CzOTO 2019, volume 1, issue 1, pp. 481-489

ANALYSIS OF THE INFLUENCE OF THE HEAT-ABSORBING SURFACE OF AN AIR-COOLED SOLAR COLLECTOR ON ITS THERMAL AND MECHANICAL PROPERTIES

doi: 10.2478/czoto-2019-0062
Date of submission of the article to the Editor: 21/11/2018
Date of acceptance of the article by the Editor: 05/01/2019

Vasyl Zhelykh[1] – *orcid id: 0000-0002-5063-5077*
Malgorzata Ulewicz[1] – *orcid id: 0000-0001-8766-8393*
Krystyna Kozak[2]– *orcid id: 0000-0001-6392-0582*
Olena Savchenko[2]– *orcid id: 0000-0003-3767-380X*
Mariana Kasynets[2]– *orcid id: 000-0002-7686-7482*
[1]Czestochowa University of Technology, **Poland**
[2]Institute of Building and Environmental Engineering, Lviv Polytechnic National University, **Ukraine**, cr_i@ukr.net

Abstract: This paper presents the analysis of existing forms of heat absorbing surfaces of air solar collectors, which gained the greatest popularity in the world. The obtained data allowed to conclude that there is a need for the development of solar collectors with air as a coolant with an improved form of heat absorber, which will reduce the operational and capital costs of solar systems and allow the efficient use of such structures in a moderate climate without additional mechanisms for the transfer of coolant. The use of computer simulation helped to compare the thermal characteristics of air-borne solar collectors of a different design. The substantiation of the expediency of installing as a heat absorber of flow turbulators in the form of a screw has been fulfilled, as well as the height of the air channel of the solar collector has been determined, in which the maximum heating of the transfer medium is observed. In addition, the loss of pressure in the air channel of the solar collector with flow turbulators was determined and the comparison of the obtained data with the values of pressure losses in the air collector of the matrix type and the air collector with V-shaped ribs was made.
Keywords: solar air collector, heat-absorbing plate, flow turbulators, thermal power, air channel

1. INTRODUCTION

At present, due to the difficult economic situation, the energy crisis and the shortage of organic fuels in the world, which is associated with the constant growth of humanity's energy needs, the use of alternative energy sources in the world has become a popular decision. The urgency and perspective of this direction of energy is also due to the need to improve the state of the environment. As a consequence, the share of solar energy is increasing, owing to its inexhaustibility, accessibility and environmental friendliness (Zhelykh et al., 2017; Misak et al., 2014). Under solar energy in heat supply is usually understood as the transformation of solar radiation into heat. The complex of equipment and auxiliary devices, by means of which solar radiation is converted into useful thermal energy is called solar heating systems. After analyzing the global market for solar collectors, it is obvious that liquid solar collectors predominate. Of the total thermal power used and re-manufactured in the world of solar collectors, the transfer medium air has no more than 1% (Weiss and Mauthner, 2012). The main reason, that limits the widespread introduction of solar air heating systems is the low heat capacity and the low density of the heat carrier. A small density means that the heat carrier can quickly heat up and cool. Therefore, air heating systems are used mainly in buildings where it is necessary to heat large volumes of accommodations in a short period of time. Perspective is also the use of solar-heated air for technological processes in agriculture and construction (Zhelykh et al., 2014). However, air systems have a number of significant advantages over liquid: the lack of freezing and boiling of coolant; higher solar energy use; easier management, longer life and lower cost of equipment. In addition, in such systems, the temperature conditions of the coolant are lower than that of liquids, therefore, the requirements for materials are less rigid, for example, light-penetrating and heat-absorbing surfaces can be made of polymers, which greatly simplifies the structure. The specified causes the urgency of the application of solar heating systems with the use of air solar collectors, but these designs require a thorough choice of the form of heat absorbent to create the most effective heat exchange with a transfer medium.

