CPC EVACUATED TUBE COLLECTOR SYSTEMS
FOR PROCESS HEAT UP TO 160 °C

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Abstract

Using water as heat transfer fluid CPC evacuated tube collector (CPC-ETC) technology generates temperatures of 80 – 160 °C under almost all weather conditions all year round.. CPC-ETC with water as heat fluid is completely self-secured against thermal standstill, even in the event of a power cut. Therefore, with this technology storage tanks can be optimized according to space considerations, load profiles and profitability; in the case of low collector areas storage tanks can often be done away with completely. This means that CPC-ETC technology is ideally suited for middle-temperature process heat, district heating, and providing high levels of solar heat support to heating systems.

1 Outline of CPC-ETC with AquaSystem

The foundations of this technology are Dewar, or Sydney, tubes. These are double-walled glass vessels, constructed in an analogously simple manner to a thermos flask. Due to the experimentation performed on thermos flasks for over a hundred years, Dewar collector tubes have a lifetime of 20 to 50 years. On the surface of the inner tube a highly selective absorber is coated – in good solar radiation conditions and under thermal standstill, this absorber is heated to temperatures of up to 350 °C. If the collector is not in thermal standstill, the heat is transferred via a thin water-carrying metal tube, which is made of copper, steel, or stainless steel depending on its use. The CPC mirror (Compound Parabolic Concentrator) guarantees that as few tubes as possible are needed per unit area and yet over 90 percent of the gross collector area is still optically used. This saves material, increases the yield and decreases the heat loss. Due to the special geometry of this set-up all light (both direct and diffuse) is used.

Fig. 1: Dewar pipes, CPC mirror, metal heat conductor and tube

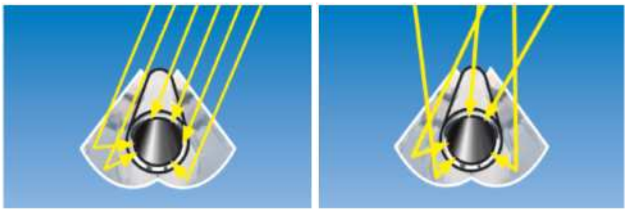


Fig. 2: Ray paths for direct and diffuse solar radiation

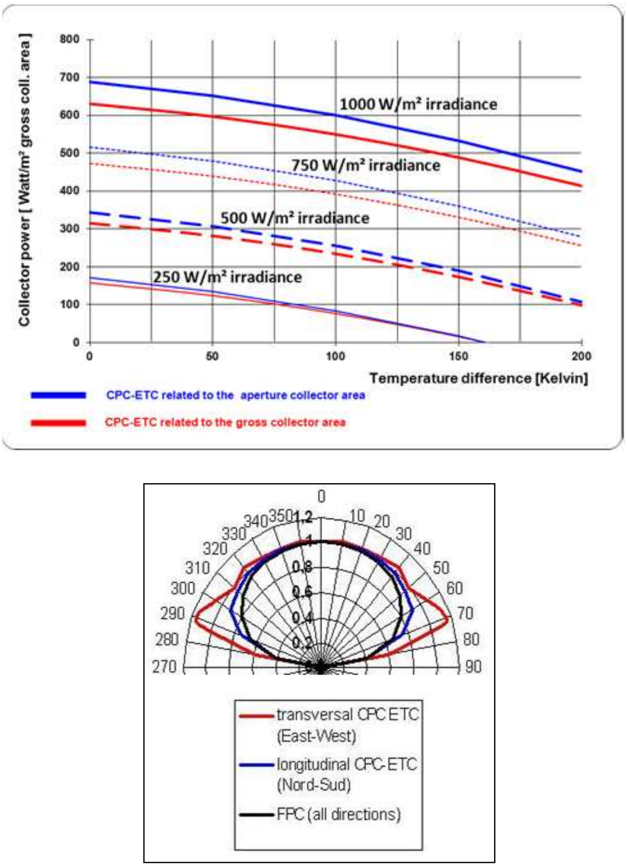
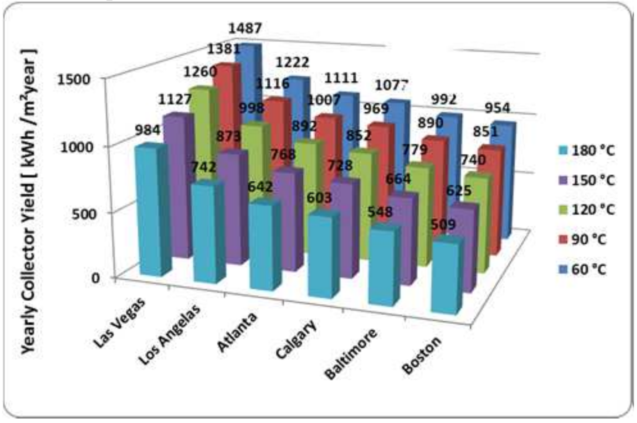


