ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 2 , February 2018

Efficiency of Heat Exchange of a Solar Air Collector with a Light-Absorbing Surface Made of Stainless Steel Shavings

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ABSTRACT: The article analyzes the main solar air heaters and ways to increase their efficiency. An efficient design of a solar air heater with an absorber made of stainless steel-flaked drain chips has been developed. The results of experimental studies on heat transfer are presented. An empirical formula is obtained for the heat exchange of a radiation-absorbing surface and an analytical formula for the efficiency of a solar air heater.

KEYWORDS: energy, energy conservation, renewable energy sources, solar radiation, solar collectors, solar air heaters, efficiency.

I.INTRODUCTION

The sharp increase in the number of people on our planet and the acceleration of the development of our time in recent years have led to an excessive increase in the demand for energy and, as a result, a reduction in fuel and energy resources throughout the world [1]. According to this development scenario [2], gas reserves will last 120 years, oil - 250, coal - 1560. For a stable pace and sustainable development, to increase energy efficiency and energy saving, energy security, dependence, reducing the amount of fossil fuel burned and improving the environmental situation throughout the world [3], for the future continuation of the human race, is the main strategy of the countries [4] and an urgent task for the whole world, wide implementation and Using renewable energy sources (RES) [5].
The most promising source for the production of thermal energy among renewable energy sources is solar radiation due to the huge amount of resources, ecological purity and widespread prevalence [6,7]. To convert solar radiation into thermal radiation, solar air collectors (SAC) [8] are used.
It should be noted that at present there is a wide variety of (solar air collector) SAC designs whose main task is to increase the thermal efficiency of the collector due to heat transfer from the absorber to the airflow. SAC on the basis of a design feature can be divided into flat SAC with artificial turbulators installed in the channel, SAC consisting of separate flat absorbers inside which the air coolant circulates and the SAC absorbers consist of different nozzles cluttering the channel cross-section (installed in the grid channel, sieves, honeycombs and etc.). Figure 1 shows a schematic of the variants of effective SAC.

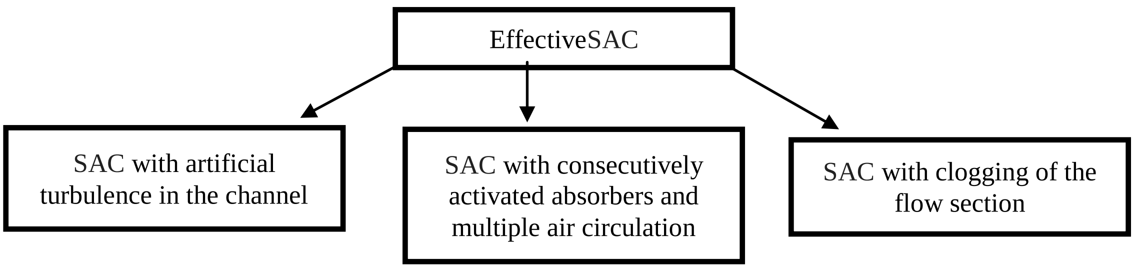

Figure 1. Scheme of options for effective SAC.
Flat SAC with artificial turbulators installed in the channel are simple, they have low aerodynamic resistance, and therefore such SAC have received more mass distribution in practical solar engineering. The thermal efficiency of such

SAC can be estimated by the formula (1) known in heat engineering [9], which takes into account not only the growth of convective heat transfer relative to a smooth channel under the same hydrodynamic conditions, but also the growth of hydrodynamic resistance. In the opinion of the authors of this work, the efficiency of the design of the thermal device can be improved by the introduction of a collector device – turbulators.

$$\bar{E}' = \frac{E'}{E'_{гл}} = \frac{\frac{Nu}{Nu_{гл}}}{\frac{\xi}{\xi_{гл}}} \quad (1)$$

