A review of solar air heater with artificial rib roughness.

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Abstract -*This analysis discusses the similarities and irregularities found in the outcomes, focusing on a broader range of factors that influence the Solar Air Heater (SAH) efficiency. Researchers have conducted numerous experiments to examine how the operation and shape of the solar air heater impact heat exchange and the movement of fluids. The types of rib roughness observed include transverse, inclined, arc-shaped, and V-shaped. The focus of this research is on understanding the physics behind the heat transfer and fluid dynamics around these rib surfaces. The analysis also covers the latest developments in the study of repeated rib roughness in SAHs, highlighting their historical context. Additionally, the application of artificial roughness on the air flow side of the absorber plate in a solar air heater is identified as a key method to improve its thermal efficiency.*

***Key Words*: Solar air heater, Repeated-rib roughness, Heat transfer enhancement.**

1.INTRODUCTION

Renewable assets are copious in nature and usable in a wide extend. Sun oriented vitality is accessible in bounty and may be a promising substitute. Sun powered vitality could be a valuable and promising renewable energy resource with applications in a variety of devices and shapes. Although specialized solar energy use potential has previously been established, these sources remain unprofitable from a business standpoint. To plan for the creation of financially valuable solar energy, one of the critical necessities is it productive collection By utilizing sun oriented collector it can be utilized specifically in a few warm applications The execution of SAH can be measured in terms of heat productivity (η), successful productivity (η_{eff}), exergy effectiveness (η_{exg}) and thermal-hydraulic execution parameter (THPP). Within the case of constrained convection based SAH, the outlet discuss temperature (To) is our alluring yield parameter not at all like characteristic convection based SAH where the mass stream rate is additionally critical. Must be considered for its execution assessment. The strategies like Multi coating, reflectors, cleaning of safeguard plate, etc. don't alter the region or length of the wind stream way; consequently, the weight misfortune remains the same. The execution assessment of such procedures can be carried out utilizing, which is the work of as it were To. Whereas, in multi-passing, alter in cross-section of SAH conduit, balances, confuses, etc. η_{eff} is considered for execution evaluation, which is the work of both To and pressure misfortune. THPP con siders contact calculate and warm exchange coefficient with regard to the baseline/reference case (smooth channel); thus, it is prescribed for the rib-roughness.

The average yearly energy use per person in the USA stands at 8000 kWh, in stark contrast to India's usage of just 400 kWh, illustrating the vastness of the subject of Renewable or Non-conventional Energy Resources. These resources, which include energy from the Sun, Wind, and Ocean, are crucial assets for a nation's economic and environmental strategy, thanks to their environmental benefits and role in sustainable development. Over the past few years, these resources have emerged as a key component of energy production. The use of renewable energy is increasingly becoming a key consideration for countries worldwide, as it is clean, abundant, and a significant source of power. There are various renewable energy technologies that are now widely used and recognized as a major industry by countries globally. The way energy is used in developing countries like India shows a trend that favors urban areas, leaving rural regions, like those in India, with a significant energy gap in availability. Energy can be categorized as either renewable or non-renewable. Non-renewable sources such as coal, oil, gas, and nuclear fuels have taken millions of years to form and are expected to run out within decades or centuries. On the other hand, renewable energy sources like solar, wind, and tidal energy are naturally replenished, ensuring their supply does not diminish with use. At present, the majority of the world's energy needs are met by fossil fuels. Recent advancements in solar air heater technology, such as the development of integrated and hybrid systems, have improved their efficiency and functionality. It's important to highlight these advancements to understand the current trends and future prospects of solar air heating technology.