Fig. 3: Collector efficiency curves for plasma coated CPC-ETC collectors and the dependence of the radiation incident angle on the fraction of used radiation for CPC-ETC and for flat collectors

The plots of collector performance show that, for a temperature difference between the collector and the surroundings of 150 Kelvin, the collector has an efficiency of over 50 for 1000 watt/m² of irradiation. Even with only 400 watt/m² of irradiation the efficiency is well over 25. In order to reach efficiencies of at least 25 for temperature differences of less than 75 Kelvin, irradiation of only 150 watt/m² will suffice – such levels can be achieved without sunshine. Therefore, if an operational pressure of 6 bars is used, water can easily be heated to 160 °C using CPC-ETC without mechanical tracking and can then be used for process heat. In addition, physical investigations have shown that the production of steam presents no problem. A particular advantage of cylindrical absorbers is the fact that the incident radiation which the collector can use is nearly independent of the radial angle of incidence. In practical terms, this means that throughout the day almost exactly the same maximum performance can be expected over many hours. In contrast to more highly-concentrating technologies, such as parabolic or Fresnel mirror collectors, CPC-ETC makes use of almost all diffuse light, which corresponds to around half of the solar radiation worldwide. Only in a few extreme areas does the diffuse light sink to a quarter of the total irradiation.

Using the Solar Keymark Output Calculator (SKOC), the following collector yields have been calculated for locations in Las Vegas, Los Angeles, Atlanta, Calgary, Baltimore and Boston, for constant medium collector temperatures of 60 °C, 90 °C, 120 °C, 150 °C und 180 °C. These are almost equal to the process temperatures in case of small solar temperature differences. SKOC is only calibrated up to 100 °C and was further developed to give the results here. However, how do the simulation results for high temperatures compare to results obtained by testing collectors according to EN (European Norm) 12975-2. As the measured stagnation temperatures correspond well with the calculated ones, it can be assumed that the calculated results are also reliable for those temperatures which were not measured.



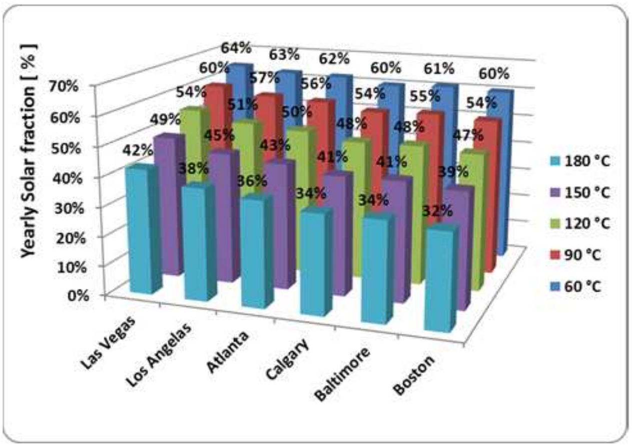


Fig. 4: annual collector yield per square meter of aperture collector area (left) and as a percentage of the irradiation (right), for a south-facing orientation and a 30 degree inclination.

