Technological efficiency of solar energy absorption by concentrating collectors

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Abstract

Reducing fossil - exhausting and non-renewable, fuels and increased concentrations of greenhouse gases on a global level, have influenced the intensive development of alternative energy sources, and thus use of solar energy has an important role in energy production from renewable sources. This paper presents the system and method of absorption solar energy using concentrating collectors, whose application in the world is year per year more pronounced. The fact, that in this way up to 2040., about 20 per cent of world electricity consumption is going to be produced, further raises the need to pay more attention for this method of obtaining energy, especially due to the fact that mainly, this source is available to all parts of the planet.

Key words: energy, Sun, solar collectors

1. Introduction

Today, energy is one of the most important components of development and functioning of the economy and society in general. Energy has a key geopolitical importance, dominant contribution to this state provide climate changes and security of energy supply, taking into account above all the fact, that the reserves of oil and natural gas are limited and concentrated in a small number of states. Struggles over access to energy sources, throughout history, have often led to the energy crisis, which caused disruptions in energy supply on the market, and their deepening often to conflicts, including wars.

Oil reserves are limited and it is assumed there are still for a maximum of forty years, gas for sixty or so, and coal for about 200 years ago. The big problem is the fact that shallow reserves of coal (near surface), as well as those of better quality are already exploited. This will make energy more expensive and complex.

In addition, the increase in population from 2.5 billion in 1950, to nearly 7 billion today, or implied 10 billion by 2050, and continuously improving of the comfort of living, results in greater power consumption. This imposes the need for finding new energy sources, preferably from renewable sources.

Besides wind energy, tide, biomass, hydrogen, and other, special attention should be paid to the energy of the sun, especially because it is partially accessible to all parts of the world, whose adsorption can be achieved by a variety of collectors.

2. Concentrating solar collectors

Systems with concentrating solar radiation are primarily intended for generating electricity in so-called „Solar power plants“, but can also be used for hot water, heating and cooling of buildings, drying, steam production, etc. German Advisory Council on Global Change (WBGU) argues that in 2050, OIE in the southern parts of Europe and the Mediterranean will be the main source of energy, and dominant role will have solar power plants.

Bearing in mind the fact that collectors are less effective in areas with few sunny days, because they use only direct component of radiation, an ideal locations for setting up these systems are located in the so-called *„Solar energy zone“*, which is roughly located between 40° of south and north latitude - figure 1. In parts of the area which are the most exposed to sunlight, average, annual insolation values are above 1900 kWh/m^2. It is estimated that only 2% of the Sahara area covered by the systems with concentrators would be enough to satisfy global demand for electricity.

Concentrators or focusing collectors are PSE in which the sun’s rays caught from the larger areas concentrate on a smaller area. The concentration ratio of the collector k can be expressed by equation 1.

$$k = \frac{A_p}{A_a} \quad \text{..................................} \quad (1)$$

where:
$A_p[m^2]$ - The solar radiation collection area,
$A_a[m^2]$ - Absorption surface

By selecting appropriate concentration relationship, it is possible to achieve desired temperature in the system, which is the biggest advantage of such systems. Unlike flat solar collectors whose concentration ratio is always $k=1$, a concentration ratio of focusing collectors can have a value of about 50 linear - focusing collectors, i.e. over 1000 for spot focusing collectors. If the concentration ratio $k \leq 10$ is sometimes necessary, and if $k \succ 10$, it is necessary to constantly direct the collector to the sun. With increasing concentration ratio, temperature of the fluid in the absorber also increase (reaching a temperature up to 2000°C), so the working fluid in these systems is usually not air but water, thermal oil, or other fluid with suitable thermal properties. [1].

The advantage of these systems, compared to flat collectors, is much higher thermal efficiency of these collectors. Thermal efficiency largely depends on the type of material used. Table 1 shows the reflective properties of some materials used to produce mirror concentrators.

