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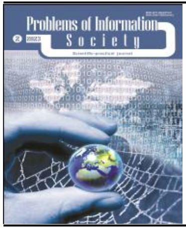

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# Modeling a system with solar concentrators and thermal energy storage

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**ABSTRACT**

Global climate change, which has upset the ecological balance, and the rate of population growth, causing an increase in the demand for electricity in the world, are accelerating the gradual transition of states to green energy. Energy generation and energy storage are two important elements in green energy systems. We select parabolic solar concentrators as instrument for energy generation and develop flat facet solar concentrators that approximate a parabolic shape surface. Not only the structure of solar concentrators is proposed, but also the structure of thermal energy storage is described and presented. Using our solar concentrators, small-scale thermal energy storage (TES), it is possible to make power plants for green buildings. Small solar power plants and the air dehumidification system based on solar concentrators have great practical potential, can provide all the energy needs of smart residential buildings in countries with a hot climate, regulate air humidity, improve agricultural productivity in mountainous areas, etc. We describe a small-scale TES and the heater based on a solar concentrator. Water can be used to transfer heat energy. Another variant of TES is based on grave. We describe not only the structure of the system with parabolic solar concentrator and TES but calculate their parameters.

## 1. Introduction

Renewable energy development is one of the leading areas of engineering at present (Baydyk et al., 2019; Baydyk et al., 2022; Johnna, 2021; Erdiwansyah et al., 2021; Gemma Oliver Gil et al., 2021; Goldschmidt et al., 2022; Heard et al., 2017; Kussul et al., 2007; Kussul et al., 2022; Sarat Kumar Sahoo, 2016). Renewable energy integration in new housing developments is trend in new applications (Gemma Oliver Gil et al., 2021). Renewable or green energy may include solar energy, wind energy, geothermal energy and other types of energy sources (Wind Energy, 2023; Mammadova, 2022; Sarat Kumar Sahoo, 2016, Sebestyén Viktor, 2021; Wind Energy Basics, 2023; Wood, 2002). We concentrate our investigation on the analysis of the solar energy generation and energy storage (Baydyk, 2019; Goldschmidt et al., 2021; Hamed, 2003, Kussul et al., 2022; Tiwari et al., 2016). The generation and storage of energy are two important elements in green energy systems. Energy storage is very important for the development of different types of batteries (for example, lithium-based batteries, development of nanomaterials incorporated to phase change material, etc.) (Alhuyi Nazari et al., 2021; Alvi et al., 2021; Ananthachar et al., 2005; Arun Kumar et al., 2015; Kosuke Harada et al., 2023; Kousksou et al., 2014; Mennel et al., 2022; Pranesh et al., 2023). One of the perspective batteries is a hydrogen storage system (Ananthachar et al., 2005; McDevitt, 2005).

This short introduction demonstrates the relevance of our investigation. Obviously, both tasks, i.e., generation of energy and energy storage, are very important topics.

Before constructing a real system, it is a good idea to do mathematical model and calculate the system parameters. Mathematical model and calculations before construction of system can give approximate parameters and efficiency of system. In this article, we describe the methodology of the system parameters evaluation and present certain calculation for our system. The calculations can also be used to do prognosis for following decades of the development of renewable energy systems. For example, in (Kosuke Harada et al., 2023) the authors formulate their model as a total cost minimization linear programming problem and consider both renewable energy facilities and the energy supply and demand of the entire country (Japan). The authors apply the model to analyze energy storage and hydrogen production at renewable energy power plants in Japan in 2050.

Low-cost solar concentrators based on multitude of small triangular flat mirrors are developed in (Baydyk et al., 2014; Baydyk et al., 2019; Kussul et al., 2022). These solar concentrators can be used for energy supply to residential houses. Small-scale residential power plant will contain flat facet solar concentrators, TES, and a powerhouse hall.

Solar concentrators can generate heat energy that is accumulated in TES at a high temperature (approximately 300-400ºC). Equipment for transformation of heat energy to electrical energy and middle/ low temperature heat energy is situated in the powerhouse hall. Medium/low temperature heat energy can be used for space and water heating, for meal preparation, etc. Electrical energy is needed for illumination and electrical device feeding.

