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Performance Improvement of Solar Air Heater through Rib Roughness on the Absorber Plate

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Abstract

To improve heat transmission in solar air heaters, a well-established method involves the insertion of ribs that are designed to change the patterns of fluid flow and induce whirling flow. This causes the thermal boundary layer to be disrupted. On the other hand, this strategy frequently results in a decrease in pressure in the flow path. It is possible to improve the efficiency of SAH ducts by utilising absorber plates that have been roughened. The notion of artificial roughness on flat surfaces is an essential strategy that may be used to improve the rate of heat transfer of air that is passing through an air heater (SAH). A significant factor that influences the rate at which heat is transmitted is the sort of geometry that is utilised and how it is recommended to be positioned within the duct. By adjusting the design of the ribs, researchers have been able to examine the heat transport and friction qualities of SAHs over the course of time. The purpose of this review article is to analyse a variety of artificial enhancers and the impact that they have on heat transmission. Enhanced substances are classified according to the shape and pattern of insertion that they possess. The different types of V-shaped rib, as well as their placement patterns, such as vertical, transverse, or longitudinal, are discussed in this article. The roughness and operating parameters of SAH have also been documented, and it has been stated that investigators were able to attain their greatest performance for these parameter sets.

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Major Findings: *Troublesome flow and secondary flow improve heat transmission and SAH performance when roughness is included. Shape, orientation, and configuration of V-wires affect Nusselt numbers and friction. These components can improve heat transfer and reduce pressure loss with proper design.*

Keywords: *Artificial Roughness, Heat Transfer, Nusselt Number, Reynolds Number, Solar Air Heater*

1.0 Introduction

Human civilisation is based on the development and utilisation of energy. Energy is essential in every field of life, whether it is domestic use, industry, or a basic but very important sector like transportation and agriculture. Energy is such an important thing, and we can see this in the fact that energy is the main powerhouse of all work in the modern era. Right management of energy and making its supply available during the time is not only a necessity of daily routine lives nowadays, but also a requirement for national development/or economic growth and stability and environmental protection. Energy powers all kinds of activities and processes at their most basic level. There is not a single sector, be it agriculture, industry, transportation, communication, medicine, or even entertainment, which is complete without energy. Various sectors require power as a source of energy, like agricultural land needs energy from electric sources to irrigate it, industries require energy to run machinery, our houses consume energy to produce light and heat and to perform other domestic works. For any country or organisation, its economic and technological development primarily depends on the availability of energy and the efficiency with which this energy is used, underlining the importance of energy. Nations capable of harnessing the proper use of energy sources are growing at a steady pace. Especially for developing nations, energy shortages can be the largest impediment to their path of development. For many decades, our energy needs have been fulfilled by traditional sources of energy like coal, petroleum, and natural gas. They are the main contributors to the global energy supply, being the sources that are used for energy production. But today, the restrictions on these energy sources and their adverse effects have become a big worry. But these are not without their problems, and the first of these is that they are scarce. We are overexploiting fossil fuels, putting our energy security at risk. The second big problem, the environmental aspect. These sources release huge amounts of Greenhouse Gases (GHG), mainly carbon dioxide and methane, into the atmosphere, which the mainly responsible for global warming and climate change. Besides this, massive destruction is also done to the environment while taking out these sources and using as the cutting of forests, soil erosion, pollution of water resources, etc. In the past few decade's energy crisis has emerged as a big global issue. A combination of ever-rising energy needs plus a dwindling supply of traditional energy sources is why this crisis emerged. Unprecedented levels of energy consumption are now unprecedentedly high as population, urbanisation, and industrialisation grow rapidly. However, conventional energy sources have their limited availability and even distributed nature, but cannot fulfil this demand. One would observe that the energy crisis affects many different levels. Energy scarcity retards the production process economically and hence it delays economic development. From a social perspective, the quality of life is compromised due to the lack of electricity and other energy sources that limit access to education, health and basic services. The energy crisis also means that more fossil fuels are used, exacerbating environmental problems again, from the perspective of the environment[1-4].

