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Designs of Solar Concentrators

This paper gives an insight into the design of concentrating solar power (CSP) systems. The basic design of several types of CSP system is presented alongside their advantages and disadvantages. These advantages and disadvantages are based on their application and construction details and the paper shows how to select the most convenient CSP system. After presenting these types of CSP systems, an example of a new type of design is explained that presents a combination of several other solar concentrators.

Keywords: *solar power, CSP system, concentrator design*

1. INTRODUCTION

Scientists and engineers are responding to climate changes by developing new technologies to reduce carbon dioxide (CO_2) emissions, capture greenhouse gases, generate energy from renewable sources and distribute energy more efficiently. Using solar power as one of nature's greatest renewable resources is beco–ming ever more appealing since the first oil crises in the mid-1970s. Since then, greater attention has been devoted to developing solar power systems, which can provide an alternative to fossil fuels. As a result of these efforts, the cost of these technologies has declined but there is still a long way to go before they are fully embraced and accepted.

There are two main approaches to using solar power: photovoltaic solar technology (PV) and concentrated solar power (CSP). Photovoltaic (PV) is a term which covers the conversion of light into electricity using semiconducting materials that exhibit photovoltaic effect while CSP uses lenses or mirrors to gather heat from a large area to a small area [1].

Concentrated solar power (also called concentrating solar power, concentrated solar thermal) systems or short CSP systems work on a basic principle which remains the same irrespective of their design. The heat from the sun is reflected by a mirror and then all that heat is focused in one much smaller area. For instance, that small area for parabolic mirror is in the focus of a parabola. Situated in the focus is a receiver (usually a tube) filled with fluid which can be oil, molten salt or any other fluid that keeps heat well. This fluid is then transported to a heat exchanger in which the exchange of heat from one fluid to the other takes place. The fluid which receives heat is most commonly water which thus creates steam. Steam is sent to a turbine and the turbine spins a generator which produces electricity. Once steam changes back into water, it can be reused or, since is still warm, used in households [2]. One way to help improve these systems is to investigate and provide some clarification in the geometry of modern-day solar concentrators.

Variety of these designs of CSP is essential so that plant designs can be optimized for each specific appli–cation and area (country) in which it will be used [3]. This will be further elaborated on some of the intere–sting examples in the design of CSP.

One of the parameters for determining which design is better will be based on how large an area can be captured and in respect to it the mass and complexity of its manufacturing. Scaling-up of first-generation tech–nologies is one of the most important priorities as the basic principle of work is to focus sunlight from the much greater area into a smaller area. Although it may seem as the best solution there are obstacles in using solar power in electricity production. The most obvious one is that solar power plant will not work at night or on cloudy days. Also, in late autumn, winter and early summer these power plants capacities are reduced. Nevertheless, research in the field of solar concentration is far from over and presents a remarkable challenge for the future.

2. EXISTING TYPES OF CSP

Systems for gaining energy from the sun that are based on concentrating sun rays in one focal point or line can be divided into four groups:

- Solar towers
- Parabolic troughs
- Linear Fresnel reflectors (LFR)
- Dishes

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These systems can be seen in Figure 1. Solar towers and dishes use the principle of focusing sun rays at one point while troughs and LFR focus sun rays into one line, which is usually designed as a pipe filled with molten salt. Different types of concentrators produce different peaks of temperatures and correspondingly varying thermodynamic efficiencies. This is due to differences in the way that they track the sun and focus light. New innovations in CSP technology are creating those systems to become more and more cost-effective.