Renewable resources of energy like solar energy are being utilized on a broad scale. But this technology has difficulties that are connected with solar energy fluctuating in nature with time of the day and the day of the year. To remove these kinds of difficulties, solar energy storage unit must be introduced in solar thermal power application (Arun Kumar, 2015). Phase change materials and materials for the design of test bench of the thermal energy storage unit can be used in this regard.

For generating power from medium or low-temperature heat sources, the Organic Rankine Cycles (ORCs) are promising approaches (Alhuyi Nazari et al., 2021; Alvi et al., 2021; Salem et al., 2021; Yu et al., 2021). In this case, ORCs can be used to indirectly produce power from solar energy. Due to intermittent nature of solar energy, storage unit should be coupled with solar ORCs to improve the output power and operating hours.

We propose the design of solar concentrators and TES [5]. Flat facet solar concentrators were proposed in 80s and the prototype of solar energy plant based on these concentrators was made in Australia, White Cliffs (1998). Afterwards, many versions of flat facet solar concentrators were proposed, developed and patented (Wood, 2002). The main goal of these works was to decrease the cost of materials and labour needed for concentrator manufacture.

During the last decade, we developed several prototypes of flat facet concentrators and improved the parabolic surface adjustment methods (Kussul et al., 2007; Kussul et al., 2011; Kussul et al., 2022). We estimate the cost of concentrators around 20 or 30 USD per square meter. This cost will enable us 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.

Tropical countries with high air humidity can be another application area for solar concentrators. In this case, it is possible to use solar powered dehumidifiers (Hamed, 2003; Solar Energy, 1977) 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 can have corrosive properties. Sometimes it is necessary to regenerate the adsorption property of the substances. In this regard, they need to be heated to high temperature. Solar concentrators can be used for hot air generation. One of the problems of the water vapour absorbents is the necessity to obtain a large area of contact with the air with this solution. To obtain a large contact area typically, the spraying method is used. In this paper, we propose a device that gives a large contact area without spraying.

Low-cost flat facet solar concentrators and gravel-based thermal energy storage are proposed for the dehumidification system feed. The solar concentrators can be combined with agricultural fields (Baydyk et al., 2022; Kussul et al., 2022; Kussul et al., 2022; Mammadova et al., 2022).

In the following paragraph, we describe the solar concentrators and their structure to realize all mentioned and possible applications.

## 2. Solar concentrators

The first models of solar concentrator prototypes were developed, manufactured, and described in our publications (Baydyk et al., 2019; Kussul et al., 2022). Figure 1 (a) (Alhuyi et al., 2021) illustrates the structure of the solar concentrator. Figure 1 (b) (Baydyk et al., 2019) illustrates the solar concentrator prototype with 210 flat mirrors.

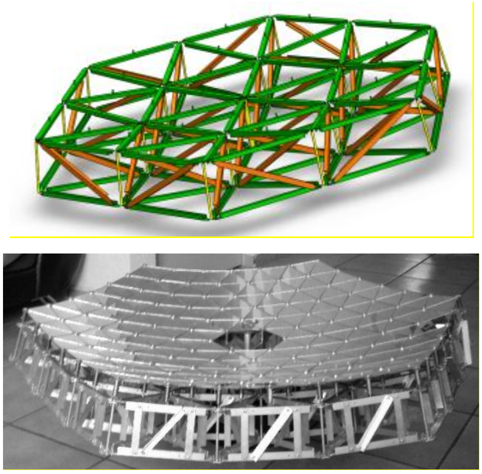

**Fig. 1.** Solar concentrator:
a) structure support; b) prototype model

Solar concentrators can be used not only in large cities like Baku, Kiev, or Mexico City to achieve different goals. The goals can include, for example, 1) preparation of hot water for domestic use; 2) food preparation. To accomplish two other goals, it is necessary to generate electricity: 3) power refrigerators and 4) air conditioning devices. For the latter two cases, it remains to develop a thermal engine to transfer thermal energy into electrical energy.

## 3. Development of the Heater

The main objective of the work is to develop the heater for the chemical reactor. The heater is based on a solar concentrator and contains storage of energy to maintain the house or reactor temperature in the absence of the sun for 3 days.

### 3.1. *Comparative analysis of heater parameters*

A heating system is developed to supply heat to a house or chemical reactor. The system must collect solar energy, transform it into thermal energy and transfer it to a house or chemical reactor. The system must have storage to store energy and transfer it to house or reactor for 3 days in the absence of the sun.