Here $E'_{гл}, E'$ – are the energy coefficients of M.V. Kirpichev a smooth-walled channel and a channel with artificial turbulators installed in them. Nu –is the Nusselt number, ξ – is the channel resistance coefficient.
The earliest works on the efficiency of convective heat transfer from moving air to the walls of the canal include research by G. Schlichting [10], and also by Z. Chukhanov [11]. According to [10], there is a relationship between the hydrodynamic resistance of flow and the heat flux, which a smooth flat surface (plate) is expressed by the formula:

$$Q = \left(\frac{\lambda}{\mu}\right)\left[\frac{T_{cm} - T_{\infty}}{U_{\infty}}\right] W_R \quad (2)$$

This paper we consider the creation of an effective absorber of a solar air collector. For more effective heat removal from the radiant-absorbing surface by air flow, chips are used from stainless steel, with flow around which a turbulent flow regime is created on a macro and micro scale, which leads to a swirling and twisting of the flow.

II. METHODOLOGY

Design of solar air collector

The solar air heater contains a light heat-insulated case of three walled two chamber plastics 1, the thickness of the case is 25 mm, the wall thickness is 1.3 mm, the cross-sectional area of the chamber is 10 mm^2, the transparent coating 9 is made of double glass with a thickness of 4 mm at a distance from each other 10 mm, three partitions are installed 3 transversely relative to the air at the bottom of the body 1, at a distance of 350 mm from each other,with a length of 500 mm, with a height of 10 mm, the "absorber" of the V-shaped corrugated metal sheet 4 is installed across the channels with respect to the movement of air reinforced on the baffles with a thickness of 1.1 mm, an opening angle of 60°, a height of the projections of 15 mm, an "absorber "From stainless steel waste shavings (spiral-helical of 12X18H10T brand, bluish coloring layer) 7, drain chips are installed transversely relative to air movement, opening angle of discharge chips 30^o, thickness of drain chips 1 - 2 mm, evenly distributed on metal grid 6, tension utye a frame 5 made of aluminumheight of the profile 16 mm, width 15 mm, the frame of the metal mesh is mounted on a metal sheet V-shaped, the metal mesh has a distance from the top point of the metal sheet V-shaped 8 mm, and from the bottom point 23 mm, supplying 10 and discharging 11 air nipples with a 32 mm channel diameter.
The solar air heater operates as follows: air injected by the fan 12 enters the space through the supply pipe 10 into the lower part of the absorber into a channel consisting of a V-shaped corrugated metal sheet 4 and the bottom of the collector 1.Air flow washing the back side of the absorber from the V-shaped corrugated metal sheet 4, the flowing partitions 3 repeatedly changes its direction. Further, the air rotates through 180 ° and enters the space between the top of the absorber from the stainless steel waste chips and the transparent coating 9, the air washes the upper part of the absorber from the stainless steel waste chips 7 longitudinally turbulized to intensify the heat exchange. Then the air through the branch pipes 11 exits the collector.

On the other hand, the algorithms have their own advantages and disadvantages. Discussion The method is based on the idea of using several data sources as input to an engine that classifies a message as either spam or ham. These data sources could comprise pieces of information from several social media. Given data from these data sources, the engine creates a graph of users and extracts basis for the classification of incoming messages, regardless of which medium is used to transfer the message. Since data collected may not be correct always, data is pre-processed to avoid any inconsistencies in the data. Filtering is done for the feature selection process where the most relevant attributes are given highest priority while classifying the data.

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Method of carrying out the research experiment:

The experiments were carried out in full-scale conditions at the helium polygon of the Fergana Polytechnic Institute in the city of Fergana, Republic of Uzbekistan. The experimental stand contains: solar collector, fan, control and measuring equipment.

