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Optimization of air chamber in solar air collector

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Abstract. Recently, environmental problems have become more acute. In 1980, the International Union for the Conservation of Nature (IUCN) prepared the World Conservation Strategy. This document interpreted the term "sustainable development" as an inseparable link between social development and nature conservation. And already in 1992, after the United Nations Conference on Environment and Development, the concept of sustainable development gained a leading status. The conference materials determined that sustainable development is a development of a society that meets the needs of today without compromising the ability of future generations to meet their own needs. Therefore, being aware of the need for energy conservation, there is increasing emphasis on the use of solar energy throughout the world to generate electricity and heat.

1 Introduction

The potential of solar energy in Ukraine is sufficiently high for widerspread use both heat-and-power engineering and photovoltaic systems in almost all regions. The period of functional operation of solar heating systems in the southern regions of Ukraine is 7 months (from April till October), in the northern regions it is 5 months (from May till September). Photovoltaic equipment can be used very effectively throughout the year [1, 2].

For solar heating in climate weather conditions of Ukraine, the exploitation of flat solar collectors that use both direct and diffuse solar radiation is effective. Concentrating solar collectors can be quite effective only in the southern regions of Ukraine.

The use of renewable source of energy in Ukraine and in the world is gaining momentum. Solar collectors are increasingly popular. However, prefabricated collectors are quite expensive and their payback period is significant. Therefore, many engineers are working on simple and lowcost designs.

Solar collectors are a number of devices with some differences in types, shape, types and purpose. There are two main types of solar collectors as liquid and air. Solar air collectors are often plain flat collectors.

The main advantages of air collectors are their simplicity and reliability. Such collectors have a simple structure. With proper care, a quality collector can work for 10-20 years, and it is very easy to manage. The heat exchanger is not needed because the air does not freeze.

On Fig. 1. shows a map of solar radiation power on horizontal surfaces within Ukraine. In the Eastern and Southern regions, solar installations will be significantly more efficient.

A potential way to reduce the cost of collectors is their integration into walls or roofs of buildings, as well as the creation of collectors that can be assembled from prefabricated components.

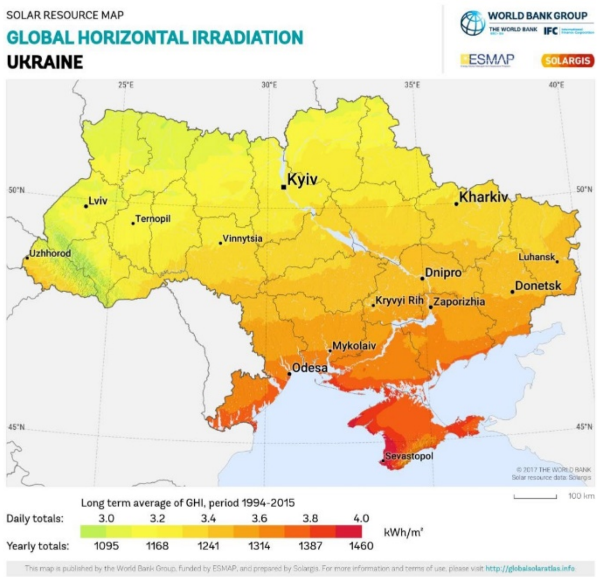

Fig. 1. Global Horizontal Irradiation for Ukraine (The World Bank, Solar resource data: Solargis, 2017).

These collectors are often used for heating. However, the opportunity to get cheap thermal energy in the summer has led to a wide range of applications of such installations for drying agricultural products. Therefore, research in this direction continues to these days [3-7].

The benefits of solar air collector:

1. Additional protection of facade (roof) materials from ultraviolet radiation.
2. Installation of skewed canopy (porch, parking space) while receiving house solar heating with solar collector is possible.
3. Saving energy. Cleaning air circulation. Highly efficient heating.

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Today the most common are the following designs of available air solar collectors: with the movement of the air through the air chambers of various forms (Fig. 2), with the movement of the air in the space between the bottom of the case and solid screen absorber (Fig. 3), and with the movement of the air between the glass and bottom absorber on a fixed path (Fig. 4).

