most Suitable Application

As already stated, the envisioned working temperature range for the current CCStaR development is between 80°C and 140°C. Therefore it would have a broad range of industrial applications, mainly in the food industry (pasteurizing, boiling, sterilizing), textile (bleaching, dyeing) and also in a variety of processes in the chemical industry. Another interesting application is solar cooling and air conditioning because the operation range of the collector allows its use in both single and double-effect absorption machines.

2.6.4 Current Stage of Development

Only two implementations of the CCStaR concept are known up to now. The first one was carried out by the General Atomic Company in the U.S. during the 1970s. In this case, prototype collectors were built and tested at the Sandia National Laboratories **[3]**. This first development aimed at the production of electricity in large plants **[1]**, but was stopped in the middle of the 1970s **[4]**. In 2004, a small prototype was built at the University of the Balearic Islands to validate the theoretical models used in the analysis of the reflector geometry [5, 6]. In 2006, a new company called Tecnologia Solar Concentradora (TSC) was founded to develop a new implementation of the CCStaR concept.
For further information see the specific collector description in this booklet (**chapter 3.14**).

2.6.5 References

2.6.5.1 References for the First Development

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[2] Ravinder Kumar Bansal. *Theoretical Analysis of Fixed Mirror Solar Concentrator.* A thesis presented in partial fulfillment of the requirements for a Master of Science in Engineering. Arizona State University, May 1974

[3] Russell, J. L, Jr. *Principles of the Fixed Mirror Concentrator.* General Atomic Company. San Diego, California. SPIE Vol. 85 Optics in Solar Energy Utilization, 1976

[4] Russell, J.L. Jr.; Schuster, J.R.; Eggers, G.H. *Development Status of the Fixed Mirror Solar Concentrator.* Proceedings of the 12th Intersociety Energy Conversion Engineering Conference. 1141-1146, 1977

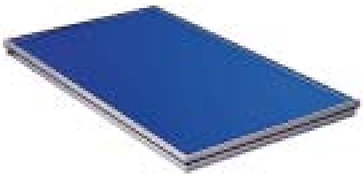
2.6.5.2 References for the New Development

[5] Martínez Moll, V.; Pujol Nadal, R.; Moià Pol, A. i Schweiger, H.; *Analysis of a Stationary Parabolic Linear Concentrator with Tracking Absorber;* 13th SolarPACES Symposium, Seville (Spain); 2006

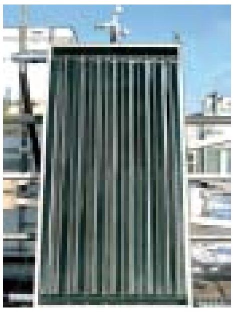
[6] Pujol, R.; Martínez, V.; Moià, A. i Schweiger, H.; *Analysis of a Stationary Fresnel Like Linear Concentrator with Tracking Absorber;* 13th SolarPACES Symposium, Seville (Spain); 2006

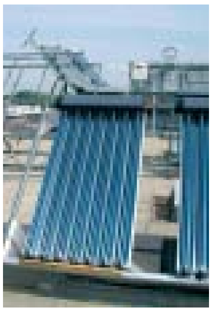
3 Overview Collector Developments

The following table gives an overview of the process heat collector developments, the working temperature and the heat transfer medium for each collector and the Task 33/IV contact person.

Advanced Flat-Plate Collectors	Collector Type Operating Temperature [°C] Heat Transfer Medium	Task 33 / IV Contact Person
	ökoTech Gluatmugl HT A large-area double-covered flat-plate collector 80 - 120 Water-Glykol	Philip Ohnewein S.O.L.I.D. Solarinstallation und Design mbH Puchstraße 85 8020 Graz, Austria
	2AR Flat-Plate Collector Double Glazed Flat-Plate Collector with Anti-Reflective Glass 80 - 150 Water-Glycol	Matthias Rommel Fraunhofer Institute for Solar Energy Systems Heidenhofstrasse 2 79110 Freiburg, Germany
	SCHÜCO Double-GlazedFlat-PlateCollector 80 - 150 Water-Glycol	R. Sillmann Schüco International KG Karolinenestr. 1-15 33615 Bielefeld, Germany

CPC Collectors	Collector Type Operating Temperature[°C] Heat Transfer Medium	Task 33 / IV Contact Person
	AoSol Stationary CPC Collector 80 - 110 Water-Glycol	Maria Joao Carvalho DER/INETI, Edificio H, Estrada do Paço do Lumiar, 22, 1649-038 Lisboa, Portugal
	Solarfocus CPC Collector 80 - 120 Water-Glycol	Andreas Simetzberger SOLARFOCUS Kalkgruber Solar- und Umwelttechnik GmbH Werkstrasse 1 4451 St.Ulrich / Steyr, Austria

	ZAE CPC Collector LoCo Evacuated Collector 120 - 180 Water-Glycol	Frank Buttinger ZAE Bayern Walther-Meißner-Str. 6, 85748 Garching, Germany

Evacuated Tube Collectors	Collector Type Operating Temperature[°C] Heat Transfer Medium	Task 33 / IV Contact Person
	Evacuated Turbular Collector ESE VACOSOL 80 - 170 Water-Glycol	Matthias Rommel Fraunhofer Institute for Solar Energy Systems Heidenhofstrasse 2 79110 Freiburg, Germany

Parabolic Trough Collectors	Collector Type Operating Temperature[°C] Heat Transfer Medium	Task 33 / IV Contact Person
	PARASOL Parabolic Trough Collector 100 - 200 Water or Steam	Dagmar Jähnig AEE INTEC Feldgasse 19 8200 Gleisdorf, Austria
	SOLITEM PTC 1800 Parabolic Trough Collector 100 - 200 Water	Klaus Hennecke DLRInstitute for Technical Thermodynamics 51170 Köln, Germany
	NEP SOLAR PolyTrough 1200 Parabolic Trough Collector 150 - 250 Water	Johan Dreyer, Antoine Millioud New Energy Partners Pty Ltd Level 2 Suite 1a 802 Pacific Highway Gordon NSW 2072, Australia

	PTC 1000 Modular Parabolic Trough Collector 80 - 300 Water	Jan Krocker Solar-Institute Jülich Heinrich-Mußmann-Str. 5 52428 Jülich, Germany
	CHAPS Combined Heat and Power Solar Collector 80 - 150 Water	Joe Coventry The Australian National University Centre for Sustainable Energy Systems Department of Engineering Canberra ACT 0200, Australia

Linear Fresnel-Type Collector	Collector Type Operating Temperature[°C] Heat Transfer Medium	Task 33/IV Contact Person
	PSE linear Fresnel Process Heat Collector 100 - 400 Water, Steam, Thermal Oil	Andreas Häberle PSE Solar Info Center 79072 Freiburg, Germany

Concentrating collector with stationary reflector	Collector Type Operating Temperature[°C] Heat Transfer Medium	Task 33/IV Contact Person
	CCStaR Concentrating Collector with Stationary Reflector 80 - 140 Water	Víctor Martínez Moll Universitat de les Illes Balears Edifici Mateu Orfila Ctra de Valldemossa, km 7,5 07122 Palma de Mallorca, Spain

3.1 ökoTech Gluatmugl HT – A Large-Area Double-Covered Flat-Plate Collector

Authors

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Research institution involved in the development and distribution

S.O.L.I.D. Solarinstallation und Design mbH
Puchstraße 85
8020 Graz, Austria

Collector manufacturer

ökoTech Produktionsgesellschaft für Umwelttechnik mbH
Puchstraße 85
8020 Graz, Austria

Description of the collector

The collector is a double-covered flat-plate collector with large-area modules.
New trends on the solar market show a shift towards the increased use of solar thermal applications for air conditioning and industry. The development of this new collector has been a reaction to this market situation: the new fields of application require high-efficiency collectors at temperature levels of about 80 - 95°C.
The new collector is similar in appearance to the standard Gluatmugl large-area collector which has been widely used in past large-scale solar thermal installations by S.O.L.I.D. The new HT collector combines the features of the standard Gluatmugl with design improvements which increase its efficiency especially in the temperature range of 80 - 95°C.
The Gluatmugl HT collector achieves low heat loss values with the aid of a double cover: in addition to the outer glazing, an inner cover was added to reduce convective heat losses. The outer cover consists of a high-transmission solar glass (unstructured float glass without AR coating on both sides). The inner cover consists of a transparent and high temperature resistant plastic film (Teflon FEP100) stretched at collector assembly in order to reduce slack. A back insulation of 120 mm mineral wool, that is thicker than in standard flat-plate collectors, has also been incorporated to reduce heat losses on high working temperatures.

