Review of thermal performance enhancement of Solar Air Heater using shapes on absorber plate

Visarion-Cătălin Ifrim
Department of Electrical Engineering
Faculty of Electrical Engineering and Computer Science
University "Ştefan cel Mare" of Suceava
Suceava, Romania
ifrimpv@gmail.com

Teodor Pop
Department of Electrical Engineering
Faculty of Electrical Engineering and Computer Science
University "Ştefan cel Mare" of Suceava
Suceava, Romania
teututp@gmail.com

***Abstract*—The increasing demand for energy and the greenhouse gas (GHG) emissions resulting from the use of conventional fuels are directing humanity towards renewable energy sources, in this case solar energy, and towards increasing investments in research and improvement of solar systems that produces both electricity and heat. For household consumers as well as for some industrial ones, the large volume of energy consumed is due to space heating, ventilation and drying. The availability of solar energy can contribute to reducing this consumption utilizing solar air heater systems. In the presence of solar energy, reducing the household energy consumption also depends on the thermal performance of these systems. Recent studies focus on improving these performances by modifying the components so that there is as much absorption of solar radiation as possible and as high a thermal transfer as possible between the absorption surface and the existing air flow through the system. The objective of this paper is to review different forms of the absorption plate and the different obstacles (roughness's) used by researchers to refine thermal performances of solar air heater systems. The role of obstacles is to create swirlers that favor heat transfer. The results presented briefly refer to thermal efficiency, thermo-hydraulic improvement factor and friction factor. The final remarks propose observations and proposals for further improvements to solar air heating domain.**

Keywords—Solar air heater; Frinction factor; Heat transfer; Absorber plate; Obstacles; Efficiency

I. INTRODUCTION

Solar air heaters are installations that harnesses the solar energy converting it into thermal energy. A panel of this kind consists mainly of the following components: a material that retains solar radiation called the absorber plate; a transparent material, most of the time it's glass, which enables the transition of air flow between it and the surface that absorbs the sun's rays and a insulation bed on the back of the panel to reduce heat losses. The conversion is done by heat transfer among the "greenhouse effect" medium that occurs between the transparent material and the absorbing surface and the air flow passing through the equipment. The energy flow for a solar air heater panel is exemplified in Fig. 1.

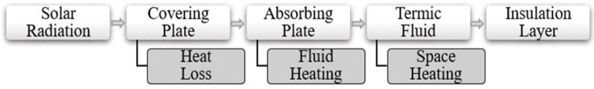

Fig. 1. Flow energy of solar air heaters

The present paper of solar air heater systems (SAHs) was performed with the help of the "Web of Science" database for the period 2017-2021. The information needed to conduct the study was extracted on February 13-28, 2022 from a total of 1355 articles constituting the publications in the domain of solar air collectors, where the words "solar air heater" were found at least once. The SAHs classification below is based on filtering and analyzing a number of 1355 articles individually. The publications were selected on the basis of the most recent publications in the analyzed field for the current study. The remaining publications dealt with the same topics or could not be part of the carried study although they are part of the area of solar air heating systems. This classification is strictly made only for the period under review and does not represent the period before 2017.

The classification of solar air heater equipment is carried out based on the components and their modifications to enhance performance. Of course, different classifications can be made: depending on the purpose of the systems; depending on the techniques applied: experimental, mathematical or computational calculus; depending on various changes made to the absorber plate for the most efficient heat transfer. The current classification exposed in this research was made strictly according to the existing analyses in the domain of solar air heating systems for the period between 2017 and 2021. The information accessed between 13 and 28 February 2022 from the "Web of Science" database where the phrase "solar air heater" was identified at least once, was individually filtered, cataloged and classified according to the shape of the absorber plate without taking into account other classifications. The selected articles are the most recent.

To analyze classifications and current stages made on other criteria or other periods we may refer to the article published in 2018 by Kumar Varun from the College of Engineering and Technology, Velammal, located in Madurai, India [1]. The work shows the effect of different ribs existing on the material

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that absorbs solar radiation. The review made is focused on the geometry of the ribs and their arrangement on the absorber plate. Numerical and experimental analyses were discussed considering the fluid inside the SAH panel as dry air or nanofluid. The influence of some forms of ribs varied as the forms: L, W, V were also discussed. The work done concludes with various results and observations.

Abundant research presenting a review of the bibliography in the field of solar air heater systems dates back to 2017 conducted by Kabeel from Faculty of Engineering, Department of Mechanical Power Engineering, Tanta, Egypt [2]. The article reviews the methods of improvement, configurations and applications used in the analyzed field. The study analyses theoretical and practical experiments as well as modifications to absorber plate aimed at improving the performance of systems. The work takes into account the addition of thermal energy storage materials, the arrangement of different fins and roughness on the absorbent material in order to highlight their benefits.

A review study catalogs the SAHs according to the material arranged on the absorbent surface of solar radiation to store thermal energy [3]. Not a few types of materials that own the ability to change their condition, their properties and the applications in which they find themselves have been analyzed. The work also analyzes techniques to improve heat transfer such as: extended surfaces, encapsulation and dispersion of conductive particles in the air flow existing in the analyzed panel.

