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Performance Enhancement In Solar Air Heater Through Design Configurations And Applications - A Review

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Abstract
The purpose of this article is to provide an overview of the literature on ways for improving, configuring, and using various types of solar air heaters. To enhance SAHs' functionality, several theoretical and experimental studies have been conducted on them. On the absorber plate, many adjustments have been done. Using fins to increase the area for heat transmission is one of the key theories for improvement. Different fin styles, including longitudinal fins, corrugated fins, and fins linked to baffles, improved performance. The performance of SAHs was also improved by recycling. Additionally, it is discovered that intentionally roughened absorbers are employed to enhance both the heat transfer and thermo-hydraulic performance of SAH. The results revealed good increase of the Nusselt number and friction coefficient for a wide range of Reynolds numbers when artificial roughness was used. The efficiency of SAHs is also significantly improved by the use of heat storage materials, particularly phase change materials (PCMs), including a variety of packing bed types and selective coated absorbers. These upgrades led to an increase in the use of SAHs in additional applications and a significant decrease in fuel consumption as well as installation and operating expenses.

Keywords: *Single-pass solar heater, Double-pass solar air heater, Fin, Heat storage, artificial roughness, Mass flow rate, Thermal efficiency.*

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I. Introduction

SAHs have been employed in a variety of applications, particularly those needing low to moderate air temperatures, to save energy. Additionally, they work well for a variety of uses, such as agricultural drying, solar water desalination, textile, and space heating [1-3]. SAHs provide a number of benefits over liquid heaters since they do not have to worry about the heat transfer medium freezing or stagnating, leaking, getting damaged, or posing a harm to the environment or human health. Additionally, they lower the associated application's energy consumption expenses. SAHs, on the other hand, have limitations because of their restricted temperature range, poor specific heat capacity (air=0.0003 kW h/m3 K; water=1.16 kW h/m3 K), fan noise, and exposed air ducts [4, 5].

SAHs come in a variety of shapes and empirical constructions, making it difficult to categorize them properly. Ekechukwu and Norton [5] reviewed many concepts in detail. A variety of SAHs for drying, including their design and working principles. Based on mode, SAHs can be divided as active, hybrid, and passive. According to their tracking axis, energy storage, expanded surface, and number of covers, as shown in Fig. 1, Tyagia et al. [6] divided the solar heaters into categories. Hot air is produced in various locations and is delivered to the intended application in inactive solar air heating systems. In active SAH, heat storage materials are frequently used to produce hot air at night. However, passive SAHs are typically used during the day. Active solar systems are simpler to design than passive solar systems because to the forced air function, but they cost more to build.

From a different angle, SAHs can be divided into single-pass and double-pass configurations with or without heat storage [6–8] based on the number of air passes. As shown in Fig. 2, air in a single-pass air solar heater flows in one direction from the air input to the air outlet, either above the absorber plate or below it. When using a double-pass air solar heater, air moves through two tunnels that can either be parallel or counterclockwise, as shown in Fig. 3.

The absorber plate and air flow duct make up the majority of SAHs. Thermal insulation with low thermal conductivity is used to minimize heat losses from the bottom and sidewalls. A glass cover with a high transmissivity and low absorptivity covers the heater's upper side. You can utilize a single or double glass cover. To examine the impact of potential changes to the SAH's primary components, many researchers built their own experimental test-rigs.In order to obtain optimal performance, the major goal of the current research is to examine and assess the various design configurations of SAHs.

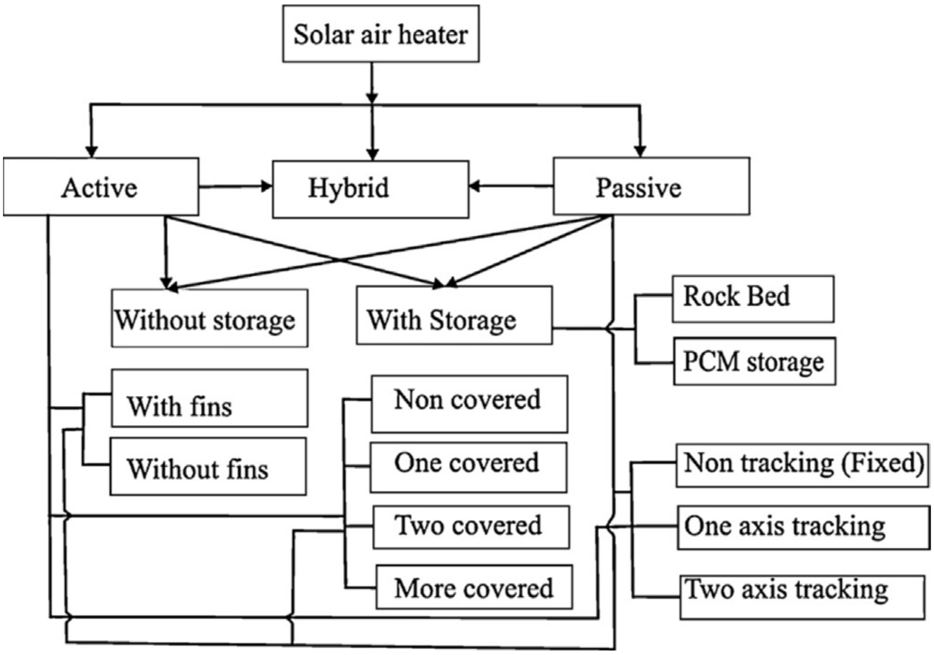

Fig. 1. Classification of the SAHs based on [6].