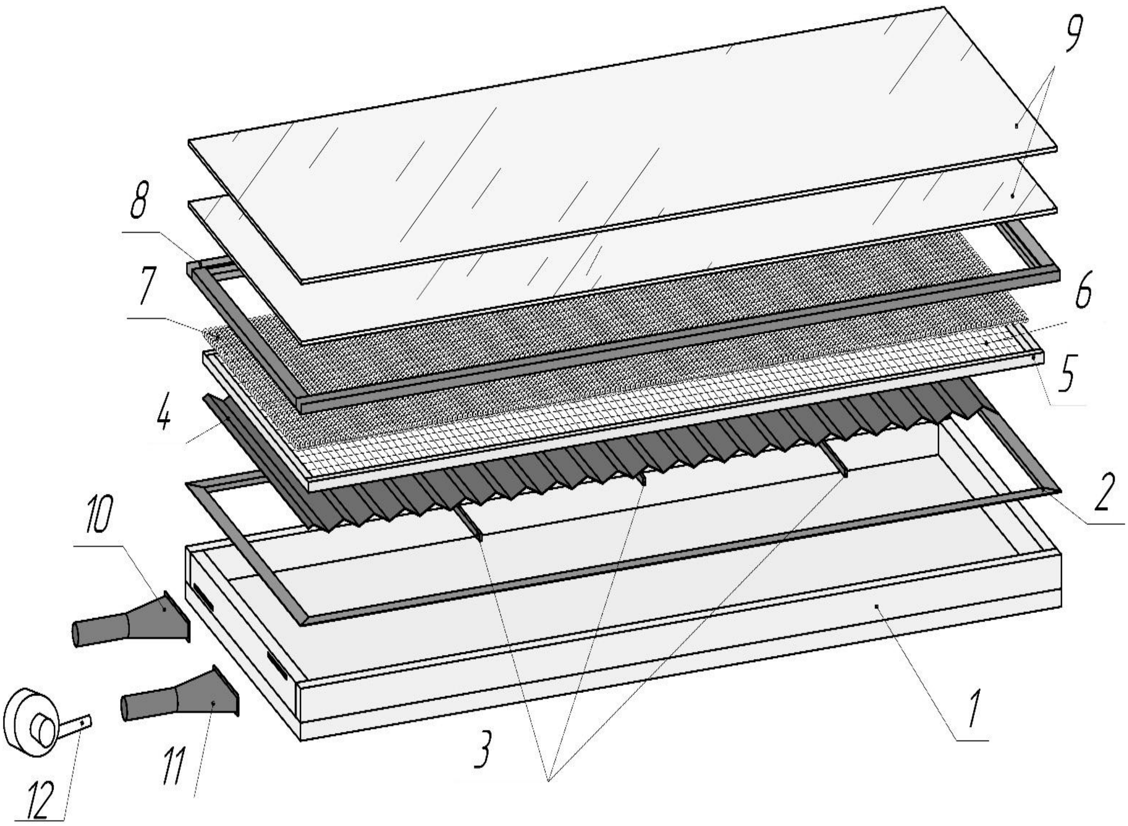

Figure 2. Dimmetry SAC.

1 - body, 2 - frame, 3 - partitions, 4 - V-shaped beam absorber, 5 - frame for metal mesh, 6 - metal mesh, 7 - shavings, 8 - skeleton for transparent coating, 9 - transparent coating, 10 - a tube for the supply of coolant, 11 - a tube for removing the coolant, 12 - an electric fan

During the experiment, the following parameters were measured: total solar radiation intensity, wind speed, outside air temperature, absorber temperature, and inlet and outlet air temperature. The total intensity of solar radiation was measured by the actinometer Savinov – Yanushevsky, a galvanometer of the type GSA-1. The temperature at the inlet and outlet of the SAC was measured with a chromel-alumel thermocouple connected to the TRM 138 information and measuring system.

Experimental studies to determine the efficiency of the solar air heater were carried out in the following order: for a fixed value of the angle of inclination of the SAC 45°, with a fixed airflow rate. The airflow was varied by changing the fan voltage, previously switched on by the recording devices.
The coefficient of efficiency is calculated by the formula

$$\eta = \frac{G c_p (T_{out} - T_{in})}{A_c H_t} \quad (3)$$

where G –is the mass flow of the coolant; c_p –is the specific heat; - inlet, outlet temperature of the coolant; A_c–is the area of the collector; H_t - arrival of total solar radiation on the collector surface.