Technologies used today in passive buildings are being developed and implemented in construction since the energy crisis of the 70s of the last century. In many developed countries, the practice of constructing buildings "zero energy" or "energy plus" that does not require any additional energy for heating or cooling, even more, can supply it to the general network. One of the methods of heating such buildings is the use of heating systems with air solar collectors (Fajst, 2008).

According to a survey of the global solar heating market, performed by Werner Weiss and Franz Mauthner ((Weiss and Mauthner, 2012) from AEE INTEC institute for sustainable technologies (Austria) within the framework of the program "Solar Heat Supply and Cooling" of the International Energy Agency at the end of 2011 in the world operated air solar collectors with a total area 2 213 434 m^2, in particular the majority (71%, 1 568 549 m^2) – with unheated air heaters. Glacial solar collectors make up 29% (644 885 m^2).

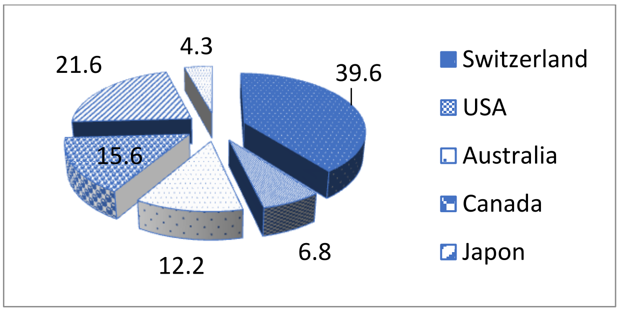


Fig. 1. The share of solar air systems in the world

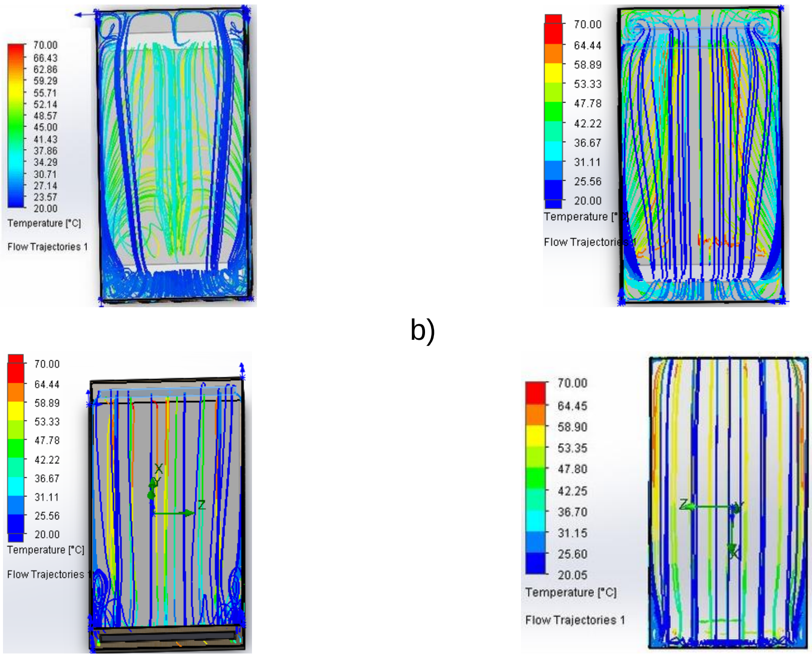
In Fig. 1 shows the diagram of the distribution of air solar systems in the world, with a heliopolis area greater than 100 000 m^2. The use of flat, non-glazed air solar collectors is effective only in countries with a hot climate. For a moderate climate, to reduce the heat loss to the environment, it is necessary to use light-penetrating coatings from tempered glass or polymers that are resistant to solar radiation and high temperatures. In addition, attention should be paid to the effective form of heat-absorbing solar energy. Currency, a large number of different forms of heat absorbents have been developed, often use fins, and V-shaped edges and matrix coating (Aoues, 2011; Razak, 2016). These coatings are quite effective compared to flat plate heat-absorbing plates, but they create a significant resistance to the flow of heat-carrier, which leads to the need to use a more powerful fan and renders such an inefficient coating for solar collectors with natural circulation. Moreover, the inventors and scientists made attempts to improve the thermal characteristics of air heaters by using a variety of reflectors (Patent 1346913 USSR). At present, this idea is used singly, since air solar collectors are positioned as inexpensive and easy to manufacture and operate, and reflectors increase the cost of the collector, in addition, the weight and durability of the design becomes higher. Therefore, it can be concluded that although there are many types of heat absorbers, one still needs to look for an absorber form that would be effective in passive solar heating systems for use in temperate regions.