Renewable resources have become extremely essential in an open society to manage the energy crisis and environmental contradictions. Renewable energy is inexhaustible and clean energy; it is energy produced using renewable energy sources. If all these sources are used, it can reduce our dependency on conventional energy sources and create a path towards an energy-sustainable future. The most crucial property of renewable energy is the natural regrowth very close to without fail. Renewables are also the only clean energy source that has effectively zero emissions of greenhouse gases. These energy sources also prevent the environment from being polluted, but also reduce energy costs, because the operational cost of renewable energy generation systems after installation is relatively low. These are the other relevant types of renewable energy besides solar power — wind power, hydropower. Wind is harnessed to generate electricity from wind energy. It is also a renewable and non-polluting energy source. The same goes for

hydro energy via large walls and hydropower projects. Because of this, it is one of the cheapest and most reliable methods of energy. Other areas include biomass energy and geothermal energy, or all the efforts related to plant growing and animal raising. Biomass energy originates from residuals such as agricultural and natural waste, and geothermal energy originates from the inner heat of the Earth. Efficient use of this kind of energy can not only solve the energy crisis but also help with waste treatment and environmental protection. Although renewable energy has its benefits, it suffers from certain challenges in its utilisation. The biggest hurdle is the initial cost. You need a huge investment to bet big on the solar panels, windmills and hydropower projects. Besides this, sustainability and storage of renewable resources is another issue, but it has to be resolved rapidly, and for that, Solar energy is an appropriate solution, just because of its ability to last for many periods without any interruption. Examples include solar energy, which is only available at certain times of the day, and storing it for later use at night is a complex, difficult task. Despite all the difficulties, well, in the current scenario, it's time for a clean energy transition. This requires establishing guidelines and rules for getting optimal use of renewable sources through cooperation between the regulators, industries, and individuals[5-8].

Solar power is the most essential of all renewable energy sources. Because the light of the sun is all over our planet, this is our closest and one of the cheapest sources of energy. Uses of Solar Energy While we have different uses of solar energy, like the generation of electricity with the help of solar panels, the preparation of hot water using solar water heaters and cooking food with the help of solar cookers. Solar energy is available almost any, this is one of the principal advantages of solar electricity. Assistance with it in rural and urban settings. Considering the remarkable potential of small power plants, solar energy is the ideal form of energy for places with a prevalent shortage of electricity, like most rural areas. It is beneficial for fulfilling domestic needs and in agriculture and cottage industries. With urban centres booming, solar energy matters for utility-scale electricity generation, but also to improve energy efficiency in buildings. Apart from this, a solar power system works as an effective protection for the environment. Almost zero greenhouse gas emissions because it is the cleanest way to generate energy. It also makes us less dependent on fossil fuels and mitigates climate change[9-13].

SAH is also a simple and simple technology which heats the air by utilising the energy obtained from the rays of the sun (Figure 1). It is a great source of delivering clean and green energy mainly for industrial, commercial and domestic needs. A SAH, where the air flows through the sun-heated solar collector, and the air gets heated and used for different purposes. SAH is an important innovation in the field of energy that not only contributes to the energy crisis but also helps in minimising the side effects of conventional energy resources. This system works simply as follows. Cold air comes into the solar collector and is heated by the absorbent surface warmed by the sun's rays. After that, this hot air exists via either natural or mechanical vents. This hot air can be used to heat buildings, dry crops, provide heat for industrial processes, and temper housing for livestock. It cannot be mass produced, it has a transparent cover, an absorbent plate, insulation, and the air can flow, hence it is more working and energy efficient. Many types of SAH are available to choose from based on the user's needs and surroundings. They consist of direct flow, indirect, and double-way heaters. Active systems use fans and blowers to actively increase the flow of air, while passive systems rely on natural flow. Its versatility makes it applicable from small household use, for example, a home and a small industrial house, to large industrial purposes.

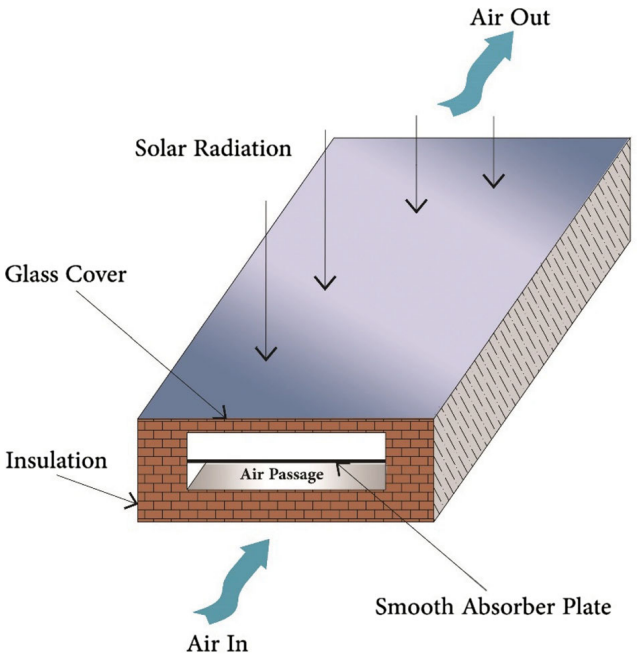


Figure 1. Convectional SAH[19].