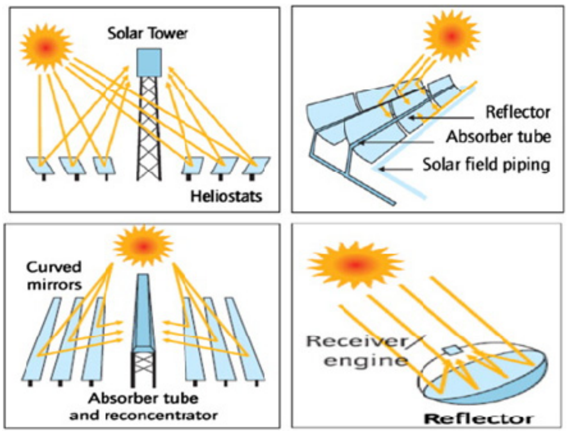

Figure 1. Currently available CSP technologies [4]

2.1 Solar towers

Solar towers turn the solar energy into electricity by the technology that uses a large number of mirrors tracking the sun called heliostats. A heliostat (from helios, the Greek word for the sun, and stat, as in stationary) is a device that includes a mirror, usually a plane mirror, which turns so as to keep reflecting sunlight toward a predetermined target, compensating for the sun's apparent motions in the sky. These heliostats focus the rays of sunlight on the receiver located at the top of the solar tower as can be seen in Figure 2.

The movement of most modern heliostats employs a two-axis motorized system, controlled by a computer. Almost always, the primary rotation axis is vertical and the secondary horizontal, so the mirror is on a simple two-axis mount. About half of the cost for the entire installation goes to heliostats and their additional equipment.

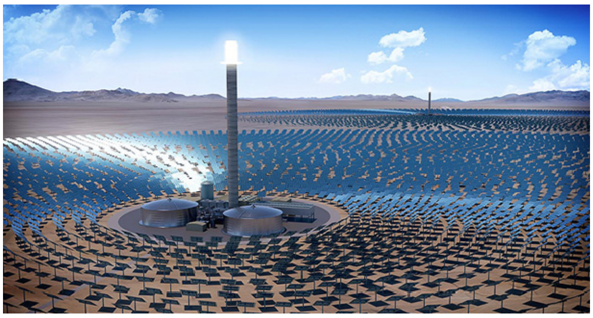

Figure 2. Solar power tower with heliostats

As mentioned before, the working fluid is heated in the receiver and used to create steam that is used in conventional turbine generators for electricity gene–ration. Earlier constructions of solar towers used steam as a working fluid, while in the present constructions a nitrate salt solution is used to achieve better trans–mission of heat and storage characteristics.

Single commercial systems are able that can produce from 50 to 200 MW of electricity. Some of the largest CSP systems that use solar power towers are Ivanpah Solar Power Facility, with 392 MW of power installed, and Crescent Dunes Solar Energy Project that has 110MW of power installed.

2.2 Parabolic troughs

CSP system that uses a trough consists of a parabola troughed reflectors (mirrors), which concentrate sun rays into a focal point which is constructed as an ab–sorber tube. The collector fields contain dozens of pa–rallel rows of tubular collectors arranged along the axis (line) North-South as shown in Figure 3. This con–figuration allows it to monitor the movement of the sun from east to west during days and provides constant focus on the sun. Tracking of the sun is done by rotating reflectors around the absorber tube. Their position pro–vides a constant reflection of the sun to absorber tube.

Heat energy passes through the tube (the working medium is oil) and is used for the production of electricity in a conventional steam generator. Individual trough systems can currently produce about 80 MW of electrical energy. The construction of trunk systems can also contain a thermal warehouse, located next to a heat exchanger at its hot stage (hot part), which allows the generator several hours of operation even after sunset. Currently, parabolic trough systems represent hybrids (mixed systems) [5], which means that they use combustion of fossil fuels for heating solar output during the reduced period of solar radiation. Also, trough systems can be integrated with existing thermal power plants.

Solar Energy Generating Systems (SEGS) in Cali–fornia, with the combined capacity from three separate locations at 354 megawatts is the second largest CSP facility and it uses parabolic trough with the combustion of natural gas.

Figure 3. Parabolic trough [4]

2.3 Linear Fresnel Reflectors

This type of reflecting mirrors is very frequently considered to belong to the group of solar towers since it has similar construction. Linear Fresnel Reflectors (LFR) use long, thin segments of mirrors to focus sunlight into a fixed absorber located at a common focal point of the reflectors (Figure 4). These mirrors are capable of concentrating the sun's energy to approxi–mately 30 times its normal intensity. This concentrated energy is transferred through the absorber into a thermal fluid (this is typically oil capable of maintaining a liquid state at very high temperatures). The fluid then goes through a heat exchanger to power a steam generator.