2 CPC-ETC with AquaSystem in comparison

It is not widely appreciated that CPC evacuated tube collectors (CPC-ETC), which do not concentrate sunlight, give a greater yield than solar collector technology which does concentrate sunlight. This is partly due to the fact that, until now, few references have been made to ETC, and partly because ETC was not developed with the target of application to super-heated water, steam or heat transfer oil. Hot water and heating are the focus of ETC development; even under unfavourable weather and climate conditions, temperatures of 95 °C should almost always be generated. In contrast, concentrating solar technology with parabolic or Fresnel mirrors was developed exclusively for high temperature applications such as solar cooling or electricity generation. For such a technology it is unavoidable that diffuse sunlight remains almost completely unused. These concentrating collectors do have important advantages when used at temperatures above 200 °C. However, such high-temperature applications are much less common than those that require temperatures between 100 and 200 °C, which is why attempts are being made to establish the technology at lower temperatures. For CPC-ETC, applications with temperatures far higher than 100 °C present themselves, since it is accepted that CPC-ETC collectors are very efficient in this temperature range compared to concentrating collectors and are not dependent on whether the sunlight is direct or diffuse. The curves below are based only on the collectors and their gross collector area, not on the whole system.

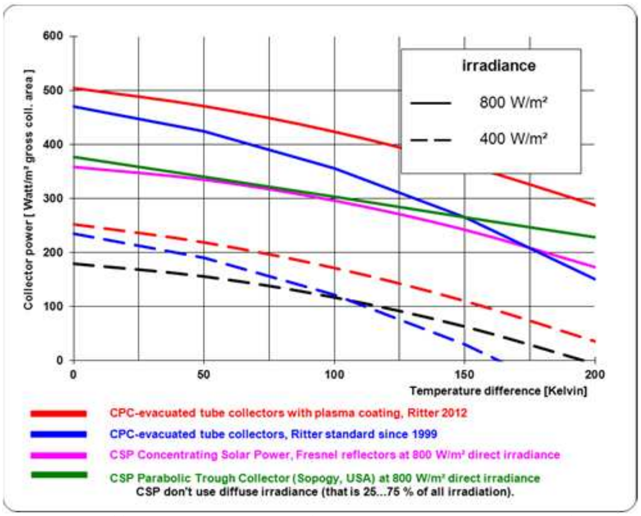
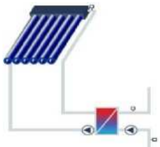


Fig. 5: Efficiency curves of CPC-ETC, Fresnel reflector and parabolic trough collectors. For Fresnel and parabolic trough collectors all irradiance has to be direct!

For the CPC-ETC and the parabolic trough collector, Solar-Keymark and SRCC certification data were used. For the Fresnel collector the curve was taken from the web site of TVP Solar for an aperture/gross collector area ratio of 80 %, (http://www.tvpsolar.com/index.php?context=applications). Even though the CSP curve has an uncertainty of 10 %, the maximum yield relationships are clear. It also has to be considered that CSP collectors need to be constantly and precisely repositioned on at least one axle by an electromechanical apparatus, while CPC-ETC collectors, once optimally installed according to latitude and usage, remain permanently mounted in one position. It is also important to clarify certain points about solar radiation:

1. In almost all locations worldwide the percentage of diffuse sunlight is well over 50 %. This percentage only sinks to around 25 % in extremely arid and inhospitable areas. All this diffuse radiation is not used by concentrating technology. In addition, if the mirrors become even slightly dirty the yield will rapidly approach zero, as direct radiation is then converted into diffuse radiation.
2. The direct radiation spectrum very rarely reaches its peak values. Without the additional diffuse radiation it is virtually impossible to obtain power above 900 W/m². The yearly average for total radiation does not exceed 600 W/m² anywhere on the planet, and the yearly average for direct radiation scarcely reaches 500 W/m². In these values we have neglected all radiation below 100 W/m², as otherwise the yearly average would clearly fall even lower.



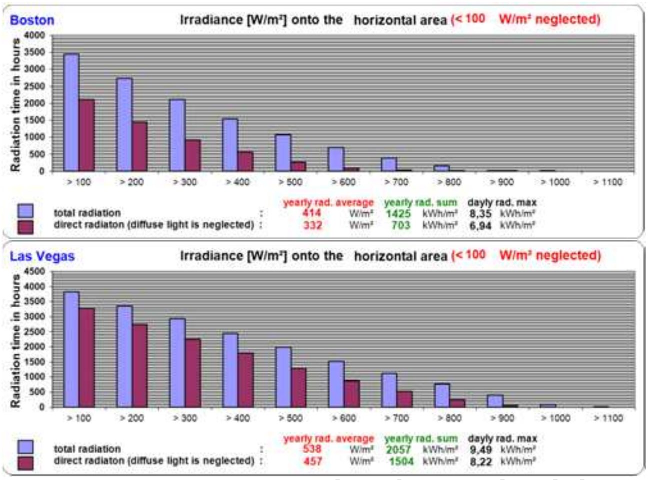


Fig. 6: METEONORM 4.0 data about total and direct irradiance in Boston and Las Vegas