Nomenclature	
H - Depth of duct, mm	e/D - Relative roughness height
I- Intensity of solar radiation, W/m2	e/H - Rib to channel height ratio
L - Length of test section of duct or long way length of mesh, mm	F_o - Collector efficiency factor
P - Pitch, mm	F_r - Collector heat-removal factor
q_u- Useful heat flux, W/m2	F_r - Friction factor for rough surface
Q_u- Useful heat gain, W	g/e - Relative gap width
T_{am} - Mean air temperature, K	g/p - Relative groove position
T_i - Fluid inlet temperature, K	Gd/Lv - Relative gap distance
T_f - Fluid outlet temperature, K	L/e - Relative log way length of mesh
T_{pm} - Mean plate temperature, K	Nu - Nusselt number
W - Width of duct, mm	Nur - Nusselt number for rough channel
w - Width of rib, mm	Nus - Nusselt number for smooth channel
ΔP - Pressure drop, Pa	P/e - Relative roughness pitch
SAHs- Solar air heaters	Pr - Prandtl number
	St - Stanton number
	W/H - Duct aspect ratio
	W/w - Relative roughness width
Greek symbols	
Φ - Wedge angle/chamfer angle, degree	
α - Angle of attack , deg.	
δ - Transition sub-layer thickness, mm	
ε - Dissipation rate,m2/s3	
η_{th} - Thermal efficiency	
μ - Dynamic viscosity, Ns/m2	
ρ - Density of air, kg/m3	
ω - Specific dissipation rate,1/s	

Table1.

2. METHODS FOR SOLAR AIR HEATER:

2.1 Experimental approach

In this methodological framework, a prototype of a solar air heater is constructed, and empirical investigations are conducted on this model. The prototype may either possess identical dimensions to those of the actual solar air heater or be represented as a scaled model (either reduced in size or enlarged). The operating parameters are employed for the assessment of the thermal performance of a solar air heater. During the experimental process, the researcher must meticulously consider factors such as the duration required for the investigation, the financial implications associated with the prototype's fabrication, the accessibility of experimental facilities, and the precision of measurement instruments. Human error, measurement inaccuracies, and atmospheric conditions encountered during the experimentation can significantly influence the reliability of the data obtained from the experimental configuration Numerous researchers have explored a diverse array of operational and geometrical parameters and endeavored to ascertain precise estimations of the heat transfer coefficient and friction factor for the roughness geometry under examination

2.2 Work in convective heat transfer

Nikuradse (1933) conducted an investigation into the frictional loss phenomena within sand-roughened circular pipes that were unheated, across an extensive spectrum of Reynolds number (Re) values, in contrast to prior investigations focused on rough surfaces. Findings: delineated three distinct flow regions predicated on the correlation between the friction factor (f) and the roughness Reynolds number (e+); identified hydro-dynamically smooth flow (070); introduced a modified law of the wall to characterize the velocity profile: u+ = 2.5ln(y/e) + R(e+)

Cope (1937) Conducted an investigation into the influence of duct cross-sectional shapes—namely circular, square, and rectangular—on thermal regulation within a smooth pipe (Subsequently, in 1941, the same researcher examined heat transfer phenomena within rough pipes (Cope, 1941)) for Reynolds numbers extending up to 50,000. Discoveries shown that the hydraulic diameter (Dh) is pertinent to non-circular channels; the heat exchange coefficient (h) and friction calculate (f) don't essentially show synchronous increments; besides, the grinding calculate does not shift consistently beneath conditions of constant heat flux and constant wall temperature.

Brouillet and Meyers (1947) Performed experimental analyses on the effects of transverse and triangular internal grooves within a turbulent flow environment. The results illustrated that the values of h and f in rough pipes are, individually, 2 and 1.5 times more prominent than those watched in smooth pipes.

Kolar (1965) Webb et al. (1971, 1972,) Tested with 60° triangular string with discuss and water as a working liquid for variable breadth to unpleasantness proportion, Re and Pr values. Comes about: The esteem of gets to be steady, and diminishes at higher Re; cost-effectiveness is an basic parameter within the plan of a heat exchanger.

Webb et al. (1971, 1972), (Dipprey and Sabersky, 1963), (Nikuradse1933) For variable relative roughness tallness (e/D) and relative unpleasantness pitch (P/e) values of the rehashed transverse ribs, covering a wide run of Pr values. Comes about: An expression for broadly utilized parameter thermal-hydraulic execution parameter (THPP) was created. A single relationship cannot work for all roughness geometries as proposed within the prior studies; because, variety in rib-geometry causes impressive changes within the values of h and f.