### 3.2. *Heating system components*

The system contains the following main components: 1) The solar concentrator; 2) Thermal energy storage; 3) Heat exchangers; 4) Piping and pumping system. For parameter calculations of the chemical reactor, we present the schematic chemical reactor and its dimensions in Figure 2. Figure 3 presents the energy storage.

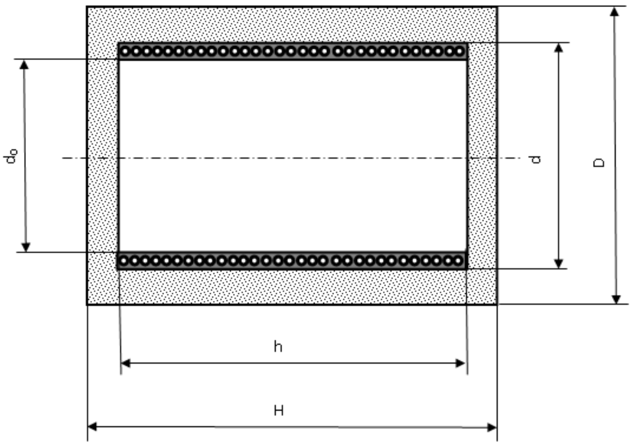

**Fig.2.** Scheme of the chemical reactor and its dimensions

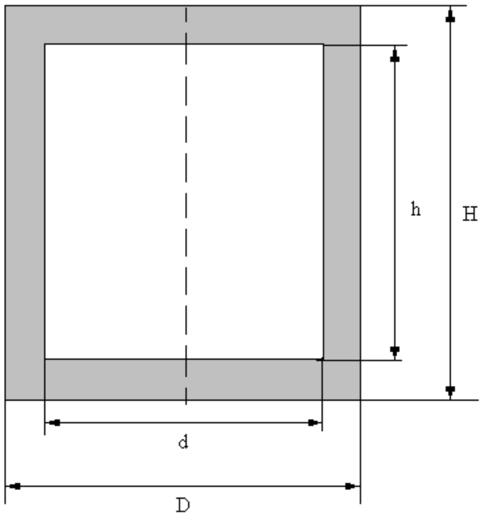

**Fig.3**. Energy storage

We present chemical reactor as a cylindrical tank with internal diameter $d_0$ and internal length $h$. Around the tank, there is a heater and thermal insulation of thickness δ. Internal diameter of thermal insulation is $d$ and internal length is $h$. External diameter (with insulation):

$$D = d + 2 \cdot \delta \,. \tag{1}$$

External length:

$$H = h + 2 \cdot \delta \,. \tag{2}$$

Average insulator diameter:

$$d_m = d + \delta \,. \tag{3}$$

Average insulator length:

$$h_m = h + \delta . \tag{4}$$

Internal temperature:

$$T_i = 55^{\circ}C . \tag{5}$$

External temperature (for example, average temperature of the coldest day and night in Mexico City):

$$T_e = 10^{\circ}C . \tag{6}$$

Thermal conductivity of insulation:

$$\lambda = 0.05\, W / m \cdot K . \tag{7}$$

Insulating area:

$$A = 2 \cdot \frac{\pi d_m^2}{4} + \pi \cdot d_m \cdot h_m = \pi \cdot d_{m\cdot} \left( \frac{d_m}{2} + h_m \right) \tag{8}$$

Heat loss:

$$W = \frac{A \cdot \lambda \cdot \Delta T}{\delta} , \tag{9}$$

where $\Delta T = T_i - T_e$.

The parameters are as follows:

$$d = 1.1m,\ h = 1.2m,\ \Delta T = 50K(^{\circ}C),$$
$$\delta = 10cm = 0.1,\ \lambda = 0.05W / mK,$$

$d_0$ = 0.65 m, $d$ = 0.7 m, $h$ = 1 m, $\Delta T$ = 45° C, $\delta$ = 0.1 m, $\lambda$ = 0.05 W/mK,

where $d$ is the internal diameter of the thermal insulation of the chemical reactor, $h$ is the internal height of the chemical reactor, $\Delta T$ is the temperature difference, $\delta$ is the thickness of the insulation, and $\lambda$ is the thermal conductivity of the insulation.