Solar plant 'AEVG Graz' (currently 3,550 m², total ~5,000 m²) for feed-in into district heating net, employing Gluatmugl HT collectors. Engineering by S.O.L.I.D. GmbH

Operating temperature level

80°C to 120°C

Stagnation temperature

The stagnation temperature was not measured in the EN12975 test. According to the measured performance parameters, these are the results for the stagnation temperature under the following conditions:

T_{amb} = 30°C ambient temperature
G = 1000 W/m² irradiation on collector
T_{stag} = 218°C stagnation temperature

Dimensions of the collectors

The Gluatmugl HT collector is basically offered in three sizes:

1 **Gluatmugl HT 14.3 m² gross area**
length / width / height:
6150 mm / 2330 mm / 175 mm

2 **Gluatmugl HT 12.0 m² gross area**
length / width / height: 5130 mm / 2330 mm / 175 mm

3 Gluatmugl HT 10.5 m² gross area
length / width / height: 5130 mm / 2050 mm / 175 mm

Due the large area of the collector modules and their competitive price, the Gluatmugl HT collectors are especially suitable for commercial large-scale solar thermal installations.

Collector parameters based on aperture area

The Gluatmugl HT collector has been tested according to EN 12975:2006 by arsenal research, Vienna. The collector performance parameters based on aperture area are:

η_0 = 0.806
a_1 = 2.58 W/m²K
a_2 = 0.009 W/m²K²

Present development state

The development of the Gluatmugl HT collector is complete; the collector is ready for the market and commercially available on the market. Gluatmugl HT collectors are already used in several large-scale solar thermal installations. Currently, over 10,000 m² of collector area with the Gluatmugl HT are installed and in operation in commercial solar plants.

Estimated time needed or planned until the collector will be on the market

The Gluatmugl HT collector is commercially available on the market.
For commercial requests please contact:
S.O.L.I.D. Solarinstallation und Design mbH
Puchstraße 85
8020 Graz, Austria
Tel: +43 - (0)316 - 292840-0
Fax: +43 - (0)316 - 292840-28
Email: office@solid.at

Estimated collector costs

The collector costs are 220 to 250 €/m² referred to gross area, depending on collector dimension (see above) and number of collectors purchased.

Other references for additional information on the collector

ökoTech Produktionsgesellschaft für Umwelttechnik mbH
Puchstraße 85
8020 Graz, Austria
Tel. +43 - (0)316 - 576077
Fax: +43 - (0)316 - 576077-28
E-mail: technik@oekotech.biz

10.5 m² collector ready for transport on truck or shipping in a standard container

3.2 Double-Glazed Flat-plate Collectors with Anti-Reflection Glass

Author
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Companies involved in the development
Testing collectors built together with **Energie Solaire**, Sierre, Switzerland and **ESE**, Rochefort, Belgium.
AR-glass from **FLABEG**, Fürth, Germany

Description of the collector
This is a double-glazed flat-plate collector with anti-reflection glass.

Operating temperature level
80°C to 150°C

Stagnation temperature
In the range of 230 to 250°C for well-insulated collectors.

Dimensions of the prototype collectors
Testing collectors typically 1 m × 2 m.

Collector parameters based on aperture area
Fraunhofer ISE measured the following collector parameters of a test collector from ESE in an outdoor test (A_{ap}=2.325 m²):

η_0 = 0.76
a_{1a} = 2.66 W/(m² K)
a_{2a} = 0.009 W/(m² K²)

Present development stage
Tests were conducted to compare single-glazed collectors and double-glazed collectors at Fraunhofer ISE's indoor solar simulator. One collector was exposed to outdoor conditions during summer 2003. A collector built by ESE was tested for its thermal performance at Fraunhofer ISE and was tested in an extended exposure test at ITC's test site in Gran Canaria.
The double glazed AR-collector from ESE is being used in a solar driven, energy self sufficient, stand-alone system for sea water desalination. It produces about 100 to 150 litres of distilled water per day. The system, developed by Fraunhofer ISE, was installed in December 2004 on the test site of ITC in Gran Canaria, Spain. The typical operating collector temperatures are between 50°C to 95°C. The system uses three modules with an aperture area of 2.325 m² each. The desalination technology is based on the membrane destillation process.

Double-glazed collector with AR-glass at Fraunhofer ISE's outdoor test site. The collector was built for first tests and comparison with a single-glazed collector (Collector components from Energie Solaire).

Estimated time needed or planned until the collector will be on the market

The collector is on the market.

Estimated collector costs

For price information please contact the company ESE: http://www.ese-solar.com.

Other references for additional information on the collector

- Rommel, Schäfer, Schmidt, Schmitt, *Entwicklung neuer doppeltverglaster Flachkollektoren mit Antireflex-Glas,* Tagungsband 13. Symposium Thermische Solarenergie, OTTI, 14. - 16. Mai 2003, Staffelstein, S. 221 - 226
- Rommel, Gombert, Koschikowski, Schäfer, Schmitt, Proc. European Solar Thermal Energy Conference estec 2003, 26 - 27 June 2003, Freiburg, Germany
- For further information see **Annex 1**

Further information on the desalination system

- Joachim Koschikowski, Matthias Rommel, Marcel Wieghaus, *Solar thermal-driven membrane distillation for small scale desalination plants,* Proceedings EuroSun Conference 2004, Freiburg, page 1-412 to 1-421

Double-glazed AR collector from ESE used in a solar driven desalination system installed December 2004 in Gran Canaria, Spain. The collectors and the desalination system are still in operation and have shown very good performance.

3.3

SCHÜCO Double-Glazed Flat-Plate Collector

Authors

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E-mail: Rsillmann@schueco.com

Research institution involved in the development

ISFH Institut für Solarenergieforschung
Hameln/Emmerthal,
Am Ohrberg 1
31860 Emmerthal
Germany

Schüco double-glazed flat plate collector

Description of the collector

This is a double-glazed, flat-plate collector with anti-reflective glass. The space between the glass panes is filled with an inert gas to reduce the heat conductivity. The collector design is similar in appearance to that of the SchücoSol collector (single glazed).
The objective was to create a flat-plate collector with high efficiency at temperatures of around 100°C for process heat and solar air conditioning. Since most of the heat lost in a flat-plate collector is lost through the front side, the development of this collector focused on the design of the double-glazing and the frame. Due to the high temperature difference between the two plates of glass in the double-glazing, mechanical stresses resulted that had to be dealt with. Another important activity was research on collector materials that function at high temperatures without any problems. Furthermore, it was essential to design the collector in accordance with the Schüco production guidelines in order to achieve industrial, automated production of high quality units at appropriate cost.

Because the design of the collector is very close to that of the SchücoSol collector, many opportunities exist for the installation and integration of the collector in a building. As one of the most important issues for solar thermal technologies, building integration is the focus of most Schüco collectors. Thus the collector can be used on facades, in roof-installations or even as a canopy. The combination of the visually attractive, full-plate selective absorber with a well-designed frame and mounting system has resulted in a high acceptance by architects and investors. Furthermore, it is possible to combine the collector with a window or PV-module in the same design.

Operating temperature level

80°C to 150°C

Stagnation temperature

235°C (measured according to EN12975)

Dimensions of the prototype collectors

2.7 m² collector
Length/width/height:
2152 mm / 1252 mm / 108 mm

Collector parameters based on aperture area

Measured parameters of a prototype according to EN12975:

η_0 = 0.8
a_{1a} = 2.4 W/(m² K)
a_{2a} = 0.015 W/(m² K²)

The parameters are based on global irradiation.

Present development stage

The development of the collector is complete. Furthermore, a large double-glazed collector with an area of about 7.5 m² (for crane mounting) has been developed.