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Figure 3. General view of the experimental setup

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III. Results and discussion of results

The fixation of all measured values for different operating modes (airflow) was performed after the basic parameters reached the steady-state conditions. Further processing of data was carried out using Excel application packages. As an example, Table 2 presents the main results of tests carried out in full-scale conditions.

Test results for the year May 5, 2016 in total solarradiation on inclined surface H_t = 0.9 kW / m2, diffuseradiation S = 0, 1 kW / m^2, at an ambient temperature T_{input}= 37 ° C.

Table 1. Results of an experiment to determine the efficiency of a solar air collector

№	G, kg/s	T_{in}	$\Delta t = t_{out} - t_{in}$	Efficiency, %
1	0.0025	37	53	0.204
2	0.0033	37	51	0.2592
3	0.0061	37	46	0.4321

ISSN: 2350-0328
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4	0.009	37	44	0.6099
5	0.015	37	31	0.7132
6	0.0233	37	21	0.706
7	0.0284	37	19	0.787
8	0.0323	37	16	0.796
9	0.0387	37	14	0.83
10	0.0438	37	13	0.87
11	0.0493	37	12	0.91

On the basis of the obtained experimental data, an empirical formula for the heat exchange on absorbers is obtained, the generalized formula for the efficiency of heat transfer of a SAC.

We obtain the generalized formula by applying the superposition method. The meaning of the superposition method is that each of the surfaces of the absorber contributes to the general process of heat transfer to the SAC.

Since the air flow is successively passed by separate absorbers, we assume that the speed in the sections is constant, the diameters of the SAC channel are the same, and the values of the Re numbers in the channels of the SAC are the same.

$$w_1 = w_2 = w_3 = w_{гл}\ ;\ d_1 = d_2 = d_3 = d_{гл}\ ;\ \ Re_1 = Re_2 = Re_3 = Re_{гл}$$

Based on the measured F_1, F_2 and F and also obtained in the experiments n_1, n_2 and A_1, A_2, it is possible to calculate the heat transfer efficiency of the heat transfer of the SAC. Table No. 3 lists the heat exchange formulas for individual absorbers in the form

$$Nu = A(Re)^n (4)$$

The representation of the heat transfer formulas in this form corresponds to the position of the similarity theory, which for liquids and gases is written in a general form

$$Nu = A_1(ReP_r)^{n_1} (5)$$

If we assume that for gases (air) $P_r \approx 1$ the formula (5) is transformed into the formula (4). The processing of the obtained experimental data made it possible to obtain for the first absorber the heat exchange formula in the form

$$Nu = 0{,}014Re^{0{,}83} \qquad (6)$$

For the second absorber

$$Nu = 0{,}22Re^{0{,}625} (7)$$

In the general case, the heat-exchange formula has the form: for the first section of the SAC, the heat-transfer efficiency formula is

$$\frac{Nu_1}{Nu_{гл}} = \frac{A_1 Re^{n_1}}{C Re_{гл}^m} = \frac{A_1}{C} Re_{гл}^{n_1 - m} \qquad (8)$$

For the second SAC site

$$\frac{Nu_2}{Nu_{гл}} = \frac{A_2 Re^{n_2}}{C Re_{гл}^m} = \frac{A_2}{C} Re_{гл}^{n_2 - m} \qquad (9)$$

The general formula for the efficiency of heat exchange of an SAC on the basis of this is obtained as:

$$\frac{Nu}{Nu_{гл}} = \frac{F_1 Nu_{гл} \frac{A_1}{C} Re_{гл}^{n_1 - m} + F_2 Nu_{гл} \frac{A_2}{C} Re_{гл}^{n_2 - m}}{F Nu_{гл}} = \frac{F_1 A_1}{FC} Re_{гл}^{n_1 - m} + \frac{F_2 A_2}{FC} Re_{гл}^{n_2 - m} \qquad (10)$$

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Table 2. Results of calculation of heat transfer SAC