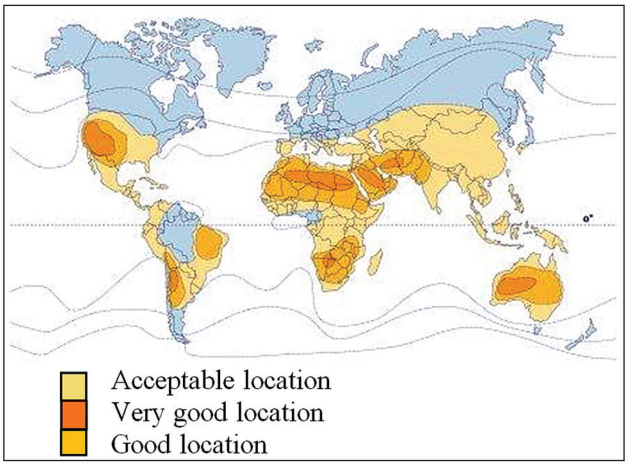


Figure 1. Solar energy zones
(source: Solar Millenium AG)

In terms of use, the concentrators (focusing collectors) can be divided into:
– Heliostat,
– Solar thermal power plants,
– Solar furnaces [2].

Table 1. Reflection of the materials used for solar energy concentrators [3]

Mirror making material	Reflection [%]
Silver	94±2
Gold	76±3
Aluminized acrylic	86
Anodically oxidized aluminum	82±5
Different aluminum surfaces	82 up to 92
Copper	75
Glass with a silver layer	88

Concentrators have drawbacks, of which only few will be listed. To set up the system with concentrators, large areas of agricultural and building land are necessary, as their installation on the roofs of commercial and residential buildings is generally impossible. Thus, for example, systems with Linear Fresnel reflectors occupy about 4–6m^2/MWh, systems with parabolic collectors around 6–8m^2, and systems with a parabolic concentrator and central receiver 8–12MWh of installed capacity, [3]. Unlike flat panels, concentrators collect little diffuse radiation, which in the warm, cloudy days can be intense. Reflective surface over time lose their original features (they get dirty), so they must be periodically cleaned or re-process their surface (in areas with low rainfall cleaning of reflective surface is done every two months). Multi-part parabolic reflectors consist of a two-part or multipart parabolic reflective surfaces that due to multiple reflections of solar radiation, lead beams that fall within their entrance point -$\theta_{acc.}$ to absorber.

Absorber walls are made of thermosetting plastic that is coated on the inside with highly reflective aluminum foil. The form of multi-parabolic collector is shown in Figure 2.

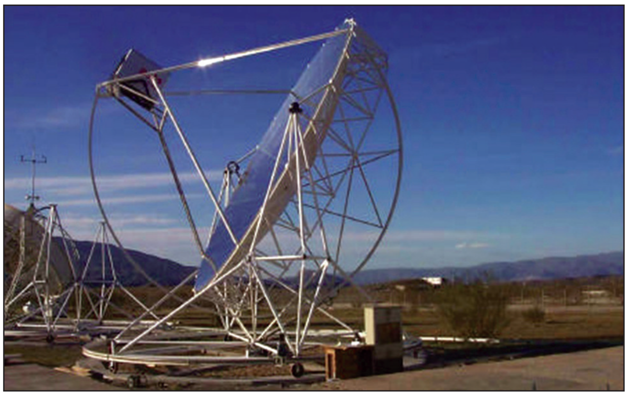
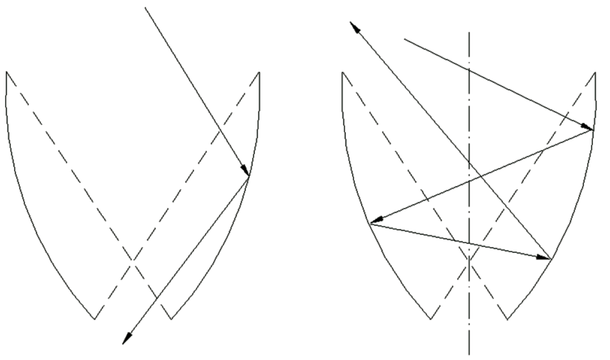


Figure 2. Multi-part parabolic collector
(Stine, 2001.)

The position of multi-parabolic reflector is determined by the entrance angle, which is defined to always “catch” direct sunlight. If the entrance angle is $\theta_{acc} = \pi$, those are flat solar collectors. If the entrance angle of the sun rays is $\theta_1 \prec \frac{1}{2}\theta_{acc}$ then the sun rays will be reflected to the absorber (receiver) which is located between the focus of a parabola, and if $\theta_1 \succ \frac{1}{2}\theta_{acc}$, the rays are reflected above the focus of a parabola and the receiver will not absorb them. Figure 3.



$$\theta_1 \prec \frac{1}{2}\theta acc \qquad \theta_1 \succ \frac{1}{2}\theta acc$$

Figure 3. Reflection of light from the CPC

Multipart parabolic collectors can have fixed and movable panel (which is driven mainly by one axis). If the concentration ratio is $k \succ 6$, temperature in intervals from 100 - 160ºC can be obtained, and the efficiency is about 50%. (Rabl, O’Gallagher and Winston, 1980). [4]. CPC collectors can achieve temperatures up to 300ºC.

