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CHAPTER 2

SUPPORT FRAME OF SOLAR CONCENTRATOR WITH FLAT TRIANGULAR MIRRORS

ABSTRACT

Green energy includes solar, wind, geothermal and other types of energy sources generation. The object of this research is solar concentrators. The problem to be solved is connected with the development of the structure frame, especially for solar concentrators with flat triangular or square mirrors that approximate a parabolic shape surface. The essence of the investigation is developing and producing several prototypes of solar concentrators that have low cost of materials but since the devices were assembled by hand, the cost their manufacture is quite high. Therefore, it is important to reduce cost through automation of solar concentrator production process. To obtain the better condition for future automation it is necessary to reduce the number of metal structural elements of solar concentrator. In this case the automation problem is simpler for its realization. The purpose of the research is to develop a new and improved design of the solar concentrator frame prototype, which should be technologically simpler than the previous one and lighter in weight. The study proposes a new frame structure design that contains fewer metal elements, is lighter than the previous one and is more convenient for the automatic assembly process. The development of improved solar concentrator design and structure can help to reduce the cost of assembly and to accelerate the solar concentrator assembly process. In case of massive production, they can be used in practice. The proposed solar concentrators can be used, in particular, for green buildings in rural areas, in reactors to accelerate the chemical process of processing organic waste, in agriculture in combination with agricultural fields. These solar concentrators are quite promising in combination with small thermal energy storage devices, with the help of which it is possible to create small power plants for green buildings that satisfy all the energy needs of residential buildings.

KEYWORDS

Solar energy, flat facet parabolic solar concentrator, thermal energy storage, support frame.

Energy consumption is growing all over the world due to new lifestyle trends in the form of the increasing use of electronic devices. Global energy consumption will grow nearly 50 % from 2018 through 2050, according to the U.S. Energy Information Administration (EIA) [1]. With the threat of global warming and the rising cost of energy, the trend towards the use of renewable and sustainable energy sources is becoming more and more popular.

The use of solar energy, for example, in Mexico or in Azerbaijan, has great potential, since these countries have good conditions for the development of this industry, which is expressed in the duration of sunny days, their number, as well as direct solar radiation on the surface [2]. Solar energy is the most powerful and affordable, as well as the use of solar energy is leading in renewable energy.

Solar power plants are designed to convert the energy of solar radiation into heat and electricity. There are the following types:

1) photovoltaic (PV) converters that are used to directly convert electricity through the photovoltaic effect [3, 4];

2) thermal concentrated solar power (CSP) that are designed to produce thermal energy for its further use or conversion into other types of energy. The mirrors and lenses are used in CSP to generate thermal energy.

Photovoltaic converters used semiconductors. The operation of the device is based on the emission of photoelectrons or the internal photoelectric effect. Currently, silicon-based photovoltaic modules (single-crystal and polycrystalline) are the most common type.

Solar concentrators are devices that capture incoming solar radiation and convert it into usable heat. This heat is transferred to the working liquid for transfer directly to the consumer, to a heat exchanger, or a heat engine (for example, Stirling or Ericsson engines) to generate electricity. The temperature level of the working liquid determines its energy performance, and the main factor is the mass flow rate of the working liquid. There are installations for the simultaneous production of electricity and hot water at the outlet.

Renewable energy has many aspects to develop. Solar, wind, geothermal energy and so on demand the special instruments and apparatus to generate electricity from different energy sources. So, industrial engineering and engineering design are very important to be developed. But not only engineering side of this problem is important. For example, the storage and transportation of renewable energy is very important too [5]. For this reason, the mathematical models are constructed to evaluate or optimize the renewable energy systems [6, 7]. In [7] the authors not only created the mathematical model but and applied the model to analyze energy storage and hydrogen production at renewable energy power plants in Japan in 2050.

It is important to integrate renewable energy sources for new housing developments to reduce demand for grid energy and carbon emissions [8]. Different technologies are oriented to include or to combine with green energy [9, 10]. An effective response to climate change is a rapid replacement of fossil carbon energy sources with green energy [10]. So, the target of decarbonization in the energy sector can be achieved. The intensification of the use of different renewable energy sources is essential for the fulfillment of the Paris Agreement or for achieving the goals of sustainable development [11].

So, green energy, and especially solar energy generation is very actual and important area of science and engineering. To create cheap and effective devices is a challenge for scientists.

2.1 LITERATURE REVIEW AND PROBLEM STATEMENT

Solar energy is one of the most accessible energy sources. Different countries actively develop the photovoltaic systems. For example, one of the leaders in these investigations is India [12]. Development and application of solar energy have been regarded by the government of India and common people, and they thought that solar photovoltaic energy can provide more energy in future compare to other renewable energies.

Not only photovoltaic systems are developed. Parabolic solar concentrators are developed [13]. The authors developed a system comprising external parabolic solar concentrators integrated with cylindrical vertical type sensible-based thermal energy storage (TES) tanks. Solar concentrators can generate thermal energy in the highest operating temperature range (≥300 °C) and can be used in solar thermal-energy applications in the industrial sector [14]. Parabolic dish concentrator converts 72 % of solar energy into usable heat [15]. With 50 % of global energy consumption in the form of heat, the market for thermal energy is vast.