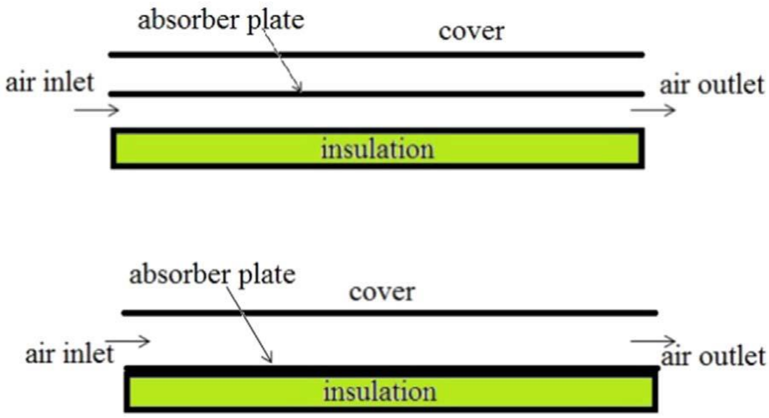

Fig. 2. Single-pass air solar heater.

2. Design configurations and experimental studies

The effectiveness of SAHs is being researched by many researchers. A single pass SAH test rig was built by Chabane et al. [9] with the intention of assessing its performance. The absorber plates were used in two different ways, and two collectors were constructed. Fig. 4 shows a diagrammatic representation of the SAH.

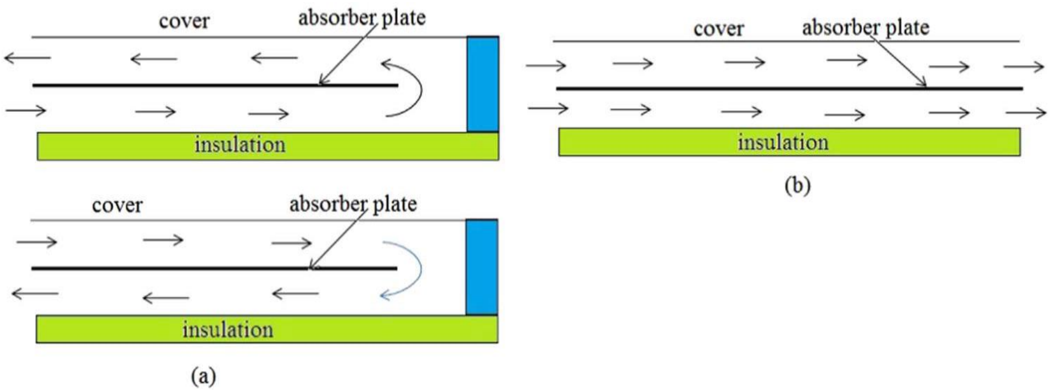

Fig. 3. Double-pass SAH (a-counter flow b-parallel flow).

As depicted in Fig. 5, Dhiman et al. [10] created an experimental setup of parallel and counter flow packed bed SAH. The performance of SAH was examined by Akpinar and Koçyiit [11] utilizing four different

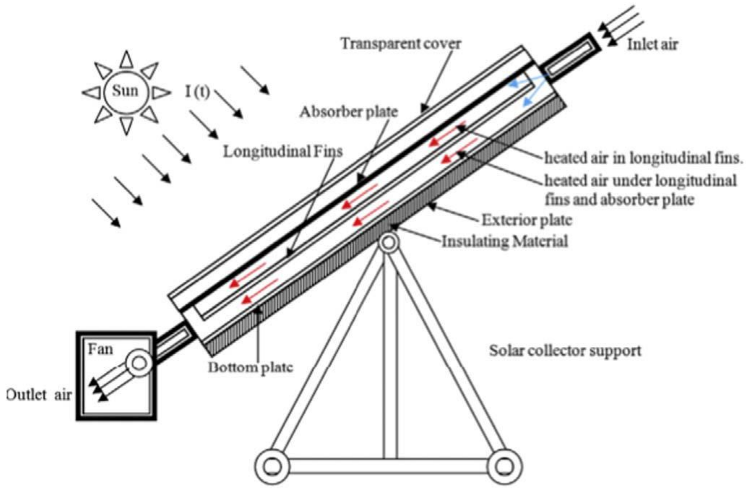

Fig. 4. Schematic view of test rig used [9].