We calculate the internal volume of the chemical reactor and average sizes of thermal insulation:

$$V = 0.785 \times 0.65 \times 0.65 \times 1 = 0.33m^3 .$$

0.03$m^3$ is free space, $d_m$ = 0.8 m, $h_m$ = 1.1 m, where $V$ is internal volume, $d_m$ is the average diameter of the thermal insulator, $h_m$ is the average height of the thermal insulator.

The area of thermal insulation is:

$$A = \pi d_m^2 \cdot \left( \frac{d_m}{2} + h_m \right) = 3.14 \times 0.8 \times (0.4 + 1) = 3.5m^2 \cdot$$

Heat losses in the tank are obtained from formula (9) with previously defined parameters.

$$W_t = \frac{3.5 \times 0.05 \times 45}{0.1} = 79\, W . \tag{10}$$

We assume that heat losses in tubes are 20% of losses in tank. In this case, total losses (the power of the solar heater) are:

$$W_{sol} = 1.2 \times W_t = 1.2 \times 79 = 95\, W .$$

## 4. TES Parameters for Water

TES must feed the chemical reactor with heat for 72 hours in the absence of the sun. Feeding time: $t_1 = 72$ *hours*

We assume that the efficiency of TES is:

$$\eta_{TES} = 0.5 . \tag{11}$$

Energy stored in TES will be:

$$E_{TES} = \frac{t_1 \cdot W_{sol}}{\eta_{TES}} , \tag{12}$$

$E_{TES}$ = 72 x 95 / 0.5 = 13680 Wh = 49.25 MJ,

where $W_{sol}$ is solar concentrator power, $t_1$ is time (storage period), $\eta_{TES}$ is TES efficiency.

From formula (12) we have:

$$E_{TES} = \frac{72 \cdot 95}{0.5} = 13680\, Wh = 49.25 \cdot 10^6 J . \tag{13}$$

Power leakage in TES:

$$E_f^{(0)} = E_{TES}\left(1 - \eta_{TES}\right) = 49.25 \times \left(1 - 0.5\right) = 24.6MJ . \tag{14}$$

On the other hand energy leakage can be calculated as:

$$E_f = \frac{\lambda \cdot A \cdot \Delta T_m \cdot \tau}{\delta} , \tag{15}$$

where $\lambda$ is thermal conductivity of insulation ($\frac{W}{m \cdot K}$), $A$ is the area of thermal insulation (m²), $\Delta T_m$ is median temperature difference (ºC), $\tau$ is storage time (seconds), and $\delta$ is thickness of thermal insulation.

$$\Delta T_m = \frac{T_{\max} + T_{\min}}{2} - T_e ,$$

where $T_{\max} = 85^{\circ}C$ is maximum temperature, $T_{\min} = 65^{\circ}C$ is minimum temperature, $T_e$ is external temperature.

$$\Delta T_m = \frac{85 + 65}{2} - 10 = 65^{\circ}C .$$

We assume that the basic material of TES is water, and the parameters of TES are as follows: thermal capacity of water is $C$ = 4180 J/kg*K, water density $\rho$ = 1000 kg/m³.

The weight of water in TES will be:

$$\varphi_a = \frac{E_{TES}}{C \cdot \left(T_{\max} - T_{\min}\right)} = \frac{49.25 \cdot 10^6}{4180 \cdot 20} = 589\, kg \cdot \tag{16}$$

Volume of water in TES:

$$V_a = \frac{\varphi_a}{\rho} = \frac{589}{1000} = 0.589\, m^3 . \tag{17}$$

TES sizes are:

$$d = 0.9\, m,$$

$$h = \frac{V \cdot 4}{\pi \cdot d^2} = \frac{0.589 \cdot 4}{3.14 \cdot 0.9^2} = 0.93\, m.$$

### 4.1. *Approach 1.*

We assume that

$$\delta^{(1)} = 0.2\, m\,. \qquad (18)$$

From equations (1) and (2) we get:

$$D = d + 2 \cdot \delta = 0.9 + 2 \cdot 0.2 = 1.3\, m,$$

$$H = h + 2 \cdot \delta = 0.93 + 2 \cdot 0.2 = 1.33\, m.$$

From equations (3) and (4) we get:

$$d_m = d + \delta = 0.9 + 0.2 = 1.1\, m,$$

$$h_m = h + \delta = 0.93 + 0.2 = 1.13\, m.$$

From equation (8) we get:

$$A = \pi \cdot d_{m\cdot} \left( \frac{d_m}{2} + h_m \right) = 3.14 \times 1.1 \cdot (0.55 + 1.13) = 5.8\, m^2.$$