The parabolic concentrators are expensive because of using large-area curved mirrors. A way to overcome these difficulties can be connected with plane mirror using. To reduce the cost, let's propose to use plane mirrors that have a cost 2–3 dollars for one square meter. For our task it is necessary only to cut them. Low cost parabolic solar concentrators based on multitude of small triangular flat mirrors that can approximate parabolic surfaces were developed [16]. These solar concentrators can be used for energy supply to residential houses [17]. Small scale residential power plant will contain flat facet parabolic solar concentrators, TES, and powerhouse hall. Let's present in **Fig. 2.1** two possible variants of their collocation. The system presented in **Fig. 2.1, *a***, is better when there are free areas or can combine the solar concentrators with agricultural fields [17]. The system presented in **Fig. 2.1, *b***, is better for economic surface using.

Parabolic solar concentrators can generate heat energy (approximately 300–400 °C) in the focal point and then can be accumulated in TES. Equipment for transformation of heat energy to electrical energy and middle/low temperature heat energy is situates in powerhouse hall. Middle/low temperature heat energy can be used for space and water heating (for example, hot water we can use for chemical reactors to accelerate the chemical process of organic waste processing [6]), for meal preparation, etc. Electrical energy is needed for illumination and electrical devices feeding.

Let's propose the design of solar concentrators and TES [6]. Flat facet solar concentrators were proposed in 80^{th} years and the prototype of solar energy plant based on these concentrators was made in Australia, White Cliffs (1998) [18, 19]. After that many versions of flat facet solar concentrators were proposed, developed and patented.

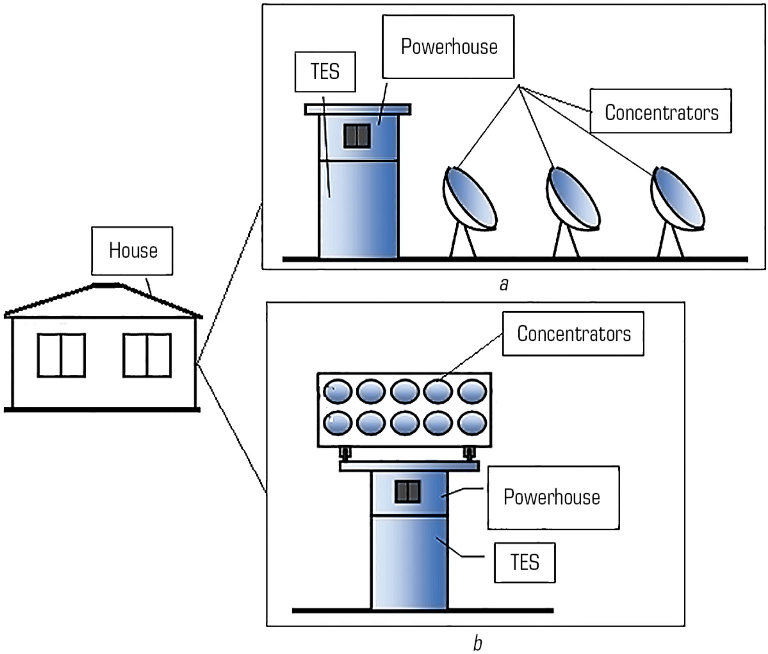


Fig. 2.1 Residential power plant: *a* – parabolic solar concentrators are collocated in special zone; *b* – solar concentrators are combined in the roof of TES and powerhouse

The main goal of these works is to decrease the cost of materials and labour needed for parabolic solar concentrator manufacture.

2.1.1 EXISTED PROTOTYPES OF SOLAR CONCENTRATORS

Last decade we developed several prototypes of flat facet concentrators and improved the methods of adjustment of parabolic surface [19–21]. It is possible to estimate the cost of concentrators near 20 or 30 USA dollars per square meter. This cost permits to supply all needed energy for the houses in countries with hot arid climate, for example, in Azerbaijan and Mexico. In countries with cold climate such as Ukraine and Canada solar energy can provide a significant part (sometimes more than half) of the energy consumed by a residential house. So, let's consider the possibility of using solar concentrators in different countries. In this regard, let's propose a brief analytical review of modern technologies of existing solar concentrators.

The proposed concentrator is useful in application both for remote consumers from engineering networks and for saving energy resources. A solar parabolic concentrator can be used with different receivers in focal point, for example, with the Stirling or Ericsson engines that can transform the thermal energy to electricity.

The parabolic concentrator with a spiral receiver for converting thermal energy and obtaining water at a temperature of 85 °C for domestic needs is described in different applications [22].

At present, among countries with low incomes, parabolic concentrators are popular, made with low characteristics, nevertheless, with a temperature suitable for heating water or cooking. Solar installations of this type are usually made from satellite parabolic antennas by coating them with a reflective surface. Solar parabolic cooking units are very popular in India, and the output characteristics are sufficient for cooking due to the scorching sun and climate [23]. In **Fig. 2.2** the solar concentrators from Repasso Energy are presented.