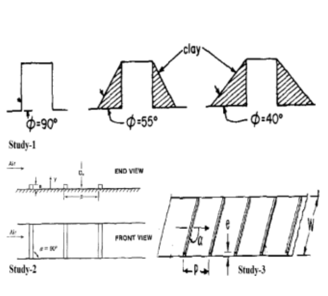
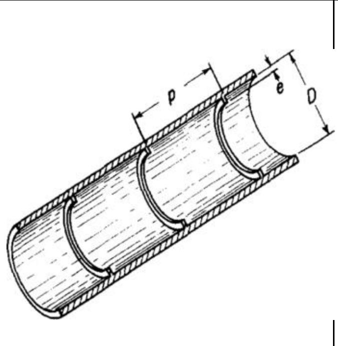
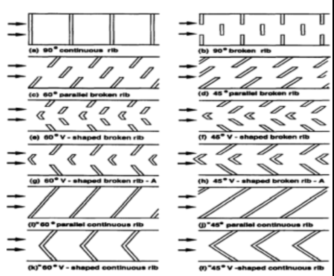
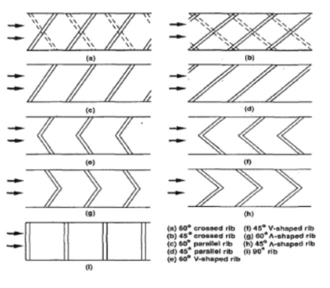
Roughness Geometry	Boundary condition and Results
	**Han, 1984; Han and Park, 1988) Transverse-cornered, transverse and inclined ribs;** L×W×H L 1275 mm, W 51–102 mm, H 51–225 mm, W/H 1–4, P/e 10–20, e/D 0.021–0.078, 30–90°, L/D 10–20, Re 8000–80,000, I 950–2500 W/m² Resulted in optimal heat transfer for square channels attributable to the pronounced secondary flow.
	**Webb and Eckert (1972)** elucidated that the transverse wire-ribs, along with the credibility of the correlation established in the antecedent investigation, were corroborated by the extant scholarly literature.
	**Han and Zhang (1992**) investigated the characteristics of V-shaped, crossed, and inclined ribs with dimensions of L×W×H 1016×50.8 ×50.8, P/e 10, e/D 0.0625, L/D 20, angles ranging from 45° to 90°, and Reynolds numbers between 15,000 and 90,000.
	**Momin et al. and Rajendra Karwa (1998)** examined V-shaped continuous ribs as a textural element on the absorber plate of a solar air heating duct, analyzing a roughness height (e/D) of 0.2-0.34, P/e 10, and Reynolds numbers spanning from 2500 to 18000.

Table 2. Heat transfer and frictional losses for fluid flow

Han et al. (1978) Examined cornered rib angle (ϕ) and P/ethe impact in angle of attack(α), on parallel plates. Comes about: created relationships for h and f based on divider similitude and heat-momentum relationship. Corner point did not have a critical impact, but P/e and have distinctly impact on the execution of rib.

2.3 Environmental studies

The sun is capable for a huge number of other renewable energies (such as wind and hydropower) as well as renewable vitality carriers (such as strong or fluid biofuels). The sun is one of the foremost capable normal and green sources of vitality, giving a ample supply of renewable and clean vitality. Sun oriented vitality can offer assistance to diminish dependence on fossil fills and it has the potential to supply a economical source of control for a long time to come. Sun powered warm vitality can be saddled through a number of diverse strategies, counting sun based warm collectors and sun oriented warm capacity, etc.

2.4 Reynolds number Re

Reynolds number decides the nature of the stream. SAH could be a warm exchanger in which warm exchange happens through constrained convection. Renolds number (Re) plays vital part in choosing its execution. But never works alone; instep, its impact changes with variety in other parameters like e/D, P/e, insolation I, etc. In lower Re implies laminar stream that's incapable to exasperate the sublayer thus lower warm exchange and weight misfortune happens. But contact is higher for moo Re due to the thickening of the sublayer.