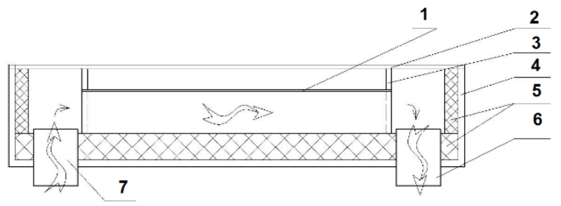

Fig. 2. Collector with the air passing through air chambers: 1 – air chamber; 2 – glass; 3 – baffler; 4 – body; 5 – insulation; 6 – air outlet; 7 – air intake.

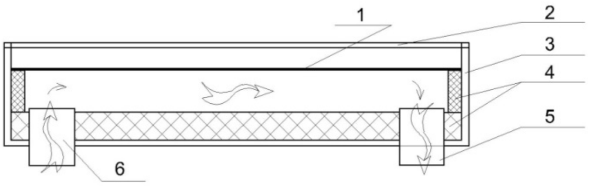

Fig. 3. Collector with the air passing between the bottom of the case and solid screen absorber: 1 – absorber; 2 – glass; 3 – body; 4 – insulation; 5 – air outlet; 6 – air intake.

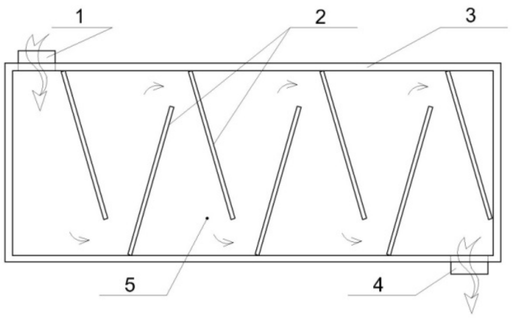

Fig. 4. Collector with the air passing between the glass and bottom absorber on a fixed path: 1 – air intake; 2 – baffler; 3 – body; 4 – air outlet; 5 – absorber.

Air passes through the absorber due to natural convection or under the influence of a fan. Since air conducts heat worse than liquid, it receives less heat from the absorber than the liquid coolant. In some solar air heaters, fans are attached to the absorber, which provide air passage and improve heat transfer. The disadvantage of this construction is that it consumes energy to operate the fans, thus increasing the cost of the system operating. However, the use of solar panels to power the fan, eliminate this disadvantage. In cold climates, the air is directed to the gap between the absorber plate and the insulated rear wall of the collector: thus avoiding heat loss through transparent surfaces.

Solar air collectors are simple devices, however have a numerous of options of constructive execution, warming, a material and a covering of an absorber, a translucent covering, and means of ensuring creation of turbulent air streams inside. Therefore, a large number of scientific studies of various authors is devoted to the study of their properties and design features [8-11, 16-19].

Proper orientation of solar collectors (direction and angle) increases their productivity. The earth's atmosphere absorbs and reflects a significant portion of solar energy. Therefore, the maximum amount of energy comes at noon, when the direct rays' stream is least delayed by the atmosphere. In the northern hemisphere geographical south is the best direction at noon, while the sun's rays strike perpendicularly upon the collector. A simple geometric calculation shows that the collector should be inclined to the horizon on the value of the latitude of ± 10 angular degrees. For example, in Kyiv, 50° 25' north latitude, which means that the angle can be 40 to 60 angle degrees [12-15].

Azimuth characterizes the deviation of the collector surface from the south; at the orientation of the collector surface straight to the south, the azimuth = 0. Since the insolation in the middle of the day is the most intense, the collector surface should be oriented to the south as far as possible. However, good results are also achieved by the deviations from the south in 45 ° to the southwest or southeast. More significant deviations can be compensated by a small increase in the surface area of the collector.

2 Methods

2.1 Investigation of air chamber's properties in solar air collectors

Taking into account the most predictable movement of the coolant inside collectors with the movement of the air through air chambers, we shall undertake a study on the efficiency of chamber forms to outline the optimized and the most effective alternative.

The principal condition of providing effective operation of the solar air collector is the maximum coverage of the air chamber walls by the airflow to relieve them from the heat. It can be achieved by creating turbulent flow. The easiest way is to arrange bafflers along the channel, which can provide the turbulence.

In order to get that done, a comprehensive research on the study of the potential of the channels with different types of bafflers.

Prototypes were made of thin-walled cylinder with a smooth inner surface. The 4 section cylinders were secured to the window glass on one level separately from each other, so as not to block the sun's access to the surfaces. Thin-walled aluminum cylindrical tube with a diameter of 70 mm, the wall thickness of 0,1 mm, and 170 mm long section between delimiters, was used as the channel. The tube was covered with CRAFTS SPRAY HighTemperature black paint to improve the perception of solar radiation. Research samples consisted of 4 sections were created for all types of bafflers. All samples were fixed in an identical lighting conditions, the temperature was measured both at the inlet and outlet of the channel with different measurements for each channel in the 20°...30° C.