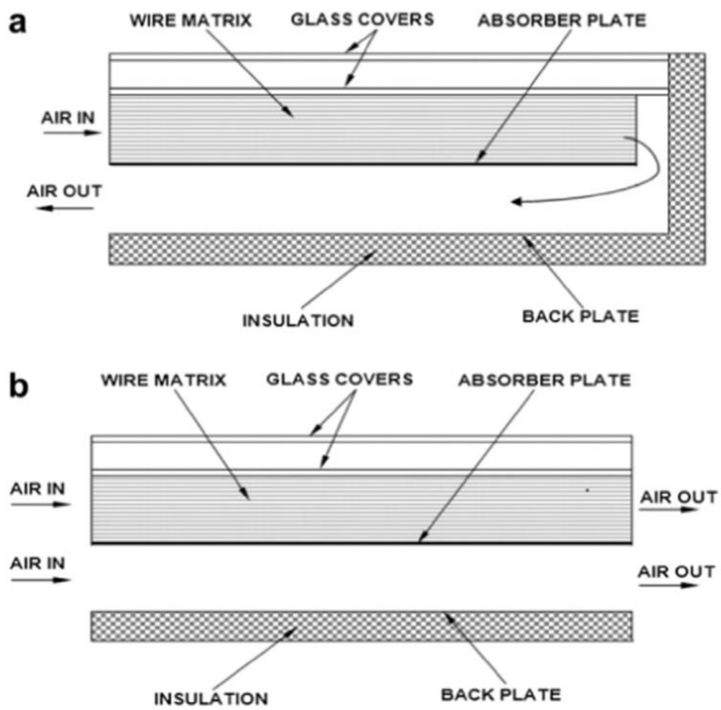

Fig. 5. Layout of the packed bed SAH, a-counter flow, b-parallel flow [10].

Fig. 6 illustrates absorber plates in the forms of triangular, leaf-shaped, rectangular, and flat plates. The effectiveness of five collectors utilizing baffles formed of closed-cell aluminum foams was studied by Bayrak et al. [12]. Above the absorber plate, the baffles were arranged both sequentially and staggeredly. In Fig. 7, the experimental equipment is depicted.

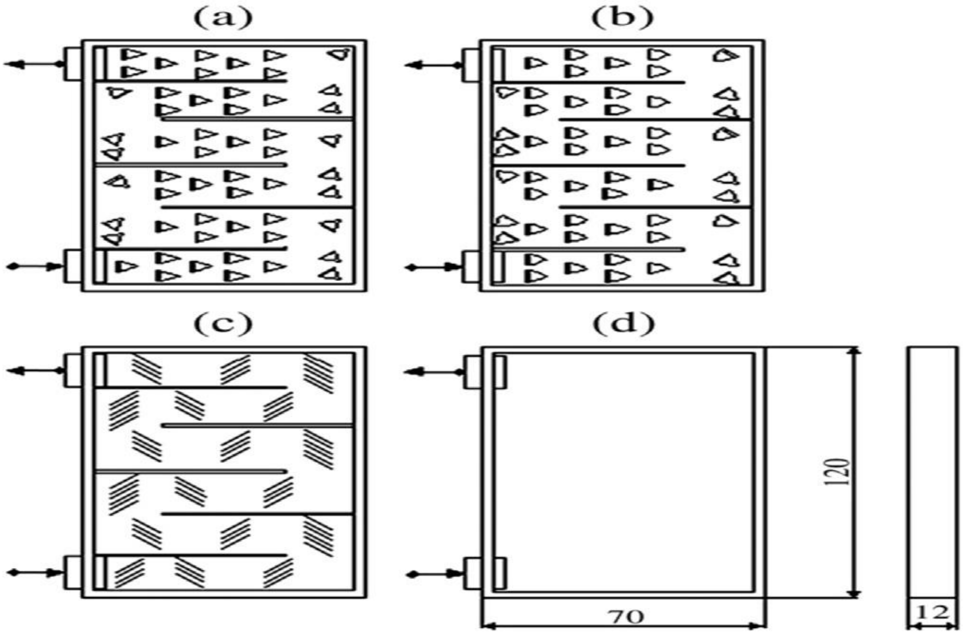

Fig. 6. Types of absorbers used in [12].

Fig. 7. Experimental apparatus of collectors [12].

Fig. 8. Test-rig of finned heater and conventional heater [13].

Fig. 8 shows the experimental test setup that El-Sebaii et al. [13] built for double pass SAH. With the identical design configurations, the finned plate SAH and the v-corrugated plate SAH were contrasted. The performance of three different single-pass air SAH types with the same design settings was experimentally investigated by Alta et al. [14]. The study's primary objective was to contrast heaters with and without fins. Additionally, the quantity of glass covers was examined.