The biggest benefit that SAH has is that it is friendly to the environment. It doesn't produce greenhouse gas emissions and is fully powered by clean and renewable energy. Its cost of operation is low, as the power of the sun charges it for free. In addition, it lowers the reliance on traditional sources of energy and encourages energy independence. This is beneficial in places where fuel is costly or unavailable. Yet, it also has a few limitations. First, the upfront installation cost of SAH is high, and the performance of SAH is weather-dependent. On cloudy days or even at night, its use is restricted. It also needs sufficient space to be installed for heavy-duty applications. However, as technology matures, these challenges are slowly being addressed. Modern designs and materials can now make it more efficient and less expensive. There will be more contributions from SAHs in the future timeline as well. This is already being promoted in many governments and organisations by providing different schemes and subsidies. Besides that, it offers a solution to the energy crisis, and adopting this technology will help reduce the carbon footprint as well. Given its potential functionality in the countryside and in urban centres, the accessibility of the tool for the masses provides a great opportunity for energy efficiency and environmental sustainability. SAH is clean and the permanent long-term solution not only for environmental problems but also for the continuously increasing energy demand. Being a long-term investment strategy, it not only cuts the costs but also acts as a stepping-stone towards a clean and green planet. The mass utilisation of renewable energy resources not only solves the energy crisis but also represents an effective strategy for sustainable development and energy self-sufficiency. SAHs are one of the instruments that must be used to ensure a secure and green world in this new phase of energy generation and consumption[14-19].

Numerous investigations have been carried out to have a better understanding of the potential for SAHs to improve heat transfer capability[20-28]. The various ribs, wire coils, twisted tapes, dimpled, corrugated, and grooved tubes, combined and compound turbulators, and so on, are all examples of the layouts that are included in this category[29-38]. Alterations of varying kinds are made to absorb plates to enhance the efficiency of SAH. The incorporation of artificial roughness is one of these alterations. Adding the ribs causes the turbulence to become more intense, which eventually results in the thermal boundary layer disturbance and an improvement in heat transmission. However, excessive heights, which are caused by significant pressure drops, degrade efficiency. Other factors that influence heat transfer include the geometric shape of the ribs, which can be triangular, sinusoidal, or any combination of these. Additional enhancements in heat transfer can be accomplished by optimising the spacing and orientation of the ribs, which might be parallel, inclined, or staggered, to fulfil the requirements for adequate air mixing. Additionally, to facilitate additional convective heat transmission, ribs can be utilised in conjunction with other surface alterations, such as corrugations or vortex generators. The material of the ribs also influences the rate of heat transfer. In terms of heat transfer performance, materials with a high thermal conductivity will perform substantially better. Maintaining a delicate balance between rib design for optimal pressure drop and heat transfer performance is essential for effective SAH optimisation. This is necessary to achieve the highest possible energy capture from solar radiation without significantly compromising the airflow resistance that these ribs entail. Using a variety of rib types, it is possible to maximise heat transmission. This allows for the discovery of the optimal rib design that maximises heat transfer while having a little impact on the rising pressure drop. This, in turn, leads to the maintenance of an ideal balance between thermal performance and energy consumption. The purpose of this research paper is to find out the best design of ribs to improve the efficiency of the system. More specifically, the paper discusses a review of several types of V-type ribs and their effect on heat transfer enhancement.

2.0 Experimental and Numerical Investigations

The single heated wall concerning SAHs is something that must be taken into consideration, even when the rough aspects are being considered. One wall is the only one that is exposed to solar radiation, which is the reason why this is the case. This is the reason why SAHs are typically placed in a rectangular configuration, with one rough wall and three smooth walls. This channel's heat transfer mechanism is distinct from that of circular tubes, annular tubes, and channels with two similarly roughened walls[39-41]. The literature reveals that there are a great number of distinct varieties of ribs available; however, in this article, some of the numerous forms of V-type ribs are discussed.