2D parabolic collectors (Parabolic Trough Collector)

Parabolic collectors or RTS collectors (Parabolic Trough Collector) consist of longitudinal parabolic reflector (several hundred meters length), which focuses direct component of solar radiation on the focal line, in which the cylinder absorber is set, Figure 4.

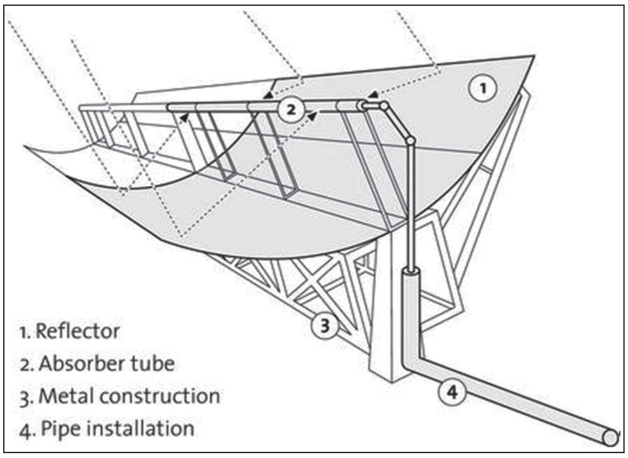


Figure 4. (source: Solar Millenium AG)

The absorber consists of a metal tube, placed in a glass cylinder, between which are air-free (vacuum) gap. A working fluid flows through a metal pipe, (thermal oil, melted with salt or steam under pressure). Selective coating (anti-reflection coating) which filters out infrared radiation, and passes light from the visible radiation spectrum protects absorber surface. Concentration ratio is usually from *k=10-85*, while working temperature in the system reach 400°C. In order to achieve a specified temperature, collectors intensively monitor the movement of the sun during the day, using:

- Mechanical, or
- Electronic (electrical) system for tracking the sun,

Which represent the largest factor in otherwise very high costs of solar thermal power plants. Of the intensity of the movement speaks the fact that required accuracy in tracking the movement of the Sun is within the limits of the part of a degree. „*Solar Field*“ consists of a large number of parallel, longitudinal, parabolic reflectors, usually set along the longitudinal axis of the north-south line. Regardless of the vast area occupied by the solar field, these high- precision optical devices have been placed with millimeter precision. Existing systems with 2D parabolic collectors in solar power plants generate about 100 kWh/year of electricity energy per m2 of the surface of collector. [5]. Degree of efficiency of transformation of radiant solar energy into useful heat is about 24% in summer (maximum 30%), i.e. up to 15% during the year.

3. High temperature conversion

For high temperature conversion of solar radiation, (400-4000°C) solar systems with concentrators of solar radiation that follows the movement of the sun are used.

Spherical concentrator

Surface of the spherical concentrator is covered with a large number of small flat mirrors reflecting approximately 92.5% of entering sunlight towards absorber vessel. Spherical concentrator can be mobile or fixed. If the spherical concentrator tracks the movement of the sun, absorber vessel is placed in focus, and if the spherical concentrator is stationary, absorber vessel is moving. The concentration ratio of spherical concentrators is in the interval of *k=50-150*, and the working temperature of medium is 300-500°C. [6].

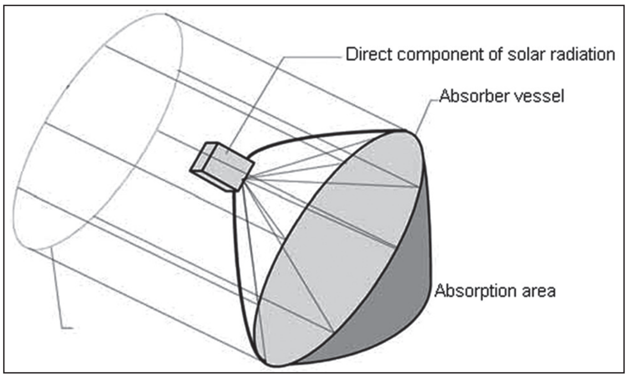


Figure 5. Schematic view of a spherical concentrator [7]

Parabolic concentrator (Parabolic dish concentrator)

Parabolic concentrator is made of unsteady concentrating PSE (concentrator) whose focus is in the absorber due to reflected sunlight. The average size of the concentrator's diameter is about 10m. The concentration ratio increases with increasing diameter of the concentrator, and therefore the temperature in its elliptical focus. Increasing the size of the parabolic concentrator is limited by the durability of the support structure and biaxial mechanical system for its launching. The concentration ratio of these systems is significantly higher than the previously mentioned systems, ranging from k=100-1500, so the temperature of working medium in the absorber ranges from 600 to 2000°C. [6], [8].