Fig. 2.2 Solar concentrators from Ripasso Energy
Source: [23]

The responsible for this project was the company Ripasso Energy. In the Kalahari Desert in South Africa two solar concentrators with diameter of 12 meters each were installed and that are synchronized thanks to a Stirling engine. Studies have shown that conventional solar panels can provide 15 percent of the energy they receive in electricity, but Ripasso has developed a device (solar concentrator) and has managed to double this amount to 34 percent, managing to generate 75 MW to 85 MW per hour that is enough to power an average of ten homes for a year [23, 24]. The solar concentrator of Ripasso is equipped with a mirror reflector with a total area of $S = \pi \cdot R^2 = 3.14 \cdot 6^2 = 113.04$ m^2, a giant disk rotates after the sun moving and constantly adjusts to extract the maximum solar energy. For comparison, producing this amount of electricity from coal burned in a Combined Heat and Power (CHP) plant releases 81 tons of CO_2 into the atmosphere.

Solarflux (USA), a company specializing in the production of parabolic solar concentrators, has developed a model, which converts 72 % of solar energy into usable heat [25]. The solar concentrator from Solarflux is presented in **Fig. 2.3**.

These characteristics were confirmed by tests conducted by the Center for Energy Research at Lehigh University in Pennsylvania, USA. Utilizing an innovative optical design and dual-axis tracking, the parabolic solar concentrator maximizes year-round solar energy capture. As a thermal concentrator, the full spectrum of solar irradiance is taken advantage of, and losses resulting from conversion into electricity are avoided. The solar concentrator had been designed from the ground up to minimize the Levelized Cost of Heat (LCOH) over the lifetime of the system. Built from environmentally resilient low-cost metal components, the concentrator is manufactured using proven techniques borrowed from the aerospace and automotive industries. With 50 % of global energy consumption in the form of heat, the market for thermal energy is vast. The parabolic solar concentrator of Solarflux provides a clean, inexpensive source of thermal energy for a wide range of applications, including industrial process heat, space heating and cooling, hot water, water desalination and purification, and remote and distributed power applications.

The Solar Invictus dish from ZED Solar (developed by AEDesign) is a parabolic concentrator with a diameter of 9 m. The total mass of the supporting structure is reduced to a minimum through the use of the structural properties of the mirrors [26, 27]. The solar concentrator from ZED solar is presented in **Fig. 2.4**.

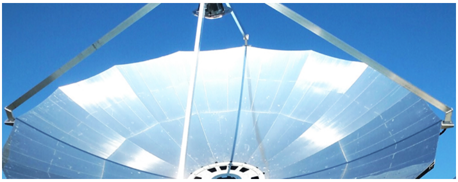


Fig. 2.3 Example of solar concentrator from Solarflux
Source: [25]

Fig. 2.4 Solar concentrator from ZED
Source: [26]

Conventional azimuth and elevation tracking, ZED Solar built its first two prototype dishes in Lahore, Pakistan in 2010 and 2012. The company delivered a prototype to Cleanergy in Omol, Sweden in 2012, 10 more prototypes for the Cleanergy pilot project in Dubai in 2014, and a prototype EOR steam receiver in Abdali, Kuwait in 2016. The size of this concentrator (9 meters) is sufficient large. It is difficult to install it, for example, in roof of the building. Such constructions require a lot of space.

In addition to the solar concentrator models described above, there are a dozen interesting ones, such as the EuroDish [28, 29], which have very good energy conversion rates. The solar concentrator from EuroDish is presented in **Fig. 2.5**.

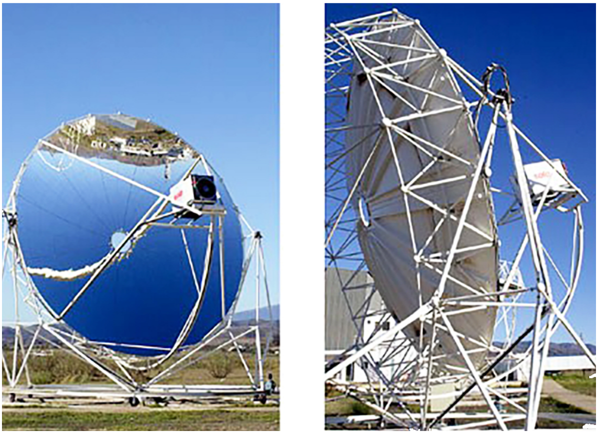


Fig. 2.5 Solar concentrator from EuroDish
Source: [29]

Industrial designs can use various energy converters, however, it should be noted that most projects use a Stirling engine to convert to electrical energy. Within the Spanish-German project EuroDish, two new prototypes of a parabolic dish with a Stirling motor were designed and built, in which it was intended to act on the following aspects:

– reduction of the price of components by identifying elements of standard use in the industry;

– development of a new manufacturing system for the concentrator disk. Tensioned membrane technology has been abandoned and a 'composite' material and mold system has been used;

– improvement of the Stirling engine SOLO V161, especially those components used in the cavity that receives concentrated solar energy;

– development of a new optimized procedure for system assembly, using new special tools;

– remote control and monitoring through the WWW;

– testing of pre-commercial units as reference systems.

The most of the described and developed models are efficient and good for green energy. The main problem that we can see is connected with their production. The manual labor and manual assembly are the points that can elevate the cost of the product. So, it is very important to simplify the solar concentrator structure for future automation of these processes.

The models of solar concentrators developed in different countries are used for different applications. Critical point is the size of solar concentrators. Nine meters of diameter (for example, as Solar Invictus has) is large for some applications. If to want to install the solar concentrators in roofs of the buildings it is necessary to reduce the diameter of solar concentrators and its weight. The weight we can reduce decreasing the number of structural elements. The other critical point for all developed and discussed above models is that every prototype is a one-piece item. The manual labor elevates the cost of solar concentrator. Before automating the solar concentrator production process, it is necessary to simplify the solar concentrator structure.

