Review of methods for improving the thermal performance of solar air collectors with flat plates

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Abstract. The latest research on improving the thermal efficiency of flat solar air collectors is carried out on the modification of the absorber surface, the organization of multiple air flow, the use of porous absorbers, the transfer of air flow to the absorber surface by impact, the integration of the absorber surface with heat accumulating materials. The formation of a laminar viscous layer on the surface of the absorber leads to the deterioration of heat transfer to the air stream. The main factor for increasing the heat transfer in flat solar air collectors is to increase the heat transfer surface and the air residence time in the collector, which is achieved by using fins, barriers, turbulizers and baffles. When installing turbulizers of different shapes on the surface of the absorber, the thermal efficiency of the collector increases from 71.4% to 93%. When the absorber surface is integrated with heat-accumulating materials and ribs, the daily thermal efficiency of the collector increases to an average of 0.4-4%. This review article presents an analysis of the scientific research conducted in the last decade on improving the thermal efficiency of flat solar air collectors.

1. Introduction

The increase in energy needs and environmental pollution are the main obstacles to the sustainable development of the energy production industry. The maximum demand for energy in various industries has been met mainly by fossil fuels, which increases the amount of greenhouse gases in the atmosphere and causes climate change. One of the urgent issues is the use of renewable energy sources such as solar energy and wind energy to meet global energy needs with minimal environmental changes. Among renewable energy sources, solar energy is the cleanest energy and does not affect the ecological balance. Solar energy can be easily and conveniently converted into thermal energy using solar collectors. A solar collector is an easy and inexpensive way to convert solar energy into thermal energy by absorbing solar radiation. Solar collectors are the main component of a water or air heating system using solar energy [1-2].

The flat solar air collector is the cheapest and easiest collector that requires no skill to use among the different types of solar collectors. Depending on the purpose of air heating, solar air collector (SAC), solar dryer and building-integrated SAC are divided into types.

FPSAC is a device that is used for air heating, building heating, ventilation and water desalination, and at the same time it has low thermal efficiency compared to water heaters. A solar dryer is made by combining a solar air collector (SAC) and a drying cabinet. If SAC is used as a modification in heating and cooling systems of buildings, these devices are called SAH. The working principle of SAC can be explained from the energy flow diagram (figure 1). FPSACs can be classified as one-way or two-way SAC depending on the number of airflow passes. In the parallel and opposite flow device, the air moves in a direct and reverse flow from the upper and lower channel. Recirculation is similar to reverse flow, but to achieve maximum efficiency, some of the outgoing heated air is mixed with incoming cold air [3]. Recirculation of part of the heated air to the incoming air ensures good air mixing and enhances convective heat transfer. Schemes of one-way, parallel, opposite and recirculating two-way SAC are shown in figure 2. The SAC classification is shown in figure 3.

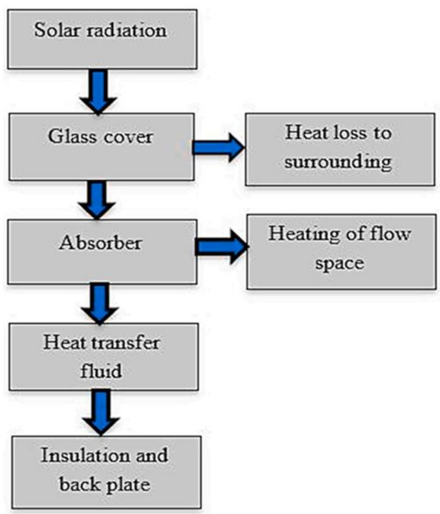

Figure 1. Energy flow of SAC.

FPSAC is a simple solar heating system that has a small convective heat transfer coefficient between the absorber surface and the air flow, which causes the heat transfer rate to decrease. Low thermal conductivity of air and high heat loss to the environment are the main disadvantages of SAC [4]. Small convective heat transfer is not only due to the small thermal conductivity of air, but also has a significant effect on conductive heat transfer. Heat transfer from the upper surface to the very lower layer of air in the air duct occurs due to conductive heat exchange, which occurs only when the air velocity is very low or zero. The air at the bottom of the air stream transfers its heat to the adjacent air layers by advection. This combined process of heat conduction and advection increases the convective heat transfer to a high level. According to the principle of formation of a laminar boundary layer or a viscous layer on a flat surface, a reduction in heat transfer to the adjacent layer, which affects the heat exchange, occurs. Therefore, in order to accelerate heat transfer from the surface, it is necessary to reduce the formation of a laminar boundary layer [5].