Airflow modification techniques are brought up by Arunkumar from Manipal Institute of Technology, India [4]. The work focuses on reviewing various techniques to modify the existing airflow in a solar air heater to increase its thermal performance and increase heat transfer among the thermal area and the airflow. The study takes into account the influence of various turbulence-producing forms used by researchers to increase thermal efficiency. Heat transfer, geometries used, flow conditions and their influence on turbulence, design considerations, absorbent surface temperature of solar radiation and thermo-hydraulic improvement factor have been widely elaborated. In order to improve SAH's performances, future possibilities are proposed in the realized work.

II. Considered Parameters

A. Dimensional Parameters

The dimensional parameters considered in this paper refer to the following: solar radiation or heat flux (I_R); hydraulic diameter (H_d); mass flow rate (m) applied to the studied SAH; width (w), height (h), length (l), side (s) and depth groove (A) of the obstacle embedded with the absorber plate. The melting temperature of phase change material (PCM) is taken into account.

B. Dimensionless Parameters

There are some dimensionless parameters that denote importance when adding different roughness on the absorbing plate of a solar air heater namely; Relative roughness height (e/D_h), hole diameter ratio (HDR), artificial roughness (AR), height ratio (h/H), relative roughness pitch (P/e, RRP), relative staggered length (w/e, r/e), relative heater height (e/H, RRH), relative roughness width (W/w), relative gap width (g/e), relative transverse pitch (b/p_t), relative longitudinal pitch (p_l/H), number of gaps (n, Ng), relative roughness height ratio (e/D_e), relative staggered pitch (p/P), relative pitch ratio (p`/p). The following parameters are significant for every type of solar air heater; friction factor of a surface type roughened (f), friction factor of a surface type smooth (f_s), Nusselt number for roughened surface (Nu), Nusselt number for smooth surface (Nu_s), Reynolds number (Re), Rayleigh number (Ra), Prandtl number (Pr), ratio of Nusselt number (Nu/Nu_s, Nu/Nu_0) and ratio of friction factor (f/f_s, f/f_0).

C. Greek Symbols

Significant effect on thermal performances of a SAH have the parameters: the angle of attack for flow/ arc angle (α); wavelength (λ), amplitude (δ) and PCM porosity (φ) for wavy channels; twist ratio (Υ) for twisted tape embedded with absorber plate.

III. Performance Improvement With Different Shapes Embedded On Absorber Plate

The structure of the absorption surface and its changes are of interest in the solar air heater area because they increase and improve efficiency and thermal performances. They also may augment the effectiveness of heat transfer and improve the fluid flow characteristics of modified systems. After analyzing the research where the words "solar air heater" were found at least once in the period 2017-2021 from the database "Web of Science", the shapes of solar radiation absorber plate are classified in the categories shown in Fig. 2. and Table 1. The performances presented in Table 1 represents the maximum values obtained in a particular study. The classification is strictly based on these publications and does not cover the research period prior to 2017.

The objective of the experiment conducted for the solar heater with absorber plate with baffled glazed-bladed was to investigate the influence of adding a different number of baffles (n equal to 800, 410 and 170) on the system's capacity at a flow rate of 0.013, 0.022, 0.031 and 0.04 kg/s. Mean and maximum values of solar radiation were 750.4 W/m^2 respectively 1120 W/m^2 [5]. The exact conditions were performed for a conventional SAH in order to see the difference between the two systems. The maximum thermal efficiency for the conventional SAH was recorded to be 37.04%. The absorber surface with 800 deflectors recorded the maximum of 86.76%, value assigned to thermal efficiency. Maximum values of thermal efficiency are recorded at 0.022 kg/s fluid flow rate.

Air flux type forced convection of heat transfer, in a solar air heater with tapered obstacles staggered over the absorbing surface, was carried out experimentally and numerically at different air flows in order to maximize thermal efficiency and create the appropriate volume for the temperature storage material in terms of effectiveness of the system under analysis [6]. The selected air flow rates were 0.1, 0.08 and 0.04 kg/s under same ambient conditions. The results of the numerical model, the speed and the temperature distribution in this case were in agreement with the results of the experimental model. The average value of thermal efficiency achieved by the analyzed panel was 70.8% corresponding to the air flow of 0.1 kg/s. In addition, it has been found that 3D cone-shapes on the absorbing material are suitable to achieve temperature storage.