2.1.2 APPLICATIONS OF SOLAR CONCENTRATORS

The tropical countries with high air humidity can be the other application area for solar concentrators. In this case it is possible to use solar powered dehumidifiers with hot air generated by solar concentrators. Special chemical substances can be used to eliminate the excessive humidity. Frequently they have active surfaces that can absorb the water vapour from the air. Sometimes the solutions are dangerous for human health or they can have corrosive properties. Sometimes it is necessary to regenerate the adsorption property of the substances. For this purpose, they need to be heated to high temperature. Solar concentrators can be used for hot air generation. Low cost flat facet solar concentrators are proposed for different applications, for example, for the dehumidification system and for the combination of solar concentrators and agricultural fields [19, 21, 30, 31]. This application was proposed as demonstrated in **Fig. 2.6**.

Low cost flat facet solar concentrators are proposed for different applications, for example, for the combination of solar concentrators and agricultural fields [30, 31].

The tropical countries with high air humidity can be the other application area for solar concentrators. In this case it is possible to use solar powered dehumidifiers [32, 33] with hot air generated by solar concentrators.

These solar concentrators can be used with small scale TES [6]. Using TES, it is possible to make power plants for green buildings. Small solar power plants can support all the energy demands of residential houses.

The most of the described and developed models are efficient and good for green energy. The main problem that it is possible to see is connected with their production. The manual labor and manual assembly are the points that can elevate the cost of the product. So, it is very important to simplify the solar concentrator structure for future automation of these processes.

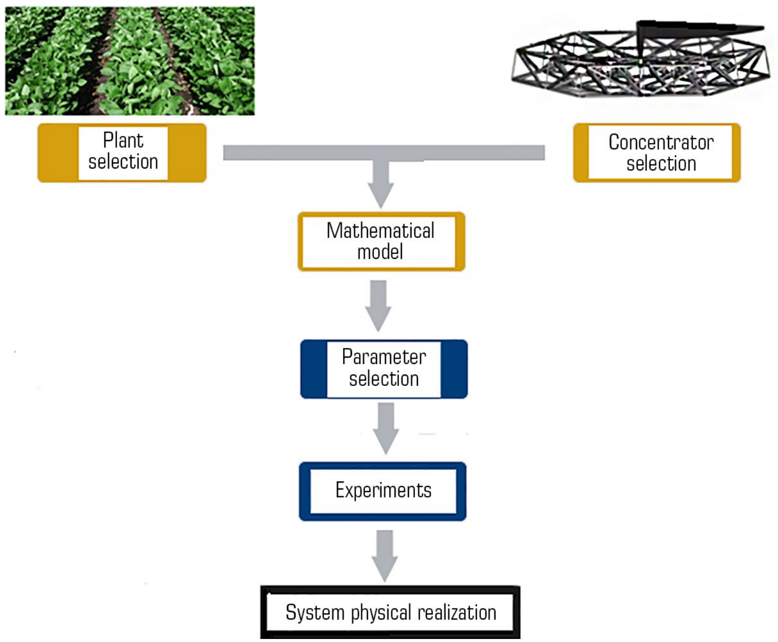


Fig. 2.6 The scheme of combining solar energy with agricultural plant

The models of solar concentrators developed in different countries are used for different applications. Critical point is the size of solar concentrators. Nine meters of diameter (for example, as Solar Invictus has) is large for some applications. If we want to install the solar concentrators in roofs of the buildings it is necessary to reduce the diameter of solar concentrators and its weight. The weight we can reduce decreasing the number of structural elements. The other critical point for all developed and discussed above models is that every prototype is a one-piece item. The manual labor elevates the cost of solar concentrator. Before automating the solar concentrator production process, it is necessary to simplify the solar concentrator structure.

2.2 THE AIM AND OBJECTIVES OF THE STUDY

The aim of the study is the development of a new structure frame prototype of solar concentrator. This will make it possible to propose new structure (support frame) of the solar parabolic concentrator with reduced cost, less weight, and better conditions for automatic production.

To achieve this aim, the following objectives are accomplished:

– give the essence and critical review the possibilities for improving the first model;

– consider the possibility to decrease the number of metal structural elements and respectively the weight of the whole structure of solar concentrator and propose the improved design with connections of metal elements with mirror triangular elements.

2.3 MATERIALS AND METHODS

Research methods are based on an analytical research method and computer simulation using the SolidWork software.

The SolidWork program was used to design 3D models of the studied parts and the whole model of solar concentrator prototype.

Scientific novelty is the development of an improved support structure of a solar parabolic concentrator. A major role in this work has the possibility to simplify the support frame of solar concentrator to collocate the flat mirrors.

2.3.1 OBJECT AND HYPOTHESIS OF THE STUDY

The object of research is the solar concentrator. The main hypothesis of the study is connected with the simplification of the frame structure of solar concentrator with flat triangular mirrors. The methods that were used are computer simulation and physical prototyping.

2.3.1.1 FIRST MODEL

The first models of solar concentrator prototypes were developed, manufactured and described in our publications [16, 20]. The support structure of the solar concentrator is presented in **Fig. 2.7**.