To investigate the effects of turbulent heat transmission and friction, Lau, Kukreja[42] used a square channel that was roughened with V-shaped ribs. This channel was modelled after the internal cooling channels seen in modern gas turbine aerofoils. Replacing 45" or 60" complete ribs was advised for internal turbine aerofoil cooling. Through the testing of thirteen different rib shapes, Taslim, Li[43] Discovered that V-shaped ribs with an inclined centre for maximum heat transmission and friction factors, pointing downstream for optimal flow, were the most effective.

As an alternative to transverse ribs, Gupta, Solanki[44] Proposed ribs that are slanted. In addition, they investigated the impact that additional roughness characteristics, such as e/D and Re, had on improvements. With an increased insolation (I), the thermal performance of SAH became even more efficient. An evaluation of the thermal performance of equivalent cross-stack discrete rib structures with staggered up and down v-apex ribs was conducted by Muluwork, Saini[45]. They examined how enhancements were impacted by other parameters.

It was investigated experimentally by Ebrahim Momin, Saini[46] How rib geometrical parameters influence the performance of ribs in a V-shaped configuration (Figure 2). The V-shaped ribs, for similar operating conditions, performed better than inclined ribs. The rate of Nu growth was found to have been lower than that of f as a result of the increase in Re.

Using repeated, 60° inclined rectangular cross-section ribs, Karwa[47] Investigated heat transfer and friction factor. Transverse ribs improved the Stanton number by 22–32 %, and the friction factor by 1.12–1.16 times.

Using liquid crystal thermography, Tanda[48] Obtained exact distributions of h in rib-roughened channels (Figure 3). Compared to a smooth channel, ribs substantially increase the friction coefficient.

The underside of the absorbing area was investigated by Hans, Saini[49] By the utilisation of multiple V-geometries (Figure 4). For the set of parameters taken into consideration, Nu and f increased, relative to the simple SAH duct.

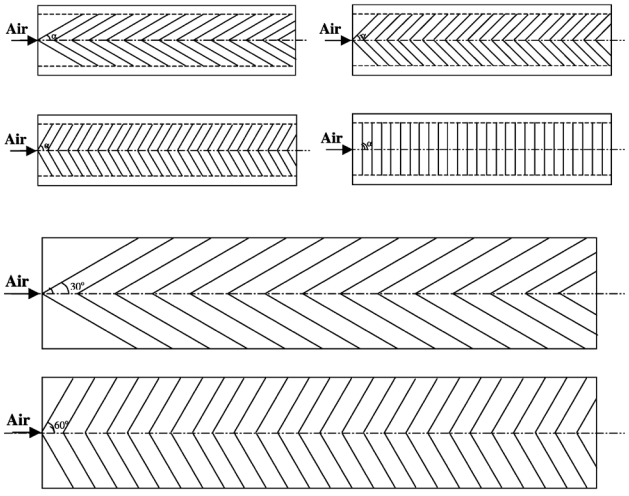


Figure 2. Different V-shaped ribs[46].

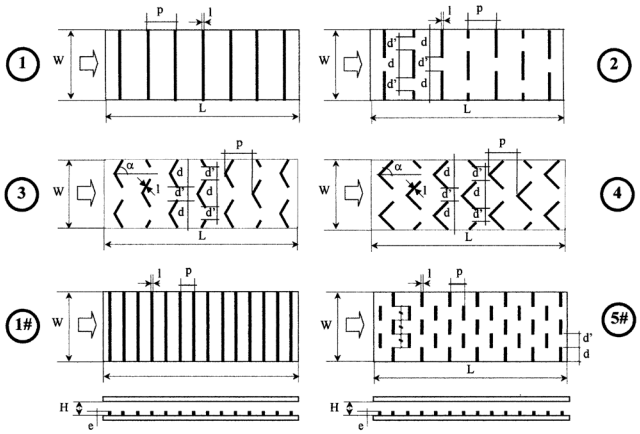


Figure 3. Different V-ribs[48].