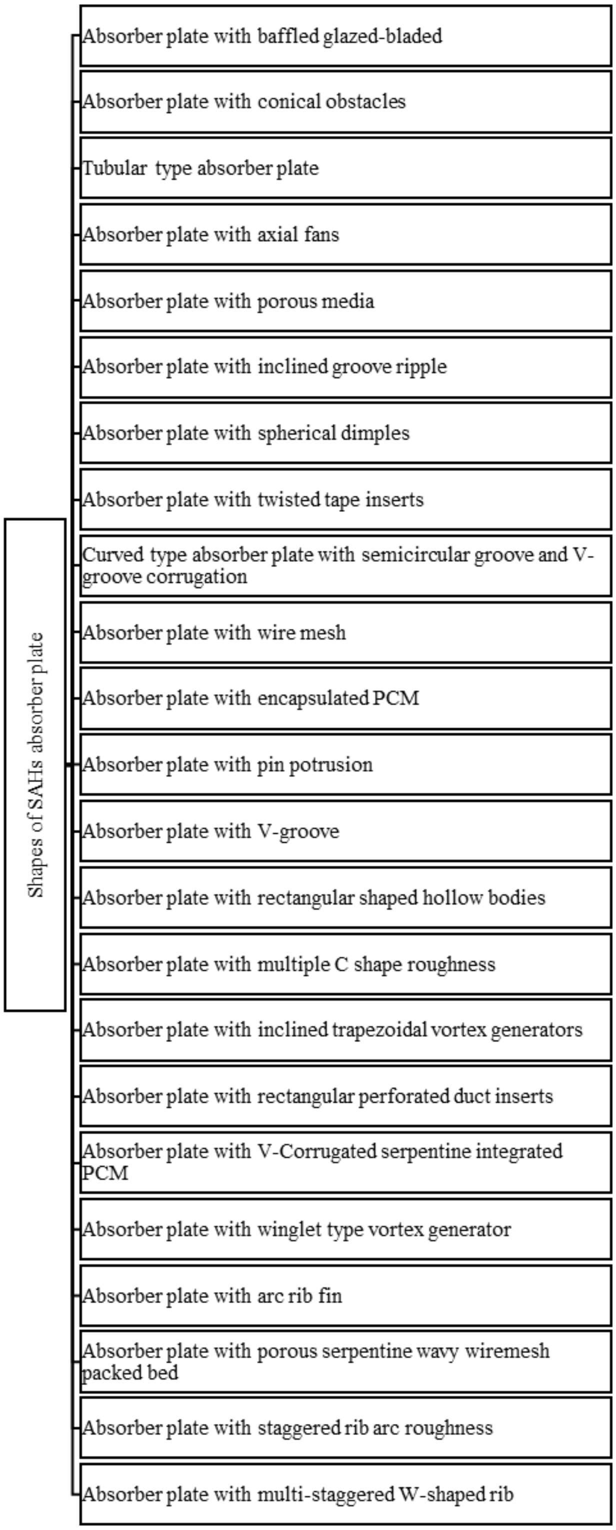


Fig. 2. Absorber plate shapes used in solar air heaters

Development on the performance of an innovative model of SAH called tubular solar air heater system (TSAH) has been experimentally investigated [7]. In the realized design, the flat solar radiation absorption surface was replaced by tubes adjacent to the direction of the existing airflow in operation. For a comparison and for a wider view, two systems were experimentally developed, a normal SAH with a flat surface and a TSAH with tubes. The results showed that the tube system has lower heat loss, higher output temperature and higher thermal efficiency compared to the normal collector. The daily maximum efficiency of a TSAH reached 83.6% for the air flow rate of 0.075 kg/s.

For experimental testing and numerical analysis, a solar system with axial fans on its absorber plate was performed [8]. The purpose of the fans is to create a swirling air flow inside the analyzed system. The study indicated that the indexes of the swirling type, the swirling state and the swirling intensity together determine a considerable influence on the thermal yield of the modified system. Two types of flow, active and passive, were numerically analyzed. The rate of increase in thermal efficiency corresponding to passive-swirl airflow model was 16.03% and for the active-swirl airflow model it was 23.83%. Experimentally the rate of increase in thermal efficiency was 13.24% under optimal conditions. Numerical and experimental results are not in agreement due to different conditions, variability and uncertainty of climatic conditions.

Experimentally adding a porous media to the absorber surface in a solar air heater system will considerably improve its thermal output [9]. The maximum value of thermal efficiency was 87%.

Considering the purpose of improving the effectiveness of the system, heat transfer and the feature of airflow in a solar air heating system, its absorber material was carried out with inclined groove ripple [10]. The sloping grooves on the corrugated plate have an important impact on the air flow causing a longitudinal swirling flow inside the system, which improves heat transfer and determines, at the same moment, a reasonable increase in pressure drop. A maximum of 94% improvement of heat transfer was reached.

The spherical dimple in the absorption surface takes part of an experimental investigation to determine the thermal performances of such a solar air heater [11]. Instantaneous thermal efficiency was between 23.45% and 35.50% for air deliveries ranging in the interval of 0.009-0.028 kg/s. Daily efficiency average was recorded between 27.47 and 33.79%.

The study conducted by Rajesh Kumar from N.I.T, Department of Mechanical Engineering, Jamshedpur, India, predicts the thermal and thermohydraulic efficiency of a solar air heater integrating twisted band inserts on its absorbing surface with twisting ratio (ϒ) equal to 2, 4, 6 and 8 [12]. For this purpose, has been formulated a mathematical model on the basis of the energy conservation equations of the various considerate elements of SAH. Designed model is numerically solved with the help of MATLAB analysis program. The effects of solar intensity, twisting ratios and mass flow on the characteristics of the system in question were investigated. At a mass flow rate of 0.025 kg/s, following the analysis resulted that the twisting ratio (ϒ) equal to 2 is the most efficient and has the highest thermal efficiency. Conventional type of solar air heater equipped with twisted band inserts had a thermal efficiency of 49.4%. The study also took into account the integration of twisted band inserts within a solar air heater with fins on the absorbing material, with thermal efficiency reaching 74.42% under the same analysis conditions.