Linear Fresnel Reflectors usually employ a secon–dary concentrator that enlarges the target area for primary mirrors, and also acts as a protective cover to reduce convective losses.

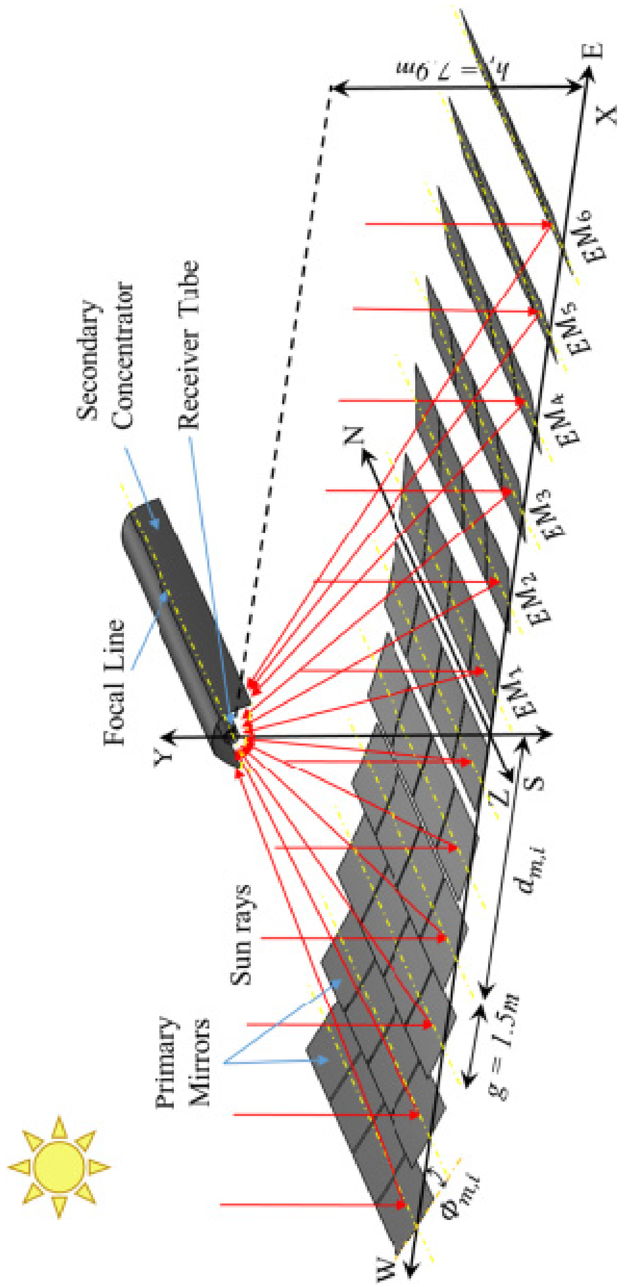

Figure 4. Linear Fresnel reflector [6]

2.4 Dishes

Another type of concentrating solar collector that optically reflects and focuses the ray of sunlight onto a small receiving area using mirrors or lenses is called a Solar Dish Collector, or more technically, a point focusing collector (Figure 5). By concentrating the sunlight to a single spot, the intensity of the receiving solar energy is magnified many times over with each mirror or lens acting as a single sun shining directly at the same focal point on the dish meaning that more overall power per square meter of the dish is achieved.

Unlike the previous solar collector which was in the shape of a long trough or has flat mirrors, a parabolic solar dish collector is very similar in appearance to a large satellite TV or radar dish making it much smaller than a long trough collector. The curved parabolic shaped dish, which is generally referred to as a “solar concentrator” is the main solar component of this type of solar heating system.

