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The Methods for Improving the Efficiency of Flat Solar Collectors

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Abstract: This article discusses the issues of increasing the efficiency of flat solar air heaters using heat exchange intensifiers. The author presents the main methods for increasing the heat transfer intensity from the absorber to the heated air in a flat solar collector, which are associated with flow separations from the absorber wall to the near-wall airflow, which practically has a low level of turbulence.

Keywords: Flat solar air heater, heat exchange, collector efficiency, roughness, aerodynamic resistance, photovoltaic module.

Introduction

Research dedicated to enhancing the efficiency of air collectors with intensified heat transfer has been conducted at the Fergana Polytechnic Institute from 2000 to 2019 [5]. These studies focused on the efficiency of flat solar air heaters (FSAH) with diffuser-convergent heat receivers, as well as with heliopreceptors of various roughnesses applied to the absorber surface.

In the mentioned studies, attention was first drawn to the fact that increasing the energy efficiency of solar air collectors could be achieved with minimal energy expenditure on promoting airflow through the heat-transfer channels at high heat exchange intensities. Consequently, the objective of these studies was to create rational intensification of heat transfer in the heat-transfer channels, where the increase in heat transfer surpasses the rise in aerodynamic resistance, investigating the nature of increased heat exchange intensity, and developing the fundamentals of engineering theory for the calculation and design of solar air heaters with high energy efficiency. One of the key factors identified to effectively enhance the heat transfer of the heater was the aerodynamic impact of the surface shape on the near-wall flow.

The authors of the mentioned studies developed criteria for evaluating the efficiency of solar heating devices for FSAH for the first time, representing formulas for the comparative efficiency of FSAH based on the coefficient of energy efficiency:

$$E = \frac{Q_{пол}}{N}, \qquad (1)$$

Additionally, formulas were developed to compare the dimensions of two FSAH (with a smooth plate FSAH chosen as the baseline) having: the same design, the same thermal power, the same equivalent diameters, the same coolant circulation rates, and the same aerodynamic losses. This undoubtedly contributed positively to the further development of thermo-aerodynamic methods aimed at enhancing FSAH efficiency.

In later years, similar research on increasing the performance of FSAH began to be conducted abroad as well.

Discussion of Results

Studies aimed at increasing the efficiency of FSAH are primarily conducted in countries with warm climates, such as Greece, India, Egypt, and China [1]. It should be noted that such research is focused on enhancing collector efficiency through the use of a photovoltaic module in the heliopreceptor channel or by increasing heat exchange through the development of the absorber surface or the use of various types of roughness, and they are experimental in nature. For instance, Tonui Y.K. and Tripanagnostopoulos Y. conducted experimental studies on improving the efficiency of a solar collector by using a photovoltaic module and fins installed in the heliopreceptor channel [1].

Figure 2 shows the dependencies of electrical and thermal efficiency of the combined solar collector. The authors of the study note that the collector efficiency with fins installed in the heliopreceptor channel increases by 20% compared to a conventional channel.

Langevaro A.M., Bhagoria J.L., and Sarviya R.M. [2] experimentally investigated the heat transfer in the heliopreceptor channel of a solar air heater, the surface of which is formed by fins with a small height and positioned at a 45° angle to the direction of the airflow. Figure 3 shows the schematic diagram of the experimental setup (a) and the arrangement of the fins (b) in the heliopreceptor.

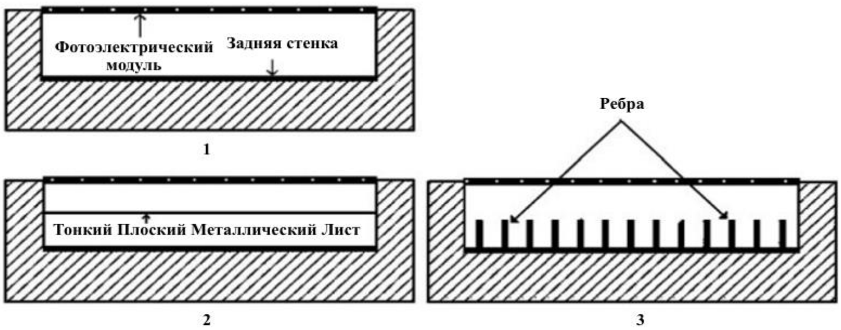
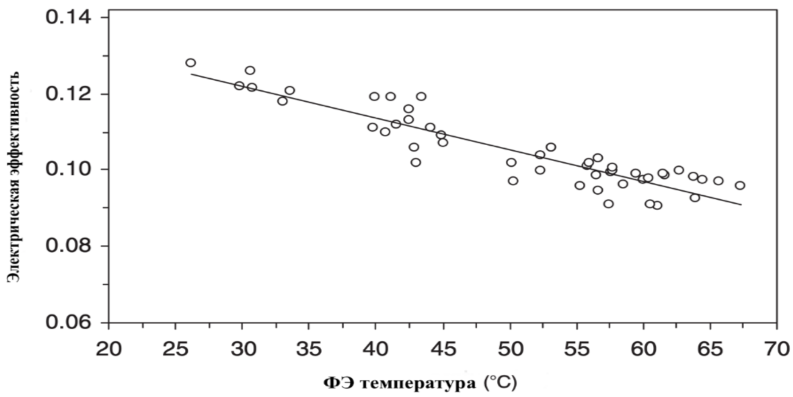