A CFD analysis on the thermal capacity of a solar collector with curved absorbing surface with semicircular groove and V-groove corrugation showed significant improvements in heat transfer [13]. The solar air heater system, with a curved absorption surface with V-grooves reached the maximum thermal efficiency of 91.93% during realized tests.

The solar air collector containing a wire mesh on the absorbing surface has been thermodynamically studied [14]. The study was conducted at an angle of inclination of 25° and 35° in the presence of a mass flow rate between 0.030 and 0.055 kg/s. Thermal, thermohydraulic and exergy analyses were calculated using data recorded experimentally. The results showed that the pressure loss through the system, the amount of useful heat and temperature at the exit of the system were raised for a lower angle of inclination of the analyzed SAH and a higher flow rate. The thermal capacity of the system was between the values of 34% and 82%, the thermohydraulic efficiency equal to interval 25-66% and the exergy efficiency with values between 3.70% and 9.65%.

The efficient use of SAHs is limited to a certain period of day because of the low intensity and unavailability of solar radiation. In competition, SAH systems show low thermal efficiency. The addition of PCM material to the absorber surface of the SAH is one of the techniques considered passive, to enhance thermal efficiency, as well as to widen its usefulness in periods without sun. To determine experimental efficiency, capsules with circular and square cross-sections filled with PCM were used on the absorber plate of a SAH. Cylindrical/square capsules were arranged in line and staggered position in the direction of fluid flow. As PCM was used paraffin wax. Average value of thermal performance factor for the analyzed systems was 50.88% [15].

To increase the performances of free convection solar air heater systems, small turbulators have been added on the absorbent surface aiming to break the viscous layer/substrate of air that runs through that surface. In order to carry out the experimental research, a unique test platform was drafted and manufactured to measure the impact of the attached turbulators. In this project were used on the absorbent surface turbulators type conical shaped pin protrusions. The results demonstrated that the optimum inclination angle of the absorbent surface was 45°. The staggered arrangement of the tapered studs proved a higher efficiency compared to their inline disposal. The maximum value recorded for thermal efficiency was 62.5% [16].

Performance characteristics analysis of the indirect solar system was achieved by simulating CFD models with three different surfaces of the absorber plate: V-grooved, smooth and rough, keeping the lower and lateral collector well insulated and the drying chamber acting as a vertical basket. Thermal efficiency average of the V-grooved, smooth and rough surfaces is 90%, 78% and 62% respectively [17].

Absorbing plate with rectangular shaped hollow bodies is inserted inside of a solar air heater system to enhance its efficiency. Because of the existence of these bodies, local turbulent currents will occur. As a result of the turbulent currents appearance, the heat transfer and coefficient of heat transfer between the absorption surface and air flow in the area will increase. The pressure loss is also less. The maximum thermal efficiency for SAH with rectangular hollow bodies was 47.62% [18].

The experimental analysis of a SAH with absorption surface with roughness type of multiple C-shapes was realized to determine hydraulic and thermal efficiencies [19]. Three angles of the C-shapes were studied for their different geometries with different Reynolds number, pitch distance and angle of attack. Double-flow arrangement with multiple C-shaped ribs provided increased heat transfer than the other settlements. Reynolds number of 15,000, the roughness angle of 90° and the relative roughness step of 24, resulted in a maximum Nusselt number of 415. This rugosity arrangement provided a friction factor equal to 0.031 and a thermohydraulic performance parameter of 3.48.

The investigation of heat transfer and fluid flow characteristics improvement mechanism, energy conversion efficiency and hydraulic thermal performance were carried out for SAH absorber plate with inclined trapezoidal vortex generators (ITVG) [20]. A numerical simulation of a simplified model provided the flow characteristics and heat transfer performances. Almost on both sides of each ITVG were observed longitudinal swirls and the frontal view of the vortex was shaped rectangular. For this study, four arrangements of trapezoidal generators were chosen: mixed staggered arrangement, aligned against the fluid flow, staggered in the direction of the flow and aligned in the direction of the fluid flow. The required test conditions were as follows: ratio of the step equal to 1, 2, and 3, ratio of the width equal to 0.267 and 0.333, ratio of height equal to 0.12, 0.24 and 0.36, the number of Reynolds with values between 6000 and 18,000. Following the study, the recommended parameters for the optimal functioning of such solar system were the following: the ratio of the width equal to 0.267, the height ratio equal to 0.24, the step ratio equal to 1, the number of Reynolds equal to 12,000. The energy efficiency was increased by a maximum of 24% for the analyzed solar system compared to a corresponding smooth SAH. The exergy efficiency of solar ai heater with inclined trapezoidal vortex generators has been improved by a maximum of 31% compared to a solar air heater with smooth absorbing surface. Both efficiencies, energy and exergy, of the system had higher values compared to other typical systems.