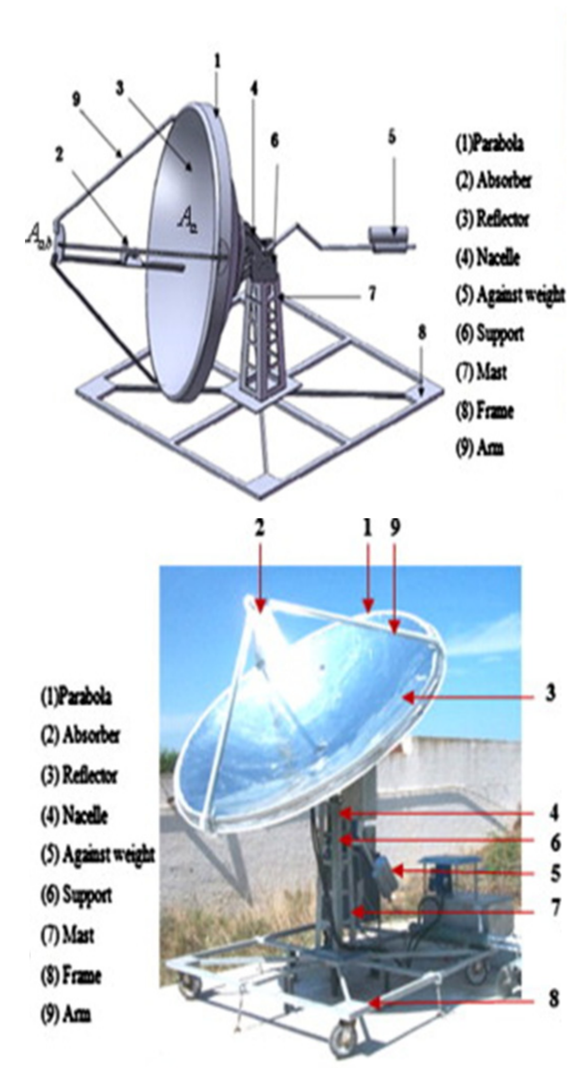

Figure 5. Solar dish [7]

Paper [8] from authors Zorana Jeli et al. has shown a safety parameters for satellite antenna which has a same shape as dish solar concentrator and as such can be used as a guide for further analysis of dish concentrators.

3. NEW TYPE OF SOLAR CONCENTRATOR

All of the systems mentioned above have their advan–tages and disadvantages. For parabolic troughs and LFR systems, the main disadvantage is that rays of sunlight are reflected along a pipe which does not have a thermal output as would be the case if the sun rays were reflected into a single point. In that respect, solar towers and dish concentrators have better performance but their disadvantage is a lack of movability. As it was said before, solar towers have heliostats which track the sun and provide an angle at which the sun rays will be reflected into the tower. For each of these heliostats, there must be a tracking system provided as well as mo–tors for necessary rotations. These motors are also nece–ssary for dish concentrators which, besides this prob–lem, also have a problem with the small surface area.

In order to compensate for these problems in the solar concentrating system, there is a new solution that may bring some advances in this field of engineering. Figure 6 shows the relation of several parabolas when focal heights change. Focal point represented with the point F remains in the same spot but the parabola is becoming more and more "flat". This problem can be noted in the case of dish solar concentrators. For the same diameter (which in this figure is 400cm), the focal point height can vary between 50 and 450 cm depending on the depth of the dish which is 200 cm max and 22.2 cm minimum. This can be a problem during the manufacturing process of a dish concentrator because there must be a compromise between focal height and dish depth.