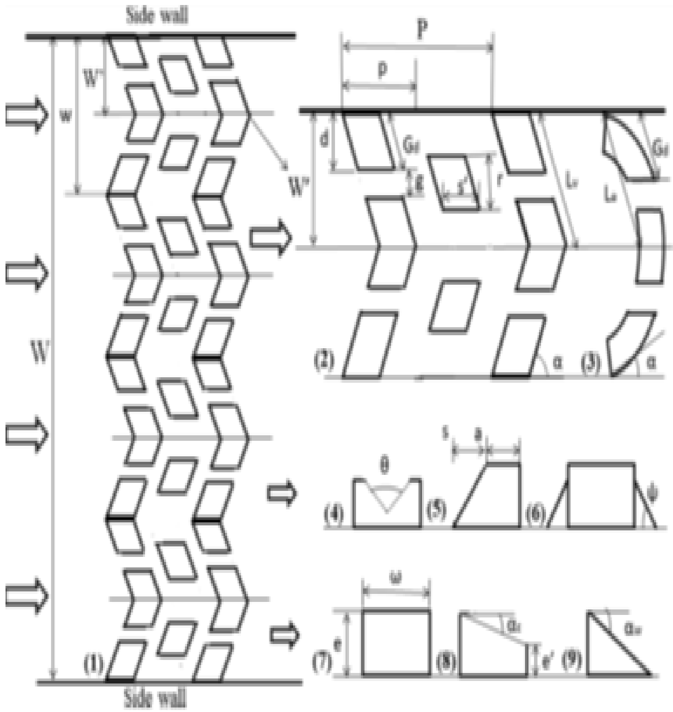


Fig. 1. All possible parameters investigated in a repeated-rib roughness.

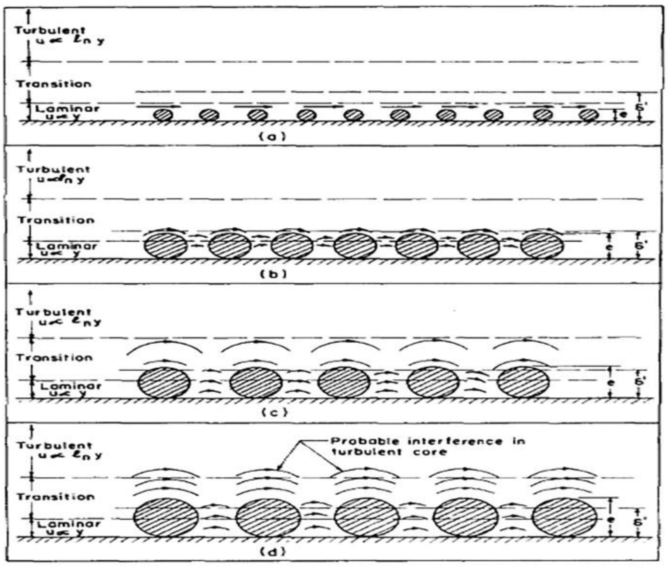


Fig.2 Prasad and Saini, 1991 Effect of e/D, P/e and rib cross section on reattachment Different roughness height above surface.

3.THERMAL HYDRAULIC PERFORMANCE OF SAH USING VARIOUS METHODS:

This concept covers the strategies utilized to survey the execution of sun powered discuss radiators, counting test setups and recreation procedures. Assessing execution is basic for comparing distinctive frameworks and making strides plan proficiency.

Henry Buelow, 1958; Rapture, 1959; LOF et al., Buelow, 1962; Near, 1963; 1964; Chiou et al.1965; Gupta and Garg, 1967; Suri and Saini, 1969; Charters, 1971; Malik, 1973; Diaz and Suryanarayana, 1981; Bhargava et al., 1982; Garg et al., 1985). Thermal effectiveness by multi-passing, multi-glazing, layered surface, wire-mesh, changing conduit shape-size-aspect proportion, permeable media, paint-materials, etc

Man Singh Azad 2024- Artificial roughness, utilizing askew chamfered cuboids, altogether upgrades sun powered discuss radiator execution, accomplishing 2.48 times change in warm proficiency compared to smooth surfaces beneath comparative conditions.

Avinash K. Hegde, Raghuvir Pai, K. Vasudeva Karanth (2024) V rib unpleasantness in sun oriented discuss radiators improves thermohydraulic effectiveness, accomplishing upto76.63% effectiveness at particular conditions, compared to smooth plans Relationships for contact calculate and Nusselt number MATLAB code for thermohydraulic and exergy effectiveness investigation.