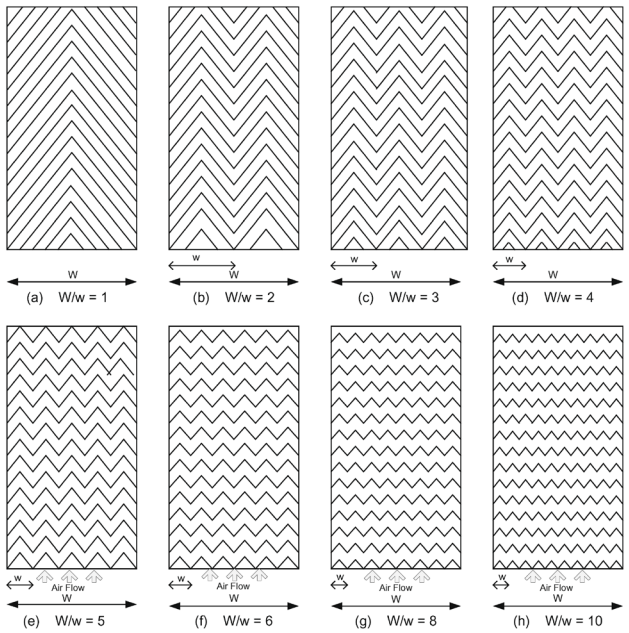


Figure 4. Multiple V-ribs[49].

According to Singh, Chander[50] V-down ribs with gaps can be used in SAH ducts to enhance heat exchange (Figure 5). When comparing V-down geometry with gap to continuous geometry, Nu is better.

An examination of V-down ribs and gaps in SAH ducts was carried out by Singh, Chander[51]. As they conclude, smooth SAH ducts have a maximum effectiveness increase of 91% when compared with roughened SAH ducts as Re increases.

Maithani and Saini[52] Developed a correlation between Nu and f via V-geometry with symmetric gaps for SAH with roughness (Figure 6). In addition, they found that the THPP of V-shapes with symmetrical gaps is higher than the THPP of discrete V geometry with staggered ribs and down V-shapes with gaps.

An analysis of the performance of a staggered rib and a multigap V-shaped down-rib was conducted by Deo, Chander[53] (Figure 7). When the Re was close to 12,000, the highest possible value of THPP was achieved.

The experimental investigation on the heat transmission properties of SAH with V-shaped and staggered ribs was carried out by Ravi and Saini[54] (Figure 8).

Using multi-V-shaped ribs with staggered components, Patel and Lanjewar[55] Studied the effects of staggered rib sizes (Figure 9). The outcome demonstrates an important

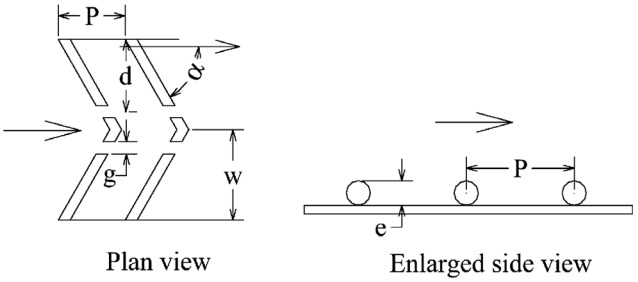


Figure 5. V-down ribs[50].

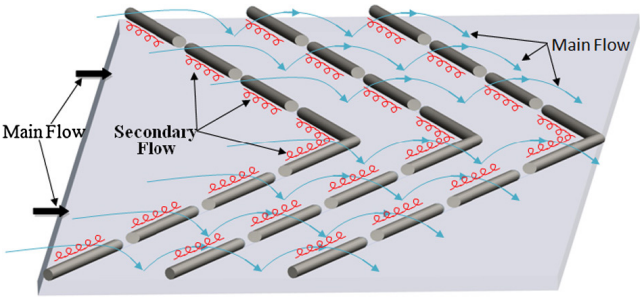


Figure 6. V-ribs with symmetric gaps[52].

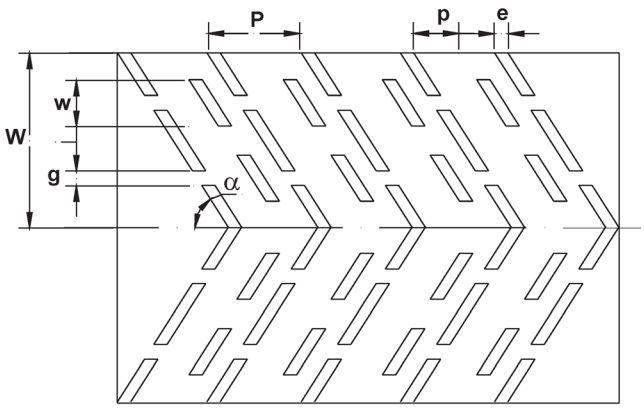


Figure 7. V-shaped down-rib[53].