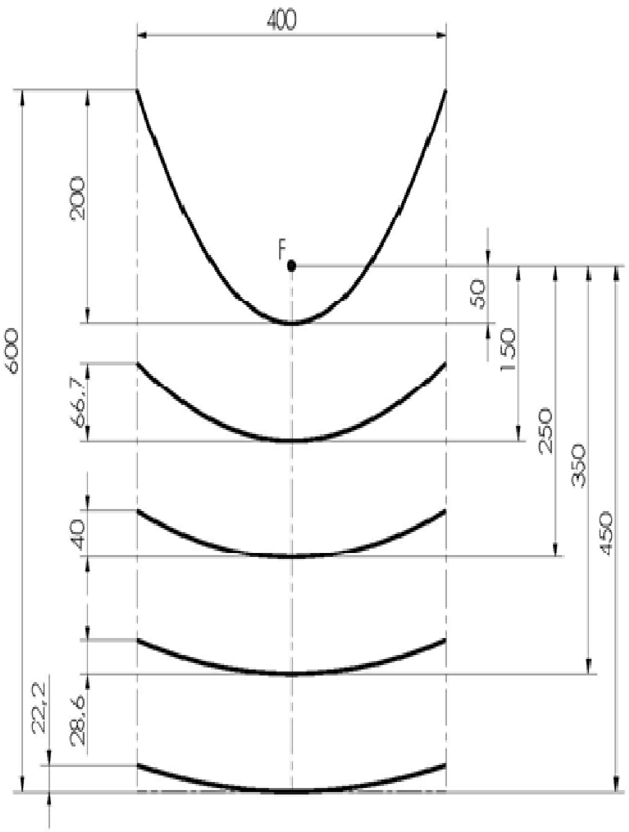

Figure 6. Segments of a parabola having a common focus F

Dish concentrators, as mentioned before, have the advantage of focusing sun rays into a single point. Their disadvantage is movability towards the sun. Also one of the disadvantages is their construction since they must have special presses and molds to press a sheet of metal into a parabolic sphere. If amateurs or hobby enthusiast wanted to construct this type of concentrators, they would find it imposable to do so before acquiring a parabolic dish.

The same simplification can be done using LFR or solar tower principle. In both cases flat mirrors are used in order to reflect sunlight. All these mirrors are placed in one horizontal line as in the case of LFR. The problem with this idea can be seen in Figure 7. The focal point is presented as a sphere which has diameter d. The parabola, shown in Fig. 7a, has a point in which sunray angles reach the parabola and reflect to focal point F. In this point can be placed flat segments which can be connected in that way that they form a parabola constructed from straight line segments and not as spline.

Each of these segment has length b as spherical diameter d. Flat segments are placed perpendicular to the axis of symmetry of the angle that is created by ray from the sun to parabola and from parabola to the focal point.

When these segments are placed in one line as it is shown in Fig 7b, it can be seen that sun rays will not correspond to the demanded trajectory. Angles β1 and β2 need to be slightly adjusted so as to have segments in one horizontal line.