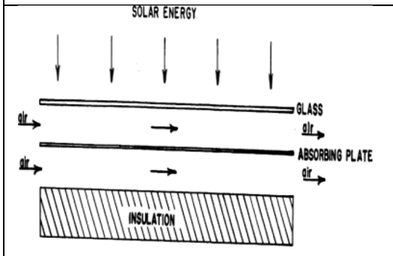
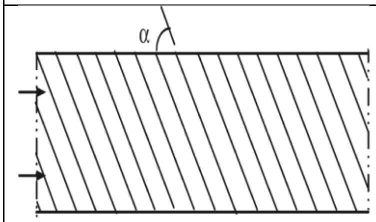
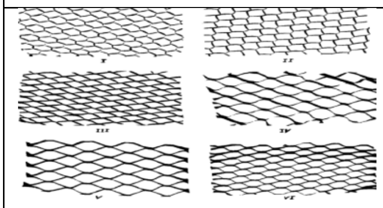
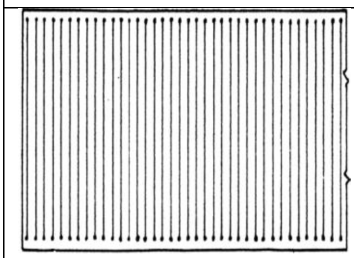
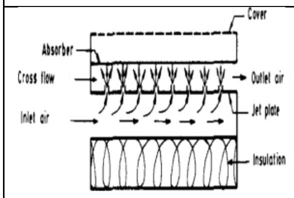
SAH configuration	Boundary condition and results
	**Henry buelow, (1956)** The shorter rectangular conduit of max conceivable contract entry with discuss streaming within the transitional flow administration had the finest execution
	**Gupta et al. (1997)** Slanted rib with crevice Ideal Re was within the run of 13,000-19,000asper thee/D esteem and the roughness was viable for the lower e/D values
	**Chiou et al. (1965)** The porous media retains daylight in profundity of SAH-duct, decreases best misfortunes and have heat transfer, volume proportion.
	**B. N. Prasad et al. (1988, 1991,2000&2013)** Transverse circular CS ribs, **Gupta et al. 1993 Transverse thin wire-Ribs,** L×W×H 1640×150×H, H 13–22 mm, W/H 6.8–11.5, P/e 10, e/D 0.018–0.052, e+ 5–70
	**Choudhury & Garg 1991** L×W×H (no ASHRAE standard), L 1000–8000 mm, H 50–100 mm, Re 300–30,000, G 50–250 kg/hm2, dia. of jet D 4–12 mm, No. of jet 0-4D, inter-spacing of jet X/D 6–12, m *jet* 0–50 kg/hm², V*jet* 1–3 m/s I 900 W/m², V*w* 1.5 m/s and T*i* 300 K

Table 3. Improve performance of a SAH

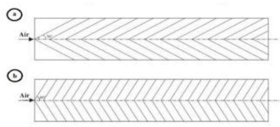
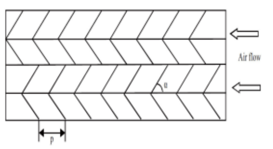
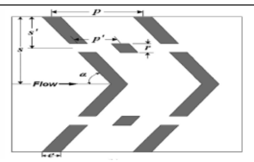
J.L. Bhagoria a, J.S. Saini b, S.C. Solanki The effect of parameters on the heat transfer coefficient and friction factor are compared with the result of smooth duct under similar flow conditions. Statistical correlations for the Nusselt number and friction factor have been developed in terms of geometrical parameters of the roughness elements and the flow Reynolds number.

4. GENERAL RIB ROUGHNESS:

Sahu and Bhagoria In their study transverse ribs as unpleasantness expressed that at higher pitch esteem reattachment focuses gotten to be less and at moo pitch esteem the number of reattachment point is unimportant due to which rate of warm exchange diminishes. The geometrical harshness and stream parameters included were pitch (p) of 10-30 mm, rib component tallness (e) of 1.5 mm, conduit angle proportion (W/H) of 8 and Re of 3000-12,000. They detailed that fake harshness increases the warm exchange coefficient 1.25 to 1.4 times smooth surface. They moreover detailed most extreme expansion in Nusselt number (Nu) and warm effectiveness happens at pitch of 20 mm.