The second part of the experiment was mathematical modeling of the air passing through the bafflers to visualize the trajectories of the motion of the fluence.

It is flexible enough to check various situations, and it is a good instrument to prepare physical tests, its verification or confirmation.

One of software packages of this kind is SolidWorks, a program complex for the complete 3D modeling with Flow Simulation program unit, which provides opportunities to create the most complex three-dimensional parametric objects and dipping them into certain environment, defining necessary parameters and characteristics, as well as obtaining an animated image of the flow process which is saved as AVI-file.

2.2 Research methodology

Four-sectional samples were fixed to the window glass on one level apart from each other to keep the access to sunlight surfaces.

The principal scheme of the holes in the baffler are shown in Fig. 5. The holes in the bafflers on Schemes 3...9 were made open-ended, changing only the configuration. Openings in the bafflers on Schemes 1...2 were made by fat contour line, then the dimmed plane was bent inwards at an angle of 45°.

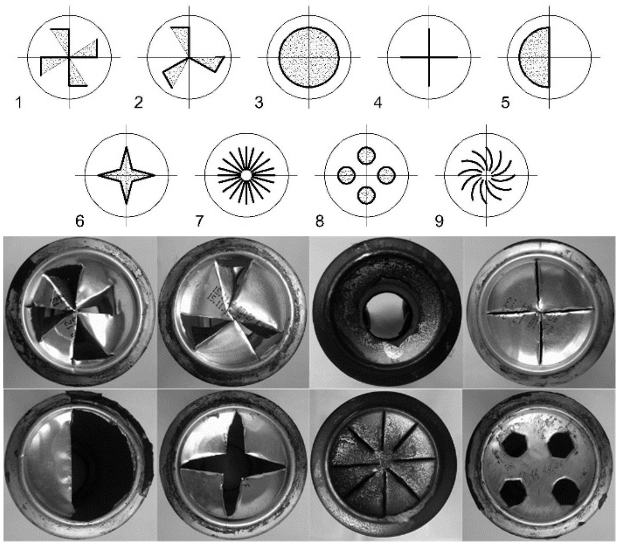

Fig. 5. The principal schemes of the holes in bafflers.

At the junction of sections, each subsequent baffler was turned on an axis at an angle of 90° from the previous for the turbulence of the flow.

Temperature measurements were carried out at the intake of an air flow in the prototype and at the outlet at different lighting levels in the winter and spring periods. Thermo Clock electric thermometer with internal and external (as thermocouple) temperature sensors was used for measurements. Temperature measurements were performed twice:

1st measurement: the temperature at the intake was measured with thermocouple;

2d measurement: the temperature at the intake was measured with the thermometer's internal sensor, and at the outlet it was measured with thermocouple.

Temperature measurements were carried out at different lighting levels, which were metered with luxmeter.

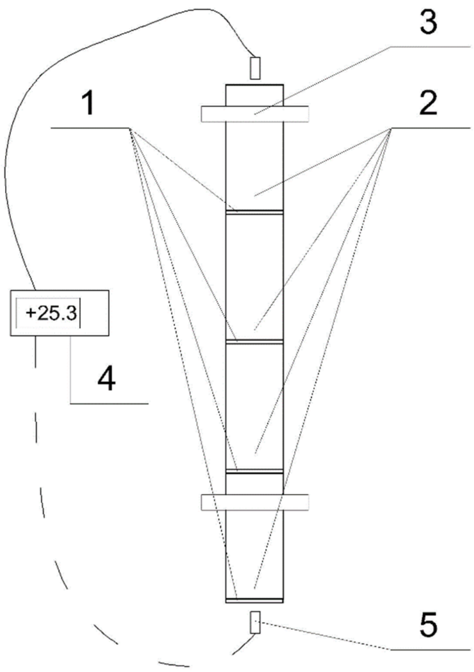

Fig. 6. A scheme for determining the effectiveness of the samples: 1 – baffler; 2 - tube sections; 3 – mounting; 4 – electric thermometer; 5 – thermocouple.

3 Results and discussion

3.1 Efficiency of channels in the field experiment

The results of studies at different levels of illumination are summarized in Table 1.