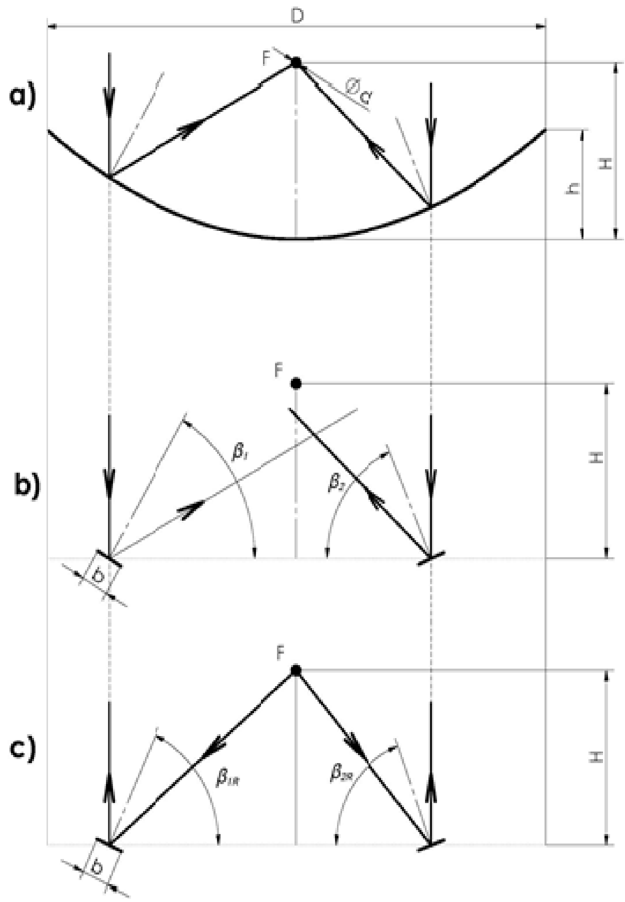

Figure 7 Parabola focus-height distance for equal area

If these segments are placed on a concentric ring so that they reflect sun rays into a focal point, they will form a new type of solar concentrator that combines "focus to point" ability of dish concentrators with the easy construction of Fresnel reflector. This concept can be called Disk Shaped Fresnel Mirrors (DSFM) and it is shown in Figure 8. Axis x-x is pointed to the sun and it tracks the angle of sun elevation which is marked as θ on Figure 8. It can be seen that by changing length L (Figure 8) it changes θ. This change is not as frequent as the solar azimuth angle. The solar azimuth angle is the azimuth angle of the sun position that can be defined as the angle between a line due south and the shadow cast by a vertical rod on the Earth. To clarify this, a concentrating system needs a rotating axis to track the sun during the day. In Figures 8 and 9 this rotation axis is marked as axis y-y. By rotating around this axis and changing the length L during a certain period of time easy tracking system can be achieved, which would possibly require less motor power or invested energy for moving. The diameter of this DSFM can be altered to a new value just by adding more rings on the disk. Figure 10 shows the basic concept of this new disk-shaped Fresnel concentrator with the receiver.

This concept is purely designed in order to show that there is more room for improvement in the sphere of designing solar concentrators. Further research will be done in order to see if it is possible to rotate this disk using less power than is required for the dish concentrator with the same reflecting surface.