Collector costs

List price for the 2.7 m² collector: 1195 €
(excl. VAT; March 2007)

Other references for additional information on the collector

Further information is given on the Schüco web sites www.schueco.com

3.4 AoSol Stationary CPC Collector

Authors

João Correia de Oliveira[1], **Rodolfo Branco**[1], **M.Collares-Pereira**[1,2], **M. J. Carvalho**[2], **Wildor Maldonado Carbajal**[1]

Research institution involved in the development

[2] **INETI – Instituto Nacional de Engenharia**, Tecnologia e Inovação – Nacional Institute of Engineering, Tecnology and Inovation, Estrada do Paço do Lumiar
1649-038 Lisboa
Portugal

Company involved in the development

[1] **Ao Sol, Energias Renováveis, Lda**
Apartado 173
2135-402 Samora Correia
Portugal

Prototype MAXI collector being tested at INETI

Description of the collector

Ao Sol produces a stationary CPC-type collector with 1.15X concentration. This collector is for domestic hot water applications.

This new collector is based on the same construction ideas as the commercial collector—a similar box and insulation but with a higher concentration and a larger size (hence the designation MAXI). The larger size results from the emerging trend to fabricate larger collectors, substantially reducing the number of units to be installed when larger systems are necessary. Larger sizes also correspond to smaller heat losses, less piping, smaller number of valves and other accessories, all contributing to lower

CPC 1.15X – AO SOL's standard product

energy costs. This is a stationary CPC-type collector without a vacuum and with an initial concentration of 1.7X (acceptance angle of 37º), truncated to 1.5X (truncation angle of 56º). It is made up of six raisers centred in six symmetrical CPC valleys with two asymmetrical CPC valleys for the headers. The absorber is V-shaped (inverted V). The collector has only two inlet/outlet connections and has a minimum backside insulation of 3 cm. The collector aperture area is 5 m².

There is enough distance between the glass and the top of the absorber to use anti-convective barriers such as TIM (Transparent Insulation Material) or Teflon film.

Operating temperature level

The collector was designed to operate in the temperature range of 80ºC to 120ºC. This is a range practical for single effect absorption cooling.

AO SOL is developing an air cooled, ammonia–water, single effect machine for the domestic sector (7 - 8 kW capacity of cooling)—which should be on the market by 2009—with support from IST (School of Engineering of the Technical University of Lisbon) and with system performance tests done at INETI. However, many other applications for the collector are possible, including industrial process heat, desalination, etc.

Stagnation temperature

Experimental values are not yet available.

Dimensions of the MAXI prototype collector

The MAXI prototype produced, shown in the figure above, has the following dimensions:
1280 × 3970 × 163 mm.

Testing

Extensive preliminary tests were performed with different prototype configurations, still in a ~2.7m² size. Main results are summarized in the table below:

A CPC collector 1.5X without convective barriers and with a standard selective absorber (Sunstrip α=0.96; $\eta \geq 0.15$);
B With a Teflon film and standard selective absorber
C With a Teflon film and a new selective absorber (Alanod α=0.94; η=0.1)
D With TIM

Present MAXI development stage

The collector will be produced in two configurations: 1) single cover collector and 2) with honeycomb TIM of 15 mm thickness.
The collector's box is designed for improved building integration, and the product will have an aesthetical appearance with an architectural ease of integration in mind.

Final collector dimensions are:
1427 × 4020 × 180 mm.
Expected performance parameters are
1 single cover MAXI
$F'\eta^o$ = 0.74 and $F'U_L$ = 3
2 MAXI with TIM
$F'\eta^o$ = 0.74 and $F'U_L$ = 2.2

Estimated time needed or planned until the collector will be on the market

The collector should be on the market by the summer of 2008.

Estimated collector costs

The projected selling price is lower than the current standard product price. The costs for the collector excluding installation works, to distributors, should be around 160 €/m².

Other references for additional information on the collector

- António Afonso, M. Collares-Pereira, J. C. de Oliveira, João Farinha Mendes, L.F. Mendes (2003), *A Solar/Gas powered absorption prototype to provide small power heating and cooling,* ISES Solar World Congress 2003, Sweden
- M. Collares Pereira, M.J. Carvalho, J. Correia de Oliveira (2003), *New low concentration CPC type collector with convection controlled by a honeycomb TIM material: A compromise with stagnation temperature control and survival of cheap fabrication materials,* ISES Solar World Congress 2003, Sweden
- J. Correia de Oliveira, R. Branco, M. Collares pereira, M.J. Carvalho (2002), *Novo colector do tipo CPC sem vácuo para aplicações de aquecimento e arrefecimento ambiente,* XI Congresso Ibérico e VI Ibero-americano de Energia Solar, Vilamoura, Algarve (Portuguese)
- M.J. Carvalho, M.Collares Pereira, J.C. Oliveira, J.F.Mendes, A. Haberle, V.Wittwer (1995), *Optical and thermal testing of a new 1.12X CPC solar collector,* Solar Energy Materials and Solar Cells, vol. 37, pág.175 - 190
- M.J. Carvalho, M. Collares Pereira, J.M. Gordon (1987), *Economic optimisation of stationary non-evacuated CPC solar collectors,* Journal of Solar Energy Engineering, A.S.M.E., vol.109, pág.40 - 45

	Linear Fit		Parabolic Fit		
	$F'\eta_0 \pm \sigma_{F'\eta_0}$	$a_1 \pm \sigma_{a1}$	$F'\eta_0 \pm \sigma_{F'\eta_0}$	$a_1 \pm \sigma_{a1}$	$a_2 \pm \sigma_{a2}$
Collector A	0.71 ± 0.01	3.8 ± 0.2	0.70 ± 0.01	3.0 ± 0.5	0.015 ± 0.010
Collector B	0.68 ± 0.01	2.8 ± 0.2	0.66 ± 0.01	0.8 ± 0.7	0.03 ± 0.01
Collector C	0.66 ± 0.01	2.8 ± 0.2	0.65 ± 0.01	2.0 ± 0.1	0.011 ± 0.008
Collector D	0.65 ± 0.01	2.6 ± 0.2	0.64 ± 0.01	2.1 ± 0.4	0.008 ± 0.006

Test results for different prototype configurations

3.5 Solarfocus CPC Collector

Author

Andreas Simetzberger, Solarfocus GmbH

Research institution involved in the development

The development of the collector is based on research results of a joint project with the Fraunhofer ISE:

Fraunhofer Institute for Solar Energy Systems
Heidenhofstr. 2, 79110 Freiburg, Germany

Company involved in the development

SOLARFOCUS GmbH
Werkstrasse 1, 4451 St. Ulrich / Steyr, Austria

Description of the collector

The CPC collector is covered with flat glass and nine absorber-reflector-units mounted in parallel.

Operating temperature

80°C to 120°C

Stagnation temperature

Not measured yet, expected to be about 220°C

Dimensions of the prototype collectors

2405 mm × 1155 mm × 70 mm

Collector parameters based on aperture area

Development goal:

η_0 = 0.8

a_{1a} = 2.7 W/(m² K)

a_{2a} = 0.08 W/(m² K²)

Sketch of the CPC Collector, total area max. 2,7 m²

Present development stage

A SOLARFOCUS stationary CPC collector has been on the market for 14 years. First knowledge of how to increase the efficiency was gained from an EU-project completed in 2000 and the EU project SoCold (COOP-CT-2004508462) completed in 2006.

The aim of the recently finished EU project was to further develop the CPC collector and to increase the performance and the working temperature of the collector. Prototype collectors are working at two solar cooling plants in Spain.

Estimated time needed or planned until the collector will be on the market

The field test during the summer of 2007 provided the first real condition results. The collectors are performing as desired. Because of price reasons a date for market launch is not decided yet.

Estimated collector costs

The goal is for the enhanced CPC collector to cost about 450 €/m².

Other references for additional information on the collector

Further information can be obtained from

SOLARFOCUS GmbH
Andreas Simetzberger, Office
Phone: +43(0)7252 50002 37,
Fax: +43(0)7252 50002 19,
www.solarfocus.at

Test facility in Barcelona, Spain: Prototypes (the two collectors on the left), Standard CPC (the two collectors on the right)

3.6 ZAE CPC LoCo EvaCo Collector

Authors

Frank Buttinger
Markus Pröll

Research institution involved in the development

ZAE Bayern
Walther-Meißner-Str. 6,
85748 Garching
Germany

Prototype of the CPC-type collector

Description of the collector

The "LoCoEvaCo" (low concentrating evacuated flat collector) is a new stationary evacuated low concentrating CPC collector with a 1.8X concentration consisting of eight parallel mounted absorber-reflector units.
The basic concept of this new collector is the integration of the absorber tube and reflectors inside an evacuated enclosure. The collector is aligned in east-west direction, the absorber tubes are arranged in parallel. For the edge-ray reflectors the V-shape design of "McIntire" is applied.