2. METHODOLOGY

Based on the literature review, it can be argued that one of the main tasks in the design of solar air heaters is the maximum increase in the area of heating and minimization of heat losses in the environment, while preserving the simplicity of the design. In addition, the distribution of heat fluxes in the air channel of the solar collector is influenced by the location of the inlet and outlet openings in the housing. The variants of arrangement of apertures in side lateral walls and at the bottom of the air collector are considered. The study of thermal characteristics of a solar air heater with two variants of the location of the input and output holes was carried out using the module engineering analysis of the automated design system. During the construction of the thermal model, the following simplifications were adopted:

- the coefficient of thermal conductivity of the material does not depend on temperature;
- the air in the solar collector is heated from the heat-absorbing plate, the temperature of which is constant.

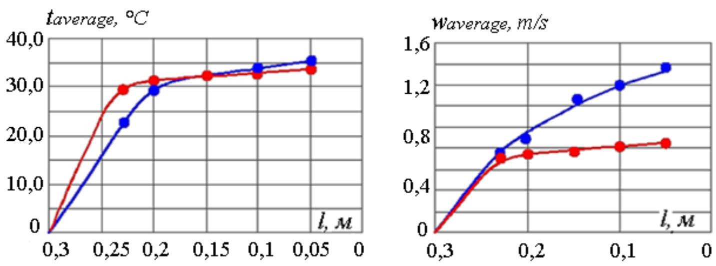
In Fig. 2 shows the distribution of the temperature of the transfer medium (air) in the air channel of the solar collector at its variable height. The inlet and outlet holes are located at the bottom of the collector (Fig. 2, a, b) and in its transverse side walls (Fig. 2, c, d). The simulation was carried out for an air channel with geometric dimensions: width – 0.8 m, length – 1.5 m, height varied from 0.08 to 0.25 m. The temperature of the heat-absorbing plate was 70°C. The air temperature at the entrance to the solar collector was 20°C, and the heat carrier flow rate was 0.03 kg/s. In Fig. 3, and shows the change in the average air temperature at the outlet from the solar collector, depending on the location of the input and output holes and the height of the air channel. During the placement of openings at the bottom of the solar collector and at the height of the air channel of 0.08 m, the maximum heating of the air was occurred. However, during the location of the collector holes in the side walls of the body, a significantly higher average velocity of the thermal medium at the outlet from the air channel was observed. Thus, at a channel height of 0.08 m, the average speed reaches 1.6 m/s (Fig. 3, b). Since in this work more interest was caused by the heating of the premises, for further research the location of the input and output holes at the bottom of the collector was selected.



a) b)

c) d)

Fig. 2. Distribution of the temperature of the coolant in the volume of the air channel, depending on its height: a) the holes were located at the bottom of the collector, h = 0,2 m; b) the holes were located at the bottom of the collector, h = 0,8 m c) the holes were located in the side walls of the collector material h = 0,2 m; d) the holes were located in the side walls of the collector material h = 0,8 m



a) b)

Fig. 3. The dependence of the change in average temperature (a) and average velocity (b) of the coolant at the exit from the solar collector from the height of the air channel and the collector structure: – the outlet and the inlets were placed at the collector's bottom; – the outlet and inlet holes were located in the side walls of the collector housing

Further reduction of the height of the air channel is not feasible as there was an increase in the air flow velocity and a decrease in the temperature of the heat carrier, in addition the possible destruction of the transparent coating under the influence of the heated heat absorber. Analyzing the obtained data, we can conclude that the maximum heating of air in an air solar collector takes place when the holes are located in the bottom of the solar collector and the height of air channel is 0.08 m.