Parabolic concentrators are usually combined with a system for producing electricity, which is in the focus of the collector. The link between the solar collector and generator is the absorber, which converts the absorbed solar energy into thermal energy of the working medium, which then transfers heat to the generator. Stirling engine with a gas turbine is mainly used [6]. They are used for providing energy in rural areas, regardless of the distribution network Figure 6.

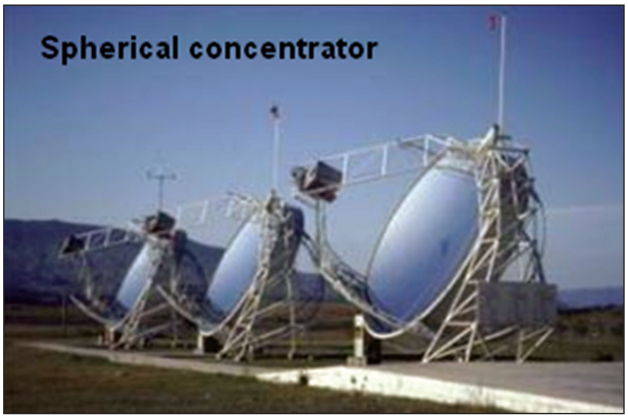


Figure 6. The system of parabolic concentrators on Solar de Almeria platform

Although considered the least developed systems for concentrating sunlight, given the relatively simple construction, the ability to easily transfer the system and the ability to connect to the distribution network, can compete with conventional systems for producing electricity. Due to the biaxial movable supporting mechanism, frequent servicing are needed, which is largely reflected in the viability of the system.

Central receiver with the heliostats field

The sun's rays are reflecting towards the central receiver (absorber vessel) which is situated high above the earth's surface, where at high temperatures water turns into steam, using multitude of computer-controlled mirrors that track the Sun (heliostats). Water steam under pressure expands in steam turbine, where converts mechanical energy into electrical energy. Technology of central receivers with heliostats field enjoys a high rating, mainly due to successful implementation on the

„Solar One" facilities, Picture 7, and „Solar Two", Picture 8. Construction of the first commercial solar power plant „Solar Tres" recently started and construction of „Solar 100" and „Solar 220" is expected. The characteristics of these plants are given in Table 2.

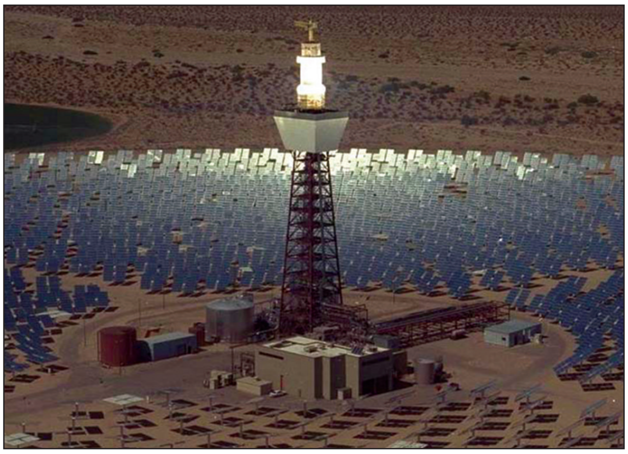


Figure 7. Photos of solar thermal power plants (Solar One) in the Mohave Desert, USA
(Source: Sandia National Laboratories)

Due to the high values of concentration ratio (up to 1500) and temperatures created in this way (up to 2000°C), the working media other than water, can be air, liquid sodium, molten salt, while in modern plants most commonly used is solution of nitrate salts due to better heat transfer and storage characteristics [8].

For example, in „Solar Two" facility, a working medium (molten-salt mixture of 60% $NaNO_3$ and 40% KNO_3) temperature 290°C using a pump is pushing out of the „cold medium reservoir" – through the central receiver (where is heated up to a temperature of 565°C) to a „hot medium tank" (each tank characterize 875000L volume). Due to large fluctuations of the solar radiation intensity and the low density of energy flux, accumulation (storage) of energy is often necessary. Figure 8 shows a solar plant built in northern Africa.