Two solar airheaters were used in a test rig created by Gao et al. [15]. While one was a cross-corrugated heater with a cross-corrugated sine-wave form bottom plate and absorbing plate, the other was a flat plate SAH with a flat absorbing plate and flat bottom plate. To investigate the performance of a SAH with a latent storage collector,

Bouadila et al. [16] built an experimental test-rig (Fig. 9). A packed bed absorber made of sphere-shaped capsules with a black coating made up the setup. The size of the capsule were chosen based on the encapsulating technique [17]. The phase change substance was contained inside spherical capsules that were made by blow molding a polyolefin mixture into capsules.

A SAH was built by Zhani et al. [18] with an aluminum absorber panel that has 20 spaced square channels with a 1 mm thickness and a 2 mm separation between each channel. The width of each flow channel was 40 mm. The air flow canal was 0.1 meters deep.

The double-pass SAH seen in Fig. 10 was created by Yamali and Solmus [19]. The major component of the heater was duct made of iron sheets that had been dyed a matte black. The copper absorber plate used for the absorber plate was painted matte black, and it was positioned horizontally on the duct's centerline. Two glass coverings were used to cover the SAH. A SAH of tubeless flat plate solar collector was utilized by Nafey et al. [20]. The heater's effective area was 0.01 meters.

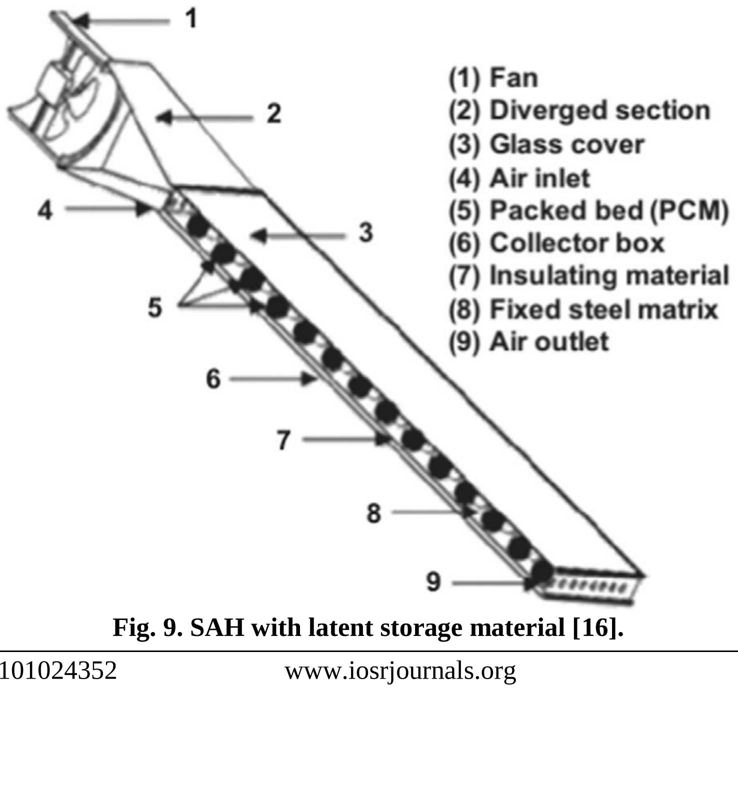

Fig. 9. SAH with latent storage material [16].

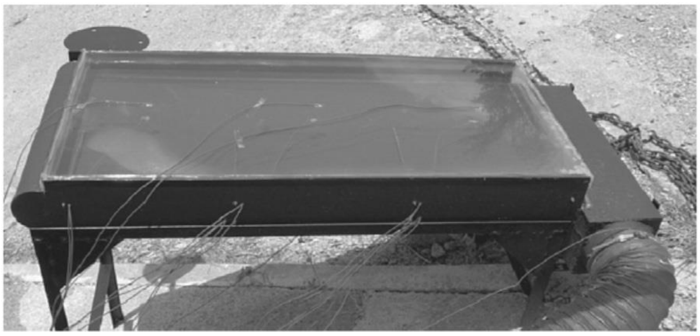

Fig. 10. A photograph of the double-pass flat plate SAH [19].

II. Methods of improvement of SAHs performance

Numerous studies have looked into how SAH performance has improved. They discovered that a variety of strategies and techniques, including the employment of fins and

heat-retaining substances. Additionally, the performance of the SAH is significantly impacted by surface roughness. As a result, numerous studies focused on enhancing SAH performance using single- or double-pass types are described.

Effect of the use of fins

The primary goal of utilizing fins is to expand the area of heat transmission, enhancing the heater's effectiveness. Consequently, the performance's impacts of fin height, number, and arrangement were studied either experimentally or theoretically.