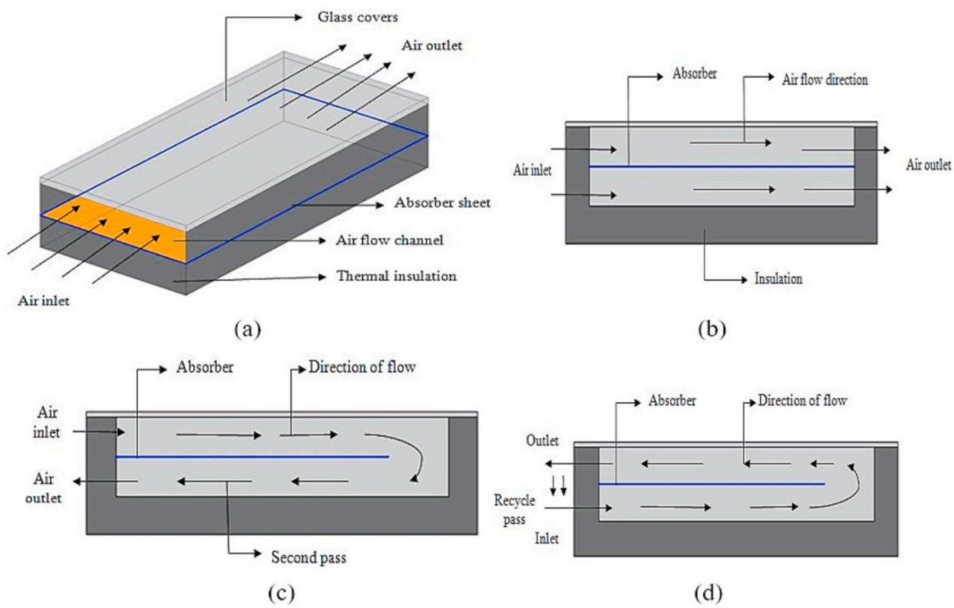

Figure 2. Schematic layout of SAC: (a) single-pass, (b) double pass parallel flow, (c) double pass counter flow, (d) double pass recycle flow.

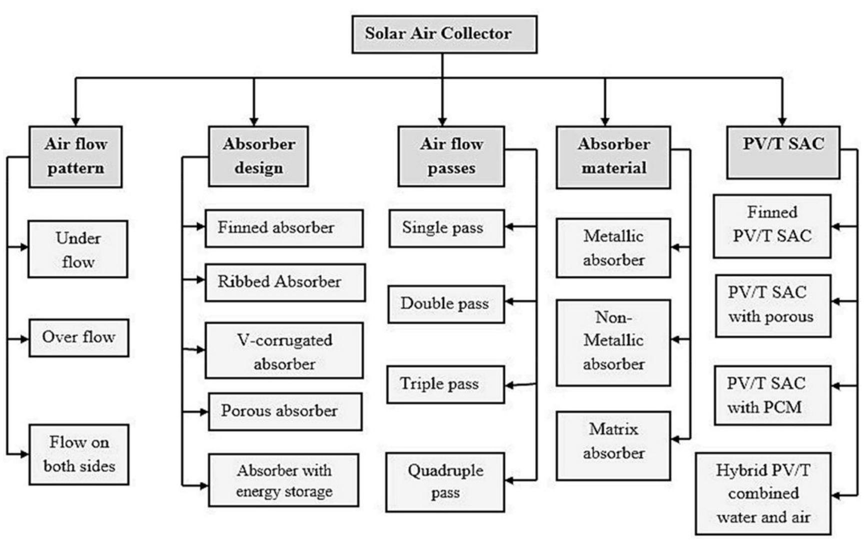

Figure 3. Classifications of FPSAC based on various developments.