The structure contains horizontal top aluminium bars, vertical bronze bars, diagonal aluminium bars and horizontal low aluminium bars. Horizontal top bars are connected as triangular cells that are the base for triangular mirrors.

The solar concentrator structure has a hexagonal shape, i.e. it has six external sides. The structure has aluminum triangles to have possibility to collocate the plane triangular flat mirrors: one mirror for one triangle. In total this prototype has 24 cells for 24 mirrors.

In **Fig. 2.8, *a*,** there are four mirrors collocated and fixed on the support structure.

In **Fig. 2.8, *b*,** the first prototype is presented in complete form with all triangular mirrors and with concentrated solar light in focal point.

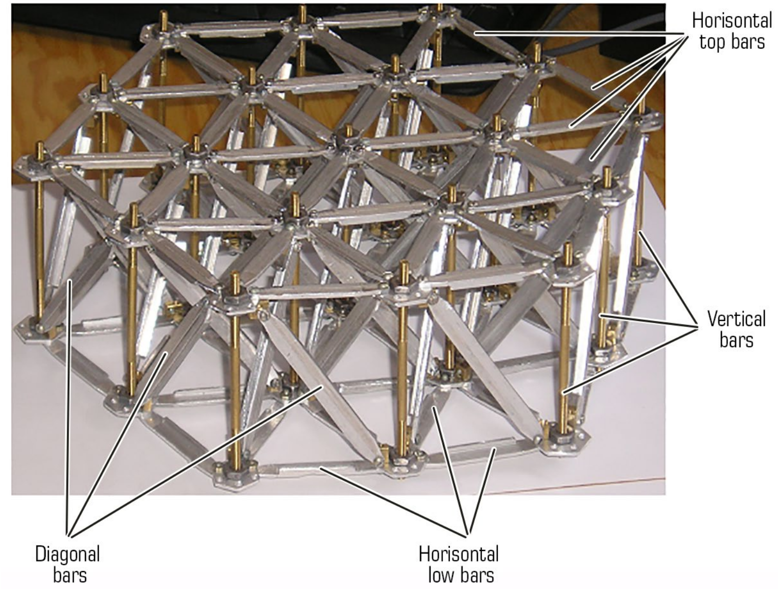
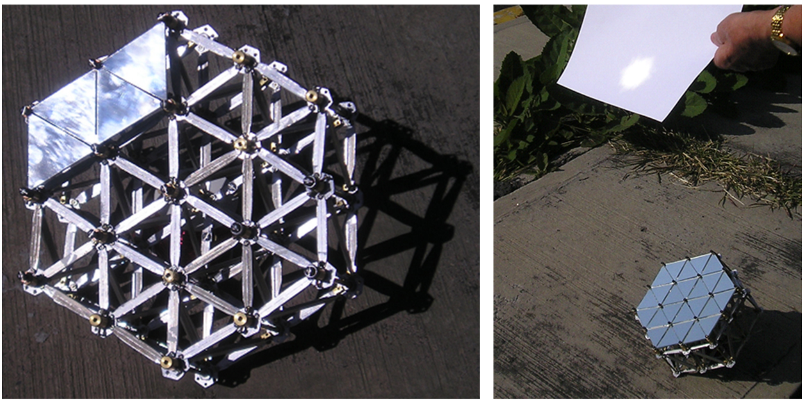


Fig. 2.7 First structure project
Source: [16]



a *b*

Fig. 2.8 Support structure frame of the first prototype: *a* – four mirrors collocated on the structure; *b* – concentration of solar energy in focal point

2.3.1.2 NUMBER OF MIRRORS

In common case it is possible to calculate the number of mirror N using the following equation:

$$N = \left(6 \cdot n^2\right) - 6, \quad (2.1)$$

where n – the number of layer. In the next paragraph, let's explain this formula in more detail. Several prototypes of one meter of diameter were made. In these prototypes we did not place the mirrors in the center (minus 6 mirrors). This hole is used for collocate the gauge with parabolic edge to adjust all screws to obtain the parabolic surface curve [16, 20].

In **Fig. 2.9**, the solar concentrator prototype is presented that contains six layers and in accordance with equation (2.1) contains 210 flat mirrors. This structure was patented in USA, Spain and Mexico. In this case we used the same principle: one cell for one flat mirror.

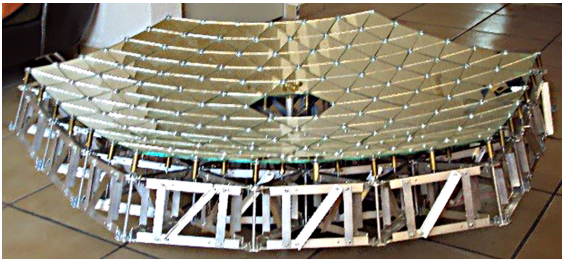


Fig. 2.9 Prototype with the first structure model
Source: [20]

The main disadvantage is the large number of elements in the structure. Let's use aluminum, which is lightweight, but the number of elements complicates the assembly of the device.

The assumptions made in the work are following: it is possible to reduce number of structural metallic elements without loss of structural strength; with reducing of number of elements we can do the structure lighter than previous structure. Simplifications adopted in the work are connected with idea that we can use structural elements of the previous prototype as basic elements of the structure of solar concentrator.