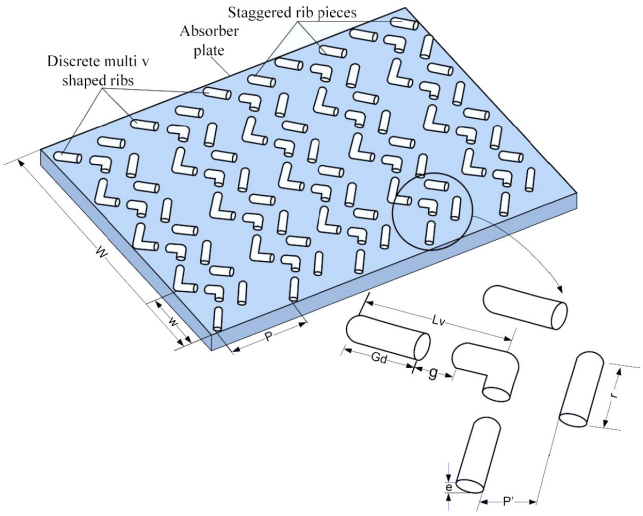


Figure 8. V-shaped and staggered ribs[54].

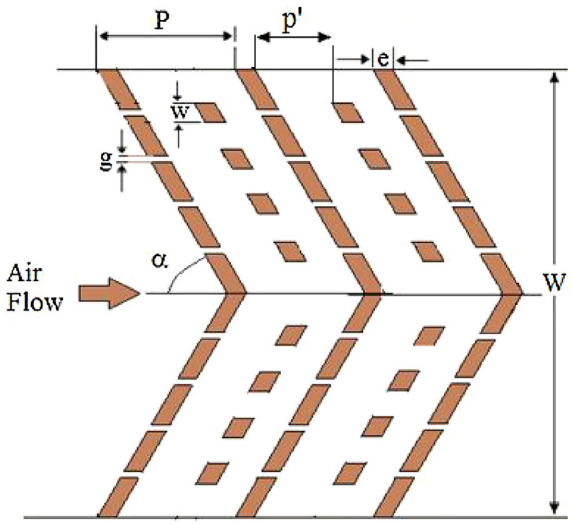


Figure 9. Multi-V-shaped ribs with staggered components[55].

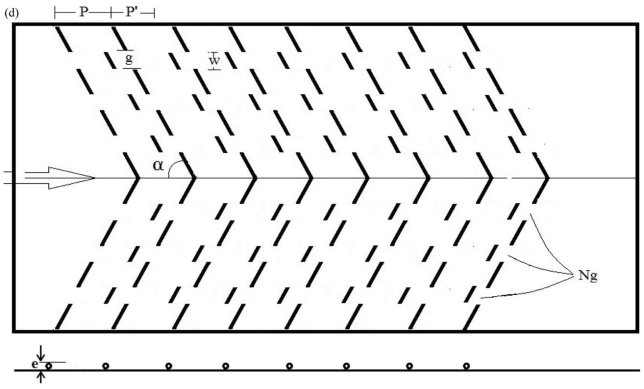


Figure 10. V-shaped ribs with aligned multigaps and staggered rib[58].

relationship between the Nu and the degree of rib stagger. The best result for THPP of 3.5 was attained.

Using V-ribs with symmetric gaps and staggered rib pieces, Jain and Lanjewar[56] Explored experimentally how to improve THPP. The effect of P/e on various Re ranges was examined by the authors.

Table 1. Parameter used

Roughness geometry	P/e	e/D	α
"Discrete V-Shaped staggered ribs"[45]	10	0.02	60⁰
"V-shape ribs"[46]	10	0.034	60⁰
"Various V shape"[47]	10	0.05	60⁰
"Transverse continuous, Transverse broken & V shape rib"[48]	4	0.15	90⁰
"Multi V rib"[49]	8	0.043	60⁰
"Discrete V down rib"[50]	8	0.043	60⁰
"V – ribs with symmetrical gaps"[52]	10	0.043	60⁰
"Multigap V down with staggered rib"[53]	12	0.043	60⁰
"Discrete multi-V-shaped and staggered rib"[54]	10	0.043	60⁰
"Discrete multiple V-shaped with staggered rib"[55]	12	0.045	60⁰
"Staggered V-rib with uniform gaps"[56]	12	0.045	60⁰
"Staggered V-rib with uniform gaps"[57]	12	0.043	60⁰
"Multi-gap V-shaped with staggered element"[58]	12	0.045	60⁰
"Aligned gap V shape rib with Staggered pieces"[59]	10	0.0433	60⁰