Radiation relationships and collector curves give only snapshots. A year-long simulation for particular locations with defined temperature conditions is much more informative. The following simulation was calculated using T*SOL 5.0 Professional to compare the performance of a particularly simple hydraulic system at 5 different locations for 5 different collector types and 3 operating temperature conditions. Only the collectors were considered. The heat loss of the piping has almost been neglected and considered to be constant. Unfortunately, some corrections and comparisons with other results (obtained using different methods) had to be made in the case of the concentrating collectors in order to quantify the effect of the mechanical power required. This accounts for the uncertainty of 10 %.

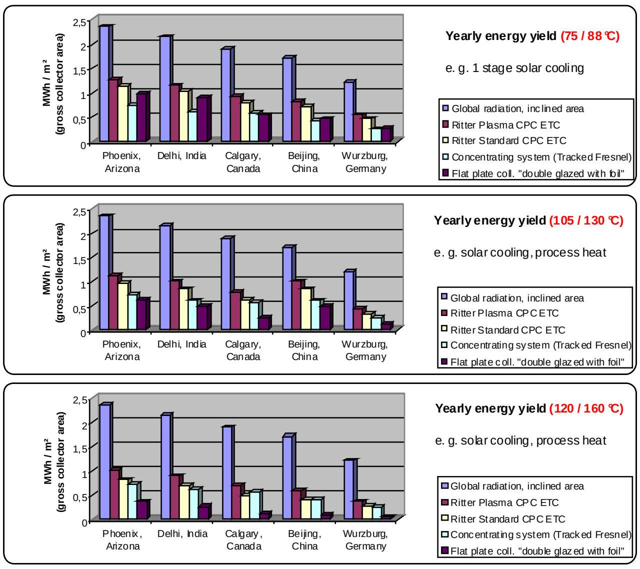


Fig. 7: One year T*SOL simulations for different temperatures, sites and collector systems

3 Applications for solar process heating, cooling and domestic heating networks

About 250 CPC ETC systems have been installed so far with water pressurized up to 8 bars and operation temperatures of 70…95 °C, 35 of them for process heat, solar cooling or district heating and 20 of them with more than 100 m² collector area. Only one CPC ETC, which does not work with water but with silicon oil and supports a Stirling engine, has been built for temperatures of 160…180 °C. Water steam generation is already proved at testing systems. At the moment a 400 m² installation is under construction for a water steam jet cooling pump with steam temperatures of 160…180 °C.

1330 m² Festo (Germany 2007) cooling and heating
1033 m² Metro Istanbul (Turkey 2009) cooling

3388 m² trade center Wels (Austria 2011) domestic heating network

458 m² Juluis Blum (Austria 2011) galvanization

221 m² Hustert Galvanic (Germany 2011) galvanization
394 m² Zehnder (Schweiz 2012) dip painting process

164 m² New York tube (USA 2010) train washing station
527 m² Elk (Poland 2009) concrete plant

417 m² Parris Island (USA 2011) cooling
550 m² Kral (Austria 2011) cooling

Fig. 8: CPC ETC applications for domestic heating networks, cooling and process heat

4 Summary

CPC ETC water technology is a high-efficient solar thermal system and already proven at lower temperatures millions of times. Obviously it is also reliable for medium-sized temperatures up to 180 °C. With water as heat fluid there is a temporary restriction to 160 °C because the boiling pressure must not be higher than 10 bars. The hydraulic system has also already proven thousands of times at temperatures up to 95 °C to be proof against thermal stagnation by self-filling and self-emptying in the case of boiling although the collectors are not tracked. For higher temperatures different pumps, valves, storages and thermal insulations are necessary. The R&D as well as the testing effort is comparably small because the collector system already exists. Depending on the geographic location for operation temperatures of 160 °C a solar efficiency of about 20...40 % is possible. The time is ripe for using CPC ETC in industrial processes for heating and cooling.

5 References

(2) Meissner, Rolf, CPC-Vakuumröhren-Kollektoranlagen für Prozesswärme bis 160 °C, Erneuerbare Energien Austria 2012-4