From equation (15) we get:

$E_f^1$ = 0.05 x 5.8 x 65 x 259200 / 0.2 = 24.4MJ,

( $\tau = t_1 \cdot 3600 = 72 \times 3600 = 259200\, seg$ ).

$$\delta^{(2)} = \delta^{(1)} \cdot \frac{E_f^{(1)}}{E_f^{(0)}} = 0.2 \cdot \frac{24.4 \cdot 10^6}{24.6 \cdot 10^6} = 0.198\, m.$$

$\delta^{(2)} \approx \delta^{(1)}$ we accept $\delta = 0.2\ m.$

### 4.2. *Gravel-based TES parameters*

The TES must feed the chemical reactor with heat for 72 hours in the absence of the sun. Feeding time is $t_1 = 72\ hours$.

We assume that the efficiency of TES is:

$$\eta_{TES} = 0.5. \qquad (19)$$

Energy stored in TES will be:

$$E_{TES} = \frac{t_1 \cdot W_{sol}}{\eta_{TES}}, \qquad (20)$$

$E_{TES}$ = 72 x 95 / 0.5 = 13680 Wh = 49.25 MJ, where $W_{sol}$ is solar concentrator power, *t*1 is time (storage period), $\eta_{TES}$ is TES efficiency.

From equation (12) we get:

$$E_{TES} = \frac{72 \cdot 95}{0.5} = 13680\, Wh = 49.25 \cdot 10^6\, J\,. \qquad (21)$$

Power leakage in TES is:

$$E_f^{(0)} = E_{TES}(1 - \eta_{TES}) = 49.25 \times (1 - 0.5) = 24.6 MJ \qquad (22)$$

On the other hand, energy leakage can be calculated as:

$$E_f = \frac{\lambda \cdot A \cdot \Delta T_m \cdot \tau}{\delta}, \qquad (23)$$

where $\lambda$ is thermal conductivity of insulation $\left( \frac{W}{m \cdot K} \right)$, $A$ is the area of thermal insulation (m²), $\Delta T_m$ is median temperature difference (ºC), $\tau$ is storage time (seconds), and $\delta$ is thickness of thermal insulation.

$$\Delta T_m = \frac{T_{\max} + T_{\min}}{2} - T_e \qquad (24)$$

where $T_{\max} = 150^{o}C$ is maximum temperature, $T_{\min} = 65^{o}C$ is minimum temperature, $T_e$ is external temperature.

$$\Delta T_m = \frac{150 + 65}{2} - 10 = 97.5^{o}C\,.$$

We assume that the basic TES material is gravel, and the TES parameters are as follows: thermal capacity of gravel: C = 800 J/kg*K, gravel density ϱ = 1500 kg/m3.

The weight of gravel in TES will be:

$$\varphi_a = \frac{E_{TES}}{C \cdot (T_{\max} - T_{\min})} = \frac{49.25 \cdot 10^6}{800 \cdot 85} = 724\, kg\,. \qquad (25)$$

Volume of gravel in TES:

$$V_a = \frac{\varphi_a}{\rho} = \frac{724}{1500} = 0.483\, m^3\,. \qquad (26)$$

TES sizes are:

$$d = 1.2\, m,$$

$$h = \frac{V \cdot 4}{\pi \cdot d^2} = \frac{0.483 \cdot 4}{3.14 \cdot 0.9^2} = 0.76\, m. \qquad d = 0.9 \text{ m.}$$

### 4.3. *Approach 2*

We assume that

$$\delta^{(1)} = 0.32\, m\,. \qquad (27)$$

From equations (1) and (2) we get:

$$D = d + 2 \cdot \delta = 0.9 + 2 \cdot 0.32 = 1.54\, m,$$

$$H = h + 2 \cdot \delta = 0.76 + 2 \cdot 0.32 = 1.4\, m.$$

From equations (3) and (4) we get:

$$d_m = d + \delta = 0.9 + 0.32 = 1.22 m,$$

$$h_m = h + \delta = 0.76 + 0.32 = 1.08\, m.$$

From equation (8) we get:

$$A = \pi \cdot d_{m\cdot} \left( \frac{d_m}{2} + h_m \right) = 3.14 \times 1.22 \cdot (0.61 + 1.08) = 6.47\, m^2.$$