Figure 1. Cross-sectional diagram of the combined solar collector



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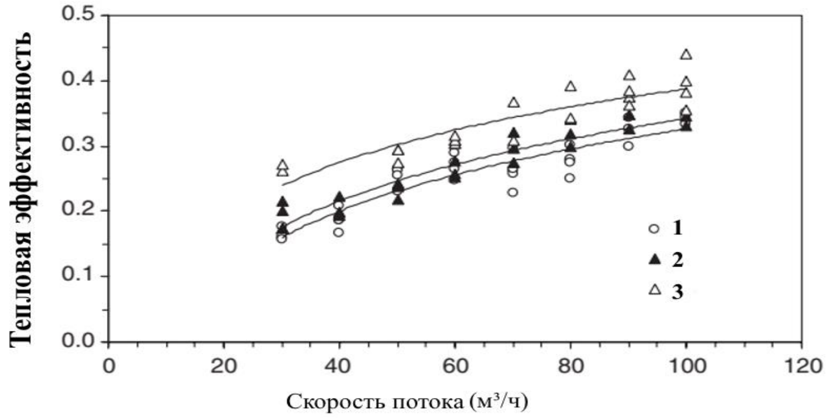

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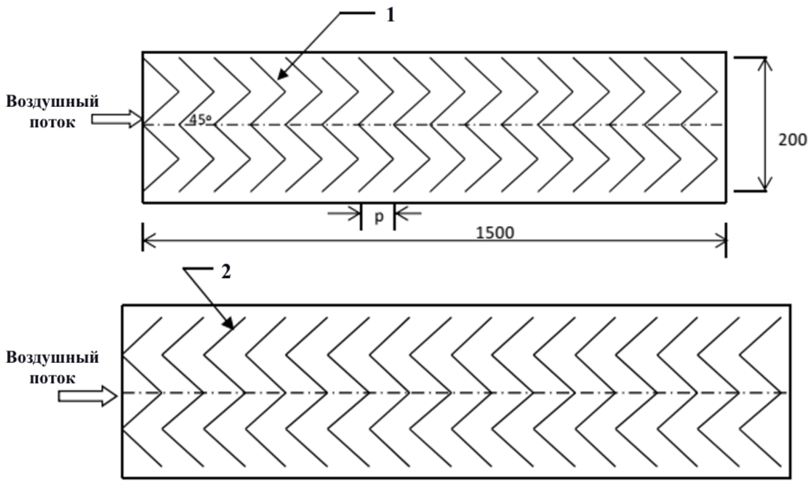
Figure 2. Dependence of photovoltaic (a) and thermal efficiency (b) on module temperature and flow velocity.

(а)



(б)

Figure 3. Schematic diagram of the experimental setup (a) and arrangement of fins in the heliopreceptor (b)

The Reynolds number in the experiments varied from 2300 to 14000. Heat transfer experiments for the straight heliopreceptor channel (without fins) are shown in Figure 4. The results of the experimental tests were compared with calculations based on the Dittus-Boelter equation, which is formulated as:

$$Nu = 0{,}023 \cdot Re^{0,8} \cdot Pr^{0,4} \cdot \left(\frac{2R}{D}\right)^{-0,2}, \qquad (1)$$