To improve the thermal characteristics of the air solar collector, in addition to the flat Heat-absorbing plates, it was decided to use as an additional heat-absorbing air flow turbulators, made in the form of a screw (annular twisted conoid) with an external diameter of 0.05 m and place them in the air channel of the solar collector at a certain distance from each other along the motion of the heat carrier (Patent No. 68773 UA). This form was chosen to ensure that the sun's rays are effectively absorbed by the surface of the heating absorber despite the angle of their fall. The best option for this task is the cylinder, but the arrangement of the cylinders in the air channel creates significant resistance to the movement of the air, so it was decided to use a twisted conoid. Since this solar collector operates on the principle of free convection, the flow turbulators are stationary, to reduce the pressure loss in the air channel (Fig. 4).

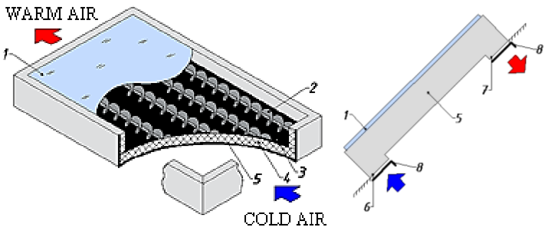


Fig. 4. Constructive appearance of air solar collector with flow turbulators:
1 – glassing; 2 – flow turbulators; 3 – heat-absorbing plate; 4 – thermal insulation;
5 – collector corps 6 – entrance hole; 7 – outlet hole; 8 – control valve.

To evaluate the effectiveness of the flow turbulators, a computer simulation of thermal processes in the air channel of the experimental solar collector was performed. In fig. 5 shows the distribution of the temperature of the thermal medium in the air channel of the collector at its variable height.

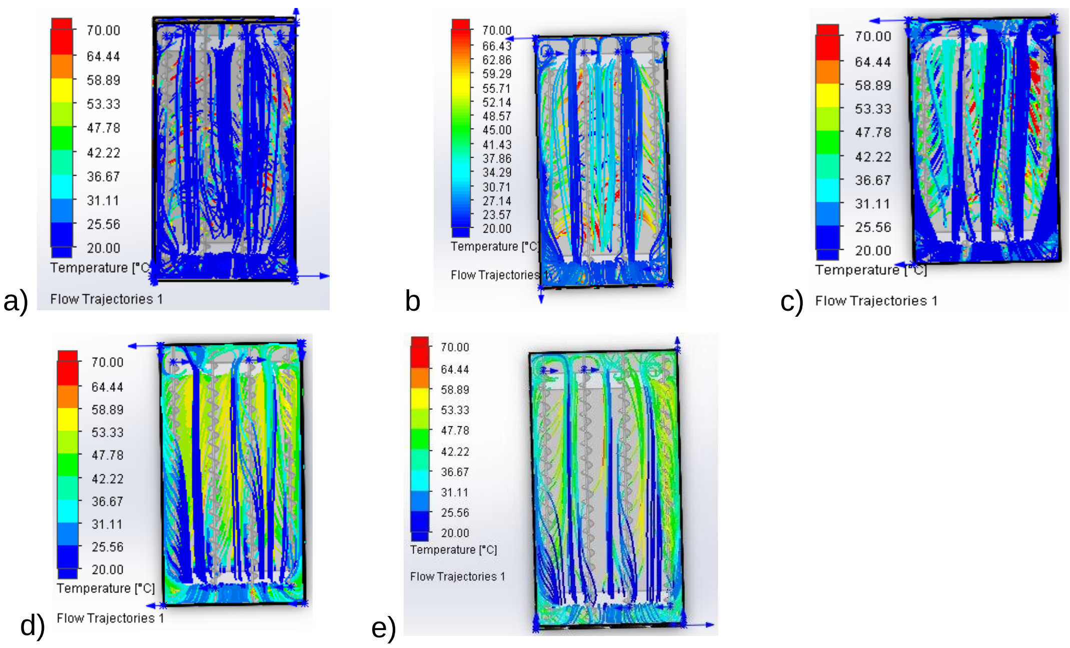


Fig. 5. Distribution of air temperature in the volume of the air channel of the collector depending on its height:
a) h = 0.25 m; b) h = 0.2 m; c) h = 0.15 m; d) h = 0.1 m; e) h = 0.08 m.