Sharma and Kalamkar Explored exploratory and numerical examination of SAH conduit with four setups of different lean nonstop transverse and truncated ribs as delineated in Fig. 1.11. The geometrical unpleasantness parameters included e/Dh 10 as 0.055, α as 90°, P/e as 10, blockage proportion (e/H) of 0.1. They found that most extreme and least thermo-hydraulic execution parameter (THPP) in case 3 and case 2 separately comparing to extend of parameters considered.

V-shape ribs are of the shape of the English letter set V, and its summit meets at the center of the channel. It has two slanted ribs assembly at midspan of the conduit, and Fig. 9 appears different variety in V-shape: (1,2) nonstop ribs V-up and V-down, (3,4) with single and numerous gaps, (5,6) amazed rib on single and different crevices, (7,8,9) multi- V with hole and amazed ribs.

Roughness Geometry	Boundary condition and result
	**Ebrahim Momin et al., (2002)** L×W×H 1200×200×20, P/e 10, e/D, 0.02–0.034, 30–90°, Re 2500–18,000, I 1000 W/m² and T_i 300 K
	**V-up–down-continuous & transverse & inclined ribs, R. Karwa, 2003 (Karwa, 2003):** All investigated ribs are in the following increasing order of enhancement
	**V-down ribs with multi gaps, Maithani & Saini (2016)** L×W×H 1100×300×25, P/e 6–12, e/D ,0.043, g/e 1–5, N*g* 1–5, d/W′ NA, 30–75°, Re 4000–18,000, I 1000 W/m²

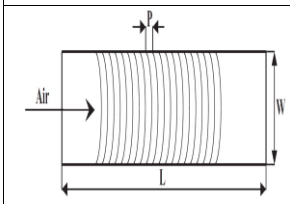
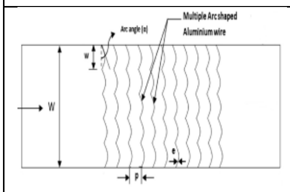
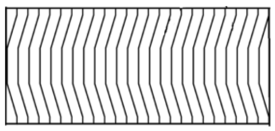
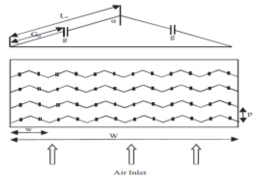
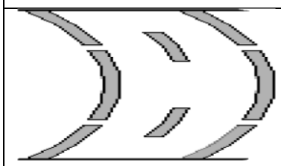
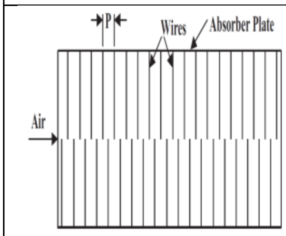
Roughness Geometry	Boundary condition and result
	**Continuous arc-down-shape ribs Sahu et al. 2016 & 2017 (**Sahu and Prasad, 2017**)** L×W×H 1500×1000×25, P/e 10, e/D 0.023–0.0422, 30–60°, Re 2000–39,000(too high for SAH), V_w 1 m/s I 500–1000 W/m² and T_i 300 K, T/I K/m²W 0.0025–0.010
	**Continuous S-shape ribs, Khushmeet et al. 2017 (Kumar et al., 2017):** L×W×H 1000×300× 25, P/e 4–16, e/D,0.022–0.054, W/w 1–4, 30–75°, Re 2400–20,000, I 1200 W/m²
	**Continuous arc-shape ribs Sharad et al. 2009 (Kumar and Saini, 2009)** L×W×H 1500×300×25, P/e 10, e/D0.0299–0.0426, 30–60°, Re 6000–18,000, I 1000 W/m², T_i NA, RNG gives max THPP
	**Multi V-shape rib with gap, Anil et al. 2012 & 2013 (Kumar et al., 2012; Kumar et al., 2013)** L×W×H 1000×300×25
	**Continuous-arc-shape ribs with gap Gill et al. 2017**
	**Transverse ribs of different cross-section, Yadav & Bhagoria (2014)** RNG, P/e 7.14–35.71, e/D 0.021–0.042, Re 3800–18,000, I 1000 W/m² and T_i 300 K

Table 4. Enhance thermal–hydraulic performance

Relative rib width, W/w: It represents the number of rib-geometry span-wise, higher the value of W/w more is the number of rib-geometry, but it decreases the measure of the rib. Stream strikes at the center of the V-shape or arc-shape ribs, and auxiliary flow induces in both the limbs of rib-geometry. The number of ribs increases spanwise with increase in W/w, with its reduced length which increments the number of secondary flows within the span-wise direction that creates a part of turbulence and mixing of generally different temperature flow.