The principle of breaking the boundary layer is based on the formation of hard roughness on the surface of the absorber. Increasing the surface area and roughness increases the contact surface of the hot absorber with air and the residence time of the air in the collector. When the air stream collides with the absorber surface, the laminar boundary layer decreases, resulting in an increased advection effect. Due to obstacles on the surface of the absorber, a secondary flow and a lump are formed, breaking the laminar boundary layer, as a result of which the degree of mixing of air flows increases. It can be seen that the

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barrier and turbulizers on the surface of the absorber are the main factor in increasing the heat transfer rate. Currently, many methods have been proposed to increase the thermal efficiency of SAC. They can include the following: increasing the area of the absorber surface, creating the effect of turbulence in the movement of air, increasing the air residence time, using a material with high thermal conductivity, creating flow turbulence in the air flow, reducing heat loss, maximum transfer of heat from the surface of the absorber to the air, correct thermal insulation selection and maximum storage of absorbed heat to the absorber, etc. [5]. Many researchers have studied different shapes of ribs on the absorber surface, such as rectangular ribs, conical ribs, inclined ribs, triangular ribs, trapezoidal ribs, and elliptical ribs. Acceleration methods improve heat transfer characteristics, but pressure loss increases. The increase in pressure loss can be reduced by minimizing the geometrical parameters of various roughness. Because when roughness increases, frictional resistance increases, which leads to a significant increase in convective heat transfer and hydraulic resistance [6].

2. Materials and methods

The main purpose of this research work is to show the various developments proposed by the researchers at the moment that are important in the development of new constructions of FPSAC and are as follows:

- Analysis of research work on selection of optimal geometric parameters and improvement of heat transfer characteristics in the modification of the absorber surface.
- To evaluate the potential of increasing the thermal efficiency of SAC and its application in research for future developments.

3. Results and Discussion

Different configurations of the absorber.
The thermal efficiency of the FPSAC is very low due to the small thermal conductivity of the air, low convective heat transfer coefficient and high loss to the environment. A classification of FPSAC for improving thermal efficiency and improving characteristics based on existing literature is presented in Figure 4. Of more interest are the two main methods of increasing the thermal efficiency of FPSAC, i.e. increasing the convective heat transfer coefficient between the air and the absorber due to increasing the absorber surface and reducing the heat loss to the environment. Figure 5 shows the most commonly used configuration of the absorber.

It is known from numerous researches that the thermal efficiency of the collector is controlled by three factors, which are the velocity of the air flow, the construction of the air flow channel and the configuration of the absorber surface. In order to increase the coefficient of convective heat transfer, due to the formation of ribs on the surface of the absorber, the area of the heat exchange surface increases and the heat transfer accelerates. A very high speed of the air flow and the presence of a rib on the surface of the absorber accelerates the forced heat transfer. Due to the installation of ribs or any kind of roughness on the absorber, the hydraulic diameter of the air flow channel decreases and the air flow speed on the surface of the absorber increases.

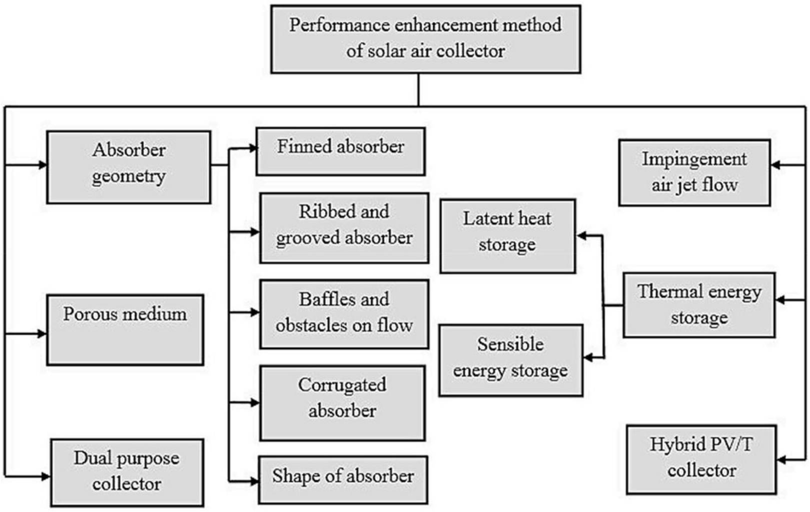

Figure 4. Performance enhancement methods of SACs.