The characteristic results of computer simulation allow us to establish that the maximum heating of air, the velocity of the heating transfer medium at the outlet from the collector, and the power of the air solar collector are observed at an air channel height of 0.08 m. Further reduction of the air channel height with the installed flow turbulators is not feasible, since during heating of the heat absorber the fracture of the glass plate is possible. Therefore, the optimal height of the air channel of the air solar collector with the installed turbulators of the air flow with an outer diameter of 0.05 m is 0.08 m. According to the received data, the thermal power of the improved air solar collector has increased by an average of 23% compared to a solar collector with a flat heat absorbing plate. In an additional experimental way (Zhelykh, 2016), the value of the pressure loss in the air solar collector with turbulators of the flow was determined . To this end, a digital manometer, connected at the entrance and exit from the solar collector, was used. As the volume flow increased, there was an increase in the value of the pressure drop. A comparison of the obtained values of pressure losses in a experimental solar air collector with the values described in the literature for known structures, in particular for a matrix type air collector (Mendaza, 2014) and an air collector with V-shaped ribs (Kim, 2010) (Fig. 6), was performed. As a result of the analysis, it was found that the loss of pressure in the air solar collector is commensurate with the loss of pressure of the air solar collectors used in air heating systems.

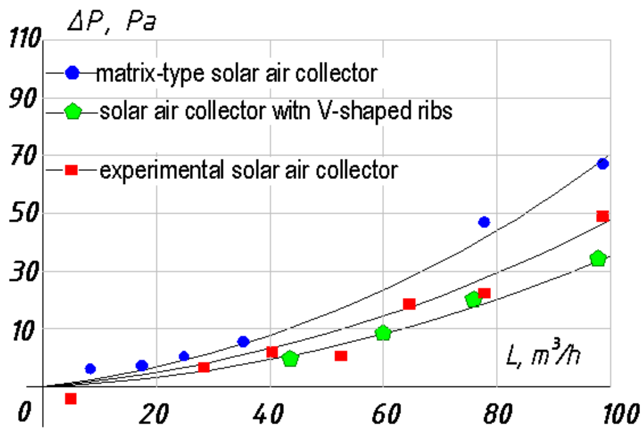


Fig. 6. Pressure loss, ΔP, Pa in the air channel of the solar collector, depending on the coolant flow, L, m^3/hour

The presented computer simulation of thermal processes that occur in the air channel of the solar collector is very fast and useful method. Similar effective simulation methods may be used in other research areas like e.g. heavy-duty machines (Domagala et al., 2018a; Domagala et al., 2018b), materials science (Tiziani et al., 1990; Bochenek et al., 2018) or special coatings techniques: plasma-sprayed (Zorawski et al., 2008), bioceramic (Dudek, 2009; Dudek, 2011) or electro-spark deposited (Scendo et al., 2014; Radek et al., 2018). It should be noted that accuracy overfitting, typically met in the numerical simulation is not reliable and should be moderated by fuzzy uncertainty (Pietraszek et al., 2014; Pietraszek et al., 2017a) and resampling from real experimental data e.g. bootstrap (Dwornicka et al., 2017; Pietraszek et al., 2017b). It has been also successfully implemented in image analysis methods (Gadek-Moszczak and Matusiewicz, 2017). Regardless, it would be advantageous to use the design of experiments approach (Maszke et al., 2018; Skrzypczak-Pietraszek et al., 2018).