The solar air heater designed with duct inserts perforated rectangular aims to divide the air at the entrance to the absorber plate. Due to the transverse flow effect, it is assumed that this modification will improve convective heat transfer by creating a pressure difference above and below the perforated plate. From the experiments it is noted that the pressure along the absorbent passage decreases with increasing height, increasing the diameter of the hole and the number of perforated rows. The experiments establish that the thermal efficiency is maximum for the value of 0.66 of height ratio compared to the 0.50 and 0.83 values, for the same type of SAH with perforated pipe inserts. In addition, by varying the number of rows and the ratio of the diameter of the hole, it is observed that maximum thermohydraulic efficiency of 81.06% and thermal efficiency of 84.8% are reached for a hole diameter ratio of 0.096 and two rows of holes [21].

For the research of a solar air heater with absorbing plate type V-Corrugated serpentine, two SAH prototypes were built and tested simultaneously, one conventional and one integrated with PCM. Four PCM arrangements and two types of paraffin wax with melting points of 40°C and 50°C, were settled on solar air heaters. Tests were conducted for the air mass flows of 0.006 and 0.01 kg/s. Acquired results indicate that the highest thermal performance, of 1.4% and 4.4%, was reached for two mass flows of 0.006 and 0.01 kg/s respectively, using PCM blocks with a higher melting temperature, PCM 50. For the two air mass flow rates, among the other scenarios considered, maximum heat improvement and optimal daily thermal performance were achieved using the same amount of these two types of paraffin (SAH using PCM 40 and PCM 50). The results showed that PCM use, increases from 53.1% to 62.6% the daily thermal performances [22].

The solar air heater collector with absorbing plate embedded with winglets type vortex generator was analyzed taking into account the following parameters: the step of relative roughness with values between 5 and 12, the angle of attack with values from 30° to 75°, the width of the relative roughness with variations from 3 to 7 and the Reynolds number with values between 3000 and 22,000. At (P/e) equal to 8 was observed optimal improvement in heat transfer, while increasing the step of relative roughness (P/e) the friction factor decreases. The presence of fin-type vortex generators on the absorber surface of the SAH creates additional mixing. Also, adding at the tip of the fin of a small hole, produces a fluid jet on the downstream side improving the heat coefficient of transfer [23].

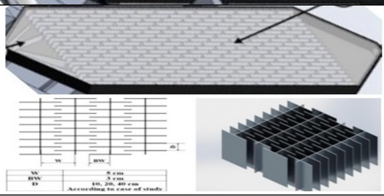
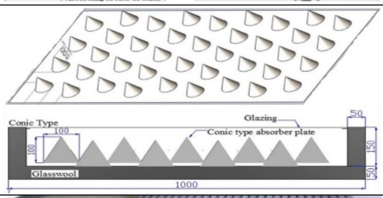
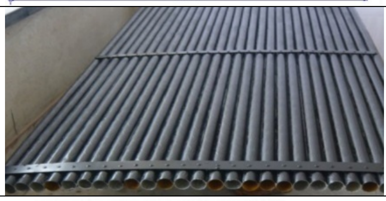
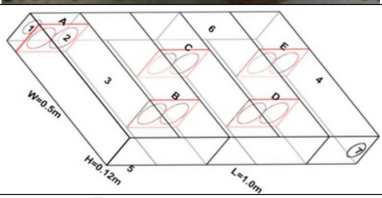
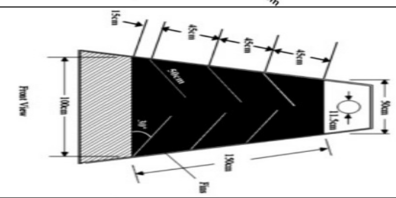
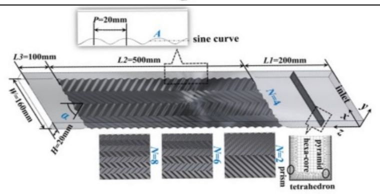
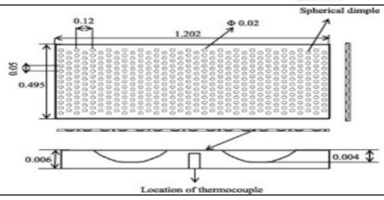
For the analysis of the influences, of an absorbing plate surface embedded with fins type arc rib, on the heat transfer performances of a solar air heating system, a thermal model was developed [24]. The arrangements of the arched ribbed fins are designed and differentiated by varying the height ratio of the relative roughness of the fins on the absorbing material. Two lengths of the absorber surface were chosen, 1 and 2 m, a configuration of ribbed fins with a single ratio of relative roughness height valued 0.0422 and a configuration with ribbed fins arched in two height ratios of different relative roughness of 0.0422 and 0.0541. It is noted the fact that increasing the mass flow rate from 0.02 to 0.06 kg/s, increases the heat transfer performance parameter, the Nusselt number and the pressure drop, while decreasing the friction factor. The values for the heat transfer performance parameter, Nusselt number, friction factor and pressure drop of the arrangement with variable arched ribbed fins are greater than the arrangement with fixed arched ribbed fins and smooth absorber plate. For the solar air heater with absorption surface with fixed arched ribbed wings, the following values for performance were obtained from the analysis: the efficiency factor with the value of 94.09%, for the mass flow rate of 0.06 kg/s and the length of 2 m; the exergy efficiency is maximum, equal to 1.5%, for the flow rate of 0.02 kg/s and an absorber material length of 2 m; the maximum effective efficiency is 74.7% at a flow rate of 0.06 kg/s and the absorber surface length of 1 m; the maximum thermal efficiency is 77.7% for the absorption surface in length equal to 1 m with a flow rate of 0.06 kg/s. Performance parameter of the heat transfer has a maximum value of 2.42 for a mass flow rate of 0.06 kg/s and an absorber plate in length of 1 m. For the solar air heater with absorption surface with wings type arched ribs, the following values for performance were obtained from the analysis: the efficiency factor with the value of 94.46% is maximum, for the mass flow rate of 0.06 kg/s and the length of 2 m; the exergy efficiency with a value of 2.5 %, is maximum, at a flow rate of 0.02 kg/s for an absorber surface in length of 2 m; the maximum effective efficiency is 76.0% for the flow rate of 0.06 kg/s and the absorption surface in length of 1 m; the maximum thermal efficiency is 79% at a flow rate of 0.06 kg/s for the absorption plate in length of 1 m. The value of the heat transfer efficiency parameter is maximum, with the value of 2.54 for the absorber plate in length of 1 m and the value of 0.06 kg/s for the mass flow rate.