From equation (15) we get:

$E_f^1$ = 0.05 x 6.47 x 97.5 x 259200 / 0.32 = 25.5MJ,

( $\tau = t_1 \cdot 3600 = 72 \times 3600 = 259200\, seg$ ).

$$\delta^{(2)} = \delta^{(1)} \cdot \frac{E_f^{(1)}}{E_f^{(0)}} = 0.32 \cdot \frac{25.5 \cdot 10^6}{24.6 \cdot 10^6} = 0.33\, m.$$

$\delta^{(2)} \approx \delta^{(1)}$, we accept $\delta = 0.33\ m.$

## 5. Solar Concentrator Parameters

The power of the solar concentrator is the sum of heat losses in the chemical reactor, in the TES energy storage and in connection tubes.

Heat losses in chemical reactor are:

$$W_{sol} = 95\,W\,.$$

Heat losses in the TES energy store are:

$$W_{TES} = W_{sol} = 95\,W, \quad (\eta_{TES} = 0.5).$$

We assume that heat losses in connection pipes are 0.2 of total losses:

$$W_{tub} = 0.2(W_{TES} + W_{sol})\,.$$

The power of the solar concentrator is:

$$W_C = 1.2\times(W_{TES} + W_{sol}) = 1.2\times(95+95) = 228\,W \quad (28)$$

The concentrator contains $N$=210 flat mirrors, which have a triangular shape with size of one side $L_1$ (Fig. 4) [5, 6].

The power of the concentrator is possible to present as:

$$W_C = N\cdot L_1^2 \cdot C_S \cdot \frac{t_M}{24}\cdot \eta_C \cdot \frac{\sqrt{3}}{4}, \quad (29)$$

where $W_C$ is the power of the concentrator, $N$ is the number of mirrors, $L_1$ is the size of a mirror side, $C_S$ is solar constant (amount of energy that reaches 1 square meter of the earth), $t_M$ is the number of hours (average) with the direct sun (not diffuse), for example, in Mexico, in a day, $\eta_C$ is concentrator efficiency.

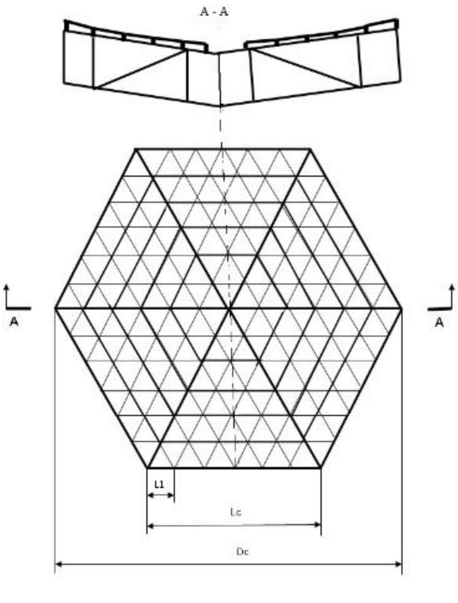

**Fig. 4.** Model of solar concentrator with parameters

From equation (20) we obtain:

$$L_1 = \sqrt{\frac{24\cdot W_C}{N\cdot C_S\cdot t_M\cdot \eta_C}\cdot\frac{4}{\sqrt{3}}} \quad (30)$$

In our case we have $W_C = 228\,W$, $N$=210, $C_S = 1000W/m^2$, $t_M = 5\,h$, $\eta_C = 0.7$.

From equation (30) we obtain:

$$L_1 = \sqrt{\frac{24\cdot 228}{210\cdot 1000\cdot 5\cdot 0.7}\cdot 2.309} = 0.13\,m \quad (31)$$

Concentrator outer diameter (see Fig.5) is

$$D_C = 12\cdot L_1 = 12\cdot 0.13 = 1.56\,m \quad (32)$$

So, we accept that

$$D_C = 1.6\,m\,, \quad (33)$$

$$L_1 = 0.13\,m\,. \quad (34)$$

The results are as follows. Basic parameter calculations show that the internal diameter of TES is 0.6m. The internal height of TES is 0.74m. The thickness of thermal insulation is 0.09m. The parameters of the solar concentrator are: external diameter is 1.6m, quantity of flat triangular mirrors is 210, and side of triangular mirror is 0.13m.