5. Summary input-output parameters of different types of rib:

Based on the research considers This segment is examined in arranged frame, where Tables 2-4 summary of different modern studies (last two decades) for trans verse-inclined, V-shape and arc-shape ribs. The left column shows the geometry of the rib, and the correct column gives the brief details of respective boundary conditions and results. These studies are arranged in chronological arrange; in any case, a few common studies by the same.

6. Conclusions:

The present review is provided an overview of recent trends in solar air heater research with rib-roughness initiated enlargement. An exertion is put to draw consideration to the chronicled foundation to highlight the evolution within the plan conjointly the part of pioneers (regularly ineffectively cited) within the advancement of SAH innovation. The parameters like shape, estimate of the channel, insolation, surrounding conditions, fabric of developments altogether influence the execution of SAH. Subsequently, these are examined in brief. Final two decades of investigate on the abuse of repeated-rib-roughness to irritate the thick sublayer to upgrade warm exchange is completely checked on, which recommends the taking after vital focuses:

- Energy and exergy assessments for different V ribs in SAH. Ideal plan parameters utilized for particular rib examination.
- Nusselt number and contact calculate altogether higher than level plate. Warm improvement figure calculated as 1.56 for rough SAH.
- Greatest heat exchange improvement found at 45°. Greatest Thermohydraulic Execution at 30°.
- V-Shape unpleasantness upgrades warm exchange execution.
- 3D cylinder roughness upgrades SAH proficiency by progressing heat exchange. Grinding losses are decreased with presented roughness elements.
- Most of the discoveries collectively concur on the comparative ideal values of the rib-geometry: e/D, P/e, , and which has too been inquired about in gas turbine blade-domain of inquire about in past. Be that as it may, the incorporation of holes and stunned ribs may alter their ideal esteem.

References:

1. B. N, PRASAD and J. S. SAINI (1988). Effect of e/D, P/e and rib cross section on reattachment

2. Prasad and Saini, (1991) Effect of e/D, P/e and rib cross section on reattachment Different roughness height above surface

3. Fahad A. Al-Sulaiman (2014) The study demonstrates that the HDH configuration with the air heater placed between the humidifier and the dehumidifier has a better performance and a higher productivity

4. Han et al. (1978) investigated the effect of angle of attack (α), cornered rib angle (ϕ) and P/e on parallel plates.

5. Avinash K. Hegde, Raghuvir Pai, K. Vasudeva Karanth 2024: Energy and exergy evaluations for various V ribs in SAH. Optimum design parameters used for specific rib analysis.

6. Man Singh Azad (2024) km Enhanced thermal performance of solar air heaters. Artificial roughness using diagonally chamfered cuboids for efficiency improvement.

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8. Prasad, R.K., (1993) Thermal performance Characteristics of Unidirectional Flow Porous Bed Solar Energy Collectors for Heating Air.

9. Mustafa M. M. Alaskari, Arwa Mahmood Kadhim (2022) Increased total thermal efficiency of Solar Air Heater (SAH). Prediction of SAH efficiency using numerical model.

10. P. D. Raturi, Hemlata Deolal, Sanjeev Kimothi (2022) Optimize hot air use with Return Flow Solar Air Heater. Analyze thermal and thermohydraulic efficiency with baffle arrangements.

11. Piyush Kumar Jain, Atul Lanjewar (2021) Augmented thermal performance of solar air heater. Evaluated V-rib roughness with staggered element geometry.

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13. Karmveer, N. Kumar Gupta, Md Irfanul Haque Siddiqui (2022) Roughness improves solar air heater performance.