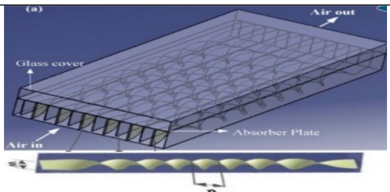
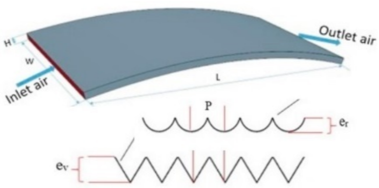
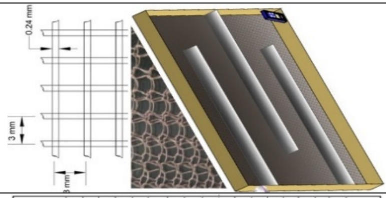
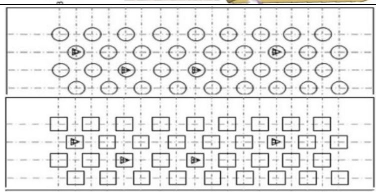
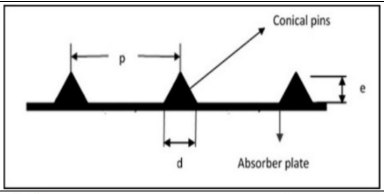
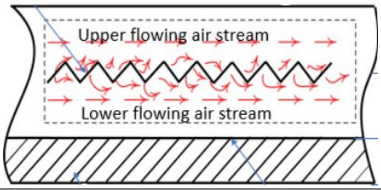
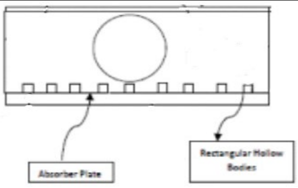
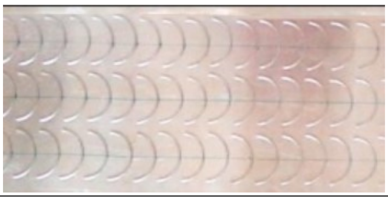
The experimental results achieved analyzing the solar air heater with porous serpentine wavy wire-mesh packed bed on its absorber plate revealed a best thermal efficiency, of 80%, and a thermohydraulic efficiency, of 74%, for mass flows of 0.04 and 0.035 kg/s respectively, and a material porosity of 93%. The numerical analysis data were obtained on a CFD instrument and the outcomes validated with experimental acquired data. Optimal values gathered for the analyzed geometric parameters were as follows: the porosity range between 85% and 95%, the wavelength with values in interval 0.05-0.075 m, the amplitude with values between 0.012 m and 0.016 m, the hydraulic diameter valued with 0.025 m to 0.046 m. Also, the mass flow rate valued between 0.01 and 0.05 kg/s. Maximum of 6.11% was obtained for exergy efficiency at a hydraulic diameter of 0.0835 m, a mass flow rate of 0.01 kg/s and a porosity of the material of 95%. Numerical results indicate a maximum increase of 24.33% of the thermohydraulic performance for SAH with packed bed from corrugated wire mesh on the absorbing plate compared to a single-bed SAH [25].

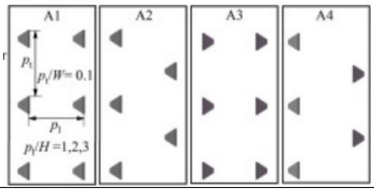
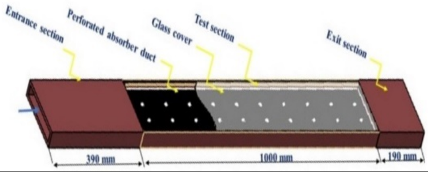
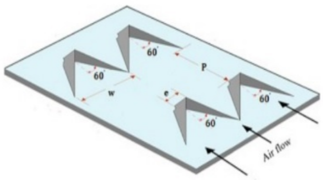
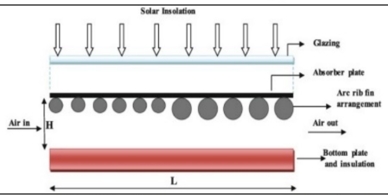
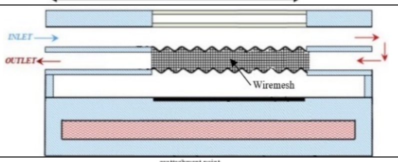
Solar air heater study with staggered rib arc elements is performed to establish the impact of the roughness of staggered elements added on the arched absorption surface utilized in solar air heating ducts. The thermohydraulic performance achieved is 2.34% [26].