## 6. Air-Water Heat Exchanger

The solar concentrator is designed with a heat receiver that works with hot air and a thermal energy store (thermo tank) that uses hot water. To transfer thermal energy from air to water, we are going to use the heat air-water exchanger. For this exchanger, we carry out the calculations of the main component parameters. The main component is presented in Fig. 5.

The sizes are:

$$D_1 = 2mm,\ D_2 = 3mm,\ D_3 = 4mm,\ D_5 = 5mm$$

All circular channels for air have a square section of size, distance between channels. $h_1 = 0.5mm, t = 0.7mm$.

Number of channels in the main component is:

$$N_C^{(1)} = 15\times 2 = 30\,,$$

$$H = \frac{N_C\cdot t}{2} + 6 = 17mm\,, \quad (35)$$

Length of each channel is:

$$l_C = \frac{\pi(D_2 + D_3)}{4} = \frac{3.14(3+4)}{4} = 5.5mm = 5.5\cdot 10^{-3}m \quad (36)$$

Air temperature difference between inlet and outlet is:

$$\Delta T = 30°K \quad (37)$$

Hydraulic channel diameter we accept:

$$d_2 = h = 0.5mm = 5\cdot 10^{-4}m \quad (38)$$

Wall area of a channel is:

$$A_C = \pi \cdot d_h \cdot l_C = 3.14 \cdot 5 \cdot 10^{-4} \cdot 5.5 \cdot 10^{-3} = 86 \cdot 10^{-7} = 8.6 \cdot 10^{-6} m^2 \quad (39)$$

### 6.1. *Heat transfer*

We accept Nusselt number $N_u = 3.7$.

Heat transfer coefficient *h*:

$$h = \frac{N_u \cdot k}{d_h} = \frac{3.7 \cdot 0.03}{5 \cdot 10^{-4}} = 222 W / m^2 \cdot K \quad (40)$$

where *k*=0.03 W/mK is air heat transfer coefficient.

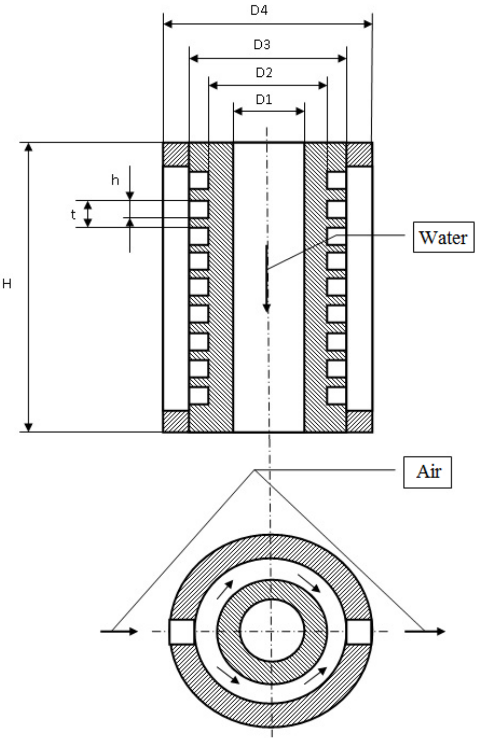

**Fig. 5.** Main component of air-water heat exchanger

Heat transfer in one second through a channel is calculated:

$$\frac{dQ_C}{dt} = h \cdot A_C \cdot \Delta T = 222 \cdot 8.6 \cdot 10^{-6} \cdot 30 = 0.057W \quad (41)$$

Heat transfer in one second through the main component is:

$$\frac{dQ_{CP}}{dt} = \frac{dQ_C}{dt} \cdot N_C = 0.057 \cdot 30 = 1.71W \cdot (42)$$

Number of main components we calculate as:

$$N_{CP} = \frac{W_{cr}}{(dQ_{CP} / dt)} = \frac{1094}{1.71} = 640, \quad (43)$$

where $W_{cr}$=1094 *W* is the maximum power of the solar concentrator (when there is sun without clouds).

Air flow is calculated as volume per second.