3. CONCLUSION

This article presents the consideration of the designs of air solar collectors with the most commonly used forms of heat absorbers. Using computer simulation, a comparison was made of the nature of the temperature distribution and the velocity of the heat carrier in the air channel of the solar collector with a different design solution. It was found that when placing the input and output holes at the bottom of the solar collector and the height of the air channel of 0.08 m, the maximum heating of the air is carried out. The construction of a solar collector with air flow turbulators, which are made in the form of a screw and installed in the air channel is proposed as an additional heat absorber. A computer simulation of thermal processes that occur in the air channel of the solar collector was performed, and it is found that the maximum speed, and the temperature of the coolant at the outlet of the collector, as well as its thermal power,were observed at an air channel height of 0.08 m and is greater by 23% compared to the thermal power of a solar collector with a flat heat-absorbing plate. The dependence of the pressure losses in the experimental air solar collector with turbulators of the flow from the volume flow of the coolant was obtained. The obtained results with the loss of pressure in known designs of air heaters were comparison. It should be noted that flow turbulators do not create a significant resistance to the movement of the coolant, the loss of pressure in the solar collector under study is commensurate with the loss of pressure of the air solar collectors used in air heating systems. Summarizing the above data, it can be argued that the proposed design of an air solar collector is sufficiently effective and it can be used in both active and passive solar heating systems.

REFERENCES

Aoues, K., Noureddine, M., Zellouf, M., Benchabane, A., 2011, *Thermal performance improvement of solar air flat plate collector: A theoretical analysis and an experimental study in Biskra, Algeria*. Int. J. Ambient Energy, 32(2), 95-102.

Bochenek, D., Niemiec, P., Korzekwa, J., Durtka, B., Stoklosa, Z., 2018, *Microstructure and Properties of the Ferroelectric-Ferromagnetic PLZT-Ferrite Composites*. Symmetry-Basel, 10 (3), art.59.

Butuzov, V., 2013, *Air solar collectors.* Plumbing, heating, air conditioning, 7, 1-5, (Russian).

Domagala, M., Momein, H., Domagala-Fabis, J., Filo, G., Kwiatkowski, D., 2018a, *Simulation of Cavitation Erosion in a Hydraulic Valve*. Mater. Res. Proc. 5, 1-6.

Domagala, M., Momeni, H., Domagala-Fabis, J., Filo, G., Krawczyk, M., 2018b, *Simulation of Particle Erosion in a Hydraulic Valve*. Mater. Res. Proc. 5, 17-24.

Dudek, A., 2009, *Surface properties in titanium with hydroxyapatite coating*. Opt. Appl., 39, 825-831.

Dudek, A., 2011, *Investigations of Microstructure and Properties in Bioceramic Coatings Used in Medicine*. Arch. Metall. Mater., 56, 135-140.

Dwornicka, R., Radek, N., Krawczyk, M., Osocha, P., Pobedza, J., 2017, *The Laser Textured Surfaces of the Silicon Carbide Analyzed with the Bootstrapped Tribology Model*. Metal 2017: 26th Int. Conf. Metallurgy and Materials, Tanger, 1252-1257.

Fajst, V., 2008, The *basic provisions of designing of passive houses / trans. from German with additions*; (Ed.) Elokhova A., Association of Construction Universities, 144. ISBN: 978-5-93093-619-3 (Russian).

Gadek-Moszczak, A., Matusiewicz, P., 2017. *Polish Stereology – a Historical Review*. Image Anal. Stereol., 36, 207-221.

Kim, M.Ch., 2001, *The Oncet of Natural Convection and Heat Transfer Correlation in Horizontal Fluid Layer Heated Uniformly from Below*. KSME International Journal, 15(10), 1451– 1460.

Maszke, A., Dwornicka, R., Ulewicz, R., 2018, *Problems in the implementation of the lean concept at a steel works – Case study*. MATEC Web Conf., 183, art. 01014.