In a SAH channel that has been roughened using a V-gap with a symmetrical rib with staggered components, Patel and Lanjewar[57] Experimented to determine the effects of variations in numerous additional gaps (n_g) and the main gap (N_g).

The insertion of additional gaps to the roughness limbs of the V-rib was found to have a significant impact on both Nu and F[58] (Figure 10). Investigators produced V-shaped ribs with aligned multigaps and staggered rib pieces while holding all other variables constant and testing different parameter values. The authors utilised the most effective arrangement of the ANN structure to predict the thermal performance of the SAH.

3.0 Results

Various experimental and numerical investigations were conducted on artificially roughened solar air heaters. The results obtained from different studies are presented in the following tables.

Table 2. Nu_r/Nu_s Enhancement

Roughness geometry	Nusselt number enhancement ratio
"V-shape ribs"[46]	2.30
"Various V shape"[47]	2.47
"Transverse continuous, Transverse broken & V rib"[48]	3.2
"Multi V rib"[49]	6.0
"Discrete V down rib"[50]	3.04
"V – ribs with symmetrical gaps"[52]	3.6
"Multigap V down with staggered rib"[53]	3.34
"Discrete multi-V-shaped and staggered rib"[54]	4.52
"Discrete multiple V-shaped with staggered rib"[55]	2.27
"Staggered V-rib with uniform gaps"[56]	2.30
"Staggered V-rib with uniform gaps"[57]	2.34
"Multi-gap V-shaped with staggered element"[58]	2.3
"Aligned gap V shape rib with Staggered pieces"[59]	2.16
"V-pattern ribs"[60]	3.09
"V-solid ribs"[61]	3.09

Table 3. f_r/f_s Enhancement

Roughness geometry	Fiction factor enhancement ratio
"V-shape ribs"[46]	2.83
"Various V shape"[47]	3.65
"Transverse continuous, Transverse broken & V shape rib"[48]	-
"Multi V rib"[49]	5.0
`"Discrete V down rib"[50]	3.11
"V – ribs with symmetrical gaps"[52]	3.67
"Multigap V down with staggered rib"[53]	2.45
"Discrete multi-V-shaped and staggered rib"[54]	3.13
"Discrete multiple V-shaped with staggered rib"[55]	4.28
"Staggered V-rib with uniform gaps"[56]	3.18
"Staggered V-rib with uniform gaps"[57]	2.79
"Multi-gap V-shaped with staggered element"[58]	3.18
"Aligned gap V shape rib with Staggered pieces"[59]	2.74
"V-pattern ribs"[60]	2.38
"V-solid ribs[61]	3.2

Using a roughened surface with aligned gaps and staggered rib pieces, Jain and Lanjewar[59] Investigated the relationship between THPP and HT rate. Table 1, Table 2 and Table 3 show the parameters used, Nusselt number enhancement ratio and friction factor enhancement ratio, respectively.

4.0 Conclusion

Different V-wire rib roughness geometries have enhanced conventional SAH performance. These V-wire rib roughness geometries are thoroughly reviewed. Different roughness parameters and their order affect heat transport and friction. Geometrical parameters express heat transmission enhancement as Nusselt numbers and pressure drop penalties as friction factors for varied roughness geometries. The utilisation of a wide range of V-wire roughness geometries, which can be formed, scaled, oriented, and arranged in a variety of different ways, makes it feasible to improve the performance of SAHs. To raise the amount of heat that is transmitted and decrease the amount of pressure drop, the designer needs to select the roughness geometry appropriately. In contrast to a plate that is smooth, a plate with V-wire ribs allows for greater heat transfer. This is because the V-rib roughness geometries generated two secondary flow cells, which resulted in the highest increase in heat transmission when compared to the transverse roughness geometries. The use of V-roughness geometries offers an additional enhancement to the process of heat transmission. Because of the reconstruction of secondary flows, the mixing of flows, and the turbulence.

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