Table 1. The temperature at the intake and outlet of the samples at different light levels

Row Nr.	$T_{outside}$	Temperature at the outlet of the sample T							
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	6,0	13,3	12,7	12,5	13	12,8	12,6	13	13,1
2	7,0	15,6	15	14,9	15,4	15,1	15	15	15,4
3	14,5	19,2	16,1	14,5	16,5	14,6	14,5	14,5	17
4	17	43,6	40,1	34	36	38,5	39,5	45,5	38
5	18,6	27,5	28	25	27,3	27,8	26,3	26,8	27,5
6	25,0	46,9	44,4	44,3	45,3	44,8	41,2	50	47,1

Considering that at the time of the study there was a constant cloudiness, the increase in solar radiation led not only to an increase in the outside temperature, but also to an improvement of the heat transfer by the collector elements.

The data of Table 1 are shown on chart (Fig. 7).

With the efficiency of the channel dividers, the difference between the inlet and outlet air flow temperatures is accepted. The results of studies at different levels of illumination are summarized in Table 2.

The results of the experimentation have shown that the most effective was sample Nr. 1, sample Nr. 7 had very close value to the first one, and samples Nr. 8 and Nr. 2 were in the third place.

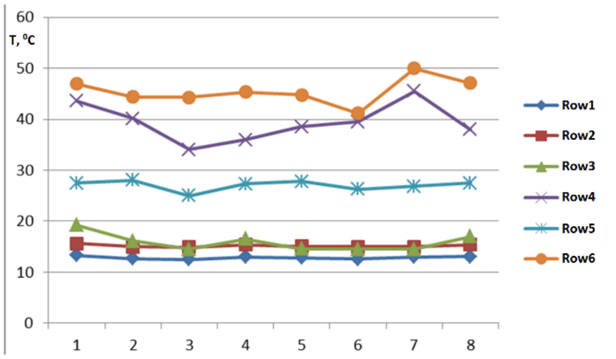

Fig. 7. Temperature distribution in the samples.

Table 2. Effectiveness of chamber bafflers.

Row Nr.	Difference between inlet and outlet temperatures of air flow							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	7,3	6,7	6,5	7	6,8	6,6	7	7,1
2	8,6	8	7,9	8,4	8,1	8	8	8,4
3	4,7	1,6	0	2	0,1	0	0	2,5
4	26,6	23,1	17	19	21,5	22,5	28,5	21
5	8,9	9,4	6,4	8,7	9,2	7,7	8,2	8,9
6	21,9	19,4	19,3	20,3	19,8	16,2	25	22,1
Average	**13,0**	**11,37**	**9,52**	**10,9**	**10,92**	**10,17**	**12,78**	**11,67**

We take the effectiveness of the sample Nr. 1 as 100%. Experimental samples in Table 3 are shown in the order of increasing.

Table 3. Experimental samples in the order of increasing of the effectiveness.

Sample Nr.	3	6	4	5	2	8	7	1
Comparative effectiveness	73,21	78,21	83,85	83,97	87,44	89,74	98,33	100

3.2 Channel efficiency in mathematical modeling

To visualize the trajectories of the fluence motion, in the second part of the experiment, Mathematical modeling of air passing through the bafflers was carried out with the aid of SolidWorks program complex with FlowSimulation program unit. The results of modeling are shown on Fig. 8-16.

Mathematical modeling has shown that bafflers of samples Nr. 1, 2 and 7 have the best performance of blowing the chamber walls.

The efficiency of the channel dividers modeled in SolidWorks was determined by the nature of the airflow trajectory after passing them separator.

4 Conclusions

Passing through the channel, the air changes its state. This is due to the differential heating of absorber surface by the sun, and owing to the bafflers that divide the channel into identical pieces. The baffler's shape influences the flow pattern in the air chamber.

The results of the multiple use of air chamber samples of solar collectors with bafflers have shown that samples Nr. 1, 2 and 7 are the best for the use, which we suggest to use for making solar collectors.