N	$Re_{гл}$	The heat transfer formula		$\frac{Nu_2}{Nu_1}$
		firstabsorber	secondabsorber	
		$Nu_1 = 0{,}014Re^{0{,}83}$	$Nu_2 = 0{,}22Re^{0{,}625}$	
1	9269	27,5	66,3	2,41
2	8222	24,9	61,6	2,47
3	7264	22,4	57,0	2,54
4	6066	19,3	51,0	2,64
5	5373	17,5	47,2	2,7
6	4333	14,6	41,3	2,83

Table 3.The efficiency of absorbers relatively of a smooth surface

Re	*9269*	*8222*	*7264*	*6066*	*5373*	*4333*
$\frac{Nu}{Nu_{гл}}$	*1,72*	*1,76*	*1,8*	*1,83*	*1,83*	*1,9*
$\frac{Nu_1}{Nu_{гл}}$	*0,5*	*0,5*	*0,5*	*0,5*	*0,5*	*0,5*
$\frac{Nu_2}{Nu_{гл}}$	*1,22*	*1,26*	*1,3*	*1,33*	*1,33*	*1,4*

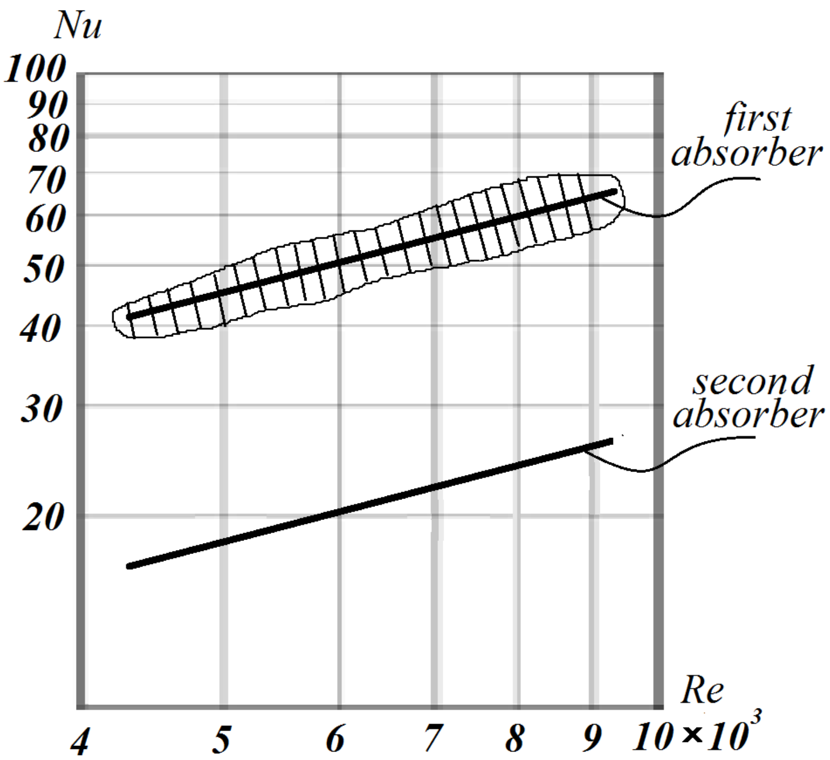

Figure4. Addiction Nu = f (Re)

It follows from Table 3 that the heat transfer efficiency of the 1st absorber practically does not change and is equal to 0.5, but due to the increase of the heat transfer efficiency of the 2nd absorber with the Re numbers from 4333

ISSN: 2350-0328

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to 9269, the efficiency of the SAC with chips is increased. This regularity, obtained because of experiments, explains the fact that by increasing the flow time through the 2nd absorber, and also due to the high efficiency of heat exchange on the surface of the shavings, the efficiency of the solar air heater increases.

Not high thermal efficiency of heat transfer of the first absorber relative to the second one is probably because the first absorber serves as the heating of the outside air in the first stage. In addition, the low thermal efficiency of the first absorber is due to the insufficient absorption of solar energy by the profiled sheet compared to the high selective absorbing matte surface of the chips that absorbs this energy.

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ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 5, Issue 2 , February 2018

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