The CPC-type collector has an initial concentration of 2.6X and is truncated to 1.8X. The asymmetrical reflectors for the headers with a concentration of 1.0X provide extra radiation and prevent longitudinal radiation losses.
The envelope of the collector consists of a metallic box covered by a flat tempered glass plate. To sustain the forces due to the vacuum inside the collector, frames are integrated between the glass cover and the bottom of the box.

Operating temperature level

The target operating temperature of the collector is 120°C to 180°C depending on the application, aperture and concentration ratio.

Stagnation temperature

Not yet measured, but theoretically estimated at approximately 260°C (Krypton at 0,01 bar) and 200°C (air at 0,01 bar).

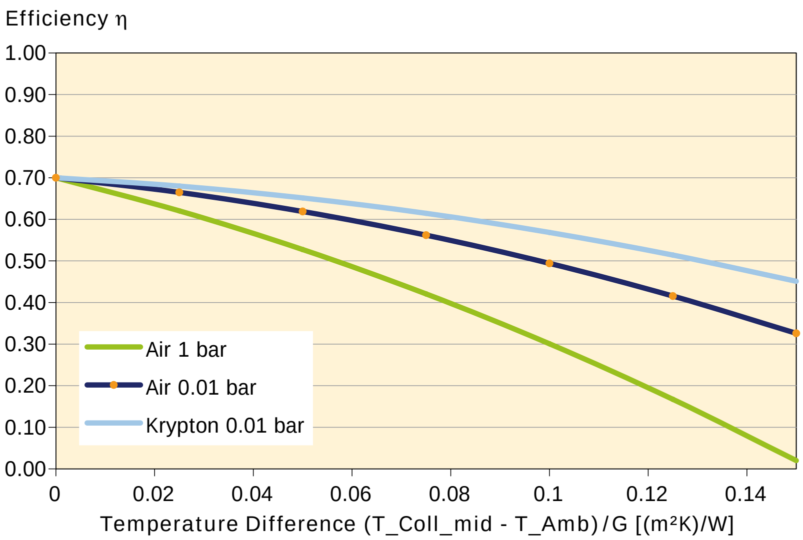
Dimensions of the prototype collectors

The built prototype has the following dimensions: 2050 × 1050 × 105 mm.

Collector parameters based on aperture area

$$\eta = \eta_0 - a_{1a} \cdot \frac{\Delta \bar{T}}{I} - a_{2a} \cdot \frac{\Delta \bar{T}^2}{I}$$

The efficiency curve is shown in the figure below. The collector has an efficiency of around 30% for air at 0.01 bar and around 50% for Krypton filling at 0.01 bar at a radiation of 1000 W/m² and an absorber temperature of 150°C.



Efficiency curves of the collector for different gas pressures at I = 1000 W/m² (based on data measured by ZAE)

Present development stage

The first test collectors are currently being investigated and outdoor exposure is being made.

Estimated time needed or planned until the collector will be on the market

The collector is designed to use simple and economical production steps. It is on the cusp from the prototype to a commercial product.

Estimated collector costs

Approximately 120 to 150 €/m² aperture area (factory costs).

Other references for additional information on the collector

- F. Buttinger, M. Pröll, T. Beikircher, W. Schölkopf: *Entwicklung eines konzentrierenden Vakuumflachkollektors für Mitteltemperaturanwendungen,* Tagungsband 17. Symposium Thermische Solarenergie 2006, OTTI e.V.
- M. Pröll, F. Buttinger, T. Beikircher, W. Schölkopf: *Simulationsprogramm zur optisch-thermischen Optimierung und Ertragsvorhersage für die Entwicklung eines solarthermischen Kollektors,* Tagungsband 17. Symposium Thermische Solarenergie 2006, OTTI e.V.

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Prototype on the outdoor test rig at ZAE Bayern

3.7

Evacuated Tubular Collector ESE VACOSOL

Author

Matthias Rommel, Fraunhofer Institute for Solar Energy Systems ISE

Company producing the collector

ESE European Solar Engineering S.A.
Parc Industriel, 39
5580 Rochefort, Belgium

Introductory remark

The collector represents to some extent the state of the art for evacuated tube collectors. It was not developed within Task 33. On the contrary: this collector and many other evacuated tube collectors have been on the market for many years and they are suitable for medium temperature applications.
The collector ESE VACOSOL is included in this brochure because it was used to carry out an intercomparision test of efficiency measurements within Task 39. The parameters reported here may be useful for a comparison against other collectors currently under development for the medium temperature range.

Evacuated tubular collector ESE VACOSOL installed on a test rig at Fraunhofer ISE

Description of the collector

Evacuated tubular collector with 7 twin-glass tubes („Sydney tubes"). A CPC reflector is mounted behind the tubes in order to reflect solar radiation that falls into the area between the tubes on the round absorbers from the back side. The heat transfer from the absorbing inner glass tube of the twin glass tube to the fluid is accomplished by an aluminum heat transfer sheet, that is in contact with the circumference of the absorber glass. The aluminum heat transfer sheet is also in contact with the copper U-tube. All 7 U-tubes are connected hydraulicly in parallel to the header tubes for the collector inlet and the collector outlet. The header tubes are insulated by mineral wool. The casing is made from aluminium sheets.

Operating temperature level

80°C to 170°C

Stagnation temperature

244°C

Dimensions of the collector

1.65 m × 0.78 m × 0.137m

Collector parameters based on aperture area

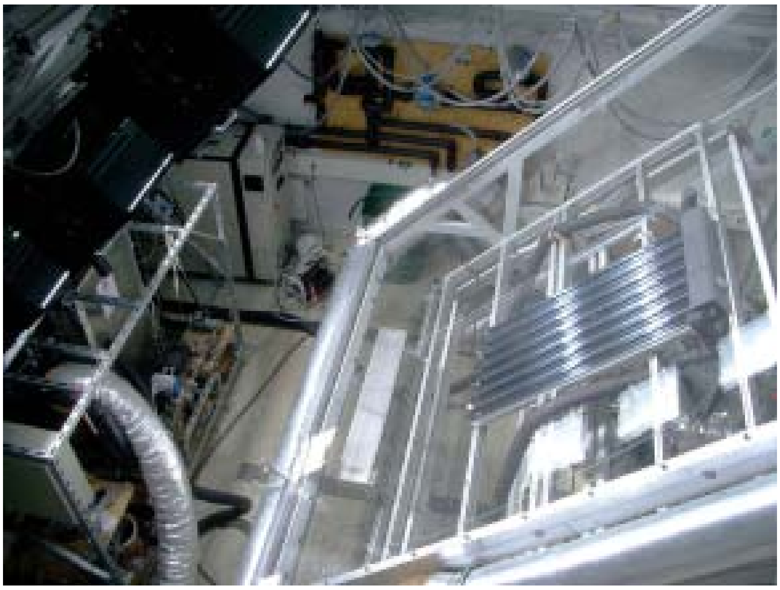
Fraunhofer ISE measured the following collector parameters (A_{ap}=1.09 m²):

η_0 = 0.6105
a_{1a} = 0.85 W/(m² K)
a_{2a} = 0.053 W/(m² K²)

The measurements were carried out on the solar simulator at the indoor test facility of Fraunhofer ISE. A special testing facility for high temperature collector efficiency tests was used. The highest mean collector fluid temperature during the test was 183°C. The global irradiation value was G=943 W/m².

Collector costs

For price information please contact the company ESE: http://www.ese-solar.com.



Efficiency curve measurement of the ESE VACOSOL collector exposed to the solar simulator. The new testing unit at Fraunhofer ISE, with which accurate performance measurements up to 200°C fluid temperature can be carried out, is at the bottom left of the photo.