Mendaza, J. M., 2014, *Solar Collectors for Air Heating Profitability Analysis.* University of Gavle, 77
http://www.diva-portal.org/smash/get/diva2:725442/FULLTEXT01.pdf

Misak, J., Vozniak, O., Datsko, O., Shapoval, S., 2014. S*olar power engineering: theory and practice*: monograph. Lviv: Lviv Polytechnic Publishing House, 340. ISBN: 978-617-607-597-4 (Ukrainian)

Patent No. 1346913 USSR. *Solar thermal collector*. Dobrundashvili Z. №39, 1987..

Patent No. 68773 UA. *Thermosyphon solar collector,* Zhelyh V., Lesyk Ch. №7, 2012.

Pietraszek, J., Dwornicka, R., Krawczyk, M., Kołomycki, M., 2017a. *The non-parametric approach to the quantification of the uncertainty in the design of experiments modelling*. UNCECOMP 2017, NTU of Athens, 598-604.

Pietraszek, J., Gadek-Moszczak, A., Torunski, T., 2014. *Modeling of errors counting system for PCB soldered in the wave soldering technology*. Adv. Mater. Res.-Switz., 874, 139-143.

Pietraszek, J., Szczotok, A., Kolomycki, M., Radek, N., Kozien, E., 2017b. *Non-parametric assessment of the uncertainty in the analysis of the airfoil blade traces*. Metal 2017: 26th Int. Conf. Metallurgy and Materials, Ostrava, Tanger, 1412-1418.

Radek, N., Szczotok, A., Gadek-Moszczak, A., Dwornicka, R., Broncek, J., Pietraszek, J., 2018. *The impact of laser processing parameters on the properties of electro-spark deposited coatings*. Arch. Metall. Mater., 63, 809-816.

Razak, A., Majid, Z., Azmi, W., Azmi, W., Ruslan, M., Choobchian, Sh., Najafi, G., Sopian, K., 2016, *Review on matrix thermal absorber designs for solar air collector*. Renewable and Sustainable Energy Reviews, 64, 682-693.

Scendo, M., Trela, J., Radek, N., 2014. *Influence of laser power on the corrosive resistance of WC-Cu coating*. Surf. Coat. Tech., 259, 401-407.

Skrzypczak-Pietraszek, E., Piska, K., Pietraszek, J., 2018. *Enhanced production of the pharmaceutically important polyphenolic compounds in Vitex agnus castus L. shoot cultures by precursor feeding strategy*. Eng. Life Sci., 18, 287-297.

Tiziani, A., Molinari, A., Kazior, J., Straffelini, G., 1990. *Effect of vacuum sintering on the mechanical-properties of copper-alloyed stainless-steel*. Powder Metall. Int., 22, 17-19.

Usachev, A., 2015, *Analysis of the dynamics of the world industry of solar energy. Analysis of the dynamics of the world industry of solar energy*. Internet Journal Naukovodenie, 7(4), 1-10, (Russian).

Weiss, W., Mauthner, F., *Solar heat worldwide. Marcets and contribution to the Energy Supply 2010*. Edition 2012 / AEE – Institute for Sustainable Tachnologies, Gleisdorf, Austria: 62.

Zhelykh, V., Kozak, Ch., Furdas, Y., Spodyniuk, N., Dzeryn, O., 2014 *Energy saving technologies in production complexes for agricultural purpose.* Journal of Lviv Politechnic National University. Theory and practice of building, 781, 230–233.

Zhelykh, V., Shapoval, S., Venhryn, I., 2017, *The potential of radiant energy and its use for low-temperature solar collectors*. Journal of Lviv Politechnic National University. Theory and practice of building, 17, 80-83.

Zhelykh, V., Kozak, Ch., Savchenko, O., 2016, *Using of Thermosiphon Solar Collector in an air Heating System of Passive House*. Pollack Periodica, 11(2), 125-133. http://real.mtak.hu/52294/1/606.2016.11.2.11.pdf

Zorawski, W., Chatys, R., Radek, N., Borowiecka-Jamrozek, J., 2008. *Plasma-sprayed composite coatings with reduced friction coefficient*. Surf. Coat. Tech., 202, 4578-4582.