The friction of the heliopreceptor channel was compared with calculations based on the modified Blasius equation (Figure 5):

$$f_x = 0{,}085 \cdot Re^{-,25} \qquad (2)$$

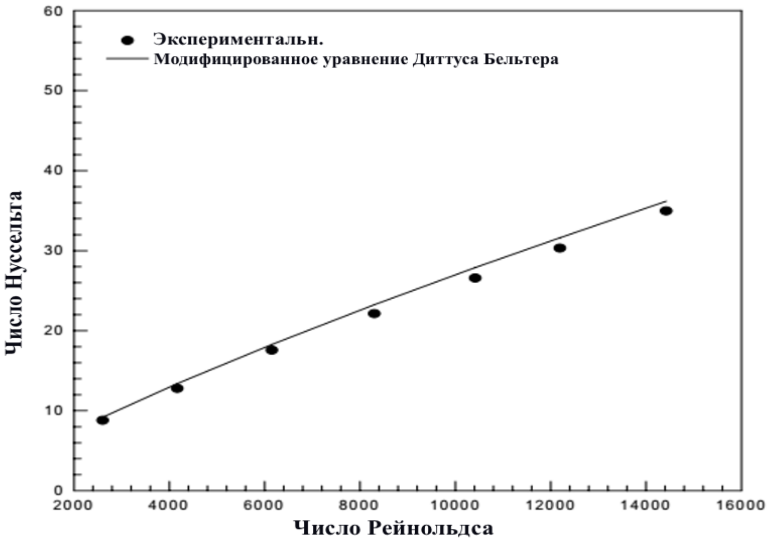


Figure 4. Comparison of experimental heat transfer data for the straight heliopreceptor channel (without fins).

The authors have demonstrated that due to the finned surface of the absorber, heat exchange can increase by up to 2.5 times compared to the heat transfer on a smooth heliopreceptor (Figure 6).

Chi-Dong Ho, Xuan Zhang, and Chung-Cheng Lin in their research [3] proposed to enhance the efficiency of the solar collector by implementing a two-way airflow in the collector and using wire mesh as the absorber (Figure 7). Figures 8 and 9 depict the schematic diagram and theoretical and experimental collector efficiencies obtained for various mass flow rates of the air coolant.

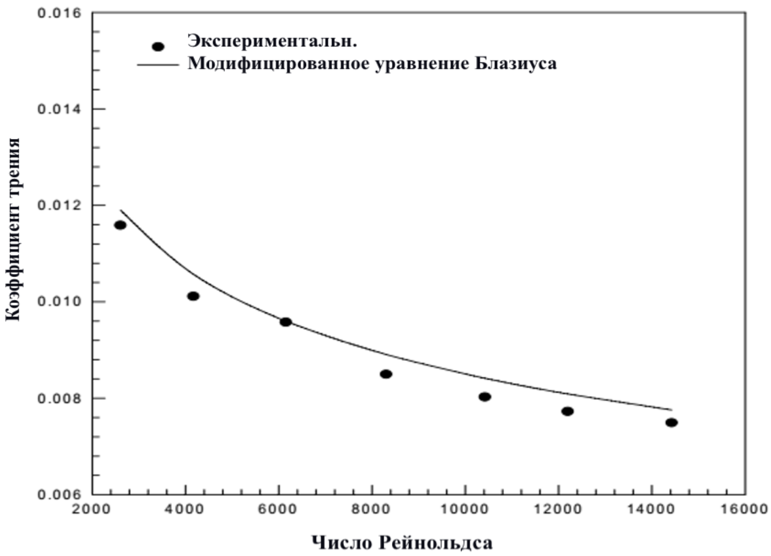


Figure 5. Comparison of experimental data on friction for the straight heliopreceptor channel (without fins).