Further Information on high temperature collector test

- Rommel et al., *Testing Unit for the Development of Process Heat Collectors up to 250°C*, estec 2007, 3rd European Solar Thermal Energy Conference, June 19-20, 2007, Freiburg, Germany

3.8

PARASOL®

Author
Dagmar Jaehnig, AEE INTEC

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Companies involved in the development
Button Energy Energiesysteme GmbH
Gurkgasse 16
1140 Wien
Austria

Solution Solartechnik GmbH
Hauptstraße 27
4642 Sattledt
Austria

Prototype tested at AEE INTEC collector test facility, Austria

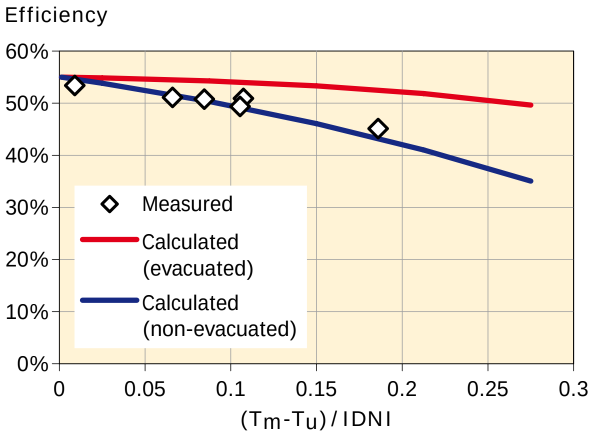
Description of the collector
The collector is a parabolic trough with glass cover. The operating temperature level is 100°C to 200°C.

Stagnation temperature
The Stagnation temperature is not yet measured, but theoretically estimated at approximately 600°C (prototype, receiver with selective coating, cover tube not evacuated).

Dimensions of the prototype collectors
Prototype dimensions: 0.5 × 4 m; focal length: 10 cm

Collector parameters based on aperture area
Measured parameters of second prototype:
$\eta_0 \quad = \quad 0.55$
See figure below for the efficiency curve

Development status
The first prototype collector was built by the company Button Energy and tested at AEE INTEC.
The prototype has an aperture width of 50 cm and a length of 4 m. Because of its small size, and therefore comparatively low weight, it can easily be mounted on factory roofs. The thermal and optical characteristics of this first prototype have been measured and several optimization possibilities were identified and implemented in the design of the second prototype.
The second, and improved, prototype has a receiver with a diameter of 12 mm, a non-evacuated glass cover tube and a selective coating.
The efficiency in the following figure is based on direct normal radiation. The x-axis shows the temperature difference between the receiver fluid and the ambient temperature divided by the direct normal radiation.
The efficiency values measured are shown as diamonds in the figure. The optical efficiency of the second prototype is around 55%. Theoretical calculations show that the thermal efficiency can be improved significantly by evacuating the cover glass tube (top curve in the figure).
As a next step, a laboratory-scale demonstration system with an aperture area of approximately 7.5 m² and a maximum collector capacity of approximately 3 kW_{th} was built. The system was connected to a heat load simulating a constant return temperature from an industrial process. This provided operating experience under realistic conditions.



Measured efficiency curve of the prototype

The collector is designed to deliver either pressurized water or direct steam. In a follow-up project, a first collector prototype to deliver steam was tested successfully.
Both projects were funded by the Austrian Ministry for Transport, Innovation and Technology as part of the research program 'Factory of the Future'. Co-operation partners are the manufacturer of the parabolic trough (Button Energy) and a number of other Austrian companies.

Estimated time needed or planned until the collector will be on the market

In 2008, a pilot installation will be installed by Button Energy at the AEE INTEC collector test facility. With approximately 20 m² of collector area, it is planned to connect the collector field to a steam jet ejector chiller with a cooling capacity of approx. 5 kW. For this pilot installation, a redesign of the parabolic mirrors is under way. If the redesign is successful, the installation of the first large-scale demonstration systems can be expected in 2009.

Estimated collector costs

No reliable estimates yet.

Other references for additional information on the collector

- Jähnig, Dagmar; Knopf, Richard-Matthias (2004): *Parabolrinnenkollektor zur Erzeugung industrieller Prozesswärme – Optimierung und erste Betriebserfahrungen,* Symposium Gleisdorf Solar 2004 (in German)
- Jähnig, Dagmar; Knopf, Richard-Matthias (2005): *Parabolrinnenkollektor zur Erzeugung industrieller Prozesswärme,* OTTI-Symposium Thermische Solarenergie, Ostbayerisches Technologie-Transfer-Institut e.V. (in German)

3.9

SOLITEM PTC 1800

Authors

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Research institution involved in the development

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Institute for Technical Thermodynamics
Lindner Höhe
51170 Köln, Germany

Company involved in the development

SOLITEM GmbH
Dennewart Str. 25-27
52072 Aachen, Germany

Description of the collector

This parabolic trough collector system is assembled from modules with an aperture area of 9 m² each. The concentrator consists of aluminum sheet kept in shape by specially manufactured aluminum profiles. Additional stiffness is provided by a torsion tube mounted at the back of the concentrator. Up to four modules installed in a series form a row; five rows can be connected to a single drive unit that is tracked via a rope and pulley arrangement. Mounted in the focal line is a stainless steel absorber tube with a 38 mm diameter that has been galvanically coated with a selective surface. A non-evacuated glass envelope reduces the convective heat losses from the absorber.

Operating temperature level

Up to 200°C

Stagnation temperature

Not applicable, system will defocus to avoid excessive temperature.

Dimensions of the collectors

Module properties:

Length: 5090 mm *Width:* 1800 mm
Height: 260 mm *Focal length:* 780 mm
Support structure:
Al-Profiles and Al-sheet 0.8 mm
Reflector: Al-coating 0.5 mm

Absorption tube:

Material: Stainless steel
Coating: Selective

Prototype installation at Sarigerme Park Hotel in Dalaman, Turkey

Ext. Diameter: 38 mm
Wall thickness: 1.25 mm

Glass envelope:

Ext. Diameter: 65 mm
Wall thickness: 2.2 mm

Present development stage

Systems are on the market.
A 180 m² plant has been in operation at Sarigerme Park Hotel in Turkey since April 2004. Two more plants are also operating in Turkey at the Gran Kaptan Hotel in Alanya and the ball-bearing company Koskeb near Ankara.

Estimated collector costs

Series production: cost estimates not yet available

Other references

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  Fax: +49(0)241 9631328,
  E-mail: a.lokurlu@solitem.de,
  www.solitem.de
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  Institut für Technische Thermodynamik,
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  Fax: +49(0)2203 66900,
  E-mail: dirk.krueger@dlr.de

3.10 NEP SOLAR PolyTrough 1200

Author
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Gordon, NSW 2072
Australia

Research institution involved in the development
CSIRO National Solar Energy Centre
Newcastle
Australia

Reflectors adhered to the mirror for photogrammetry tests

Description of the collector
The NEP SOLAR PolyTrough is a parabolic trough system consisting of composite carrier mirror panels and a steel torque tube. The mirror panel carriers are made of polymeric composite materials, and are light weight, stiff in bending, and quite capable of offering the form precision and stability required. The mirror surfaces are highly reflective aluminum sheets achieved using physical vapour deposition and a polymer coating. Solar tracking is achieved through a microprocessor controlled stepper motor and reduction drive.

Operating temperature level
The target operating temperature of the collector is 150°C to 275°C depending on the application.

Stagnation temperature
The control system is programmed to take the collector off-focus to avoid stagnation if required. The solar tracking system can be fitted with a battery back-up.

Typical dimensions of the collectors
Width (aperture) of trough: 1.20 m
Length of one trough panel: 6.00 m
Length of one standard module: 24 m
Focal length: 0.65 m
Geometric Concentration Ratio: 45

Typical collector parameters based on aperture area
The thermal efficiency parameters have not yet been tested. The materials selected for the collector are, however, high quality materials specially developed for concentrating solar collector applications. The polymer carrier is highly accurate and retains shape under load. The use of specialty materials in the panels ensures form stability. Wind induced bending loads are carried by the polymer mirror panels which in turn are carried over to the torque tube that efficiently carries the torque back to the solar tracking system. Overall, it is expected that the collector will perform well within the performance range of its competitors.

Present development stage
The proof-of-concept prototype was built and installed at the CSIRO National Solar Energy Centre in Australia in March 2006. Following a complete and thorough design optimisation phase, prototype mirror panels were built and tested in the first half of 2007. A 50 m² pre-commercialisation prototype was installed in November 2007 and will undergo testing through to the second quarter of 2008.