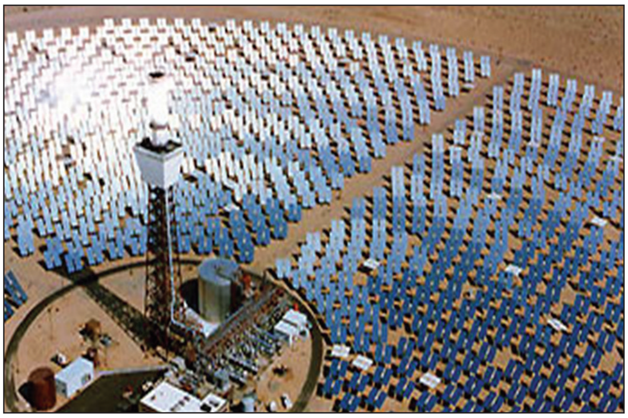


Figure 8. View of solar power plant [9]

In a system for storing heat, energy collected during sunny periods, i.e. energy is draw during periods when solar radiation does not exist or it is not enough. If the solar radiation is intense, solar field generates enough energy to run electricity generators and energy storage in the system for storing heat, allowing operation of the generator a few hours after sunset, thus increasing the efficiency of concentrating solar radiation.

Large heliostat areas (50-150 m2) and a large installed capacity of gas turbines characterize these systems (over 10MW) [10]. The study, „Solar powered power plants 2020" carried out by Greenpeace in collaboration with European industry for solar powers, shows that the amount of solar energy used in this way in the world can reach up to $54 \cdot 10^6$ MWh

Table 2. Characteristics of solar thermal power plants

Solar power plants	Solar One /Two	Solar Tres	Solar 100	Solar 220
Power of the plant [MW]	10	15	100	220
The efficiency of solar radiation transformation into electricity [%]	7,6	13,7	16,6	18,1
Accumulation [h]	3	15	13	13,1
Solar field surface [$10^3 m^2$]	81,4	231	1311	2642

Table 3. Annual insolation values, comparing unit prices for electricity generated by solar power plants with the local electricity prices and incentives in the three countries in the Mediterranean region and Serbia [11]

Country	Location	Annual value of insolation [kW/m^2]	Price of the electricity produced by FN solar power plants (c€/kWh)	Unit price of electricity (c€/kWh)	A measure of incentives - the purchase price (c€/kWh)
Spain	Oveido	1214	37,7	~9	41,44< 100 kW
	Almeria	1787	27,7		21,62> 100 kW
Portugal	Porto	1644	29,0	~12	~ 55 < 5 kW
	Faro	1807	27,9		~31-37 >5KW
Tunisia	Tunic	1646	31,2	~2-5	
	Gafca	1793	28,4		
Serbia		1400-1578		~1,1 – 12,7	23

in 2020., and according to projections, over in 2040., over 20% of total world energy needs will be able to be covered by solar power plants.

4. Power plant construction costs

The investment costs for FN solar power plants, depending on the structure, size, heat storage systems, as well as the size of the power plant are 2000-5000€/kW (usually around 4000 €/kW, about three-quarters of these prices are the costs of FN modules. [11]. In Table 3 are given prices for electricity generated by solar FN power plants, as well as the subsidized purchase price of electricity in Serbia and in Mediterranean countries (Spain, Portugal, Tunisia).

The introduction of alternative energy sources contributes to increase energy efficiency, i.e. leads to reduced consumption of energy resources and reduce greenhouse gas emissions. [12], [13].

5. Conclusion

The increase in population from 2.5 billion in 1950., to nearly 7 billion today, or implied 10 billion by 2050., and continuously improving of the comfort of living, leading to increased energy consumption. This imposes the need for finding new energy sources, preferably from renewable sources, because the supply of fossil fuels is exhaustive.

Reduction of fossil fuels on the one hand and increased concentrations of greenhouse gases on a global level, on the other hand, influenced on the intensive development of alternative energy sources, resulting in the use of solar energy has an important role in its producing.

The fact, that in this way up to 2040, about 20 per cent of world electricity consumption is going to be produced, further raises the need to pay more attention for this method of obtaining energy, especially due to the fact that more or less, this source is available to all parts of the planet.

The costs of building solar power plants are getting low, and the production of electricity by absorbing sunlight with the state incentives in many countries is becoming more profitable.

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