A channel has flow:

$$\frac{dV_C}{dt} = \frac{\frac{dQ_C}{dt}}{C_P \cdot \Delta T \cdot \rho}, \quad (44)$$

where $C_P$ is the thermal capacity of air, $\Delta T$ is the difference in temperature at the air inlet and outlet, and $\rho$ is air density. So, we have $C_P$ =1000 *J/kgK*, $\Delta T$ =30°K, $\rho$ =0.9 *kg/m*³ (con 115 °C).

$$\frac{dV_C}{dt} = \frac{0.057}{10^3 \cdot 30 \cdot 0.9} = 2.11 \cdot 10^{-6} m^3 / s \quad (45)$$

Air flow speed is: $u = \frac{\frac{dV_C}{dt}}{S_C} = \frac{2.11 \cdot 10^{-6}}{0.25 \cdot 10^{-6}} = 8.44 m / s \cdot$

Total air flow is calculated as:

$$\frac{dV_T}{dt} = \frac{dV_C}{dt} \cdot N_{CP} \cdot 30 = 2.11 \cdot 10^{-6} \cdot 640 \cdot 30 = \quad (46)$$

$$= 0.04 m^3 / s = 40 \ liters / s$$

### 6.2. *Water side*

Let it be the temperature difference $\Delta T$ =5°K.

Channel sizes are $D_C = 2 \cdot 10^{-3} m$, $L_C = 17 \cdot 10^{-3} m \cdot$

The wall area of a channel is calculated as follows:

$$A_C = \pi \cdot D_C \cdot L_C = 3.14 \cdot 2 \cdot 10^{-3} \cdot 17 \cdot 10^{-3} = 107 \cdot 10^{-6} m^2 \quad (47)$$

Nusselt number is $N_u = 3.7$. Heat transfer coefficient *h* we can calculate as:

$$h = \frac{N_u \cdot k}{D_C} = \frac{3.7 \cdot 0.5}{2 \cdot 10^{-3}} = 925 W / m^2 \cdot K,$$

$k$ =0.5 $W / m \cdot K$,

$$\frac{dQ_C}{dt} = h \cdot A_C \cdot \Delta T = 925 \cdot 107 \cdot 10^{-6} \cdot 5 = 0.495W$$

In this case, the total heat transfer is:

$$\frac{dQ_t}{dt} = 0.495 \cdot 640 = 316W \cdot$$

This value is less than the maximum power of the solar concentrator (1094W).

To increase heat transfer on the water side, we install an additional bar to the water channel (Fig. 6).

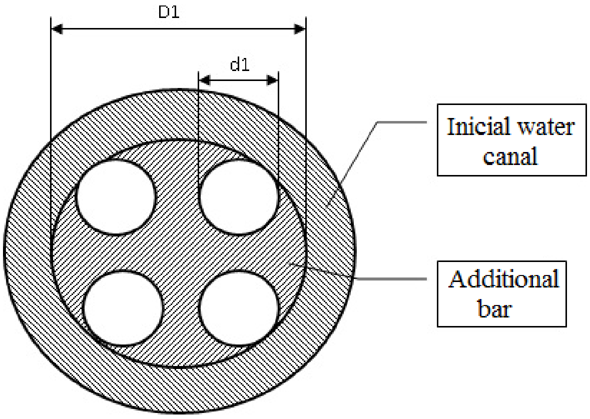

**Fig. 6.** Waterway

In this case, the main component has four water channels with diameter $d_1$ instead of one channel with diameter $D_1$. It is easy to calculate that each new channel will have: $\frac{dQ_C}{dt} = 0.495W$. The total heat transfer will be $\frac{dQ_t}{dt} = 0.495 \cdot 4 \cdot 640 = 1264W$, that is more than 1094W.

## 7. Conclusion

Different types of solar concentrator applications were discussed. The model of the solar concentrator applicable for all these applications was described. The light on roofs of buildings can be used. Its weight enables us to use it in agricultural fields. The diameter of the solar concentrator can be from one to two meters. The cost is small because of the flat triangular mirrors. The theoretical proposal of the heating system was described. For example, the chemical reactor was selected and developed. The heating system contains the solar concentrator, TES, chemical reactor temperature control scheme, and piping system to connect the heating system components and heat exchangers.

The basic parameters of the heating system components, such as the solar concentrator, the TES (hot water and hot gravel-based versions), and the air-water heat exchanger were calculated. The possibility of using the solar concentrator prototypes was analyzed. For these experiments, the prototype with 210 flat mirrors placed on the parabolic surface was chosen. To increase heat transfer on the water side, we installed an additional bar to the water channel.

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