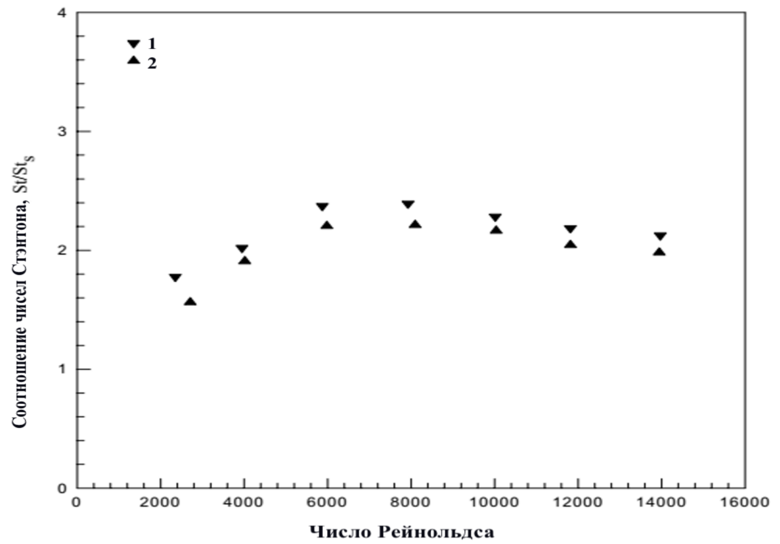


Figure 6. Increase in heat transfer on the finned surface of the heliopreceptor compared to the smooth surface of the absorber. 1, 2 - types of roughness.

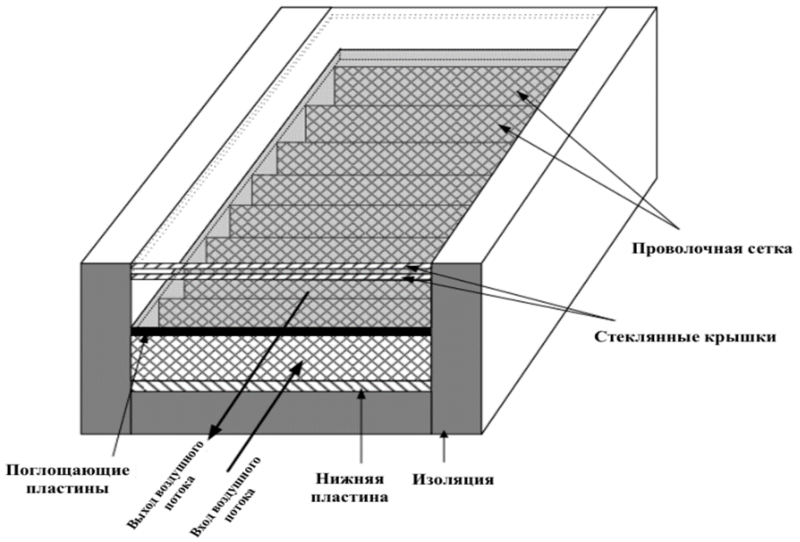


Figure 7. Schematic of airflow in a two-way solar collector.

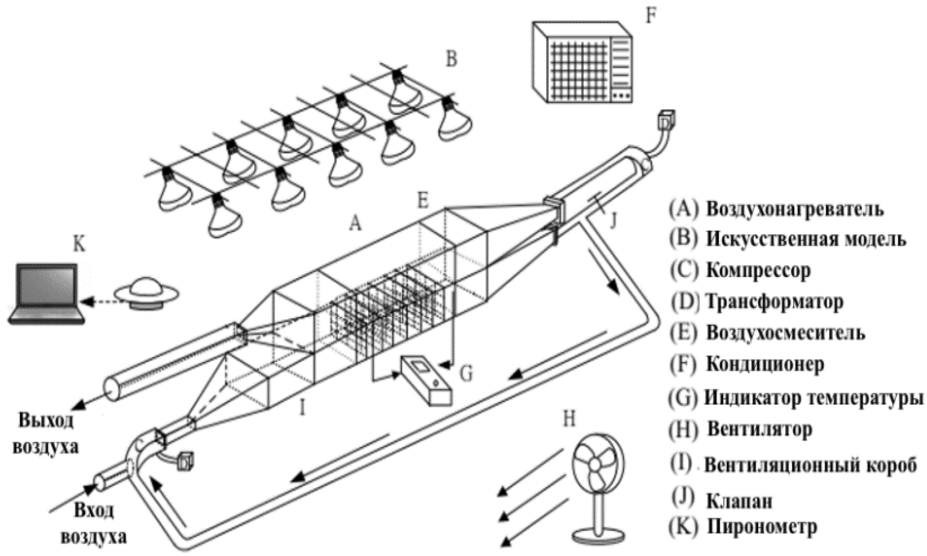


Figure 8. Schematic diagram of the experimental setup for investigating heat transfer in a two-way collector with wire mesh.

On Figure 9, theoretical and experimental collector efficiencies obtained for various mass flow rates of the air coolant are depicted. As seen from the graphs, the wire mesh increases the collector efficiency by enhancing the heat transfer intensity from the absorber to the airflow.