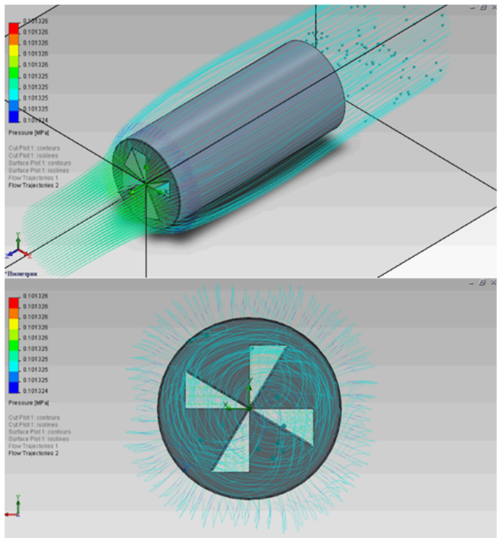

Fig. 8. Mathematical modelling: samples Nr. 1.

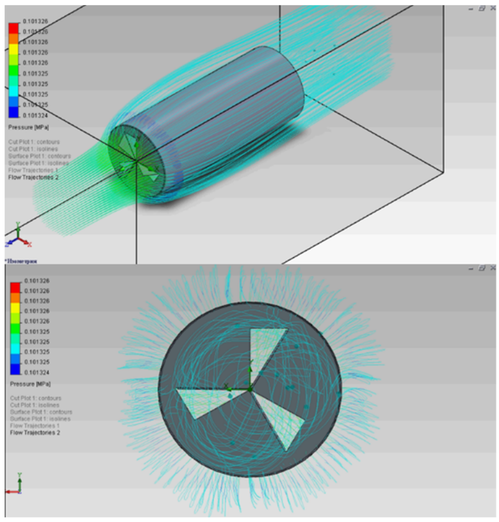

Fig. 9. Mathematical modelling: samples Nr. 2.

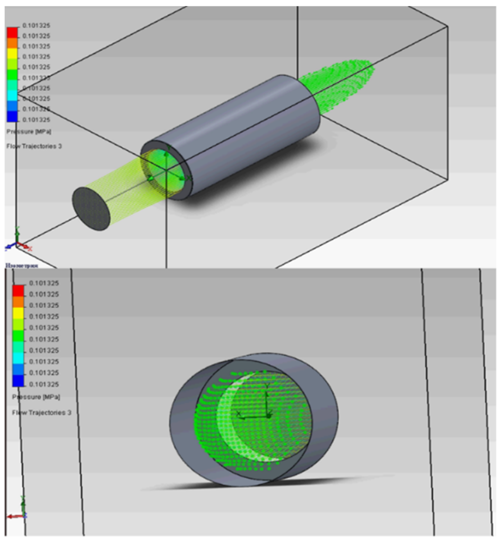

Fig. 10. Mathematical modelling: samples Nr. 3.

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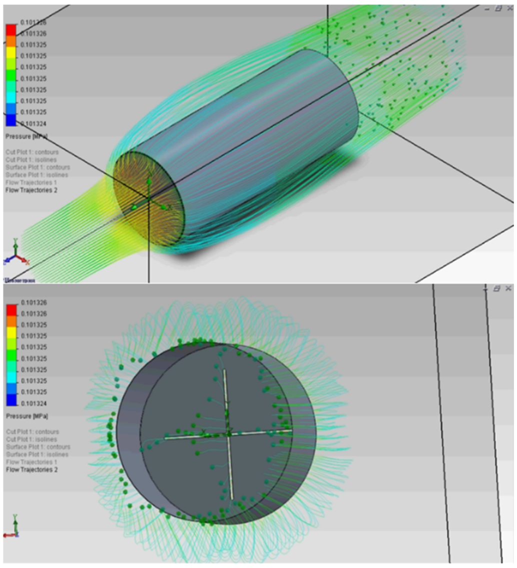

Fig. 11. Mathematical modelling: samples Nr. 4.

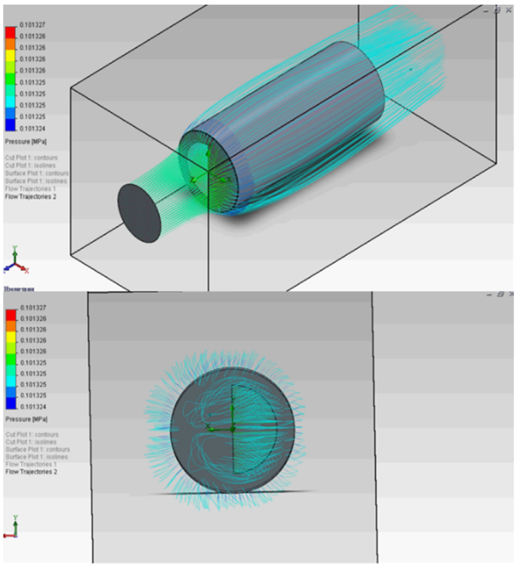

Fig. 12. Mathematical modelling: samples Nr. 5.