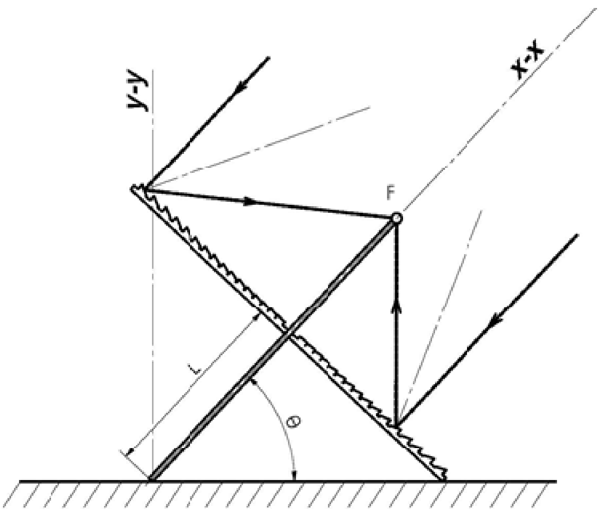

Figure 8 Disk shaped Fresnel mirrors

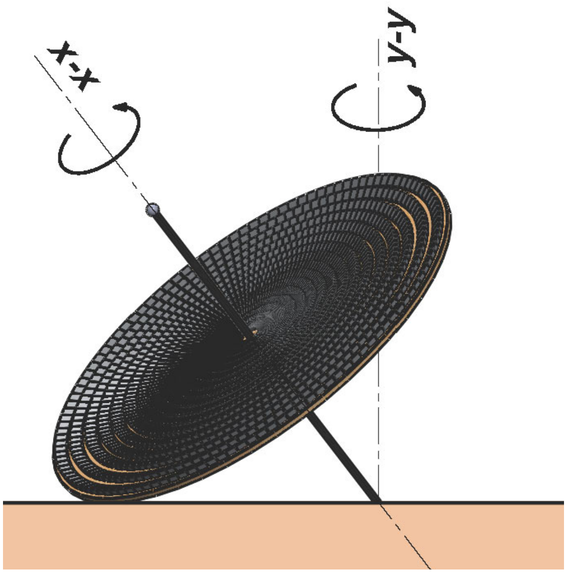

Figure 9 Axis of rotation

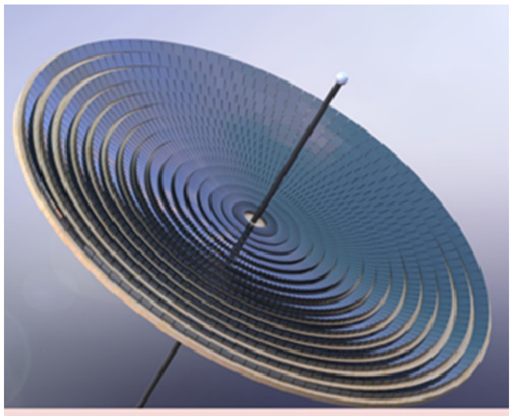

Figure 10. Disk reflector and receiver

4. CONCLUSION

This paper shows basic functional principles of solar power plants and their different constructions and wor–king types. It also describes how several spread con–cepts of variable designs can be combined into the crea–tion of a new concept that may provide optimum results. New disk concept provides considerable benefits and enables an upgrade of current technology. New design in the field of solar concentrators is presented here. Further research should result in more precise dimen–sions and controlling mechanism for disk-shaped Fresnel reflector.

REFERENCES

[1] Slooff, L.H., Bende, E.E., Burgers, A.R., Budel, T., Pravettoni, M., Kenny, R.P., Dunlop, E.D. and Büchtemann, A.: *A luminescent solar concentrator with 7.1% power conversion efficiency*, Physica status solidi (RRL)-Rapid Research Letters, Vol. 2, No. 6, pp. 257-259, 2008.

[2] Boerema, N., Morrison, G., Taylor, R., and Rosengarten, G. *High temperature solar thermal central-receiver billboard design,* Solar Energy, pp. 356-368, 2013.

[3] Zhang, H.L., Baeyens, J., Degrève, J. and Cacères, G.: *Concentrated solar power plants: Review and design methodology,* Renewable and Sustainable Energy Reviews, 22, pp. 466-481, 2013.

[4] Kumar, A., Prakash, O. and Kaviti, A.K.: *A comprehensive review of Scheffler solar collector,* Renewable and Sustainable Energy Reviews, Vol. 77, pp. 890-898, 2017.

[5] Price, H., Lupfert, E., Kearney, D., Zarza, E., Cohen, G., Gee, R. and Mahoney, R.: *Advances in parabolic trough solar power technology*, Journal of solar energy engineering, Vol. 124, No. 2, pp. 109-125, 2002.

[6] Prasad, G.C. et al, (2017.) "Optimization of solar linear Fresnel reflector system with secondary concentrator for uniform flux distribution over absorber tube." Solar Energy, 150, pp. 1-12

[7] Skouri, S et al., (2013.) "Optical, geometric and thermal study for solar parabolic concentrator efficiency improvement under Tunisia environ–

ment: A case study." Energy conversion and management, 75, pp. 366-373

[8] Jeli, Z., Stojicevic, M., Cvetkovic, I., Duta, A. Popa, D.L., 2017. A 3D analysis of geometrical factors and their influence on air flow around a satellite dish. FME Transactions, 45(2), pp.262-267.

[9] Margaritou, M.D. and Tzannatos, E., (2018.) A multi-criteria optimization approach for solar energy and wind power technologies in shipping. FME Transactions, 46(3), pp.374-380.

ДИЗАЈН СОЛАРНИХ КОНЦЕНТРАТОРА

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Овај рад даје увид у дизајн концентрисаних соларних система (CSP). Приказано је неколико типова већ постојећих система са њиховим предностима и манама. Ове предности и мане су базиране приликом употребе ових система као и њиховим конструктивним карактеристикама и овај рад даје препоруку за одабир најпогоднији систем. Након презентације ових типова CSP система дат је приказ новог дизајна соларног концентратора који је настао као комбинација неколико различитих типова соларних концентратора.