2.3.2 MATERIALS

The materials that were used in the study are metallic components for support frame. It was used aluminum bars (**Fig. 2.7–2.9**). The structure in this case is sufficiently light and firm.

Before constructing the prototypes, it is possible to simulate the elements and structure of solar concentrator using SolidWork.

2.3.3 METHODS

As method that was used in the study is a geometrical model of solar concentrator. It was selected the diameter of solar concentrator 1.6 meters. With calculations using this model it was demonstrated the possibility to obtain sufficient thermal energy with proposed solar concentrators.

2.3.3.1 GEOMETRIC MODEL OF SOLAR CONCENTRATOR

This part presents the mathematical description of the model. The sketch of solar concentrator is drawn in the SolidWorks software environment (**Fig. 2.10**).

The main parameters are shown in the **Table 2.1**.

We want to explain the values from the **Table 2.1**. They were obtained for our prototype of solar concentrator. The concentrator contains $N=210$ flat mirrors, which have a triangular shape with size of one side L_1 (**Fig. 2.10**) [6].

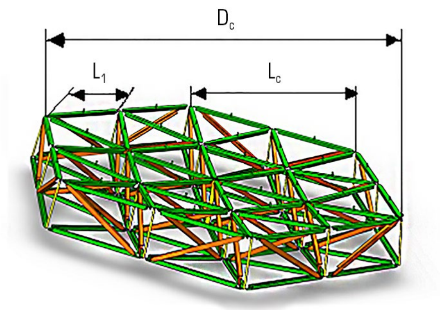


Fig. 2.10 Model of solar concentrator with parameters
Source: [6]

Table 2.1 Parameters of the parabolic concentrator

Parameter name	Value	Unit
Concentrator diameter (D_c)	1.6	m
Size of a mirror side (L_1)	0.13	m
Solar constant (kW per square meter) (C_s)	1.361	kW/m^2

The surface area of the parabolic concentrator can be calculated using equation:

$$A_c = \frac{\pi D_c^2}{4} = \frac{3.14 \cdot 2.56}{4} = 2.01\,\text{m}^2. \quad (2.2)$$

The power of the concentrator with this area is possible to present as:

$$W_C = N \cdot L_1^2 \cdot C_S \cdot \frac{t_M}{24} \cdot \eta_C \cdot \frac{\sqrt{3}}{4} = 210 \cdot 0.13^2 \cdot 1361 \cdot \frac{7}{24} \cdot 0.7 \cdot \frac{\sqrt{3}}{4} = 2091.53\ \text{W}, \quad (2.3)$$

where W_C – the concentrator power; N – the number of mirrors; L_1 – the size of a mirror side; C_S – the solar constant (amount of energy that reaches 1 square meter of the earth) (C_s= =1.361 kW/m^2) [34]; t_M – the number of hours (average) with the direct sun (not diffuse), for example, in Mexico, 7 hours of sunlight per day; η_C – the concentrator efficiency (η_C=0.7).

Satellites have directly measured the amount of energy arriving at Earth from the Sun as sunlight. Although this value varies slightly over time, it is usually very close to 1,361 watts of power per square meter (1.4 kW).

The concentrator contains N=210 flat mirrors, which have a triangular shape with size of one side L_1 (**Fig. 2.8**) [6]. So, there is concentrator power (W_C) more than 2 kW that is sufficient to built a system with thermal energy storage and use it for chemical reactor heating.

2.3.3.2 CALCULATION OF NUMBER OF STRUCTURAL ELEMENTS

To calculate the number of structural elements we present schematically part of solar concentrator structure. We can on the base of every external side (side L_C in **Fig. 2.10**) demonstrate the triangular zone that begins from outside line to the central point of solar concentrator structure. One triangle it is schematically presented in **Fig. 2.11**. The one triangle corresponds to triangle ABC (in this case AB=L_c).

We can on the base of every side demonstrate the triangle that begins from outside line to the central point of solar concentrator structure. We want to consider one triangle as it is schematically presented in **Fig. 2.11**. The one triangle corresponds to triangle ABC (in this case AB=L_c).

It is possible to see the triangle ABC (magenta colour), where point C is the central point of structure of solar concentrator and near this point we begin to place four triangular mirrors. Triangle ABC is 1/6 part of the solar concentrator structure (for this reason in equation (2.1) let's multiply by 6). There are seven lines which are parallel to AB line (blue colour). So, every zone has 49 triangular mirrors. In total, there is the solar concentrator with 288 mirrors (49*6–6=294–6=288 mirrors) if we do not include six mirrors in center of the solar concentrator structure.

Every mirror is collocated on cell from three upper aluminum bars that are connected with three vertical bars with other three lower aluminum bars. To make the system from bars tough three diagonal bars were added. So, every cell includes 12 bars. If the structure contains 288 mirrors so it is necessary to construct it 3456 metal bars.

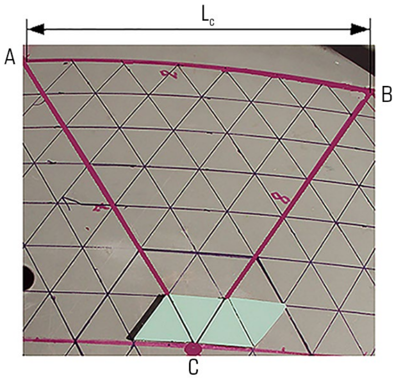


Fig. 2.11 Triangle ABC of solar concentrator

In the first type of structure every triangular mirror has the support cell for every mirror (**Fig. 2.7, 2.8**). Every vertex of the triangle has a fixing screw.