Estimated time needed or planned until the collector will be on the market
The first serial version of the NEP SOLAR Polymer Carrier PTC will be on the market in 2008.

Estimated collector costs
It is currently estimated that the first serial version of the collector (for a small pilot or demonstrator project) will be sold at an ex-works price of 360 €/m² complete with all standard supports and tracking equipment. Once full-scale production commences, it is expected that the

price will be 250 €/m². Given the modular and light weight design, the shipping and assembly costs to the client will be minimal. All components are designed to stack in standard ISO shipping containers and to be handled without the need of mechanical lifting equipment.

Other references for additional information on the collector

The New Energy Partners website has some information: http://www.newenergypartners.com

Further information can be obtained from NEP SOLAR

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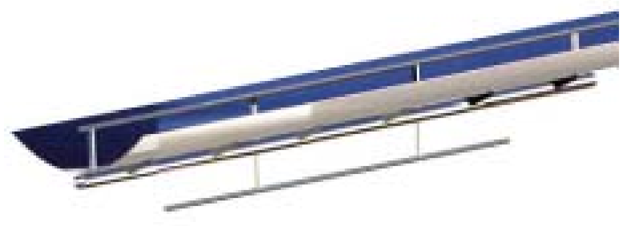
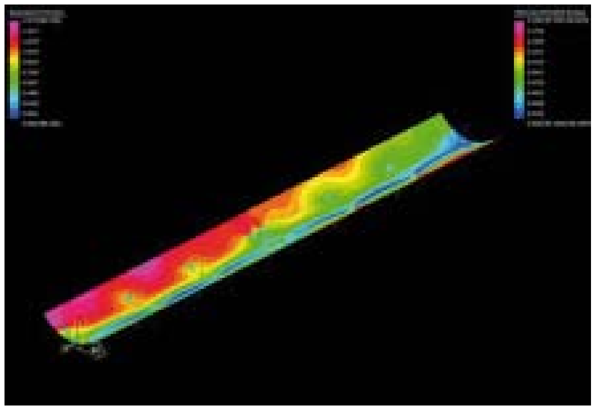
E-mail: johan.dreyer@newenergypartners.com

The development of this collector has been supported by the Australian Government under the Renewable Energy Development Initiative.



CAD model of the PolyTrough 1200



Finite Element results

First panel from prototype tooling

Panels ready for despatch to site

3.11 PTC 1000 Modular Parabolic Trough Collector

Authors

Jan Kroker, Hoffschmidt, Schwarzer, Späte

Research institutions involved in the development

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52428 Jülich
Germany

Deutsches Zentrum für Luft und Raumfahrt
Institute for Technical Thermodynamics
Linder Höhe
51170 Köln
Germany

Testing of the PTC 1000 at the SIJ

Companies involved in the development

Solitem GmbH
Süsterfeldstraße 83
52072 Aachen
Germany

Alanod Aluminium Veredelung GmbH & Co. KG
Egerstraße 12
58256 Ennepetal
Germany

Description of the collector

This is a small single axis-tracking parabolic trough collector with the rotation axis equal to the absorber tube axis. The absorber stays in one position during processing and flexible pipe connections are not needed.
Mirror: Alanod 4200 GP Miro-Silver 2.
Absorber tube: standard Sydney tube.
Cover glass: anti-reflective solar-glass from Flabeg.
Drive: stepper motor with worm gear and sensors for tracking the sun.

Operating temperature level

120°C to 200°C with high efficiency

Stagnation temperature

Stagnation experiments have shown temperatures around 590°C.

Dimensions of the prototype collectors

The collector has an aperture area with a width of 1 m and a length of 2 m. Therefore it can be easily used for roof installations.

Collector parameters based on aperture area

Measured at the SIJ collector test facility with temperatures up to 100°C, the following efficiency parameters were determined:

η_0 = 0.70
a_1 = 0.2044 W/(m² K)
a_2 = 0.001545 W/(m² K²)

The capacity is about 1 kW. The collector has an efficiency of around 60% at a radiation of 800 W/m² and a temperature of 160°C.

Present development state

The first test collectors have been built and experimentally investigated. In addition, outdoor exposure experiences have been made. The weak points of the prototypes' designs have been detected and alternative absorber systems have been investigated.

PTC 1000 at the SIJ collector test facility

Estimated time needed or planned until the collector will be on the market

A series production is planned to be realised within the year 2010.

Estimated collector costs

The costs of the prototypes were approximately 400 €/m². Throughout a series production the costs will be reduced to 150 €/m².

Other references for additional information on the collector

- Miriam Ebert: *Entwicklung eines modularen Parabolrinnenkollektors,* Diplomarbeit, Jülich, Juni 2004
- Jan Kroker: *Optimierung und Vermessung eines Absorbersystems für Parabolrinnen, Diplomarbeit,* Jülich, Juli 2006
  Abstract submitted at:
  Estec2005, the 2nd European Solar Thermal Energy Conference, Freiburg, 21-22 Juni 2005
  OTTI, 15. Symposium Thermische Solarenergie, Bad Staffelstein, 27. - 29. April 2005

Further Steps

- Modelling with the toolbox CARNOT under MATLAB/Simulink.
- Optimisation and further development towards a series production.
- Collector tests after optimisation due to standard EN 12975.
- Optimisation of the collector regarding its' costs.

Applications

Applications include supplying process heat for hotels, hospitals and industry applications and for supplying cooling energy.

3.12 CHAPS - The Combined Heat and Power Solar (CHAPS) collector

Authors
Joe Coventry, Andrew Blakers

Research Institution involved in the development
The Australian National University
Centre for Sustainable Energy Systems
Department of Engineering
Canberra ACT 0200 Australia


Prototype CHAPS system

Description of the collector
The CHAPS collector is a parabolic trough system consisting of glass-on-metal mirrors that focus light onto high efficiency monocrystalline silicon solar cells to generate electricity. Water, with anti-freeze and anti-corrosion additives, flows through a conduit at the back of the cells to remove most of the remaining energy as heat. The thermal energy may be used via a heat exchanger for industrial applications, building heating and domestic hot water.

Operating temperature level
The operating temperature of the collector is limited by the inclusion of solar cells. The electrical efficiency of the system reduces as operating temperature increases. Therefore the system is ideally suited to lower temperature applications (< 80ºC) where electrical system efficiency is maintained above 10%, however, temperatures up to around 150ºC are feasible, with electrical efficiency still in the order of 8%.

Stagnation temperature
Not applicable. The receiver is destroyed well below the stagnation temperature so preventative measures are included to avoid the possibility of stagnation conditions occurring. For example, the tracking system uses a dc actuator with battery backup. This is combined with automatic collector 'parking' in case of over-temperature conditions.

Typical dimensions the collectors built so far
Width of single trough: 1.55 m
Length of single trough: 24 m
Focal length: 0.85 m

Collector parameters based on aperture area
The thermal efficiency parameters are estimated, but based on data measured at operating temperatures lower than 80ºC. It is assumed that the insulation is improved for higher temperature applications. Efficiencies are based on DNI (direct normal irradiation) and on the total aperture area of the mirror.

	Thermal efficiency	Electrical efficiency
η_0	0.56	0.126
a_{1a}	0.0325 W/(m² K)	0.355
a_{2a}	0.00313 W/(m² K²)	

Although it is not strictly correct to plot electrical efficiency on the same axes as for a thermal efficiency curve, this has been done for the sake of comparison. The parameters are based on a solar radiation of 1000 W/m² assuming ambient temperature of 25°C. Actually, the absolute temperature of the receiver is what matters for electrical performance so technically the temperature difference (T_m - T_{amb}) should be in reference to a baseline T_{amb}.

Present development stage
Efficiency measurements have been carried out on a single trough prototype. Longer term durability testing of mirrors, receivers and the tracking system has taken place on a 15 m long prototype system (pictured above), which has been in operation for about three years. The first deployment of the CHAPS collector on a reason-

able scale is the Bruce Hall system – a 300 m² system providing electricity and thermal energy for heating and hot water to a student college on campus at the Australian National University. Commercialisation opportunities for the technology are currently being sought.