Longitudinal fins

Foued et al. [9] conducted an experimental investigation into the effects of air mass flow rate on the output temperature, heat transfers via the solar collector, and thermal efficiency. A layout design for the components of a solar box with and without fins is shown in Fig. 11. The impact of fin arrangement, fin height, and fin number was nonexistent.

The mathematical model for forecasting the impacts of fin height and number on performance, entropy production, and heat transfer characteristics of doublepass SAH with longitudinal fins was presented by Paisarn [21]. The findings showed that efficiency rises as fin height and number grow, and that entropy generation decreases as fin height and number increase. The impact of the air mass flow rate was not taken into account.

The experimental thermal performance of a double and single-pass SAH with attached fins and using a steel wire mesh as an absorber plate was examined by Omojaro and Aldabbagh [22]. It was discovered that the efficiency of the double pass is found to be higher than that of the single pass by 7-19.4% for the same flow rate. The single and double pass SAH's maximum efficiencies were 63.74% and 59.62%, respectively. Moreover, as the height of the first pass of the double pass SAH is increased, the efficiency continues to decline. Additionally, their findings demonstrated that using steel wire mesh layered as an absorber plate and packing material showed a significantly greater improvement in efficiency. It was not taken into account how mesh height and number will affect the results.

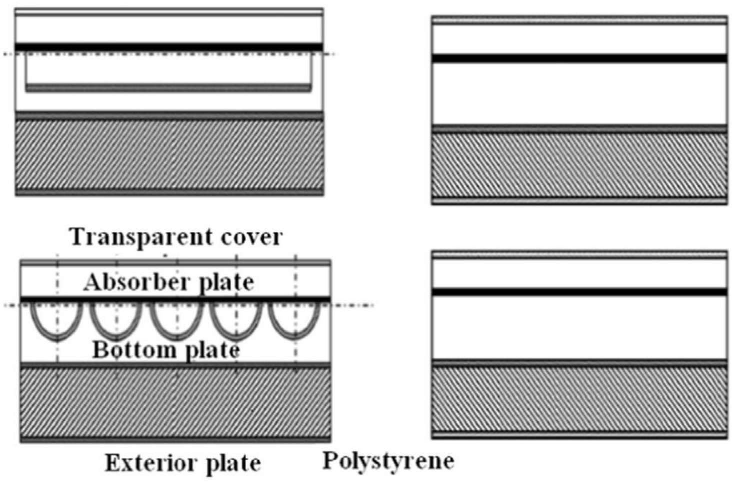

Fig. 11. A solar box with and without fins [9].

Attaching baffles

The test-rig created by Bayrak et al. [12] was intended to conduct theoretical and experimental research using the staggered baffles that are depicted in Fig. 12. The air mass flow rates used for these measurements were 0.016 kg/s and 0.025 kg/s. The heaters with a 6 mm thickness and an air mass flow rate of 0.025 kg/s obtain the best SAH efficiency and air temperature rise, whereas the non-baffle SAHs and an air mass flow rate of 0.016 kg/s reach the lowest values. The impact of baffle size and number was not considered in the study.

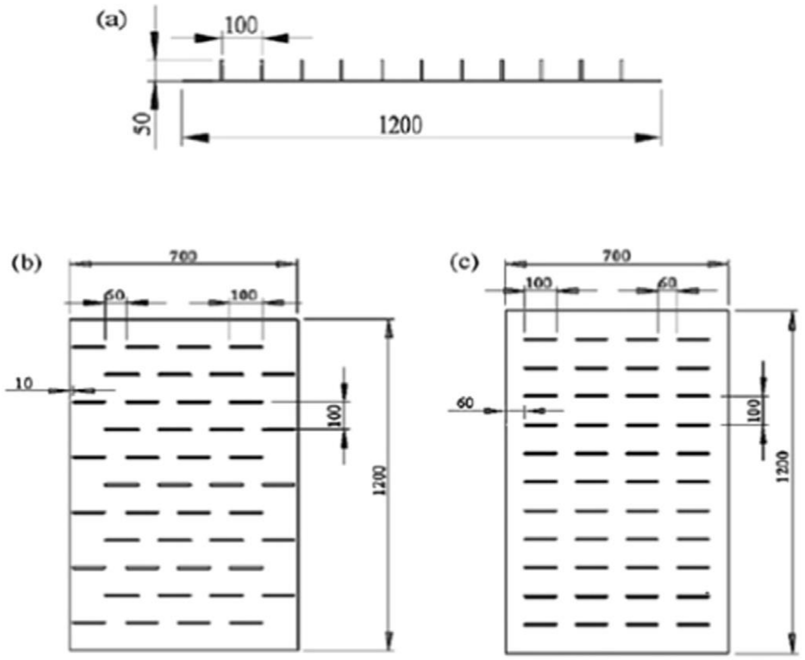

Fig. 12. The aluminum foams (a) side view of the sequence and staggered arrays, (b) top view of the staggered array, and (c) top view of the sequence array [12].