The problem of this prototype is complexity of the solar concentrator structure (**Fig. 2.10**) and large number of structural metal elements for automatic assembly.

Next, let's look at the frame improvements of the prototype of solar concentrator.

2.3.4 SOFTWARE

The methods that were used in the study are simulating of the support structure using SolidWork. After that the hardware as prototypes of solar concentrators were made to validate the proposed solutions. At the first stage we used SolidWork software to simulate the the 3D models of structure of solar concentrator.

2.4 NEW STRUCTURE OF SOLAR CONCENTRATOR WITH FLAT TRIANGULAR MIRRORS

2.4.1 REDUCING THE NUMBER OF STRUCTURAL ELEMENTS

The second structure of the support frame was developed after the model described in Section 2.3.1.1. New structure is presented in **Fig. 2.12**. Instead of triangular cells for every mirror it was proposed to have parallel bars in every zone of structure to collocate several mirrors. As for the first prototype and for the second prototype the structure has six zones (hexagon shape); so, the structure in the both cases have six external sides. In **Fig. 2.12, *a*** is presented the structure from parallel bars. In **Fig. 2.12, *b*** one zone with screws (black points) that are used to fix the triangular mirrors. The same scheme is used for all six triangular zones of concentrators [35].

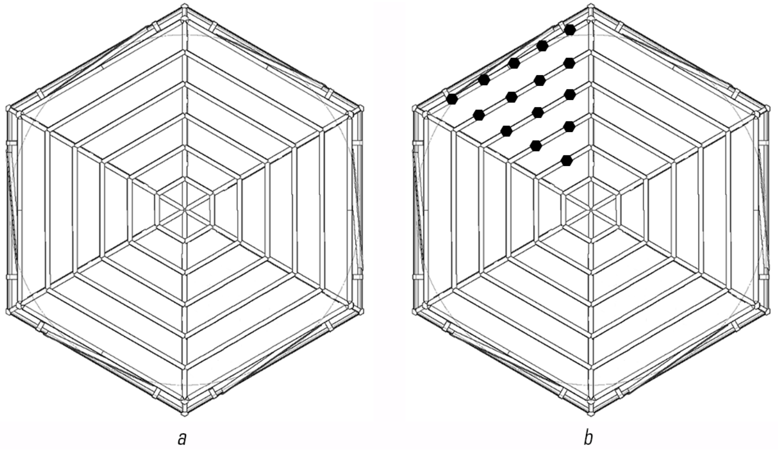


Fig. 2.12 The second structure model:
a – structure from parallel bars; *b* – one zone with screws (black points)

In **Fig. 2.13**, let's present the scheme of screw connection for mirrors with metallic elements that we use. This connecting node contains distance ring; washer (to protect mirror) and screw.

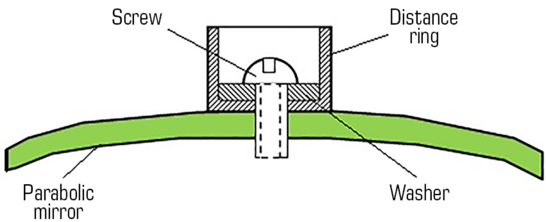


Fig. 2.13 Scheme of screw connection for mirrors

For the first model the number of metal structural elements has been calculated in case of seven parallel lines in every zone (**Fig. 2.9**). It was 3456 aluminium bars.

2.4.2 CALCULATION OF STRUCTURAL ELEMENTS

If to analyze the second model with seven lines we decrease by 56 the number of metal elements (in **Fig. 2.12** we demonstrate only six lines in every zone). In **Fig. 2.14**, let's present the structure with mirrors in one zone.

The total number of triangular mirrors *N* we can calculate as in equation (2.1). But the number of horizontal top bars, vertical bars, diagonal bars and horizontal low bars (**Fig. 2.7**) will decrease significantly.

In **Fig. 2.15**, let's present the simulation of the solar concentrator structure with flat triangular mirrors with new support frame.

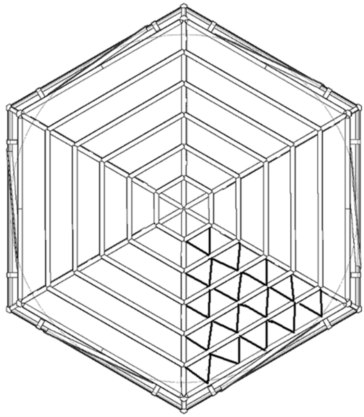


Fig. 2.14 Structure with mirrors

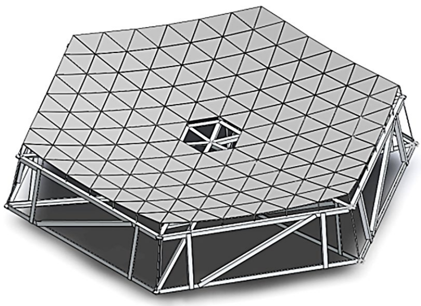


Fig. 2.15 The concentrator with the second structure model

For example, it is possible to analyze the situation with horizontal top bars. Number of bars in the center of prototype is not changed: six radial bars and six perimertric bars. In total, there are 12 bars in the center with length of triangular size *a*. With every new line the gain will be more significant. The primer line after center in the first prototype (**Fig. 2.9**) had $K_1=(7-1\cdot 6=36$ bars with length of triangular size *a*.