Estimated time needed or planned until the collector will be on the market

The collector is now ready for market development.

Estimated collector costs

The estimated collector costs will be in the order of 425 €/m² plus site specific costs in the order of 235 €/m². This estimate is for systems between 100 m² and 1000 m² at pilot production levels. Note that site specific costs include items such as thermal storage, plumbing, structural work, installation, etc and will vary significantly depending on the location.

Other references for additional information on the collector

The website at the Centre for Sustainable Energy Systems has some information:
http://solar.anu.edu.au

300 m² Bruce Hall system under construction

Further information can be obtained from the centre manager:
Ray Prowse:
Phone: + 61 (0) 2 6125 4884
Fax:+ 61 (0) 2 6125 8873

Also see

Performance of a concentrating photovoltaic/thermal solar collector
Solar Energy, Volume 78, Issue 2, February 2005, Pages 211-222
Joe S. Coventry

300 m² Bruce Hall system

3.13 PSE linear Fresnel Process Heat Collector

Author

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Research Institution involved in the development

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Description of the collector

The PSE linear Fresnel process heat collector is designed for applications with a thermal power starting at approximately 50 kW_{th} up to about 5 MW_{th}. Due to its low wind load and high ground coverage, the collector is ideally suited for installations on flat roofs. Eleven individually tracked mirror rows concentrate the direct sunlight to a stationary vacuum tube receiver with secondary CPC reflector. The collector size is modular in steps of 4 m length (22 m²).

Prototype in Freiburg, Germany

Operating temperature level

The target operating temperature of the collector is 150°C to 200°C with pressurised water as the heat transfer fluid. Higher operating temperatures can be realised with suitable thermal fluids.

Stagnation temperature

The control system is programmed to gradually de-focus single reflector rows to limit the maximum fluid temperature. Under stagnation conditions the collector is completely de-focused and stagnation temperature is approximately equal to the ambient temperature. A battery back-up maintains power for controlled shut down in case of power outage.

Typical dimensions of the collectors built so far

Total width: 7.5 m
Width of single reflector: 0.5 m
Aperture width: 5.5 m
Length: modular in steps of 4 m (22 m²)
Focal length: 4 m

Typical collector parameters based on aperture area

The aperture area of the linear Fresnel collector is defined as the glass area of the primary reflectors. In the case of a parabolic trough this area is defined as the projection of the curved reflector area.
Based on this reference area the optical efficiency is in the range of 60%.
Heat losses can be modelled with the quadratic approximation:

$$\dot{q} = u_1 \Delta T^2$$

$$u_1 = 4.3 \cdot 10^{-4} \frac{W}{m^2K^2}$$

When calculating the collector yield a two dimensional incident angle modifier needs to be taken into account.
500 W/m² can be used as a site independent number by rule of thumb for the peak thermal power output of the collector.

Present development stage

The first full-scale prototype was manufactured in late 2005 in Freiburg, Germany and was operated and evaluated during the summer of 2006. The second unit with 132 m² was installed August 2006 in Bergamo, Italy to power an NH_3/H_2O absorption chiller. The largest installation in operation is a 176 kW_{th} solar cooling project in

Prototype in Bergamo, Italy

Seville, Spain where the collector powers a double effect LiBr chiller. Further projects for solar cooling and industrial process heat applications are under development.

Estimated time needed or planned until the collector will be on the market

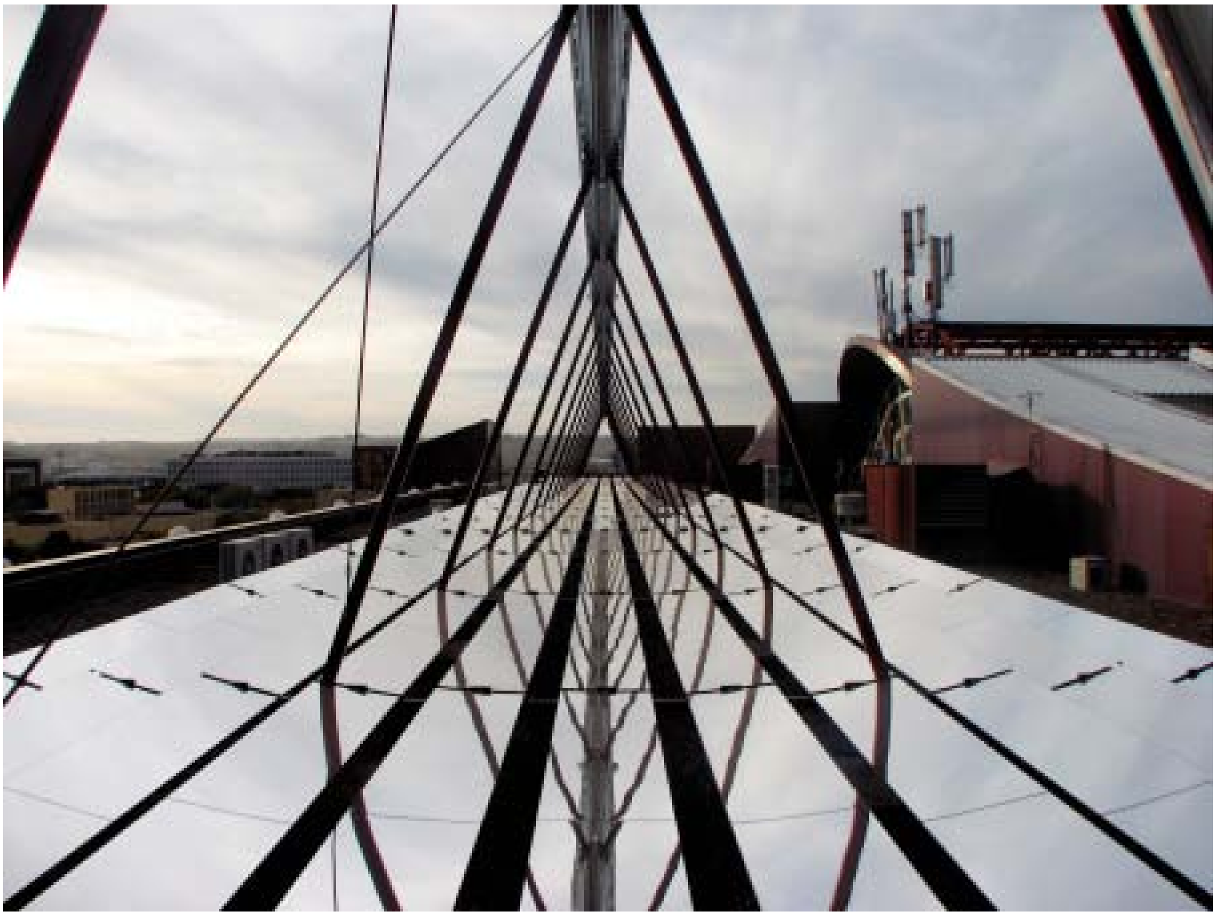
The collector is commercially available.

Estimated collector costs

The relatively simple construction results in a competitive price.

Other references for additional information on the collector

- A. Häberle, M. Berger, F. Luginsland, C. Zahler, M. Baitsch, H.-M. Henning, M. Rommel, *Linear Concentrating Fresnel Collector for Process Heat Applications,* Proceedings of the 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies, June 20, 2006, Seville, Spain
- A. Häberle, M. Berger, F. Luginsland, C. Zahler, *Practical Experience with a Linear Concentrating Fresnel Collector for Process Heat Applications,* Proceedings of the 14th International Symposium on Concentrated Solar Power and Chemical Energy Technologies, March 4-7, 2008, Las Vegas, Nevada, USA



The PSE linear Fresnel Collector in Sevilla, Spain

3.14 Concentrating Collector with Stationary Reflector (CCStaR)

Author

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Universitat de les Illes Balears

Research institutions involved in the development

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Edifici U, planta 0
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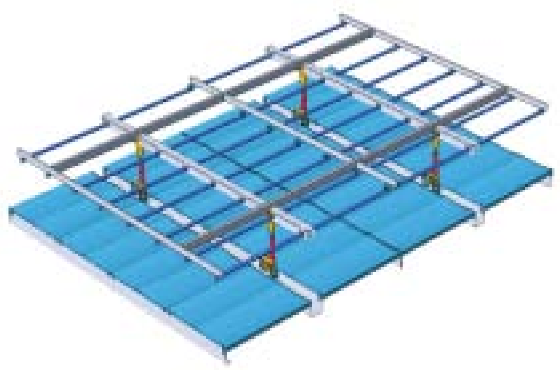
Spain

Company involved in the development

Tecnologia Solar Concentradora S.L. (TSC)
C./ Roger de Llúria, 29, 3er, 2a
08009, Barcelona
Spain

Description of the collector

The CCStaR collector is a "Fixed Mirror Solar Concentrator". The concept is described in **Chapter 2.6** of this booklet. The collector consists of an array of evacuated tubes forming a receiver grid linked to the reflector through a set of articulated arms. These arms position the grid according to the transversal reflector-sun angle, see the figure below.
The reflecting surface consists of 16 high-reflectivity aluminum sheets integrated into specially moulded sandwich structures and assembled together to form modules of 24 m².