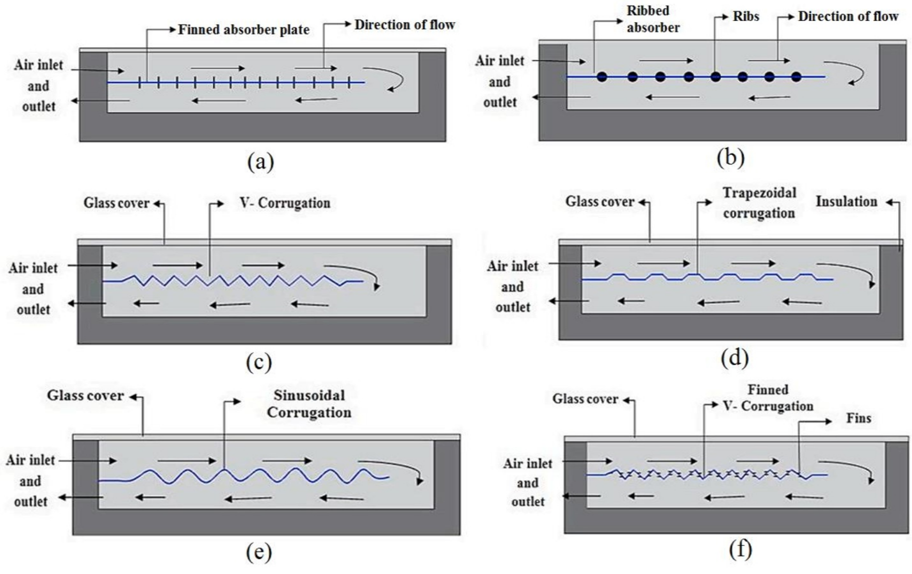

Figure 5. SACs with different absorber plate enhancements: (a) finned absorber, (b) ribbed absorber, (c) V-corrugation, (d) trapezoidal corrugation, (e) sinusoidal corrugation, (f) finned corrugation.

Ribbed absorber.

Thermal characteristics of finned and non-finned SAC were studied by Daliran and Ajabshirchi [7]. The experimental and theoretical values of maximum temperature and thermal efficiency were 74.5°C, 21% and 83°C, 22%. Hosseini et al., who conducted a study on SAC with right angle ribs. [8] concluded that this type of SAC has 12.5 and 5.5% higher efficiency than elliptical and triangular fins. According to the experimental studies conducted on SAC with conical ribs, the thermal efficiency of SAC was 74.6% when the air consumption was 0.1 kg/s, and 19.3% when it was 0.04 kg/s. A numerical study of SAC with rectangular, triangular and elliptical ribs is also presented in the research paper. Singh and Dhiman [9] investigated a SAC with fins and a baffle combined and found that the heat transfer in this SAC was much higher than that of a fin-only SAC. They concluded that the thermal efficiency of the finned and baffled SAC was 81%, and the thermal efficiency of the finned only SAC was 79%. Singh [10] conducted experimental and numerical studies of the geometrical parameters of three different finned absorbers in two-way SAC. Three rib configurations, checkerboard, linear, and hybrid checkerboard configurations were used for comparison. The hybrid checkerboard arrangement of the fins has 3.5% and 38% higher thermal-hydraulic efficiency compared to the linear and checkerboard arrangement, the main reason for which is the wave-like movement of the air flow in the air channel. In addition, the thermal-hydraulic efficiency of the two-way SAC was 79%, which is 13% higher than that of the one-way.

V-type bumpy absorber.

When V-type ribbed absorbers are used, heat transfer distribution on the absorber surface is improved due to the formation of circulating secondary flows. It has been noted that the use of V-type ribbed absorbers with different curvatures is highly effective to increase the thermal efficiency of SAC. Singh Patel and Lanjewar [11] studied a V-type ribbed absorber. The investigated parameters are: rib to height ratio 6, 8, 10, 12 and 14, rib height to hydraulic diameter ratio 0.043, flow inlet angle 60°, stepped rib to pitch ratio 4, number of main slots 3, number of secondary slots 4, Reynolds number 4000 -14500 range. It is determined that the maximum indicator of thermal-hydraulic efficiency is equal to 10. Zulkifl et al. In the research work of [12], a V-type ribbed absorber was prepared with a Fresnel lens and a glass coating and their comparison was made. The obtained results show that the thermal efficiency of the collector covered with Fresnel lens was 71.18%, and that of the ordinary glass collector was 54.10% when the solar irradiance was 755 W/m^2.