In new version (**Fig. 2.12, 2.14**) line 1 has $K_2=(2\cdot 6)l=12l+2a$ bars, where $l=2a$. If the first line has bar with length (*a*) the second line has the size of (2*a*). And every new line will have the size ($n\cdot a$), where *n* is the number of lines.

It is possible to imagine the prototype with two lines. In this case for the first prototype $K_1=(11-2)\cdot 6=54$ bars. For the second prototype $K_2=(3\cdot 6)l+2a=18l+2a$ bars with length ($l=3a$).

If the frame has three lines for the first prototype $K_1=(15-3)\cdot 6=72$ bars. For the second prototype $K_2=(4\cdot 6)l+2a=24l+2a$ bars with length ($l=4a$) and so on.

This reducing of number of bars is described only for horizontal top bars. But if the vertical, diagonal and horizontal low bars analyzed too, the savings will be greater. In total, if for the first prototype it was said about thousands of structural elements, then in this new case it is only about tens elements.

If the structure contains six or seven lines in one zone, there is the solar concentrator from one to two meters of diameter. It is not heavy and can be carried, transported and installed in different places. The advantage of new model is less consumption of metal bars. So, in this case the solar concentrator will be light in comparison with the weight of previous one.

2.5 DISCUSSION

It was proposed the geometrical model of solar concentrator and the results of calculations with this model (equations (2.2) and (2.3)) demonstrated that it is possible to build solar concentrator with 1.6 meters of diameter to obtain sufficient energy for heating. Due to its small size and weight the concentrator can be easily transported and installed. This solar concentrator is possible to install on the roofs of the buildings as TV antennas.

The main result that was obtained is a development of new support structure for prototype of solar concentrator. New support structure (support frame) of a solar parabolic concentrator was developed to reduce the number of structural elements, and as consequence of this, to reduce the cost and make construction lighter and easier to automatic assembly (**Fig. 2.12, 2.14**).

This prototype, in comparison with the first model developed earlier (**Fig. 2.7, 2.8**), contains less metal elements in the structure. It is not necessary to construct the cell for every triangular mirror from metal elements as it was made in the first prototype. For mirror supporting is sufficient to have horizontal bars as it is presented in **Fig. 2.12, 2.14**.

Green energy is a future of energetic development. So, any contribution to the technological aspects of this solar energy capture process is very important.

It was developed and described new frame of solar concentrator prototype in what the parabolic surface was approximated by triangular plane mirrors. After analysis of the first model of solar concentrator the possibilities for its improving were found. The first prototypes are presented in **Fig. 2.7, 2.8**. For the comparison the new structure is presented in **Fig. 2.12, 2.14**. The new structure has advantages compared to the previous version. For example, fewer structural elements that allows for easier assembly process. Fewer automation steps result in shorter build times. Also, in this case, the prototype structure becomes lighter. It is easier to transport and install this compact solar concentrator prototype with diameter of 1.6 meters.

This new structure is more convenient for automation of the assembly process of solar concentrators in future.

The parabolic solar concentrators provide a clean, inexpensive source of thermal energy for a wide range of applications, including industrial process heat, space heating and cooling, hot water, water desalination and purification, and remote and distributed power applications.

The proposed solar concentrators can be used directly to produce heat energy. To produce electrical energy, it is necessary to use Stirling thermal motor or Ericsson motor in focal point to convert heat energy to electricity.

The proposed solar concentrators can be used for different applications, for example, for green buildings in rural areas, or for chemical reactors to accelerate the chemical process of organic waste processing. Other application is to use solar concentrators in combination with agricultural fields. These solar concentrators can be used with small scale TES. Using TES, it is possible to make power plants for green buildings. Small solar power plants can support all the energy demands of residential houses.

The limitations of the study that must be taken into account when trying to apply in practice are connected with necessity to develop or to adapt existing sun tracking system, which can increase the efficiency of solar concentrator system. It is important to investigate as well as in further theoretical studies of solar concentrator systems to improve their structure and work.

CONCLUSIONS

1. In comparison with existed models of solar concentrators it was proposed the concentrator from one meter of diameter to two meters of diameter that is less than it is known from literature (for example, 9 meters). It was demonstrated with geometrical model that diameter of 1.6 meters is sufficient to produce thermal energy. The number of structural elements was more than three thousand elements.

2. The new model of support frame of solar concentrator was proposed. The result is a decreased number of structural metal elements. New design of frame structure is presented which contains less metal elements and it is lighter in comparison with previous one and more convenient for automatic assembly process. Instead of thousands of structural elements as for the first prototype in this case we are talking about several tens. The disadvantage is connected with the size of elements. For the

first concentrator all elements are unified; there are only three types. For the second solar concentrator there are different elements with different sizes but there are much fewer of them. The cost of the both types of concentrators is small because of using the flat triangular mirrors. With this investigation the cost of solar concentrator can decrease even more. It was proposed the scheme of screw connection for mirrors with metallic elements. This connection method is safe and reliable.

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