Sketch of Tecnologia Solar Concentradora's CCStaR-collector

The receiver grid consists of 32 standard "Sydney tubes" connected to two fluid collectors.

Operating temperature level

90ºC to 160ºC

Stagnation temperature

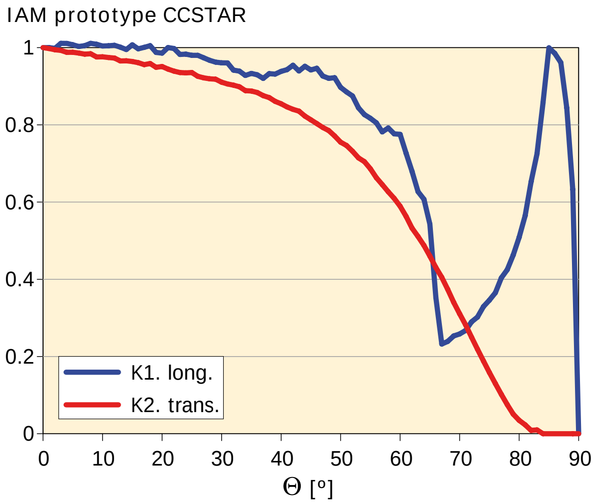
Measured stagnation temperature is 295ºC for a normal direct irradiation of 710 W/m² and T_a=20ºC.

Dimensions of the collector

Each collector module is 4.4 × 6 m and the maximum reflector-receiver distance is about 800 mm.

Collector parameters based on aperture area

Efficiency of the whole module has not yet been measured, but preliminary measurements of an single receiver tube show a peak optical efficiency of about 75%.
The Incidence Angle Modifier has been determined through detailed raytracing analysis. The figure below shows these calculated transversal and longitudinal IAM curves.



IAM curves of the CCStaR prototype

Present development stage

In June 2006, the company TSC began to develop a commercial collector based on the principle of a Fixed Mirror Solar Concentrator. In January 2008, the first prototype module was installed and started operation.

The project has public co-funding through the CIDEM (innovation promotion agency from the Generalitat de Catalunya), as well financing from the PROFIT program of the Spanish Government.
Currently, operation tests are being conducted in order to further optimize the design and to compare different materials and component suppliers for the most critical parts.

Estimated time needed or planned until the collector will be on the market

Market introduction of the product is planned for 2009 or the beginning of 2010. Prior to that demonstration plants will be built.

Estimated collector costs

Production costs for small series will be around 200 €/m².

Other references for additional information on the collector

- Martínez Moll, V.; Pujol Nadal, R.; Moià Pol, A.; Schweiger, H.: *Analysis of a stationary parabolic linear concentrator with tracking absorber*, 13th SolarPaces Symposium, Sevilla (Spain), 2006
- Pujol, R.; Marínez, V.; Moià, A. i Schweiger, H. *Analysis of stationary Fresnel like linear concentrator with tracking absorber*, 13th SolarPaces Symposium, Sevilla (Spain), 2006
- Martínez, V.; Alorda, B.; Moià, A. and Pujol, R. *Low cost orientation system for a concentrating solar collector with static reflector and tracking absorber*, ICREPQ '06; Palma de Mallorca (Spain); 2006

4 Appendix 1: Description of the IEA Solar Heating and Cooling Programme

The *International Energy Agency* (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first "oil shock", the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.
The IEA provides a legal framework, through IEA Implementing Agreements such as the *Solar Heating and Cooling Agreement*, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.
The *Solar Heating and Cooling Programme* was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia	European	Italy	Portugal
Austria	Commission	Mexico	Spain
Belgium	Germany	Netherlands	Sweden
Canada	Finland	New Zealand	Switzerland
Denmark	France	Norway	United States

A total of 39 Tasks have been initiated, 30 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities-Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops-have been undertaken.
The Tasks of the IEA Solar Heating and Cooling Programme, both underway and completed are as follows:

Current Tasks:

Task 32	Advanced Storage Concepts for Solar and Low Energy Buildings
Task 33	Solar Heat for Industrial Processes
Task 34	Testing and Validation of Building Energy Simulation Tools
Task 35	PV/Thermal Solar Systems
Task 36	Solar Resource Knowledge Management
Task 37	Advanced Housing Renovation with Solar & Conservation
Task 38	Solar Air-Conditioning and Refrigeration
Task 39	Polymeric Materials for Solar Thermal Applications

Completed Tasks:

Task 1	Investigation of the Performance of Solar Heating and Cooling Systems
Task 2	Coordination of Solar Heating and Cooling R&D
Task 3	Performance Testing of Solar Collectors
Task 4	Development of an Insolation Handbook and Instrument Package
Task 5	Use of Existing Meteorological Information for Solar Energy Application
Task 6	Performance of Solar Systems Using Evacuated Collectors
Task 7	Central Solar Heating Plants with Seasonal Storage

Task 8	Passive and Hybrid Solar Low Energy Buildings
Task 9	Solar Radiation and Pyranometry Studies
Task 10	Solar Materials R&D
Task 11	Passive and Hybrid Solar Commercial Buildings
Task 12	Building Energy Analysis and Design Tools for Solar Applications
Task 13	Advance Solar Low Energy Buildings
Task 14	Advance Active Solar Energy Systems
Task 16	Photovoltaics in Buildings
Task 17	Measuring and Modeling Spectral Radiation
Task 18	Advanced Glazing and Associated Materials for Solar and Building Applications
Task 19	Solar Air Systems
Task 20	Solar Energy in Building Renovation
Task 21	Daylight in Buildings
Task 23	Optimization of Solar Energy Use in Large Buildings
Task 22	Building Energy Analysis Tools
Task 24	Solar Procurement
Task 25	Solar Assisted Air Conditioning of Buildings
Task 26	Solar Combisystems
Task 28	Solar Sustainable Housing
Task 27	Performance of Solar Facade Components
Task 29	Solar Crop Drying
Task 31	Daylighting Buildings in the 21st Century

Completed Working Groups:

CSHPSS	Central Solar Heating Plants with Seasonal Storage,
ISOLDE	Materials in Solar Thermal Collectors, and the Evaluation of Task 13 Houses

To find Solar Heating and Cooling Programme publications and learn more about the Programme visit www.iea-shc.org or contact the SHC Executive Secretary, Pamela Murphy, E-mail: pmurphy@MorseAssociatesInc.com.

5 Appendix 2: Task 33 / IV Solar Heat for Industrial Processes

Task 33/IV was a collaborative project of the Solar Heating and Cooling Program and the SolarPACES program of the International Energy Agency (IEA) in which 16 institutes and 11 companies from Australia, Austria, Germany, Italy, Spain, Portugal, Mexico were involved. The aim of the project was the development of solar thermal plants for industrial process heat.
To reach this goal, studies of the potential were carried out for the countries involved, medium-temperature collectors were developed for the production of process heat up to a temperature of 250°C, and solutions were sought to the problems of integrating the solar heat system into industrial processes.
In addition, demonstration projects were realised in cooperation with the solar industry.
Knowledge was transferred to industry via the Task's industry newsletters, conferences and via the following four booklets:

- Design Guidelines - Solar Space Heating of Factory Buildings
- Medium Temperature Collectors
- Pilot Plants - Solar Heat for Industrial Processes
- Potential for Solar Heat in Industrial Processes

Further information

www.iea-shc.org/task33

TASK 33/IV Participants

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