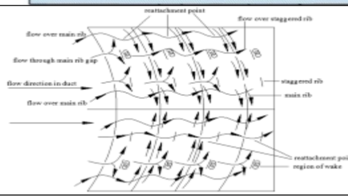
The study for a solar air heater containing W-shaped ribbed absorption material shall take into account the effect of W-shaped multi-staggered rib indexes on the performance of the SAH channel [27]. The values of the dimensionless factors used were: the staggered relative step between 0.45 and 0.75; the staggered relative length of the ribs between 1.5 and 6.0; the Reynolds number within the operable interval of 4000-14,000; the relative roughness step equal to 12; the height of the relative roughness equal to 0.0432; the angle of attack equal to 60°; relative width of space equal to 1; and number of voids with a value of 2. The optimal values of (w/e) and (p/P) corresponds to the values of 4.5 and 0.65 respectively. The resulting maximum friction factor is 0.025 for Reynolds number equals to 12,000.

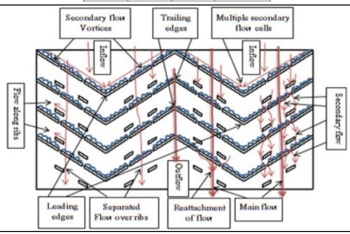
TABLE I. DIFFERENT SHAPES EMBEDDED WITH ABSORBER PLATE IN SAHS

No.	SAH Type/ Reference	Absorber Plate Geometry	Operating Parameters	Optimized Parameters	Key Results
1	Conventional SAH [5]		m = 0.013; 0.022; 0.031; 0.04 kg/s; I_R = 750-1120 W/m^2.	m = 0.04 kg/s.	Thermal efficiency: 37.04%.
2	SAH with baffled glazed-bladed on the absorber plate [5]		m = 0.013; 0.022; 0.031; 0.04 kg/s; I_R = 750-1120 W/m2.	m = 0.04 kg/s; n =800; l = 200 cm; h = 8 cm.	Thermal efficiency: 86.76%.
3	SAH with conical obstacles on its absorber plate [6]		m = 0.04; 0.08; 0.1 kg/s; Re = 3800-18,000; Nu = 2.8-3.2; P/e = 7.1-35.7; e/D_h = 0.02-0.04.	m = 0.1 kg/s; I_R = 950 W/m2.	Thermal efficiency: 70.8%.
4	SAH with tubular type absorber plate [7]		m = 0.025-0.075kg/s.	m = 0.075kg/s.	Thermal efficiency: 83.6%.
5	SAH with axial fans on its absorber plate [8]		m = 0.01944-0.06480 kg/s.	α = 45°.	Thermal efficiency growth rate (TEGR): 23.83%.
6	SAH with porous media on its absorber plate [9]		m = 0.012-0.061 kg/s; I_R = 574; 651; 740 W/m^2.	m = 0.032 kg/s.	Thermal efficiency: 87%.
7	SAH with inclined groove ripple on its absorber plate [10]		Re = 12,000-24,000; N =6; 8; α = 45°; 60°.	A = 2 mm; N = 8; α = 45°; I_R = 800 W/m^2; Re = 12,000.	Thermal efficiency: 94%; Nu/Nu_0: 3.38.
8	SAH with spherical dimples on its absorber plate [11]		m = 0.009-0.028 kg/s; I_R = 300-1000 W/m^2.	m = 0.028 kg/s.	Thermal efficiency: 35.50%.

No.	SAH Type/ Reference	Absorber Plate Geometry	Operating Parameters	Optimized Parameters	Key Results
9	SAH with twisted tape inserts on its absorber plate [12]		I_R = 500-1000 W/m^2; m = 0.013-0.05 kg/s; ϒ = 2; 4; 6; 8.	ϒ = 2; m = 0.025 kg/s;	Thermal efficiency: 74.42%.
10	SAH with semicircular groove and V-groove corrugation on its curved absorber plate [13]		e/H = 0.125-0.3; P/e = 0.834-3; m = 0.0172-0.0472 kg/s; I_R = 800-1100 W/m^2.	P/e = 0.834; m = 0.0472 kg/s.	Thermal efficiency: 91.93%.
11	SAH with wire mesh on its absorber plate [14]		m = 0.030; 0.055 kg/s; α = 25°, 35°.	m = 0.055 kg/s; α = 25°.	Thermal efficiency: 82%; Thermohydraulic efficiency: 66%; Exergy efficiency: 9.65%.
12	SAH with encapsulated PCM on its absorber plate [15]		m = 0.00879-0.01484 kg/s.	PCM = 64°C; m = 0.01484 kg/s; h = 5 cm; s = 4 cm.	Fiction factor (f): 4,616%; Thermal efficiency: 69.33%; Thermal performance factor (TPF): 50.88%.
13	SAH with pin protrusion on its absorber plate [16]		Ra = 50,000-90,000;	α = 45°; RRP = 0.125; RRH = 0.01636.	Thermal efficiency: 62.5%.
14	SAH with V-groove on its absorber plate [17]		I_R = 600; 700; 900 W/m^2; m = 0.01-0.06 kg/s.	m = 0.01 kg/s.	Thermal efficiency: 90%.
15	SAH with rectangular shaped hollow bodies on the absorber plate [18]		I_R = 0-2.000 W/m^2; m = 0-30 m/s;	w = 25 mm; h = 25 mm; l = 40 mm.	Thermal efficiency: 47.62%.
16	SAH with multiple C shape roughness on the absorber plate [19]		Re = 3000-15,000; α = 30°; 60°; 90°; P/e = 8-24.	P/e = 24; 8; Re = 15,000; 3000.	Thermohydraulic performance parameter (THPP): 3.48; Friction factor (f): 8.2%; Thermal efficiency: 41%;