Research conducted by Gaurao N. and Dr. Lavankar S.M. [4] focused on studying the thermo-aerodynamic characteristics of a solar collector with roughness protrusions located on the absorber surface, as shown in Figure 11.

The experiments were conducted on a setup, the schematic diagram of which is depicted in the following Figure 12.

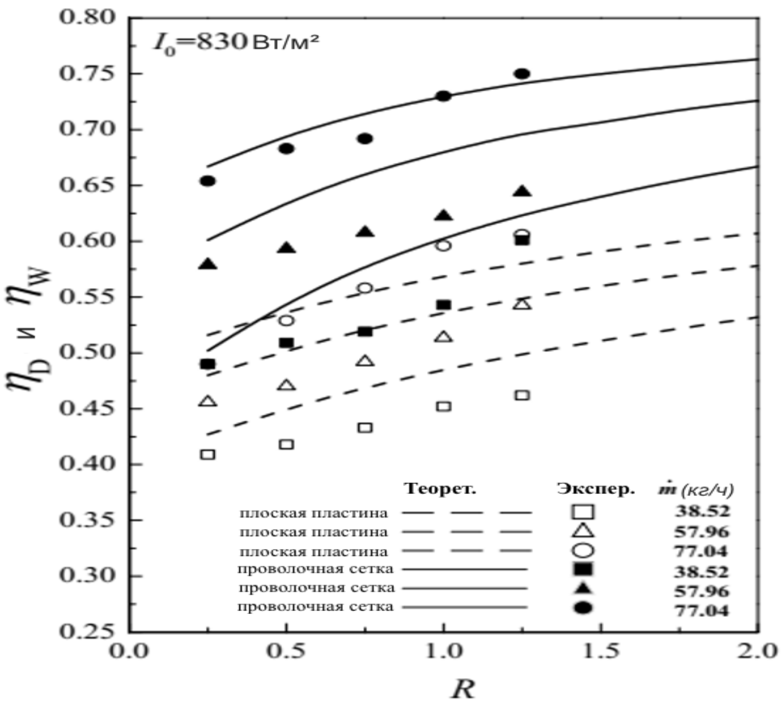
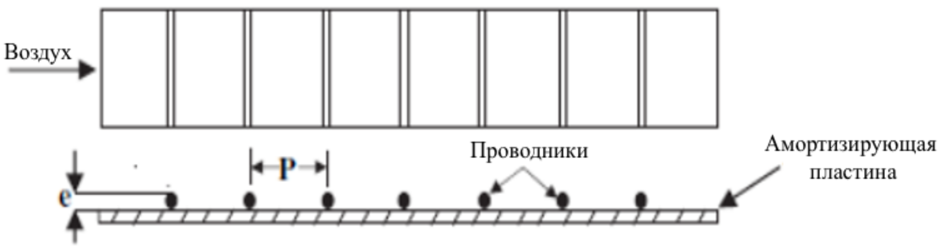


Figure 9. Dependency of theoretical and experimental values of collector efficiency with a wire mesh absorber at various air mass flow rates.

Experimental data on thermo-aerodynamic characteristics were processed in the form of a dependency:

$$THP = \frac{\left[\frac{Nu}{Nu_{гл}}\right]}{\left[\frac{C_{fгл}}{C_f}\right]}, \quad (3)$$

Where THP is referred to as the thermo-aerodynamic efficiency coefficient, which in experiments reached values of two or more. The authors have taken an important step in understanding the mechanism of flow around the roughness protrusions shown in Figure 13.



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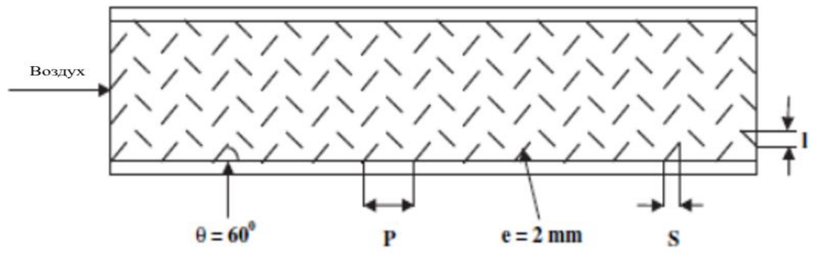