The performance of a SAH with double-pass as well as recycling fins and baffles was evaluated theoretically and practically by Ho et al. [23] as shown in Fig. 13. The experimental findings differ from the theoretical predictions by 1.5 to 23%. SAHs with various designs, such as the single-pass, double-pass with recycle, fined double-pass with recycled, and fined plus baffled double-pass with recycle, are compared for performance. The collector efficiency of the fined plus baffled double-pass with recycled design is significantly higher than the other designs under varied reflux ratios and mass flow rates, according to theoretical and experimental results. When both the collector efficiency and the required pumping power are taken into account, the ideal reflux ratio of the fined plus baffled double-pass design is approximately 0.5.

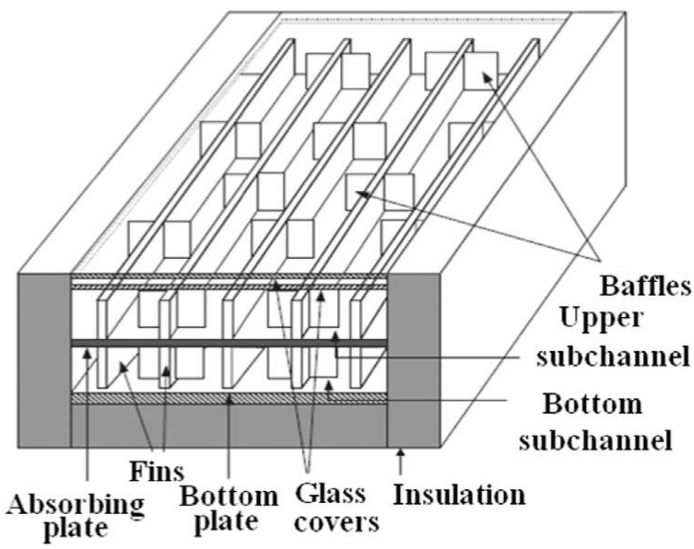

Fig. 13. A schematic drawing of a fined plus baffled double-pass SAH [23].

Corrugated fins

Under the same working conditions, Karima and Hawlader [24] tested flat plate, finned, and v-corrugated SAHs experimentally and conceptually. In comparison to flat plate collectors, it was discovered that the v-corrugated collector is 5–11% and 10-15% more efficient in double pass and single pass modes, respectively. Additionally, all three collectors' efficiency rose with increasing mass flow rate and reached saturation above 0.056 kg/m2 s. The flat plate collector and v-groove collectors had the greatest increase in efficiency in the double pass mode. The layout of the tested collectors is shown in Fig. 14.

The impact of air mass flow rate on pressure drop was examined experimentally and theoretically by El-Sebaii et al. [13]. The double pass v-corrugated and finned plate SAHs' thermal and thermohydraulic efficacy was also researched. The double pass v-corrugated plate SAH is 9.3–11.9% more efficient, according to their findings, than the double pass finned plate.

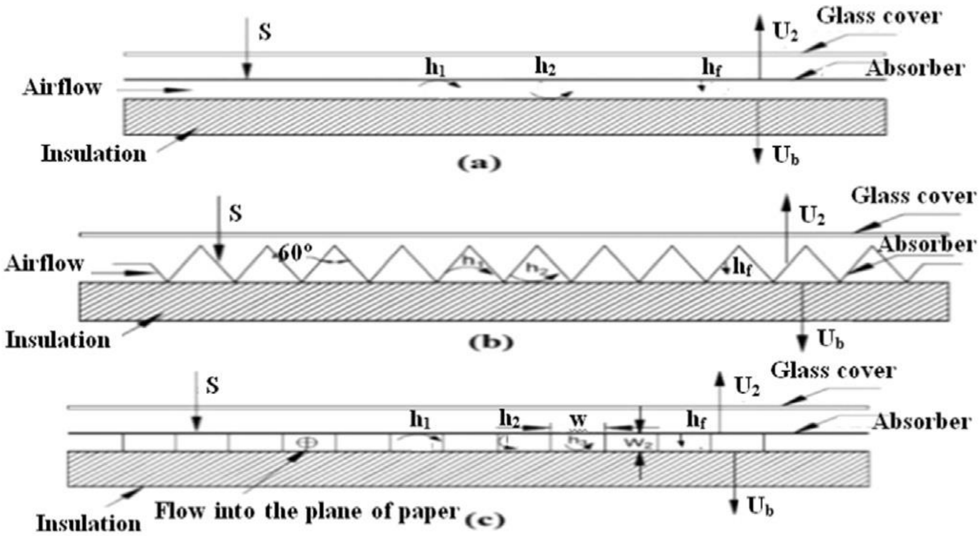

Fig. 14. Layout for a- Flat plate solar air collector, b- V-groove air collector and c-Finned collector [24].