Barrier absorber.

The convective heat exchange between the air and the absorber can be increased by disrupting the air flow and mixing the air flow. The area of the heat exchange surface and the contact time of the absorber with the air are effective factors for the acceleration of convective heat exchange. The heat loss from the boiling capacity of the absorber is much higher and the uniform distribution of heat through the air reduces the boiling zone. A baffled absorber increases the heat transfer surface area and air residence time for large amounts of heat transfer. Fiuk and Dutkowski [13] investigated the effect of two designs of wavy surface absorber on thermal efficiency. The surface structure of the absorber consists of three corrugated panels, made of aluminum and painted in a special color. The first design differs from the second in that the sheets are placed in the opposite direction. The experiments were carried out under the influence of artificial radiation in laboratory conditions in a stationary state. radiation intensity is in the range of 0-990 W/m^2. Experiments showed that the highest efficiency reached 73.8% when the radiation intensity was 756 W/m2. 46% in a regular collector. Hu et al. [14] studied barrier narrowing of the first chamber at SAC. Modeling results show that the width of the first chamber has a large effect on the thermal efficiency, but a small effect on the pressure drop. The maximum thermal efficiency was achieved when the Reynolds number was in the range of 1.8-$5.5 \cdot 10^3$, when the obstacles were uniformly distributed and the width of the first chamber was 200 mm, that is, it was 16.90% higher than the remaining widths. Khanlari et al. [15] investigated the thermal efficiency of a new cruciform barrier absorber in a parallel flow SAC. In the research work, two-way SAC with two barriers, one barrier and no barriers were developed and tested. Barriers are made in the form of a plus. The performance of SAC has been investigated numerically and experimentally. The experiments were carried out when the air mass consumption was 0.009 kg/s and 0.011 kg/s. According to the results of the experiment, the average thermal efficiency was 62.10-66.32% without barriers, 65.72-69.62% with one barrier, and 71.12-75.11% with two barriers. The highest thermal efficiency of 84.30% was achieved when the mass consumption of air was maximum. The maximum deviation between experimental and numerical research results was 9.5%.

Different absorbers and turbulators.

Sevik and Abuska [16] compared the energetic and exergetic analyzes of SAC with bendable air duct made of aluminum foil and simple flat SAC. The effect of the aluminum foil air channel on increasing productivity was determined at air mass consumptions of 0.013, 0.03 and 0.044 kg/s. The average energetic and exergetic efficiency of SAC with bending air ducts was 81.3% and 25%, respectively. According to experimental results, the thermal efficiency of this type of SAC is 15.9-41.2% higher than that of ordinary SAC. Skull et al. [17] experimental and numerical study of turbulent-convective heat exchange in the SAC tract with a wing-type reciprocating generator placed on the absorber plate. Experiments were conducted in the range of Reynolds number 4100-25500. Two types of generators are used: rectangular and trapezoidal. Experiments show that the greatest values of heat transfer and friction resistance coefficients are 7.1 and 109.5 times higher than the smooth air channel, and the maximum thermal efficiency reaches 1.84. In order to reduce the pressure loss in the SAC, both reciprocating generators were changed to rectangular and trapezoidal reciprocating generators with wing-shaped openings. According to the research results, the greatest values of heat transfer and friction resistance coefficients are 6.78 and 84.32 times higher than the smooth air channel, and the maximum heat efficiency reaches 2.01.

4. Conclusion

The scientific research conducted in the last 10 years on SAC design, thermal efficiency, heat transfer characteristics and different configurations of SAC absorber were analyzed and the following conclusions were drawn:

- The main disadvantages of SAC include low thermal efficiency and high heat loss due to the low thermal conductivity of air and the formation of a laminar boundary layer.
- The formation of roughness on the surface of the absorber increases the turbulence effect of the secondary air flow and piles are formed in the dead zone.
- The area of the heat transfer surface and the air residence time are important factors in increasing the difference between the inlet and outlet temperatures of SAC air. The installation of fins, baffles and turbulizers in the air flow path to increase the heat transfer surface area and residence time is an important factor in increasing the thermal efficiency of the SAC. When they are installed, a secondary flow is created and the effect of complete mixing of air currents is achieved.

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