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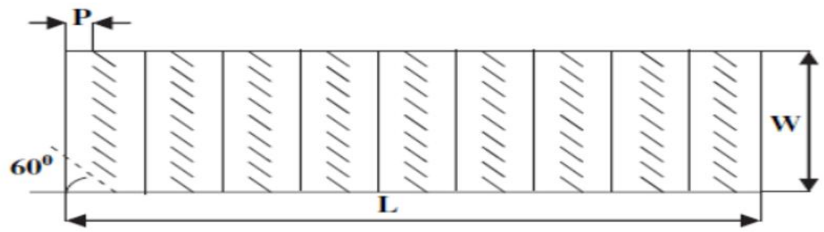

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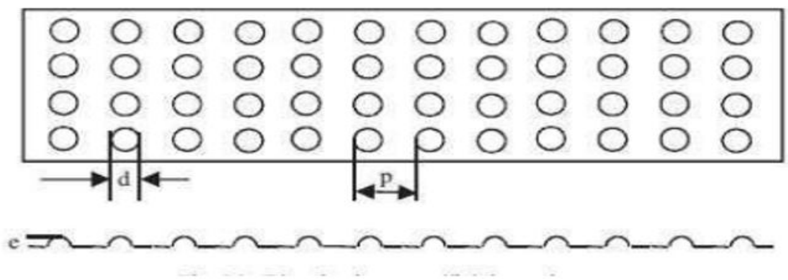

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Figure 11. Shapes of the investigated roughness protrusions.

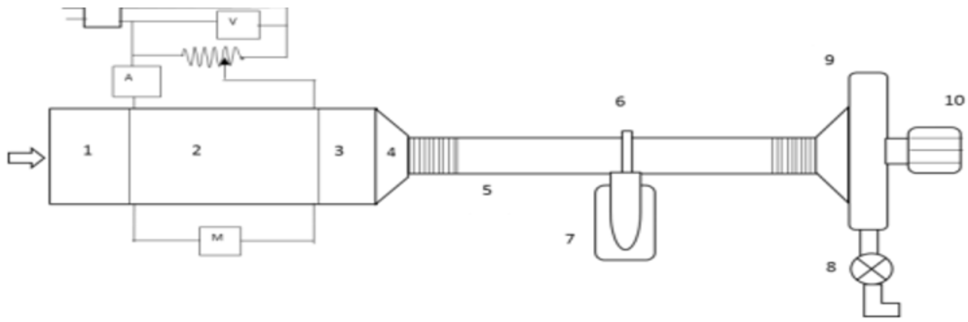

Figure 12. Schematic diagram of the experimental setup.

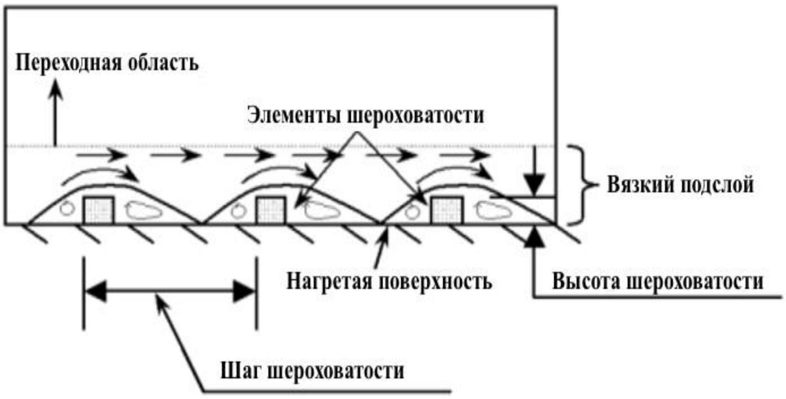

Figure 13. Schematic of flow around roughness elements.

The diagram suggests that the intensification of heat transfer from the absorber surface with protrusions is primarily associated with boundary layer separations from the protrusions, and the height and shape of the protrusions influence the aerodynamic resistance of the collector.

Conclusion

1. Analysis of scientific research on heat exchange efficiency in FSAH has shown that studies aimed at enhancing the efficiency of flat solar air heaters have made significant progress both abroad and in our country.
2. Research has been conducted on the thermal and aerodynamic characteristics of FSAH of various designs, which contributes significantly to the development of the theory of efficient heat recovery.
3. However, an analysis of foreign studies on heat transfer intensification in FSAH has revealed that the proposed methods for enhancing heat transfer in FSAH are currently disparate, and there is no unified view on organizing the most advantageous method for conducting the heat transfer process in FSAH while considering heat recovery efficiency**.**

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