Effect of artificial roughness

In order to improve forced convection heat transfer, which necessitates turbulent flow at the heat transfer surface, artificial roughness was frequently applied. The heater's thermo-hydraulic performance is therefore improved by using it to improve heat transfer. The turbulent is preferred to occur close to the heat transfer surface in order to reduce the power requirement for forced convection heat transfer, which requires energy from a fan or blower. This can be accomplished by keeping the element height low in relation to the size of the heater duct. Dimensionless geometrical parameters are utilised [25] as follows to describe roughness:

1. Relative roughness pitch is the ratio of the height of the ribs to the space between two adjacent ribs.
2. Relative roughness height, which is calculated as the product of rib height and corresponding air passage diameter.
3. Angle of attack: the angle at which the ribs are inclined with respect to the direction of air flow through the duct.
4. The ratio of a duct's width to height is called an aspect ratio.
5. The roughness element's shape. It can take the form of two-dimensional ribs or three-dimensional components, transverse or inclined or V-shaped continuous or broken ribs with or without gaps. The element could also have a hollow, arc-shaped wire, a dimple, or compound rib grooves. The square shape of the ribs is the most typical. To explore the effects of various forms, including chamfered, round, and semi-circular,

A two-dimensional CFD model of a SAH with an equilateral triangle sectioned rib roughness on the absorber plate was proposed by Yadav and Bhagoria [26], see Fig. 15. The research focused on the effects of three Reynolds number, relative roughness height, and relative roughness pitch are factors affecting a roughened heater's thermos-hydraulic performance (Re). The findings demonstrated that while the average friction factor lowers with an increase in Re, the average Nusselt number tends to grow in all On the other hand, the average Nusselt number and the average friction factor rise as relative roughness height increases for a constant value of relative roughness pitch while decreasing when relative roughness pitch increases. The highest Nusselt number and friction factor augmentation were observed to occur at Re of 15,000 and 3800 for relative roughness height of 0.042 and relative roughness pitch of 7.14, respectively. Over a smooth channel, the greatest enhancement of the Nusselt and friction factors was discovered to be 3.073 times and 3.356 times, respectively. For the range of parameters examined, the thermohydraulic performance parameter value ranges from 1.36 to 2.11.

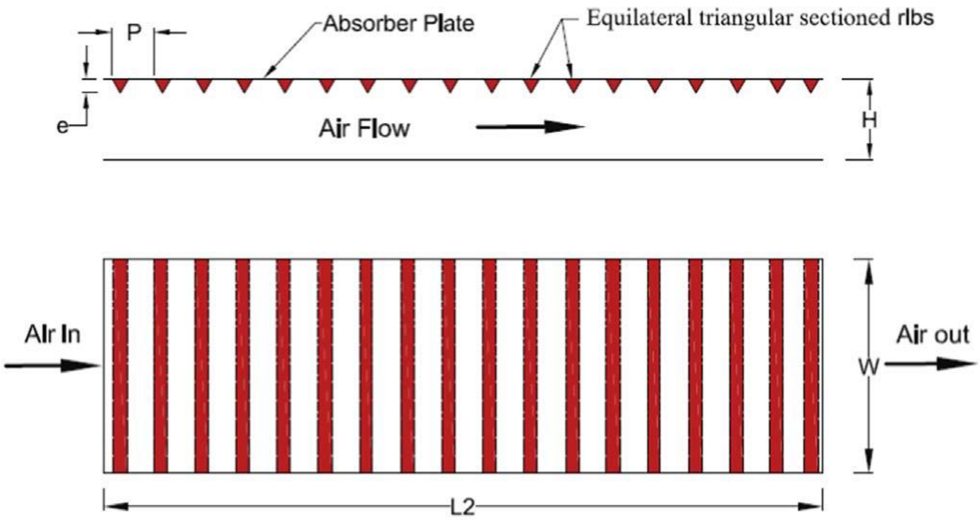

Fig. 15. Schematic representation of a roughened absorber plate [26].

Effect of the use of heat storage materials, absorbers coating and packed bed

Along with its role in energy conservation, energy storage improves the efficiency of energy systems. These systems are frequently employed when using intermittent energy sources, such solar energy. As a result, it is extensively utilised in regions with variable solar energy and regions with a large shift in temperature between day and night. As a result, solar energy systems, particularly SAHs, can be integrated with an energy storage system that has a wide range of applications. The amount of area needed for energy storage is also decreased by energy storage devices. According to Fig. 16, storage materials are divided into latent and sensible categories [7].

PCMs (phase change materials) are the most well-known heat storage materials. PCM is a solid material that can be melted to store energy while maintaining a constant melting temperature. The melting temperature may be adjusted within a narrow range, and the heat is then recovered. Therefore, these materials are utilised to store heat on bright days so that it can be recovered on gloomy or overcast days. Popular substances that can be utilised as PCM include hydrated salts, paraffins, non-paraffins, and fatty acids (such as calcium chloride hexahydrate, or Glaubers salt).