No.	SAH Type/ Reference	Absorber Plate Geometry	Operating Parameters	Optimized Parameters	Key Results
17	SAH with inclined trapezoidal vortex generators on the absorber plate [20]		Re = 6000-18,000; p_l/H = 1; 2; 3; e/H = 0.12; 0.24; 0.36; b/p_t = 0.267; 0.333;	p_l/H = 1; Re = 12,000; e/H = 0.24; b/p_t = 0.267.	Energy efficiency: 24%; Exergy efficiency: 31%.
18	SAH with rectangular perforated duct inserts on the absorber plate [21]		HDR = 0.096; 0,21; h/H = 0.66, 0.50, 0.83; Re = 12,000-18,000.	HDR = 0.096; h/H = 0.50; 0.66; n = 2.	Thermal efficiency: 84.4%; Thermohydraulic efficiency: 81.06%.
19	SAH with V-Corrugated serpentine integrated PCM on the absorber plate [22]		m = 0.006, 0.01 kg/s; Wax = C16; C30; PCM = 40°C; 50°C.	PCM = 50°C; m = 0.01 kg/s.	Thermal efficiency: 62.6%.
20	SAH with winglet type vortex generator on the absorber plate [23]		P/e = 5-12; α = 30°-75°; W/w = 3-7; Re = 3000-22,000.	α = 60°; W/w = 3; P/e = 5.	Friction factor (f): 3.94%.
21	SAH with arc rib fin on the absorber plate [24]		e/D_e = 0.0422; 0.0541; m = 0.02-0.06 kg/s.	m = 0.02; 0.06 kg/s.	Effective efficiency: 76%; Exergy efficiency: 2.5%; Thermal efficiency: 79%.
22	SAH with porous serpentine wavy wiremesh packed bed on the absorber plate [25]		φ = 85%-95%; m = 0.01-0.05 kg/s; λ = 0.075-0.05 m; δ = 0.012-0.016 m; H_d = 0.046-0.025 m.	m = 0,04; 0.03kg/s; λ = 0.075 m; φ = 90%; δ = 0.012 m; I_R = 1000 W/m^2; Dh = 0.0835 m.	Thermal efficiency: 80%; Thermohydraulic efficiency: 74%; Exergy efficiency: 6.1.

23	SAH with staggered rib arc roughness on the absorber plate [26]		Ng = 2-5;
			g/e = 0.5-2.0;
			p'/p = 0.2-0.8;
			Re = 3000-14,000;
			r/e = 1.5-4.5.
				e/D_h = 0.045;
				α = 30°;
				p/e = 10.
					Thermohydraulic performance parameter (THPP): 2.34.
					Friction factor (f): 4.01%.

24	SAH with multi-staggered W-shaped rib on the absorber plate [27]		p/P = 0.45-0.75;
			Re = 4000-14,000;
			w/e = 1.5-6.0.
				Re = 12,000;
				P/e = 12;
				AR = 10;
				α = 60°;
				e/D_h = 0.0432;
				g/e = 1;
				w/e = 4.5;
				n = 2;
				p/P = 0.65.
					Thermohydraulic performance parameter (THPP): 3.24;
					Friction factor (f): 2.5%;
					Nu/Nu_s: 4.1.

IV. Conclusions

This paper exposes a brief review of different obstacles embedded with the absorbing plate of solar air heaters used by researcher to augment the heat transfer and SAHs thermal performances [28], [29]. For every system analyzed, the variation of different parameters plays an important role as the thermal efficiency increased as well as the exergy, energy and effective efficiencies. The optimum values of the studied systems correspond to the maximum thermal efficiency. To reach the maximum heat transfer for a SAH the friction factor has to be minimum [30]. Minimum friction losses retrieve maximum heat transfer. It is found that the solar air heater with inclined groove ripple on the absorbing plate has the maximum thermal efficiency of 94%. For further studies and better understanding would be interesting to plot different graphs with every SAHs efficiencies. To reach this goal, the solar air heaters part of the study should be tested under the same conditions. However, even in different conditions few researchers supply the complete set of values as a table of monitored and modified parameters. For that reason, CFD analysis is proposed to support the studies mentioned. That way we can reach a comprehensive knowledge of solar air heaters.

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