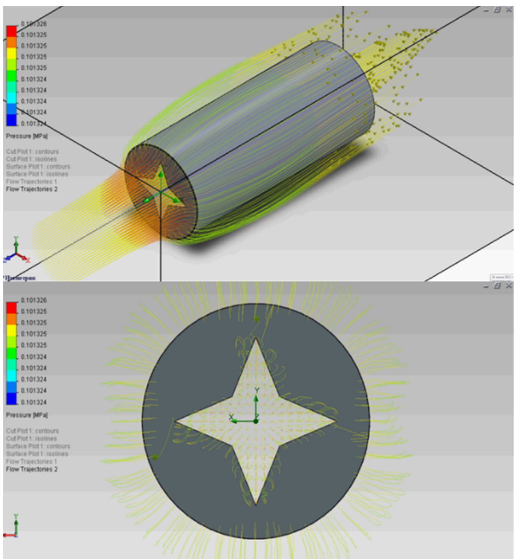

Fig. 13. Mathematical modelling: samples Nr. 6.

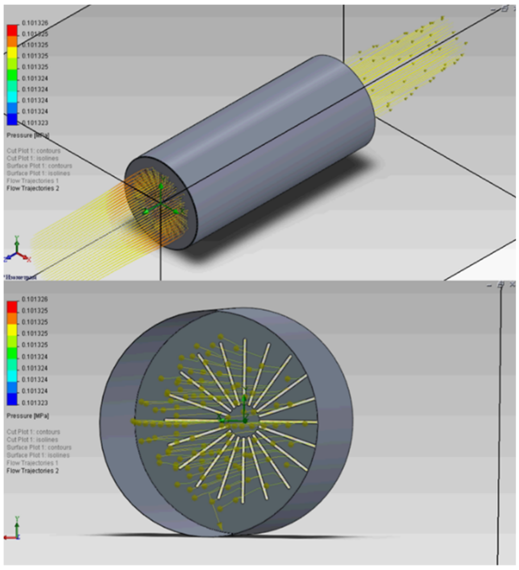

Fig. 14. Mathematical modelling: samples Nr. 7.

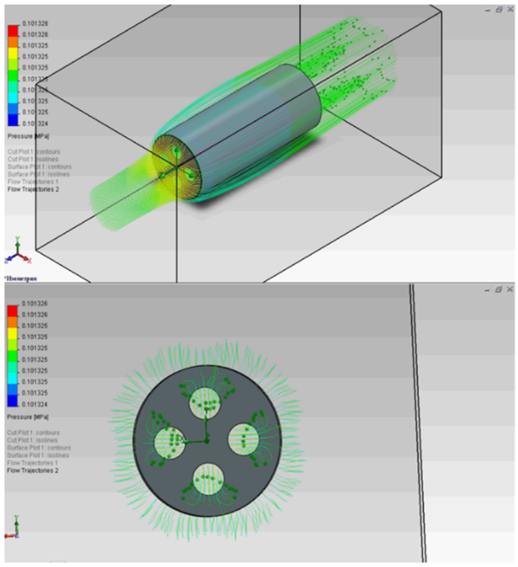

Fig. 15. Mathematical modelling: samples Nr. 8.

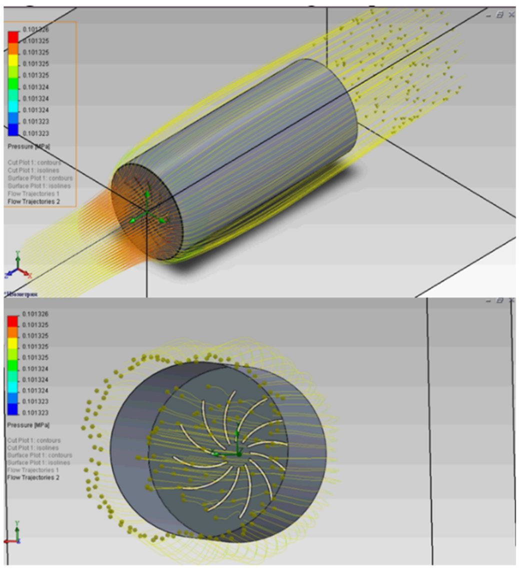

Fig. 16. Mathematical modelling: samples Nr. 9.

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