The output air temperature resulting from the discharge process was predicted by Alkilani et al. [3] through the study of a SAH integrated with PCM. Eight different mass flow values, ranging from 0.05-0.19 kg/s, were used in the investigation.

The system setup is shown in Fig. 17. The system was depicted as having a single glass cover and a PCM unit that was divided into cylinders that served as an absorber. The research flow regime involved cross-flow of air through the cylinder. Paraffin wax with a mass fraction of 0.5% aluminium powder made up the PCM. It was an indoor research. In the simulation, air was circulated over the cylinders at 28 °C ambient temperature while the PCM was initially heated to liquid phase (50 °C) by a solar simulator. At each mass flow rate, the crucial factor—freezing time—was investigated. The longest time (about 8 hours) was discovered at a flow rate of 0.05 kg/s. The freezing time had an inverse relationship with the flow rate.

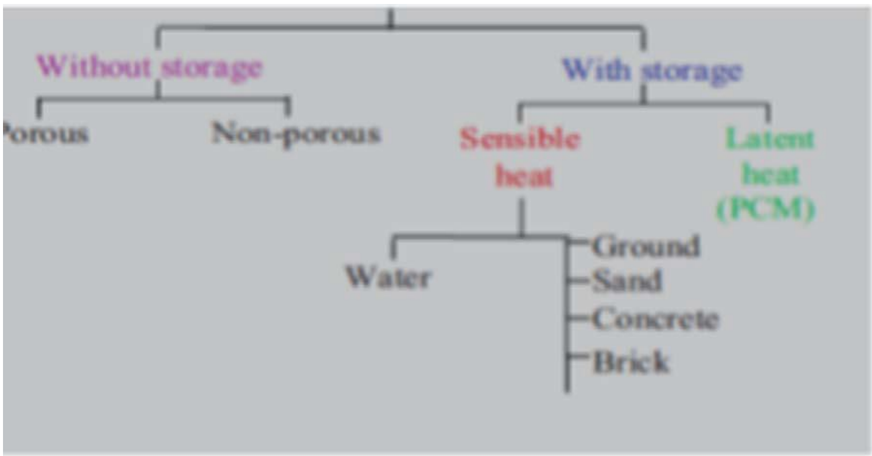

Fig. 16. SAHs with and without storage materials [14].

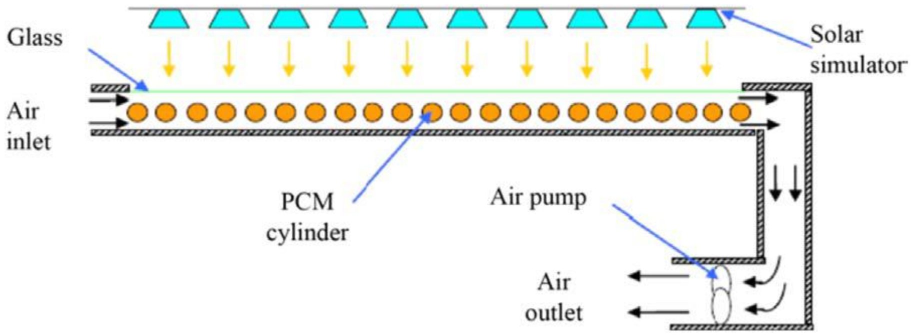

Fig. 17. A SAH with PCM cylinders [9].

III. Conclusions

The following conclusions can be drawn from the review:

1. Using fins increases the area of heat transfer and hence improves performance. Approximately 64% of efficiency is possible with double-pass SAH.
2. Both excessive mass flow rate increases and decreases in air flow rate have the same effect on the SAH's thermal efficiency because of leakage.
3. Attaching baffles and the recycling procedure both increase the heater's effectiveness. However, the designer must be careful while deciding on the height and width of the baffles. The most effective SAH was discovered to be the v-corrugated SAH, while the least effective was the flat plate SAH. The v-corrugated SAH is 5-11% and 10-15% more efficient in a double pass, according to the results.
4. It was discovered that choosing the best fin and baffle characteristics was not decided for all mass flow rates, but could be examined for each mass flow rate. The greater the outlet, the stronger the solar intensity Temperature and useable energy increased, while efficiency fell.
5. Thermohydraulic performance of SAHs is improved by artificial roughness. The Nusselt number and friction coefficient can rise by 3.073 times and 3.92 times over smooth ducts, respectively, and the maximum efficiency can reach 64.24% when artificial roughness is used.
6. There are several kinds of packing beds and storage items that are excellent for the functionality of SAHs. Heat is frequently stored using phase change materials (PCMs) from the charging process during sunny hours to the discharging process.

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