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# "A comparative study of Thermo-hydraulic performance analysis of a solar air heater with quarter circular ribs on the absorber plate"

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***Abstract-*** **The thermo-hydraulic features of a solar heater with quarter-circular ribs on the absorber plate are read numerically. Comparisons of three different systems of quarterly round ribs are performed. The ribs are periodically aligned in a manner opposite to the flow. Numerical simulations of difficulty, intensity, and energy saving calculations are performed on a two-dimensional computer system using the finished capacity of the ANSYS-Fluent-18 multi-grid solver. A constant and uniform temperature of 1000 W / m 2 is supplied to the aluminum collection plate. Many input parameters are valid, i.e.. flow parameters such as Reynolds number and fluctuation parameters such as tone weight relative to coarse lengths vary. The number of Reynolds varies from 3800 to 18000, while the average height varies from 7.14 to 17.86, and the average height is kept to a minimum, i.e., 0.042. The effect of the sound weight associated with the Reynolds number on the thermo-hydraulic performance of the solar heater with the ribs is analyzed here. The geometry of the ribs developed in the investigated width of the borders is available. Pump power calculations are performed. The structure of temperature, pressure, and speed are illustrated to better understand flow physics. It has been found that a solar wind heater with a quarterly rounded shaft with a relative length of 7.14 delivers a maximum heat enhancement (representing total energy efficiency) of 1.88 in the taught parameter range. Nusselt numbers and friction factor correlations are proposed by performing non-linear analysis.**

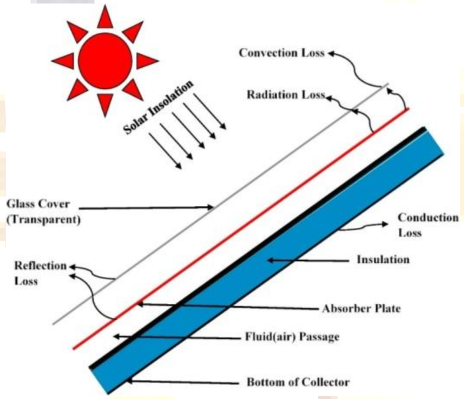
**Keyword:** Solar air heater,Nusselt number, Heat transfer, Friction factor, Quarter-circular rib Absorber plate Flow separation, Thermal enhancement ratio

## I. INTRODUCTION

Solar air heater (SAH) is a very simple tool that uses solar energy on a suction plate, and the hot energy used to heat active fluid, that is, air. This is an unusual energy technology with a wide range of applications used for air heating first in the area of thermal energy, coal drying, and minerals. In contrast, agricultural use includes the drying of vegetables, fruits and food. SAH is a simple, inexpensive, competitive resource with minimal nutrition. The solar thermal structure is shown in Fig. 1. It is a common temperature change where a single wall of the duct is exposed to the sun [1-3]. The upper wall exposed is called the absorber plate, which captures the radiance of the sun; as a result, heat transfer occurs in the duct [4]. The normal SAH heat transfer rate is usually weak because the air temperature with very low air temperature. Numerous research projects have been discovered, which suggest increased heat transfer by exposing the most important area [5]. It is also recommended that there be disturbance in the flow area by adjusting the vertical elements on the suction plate [6]. Shapes of shapes, various sizes, and shapes lead to the successful development of SAH. The provision of ribs in the area of the absorber plate creates turbulence, flow disintegration, flow retardation, and reattachment near the wall, known as the viscous sub-layer [6 - 12]. Thus, leading to increased heat transfer. In addition, high pumping power is required to maintain the flow against the rib cylinders. Therefore, researchers are interested in using viscous layer surfaces as a turbulence to achieve improvements in heat transfer by placing hard ribs on top [13 - 16].

The concept of improving heat transfer has a profound effect on the flow of channels and pipes [17 - 21]. Generally, SAH is a rectangular, triangular, and semi-circular cross-section duct. But the fundamental features of heat transfer changes due to the presence of rib turbulators, as well as the supply of ribs make it challenging from both numerical and analytical (thermo-hydraulic performance) observations [22,23]. Mangrulkar et al. [24] experimentally and numerically tested the thermo-hydraulic function of a river cross-section heat exchanger with scattered line tubes. The authors obtained a maximum thermal improvement (TER) rate of 1.35 pitch at a maximum axis ratio (PR) of 1.5 at Re 21000. Chamoli et al. [25] statistical investigations to study the thermo-hydraulic function of a circular tube connected to a novel antenna-shaped vortex generator. The authors considered the height (PR), anchor wing aspect ratio (σ), and the Reynolds (Re) number as temperature-enhancing parameters ranging from 1 to 2.5, 0.4 to 1.2, and 3000 to 1.2 - 18000 respectively. They reported a TER limit of 1.72 for PR 1, σ 0.4, and Re 3000. Bhatta-charyya et al. [26] investigated to study the heat transfer and analysis aspect of the inconsistency of the insertion of an internal or moving angular cut baffe into a turbulent flow system and identified a TER 2.9 limit of 0.1 pitch and a 60◦ cutting angle. Kumar et al.per- developed statistical analysis to evaluate the thermo-hydraulic function of a triangular tube with square ribs and rectangular ribs facing forward. Report the 1.44 TER magnitude of the 1.44 SAH line with 10 square rows (P / e) and the corresponding solid length (e / Dh) at Re = 18000 when the authors obtained the TER maximum of 2.15 for the forward-facing chamfered rectangular ribbed triangular SAH duct with P/e of 12 and e/Dh of 0.043, rib aspect ratio (e/w) of 1.5, rib chamfered ratio (e/e') of 0.75 at Re 17000. Sivakumar et al. explored the thermodynamic study considering SAH with fins on the surface of the absorber plate. They reported a maximum increase in energy efficiency and exergy efficiency of 12% and 11% respectively in SAH with pin-fins than that of a smooth one.

**Fig. 1.Outline of a solar air heater**



## II. Problem description

SAH is a typical heat exchanger used for heating applica- tions. Heat transfer through a SAH is strongly influenced by different pertinent input parameters, namely entry velocity of the fluid and shapes, sizes, and orientations of ribs. the pictorial illus- tration of a 2D computational domain, where flow and heat transfer simulation is being done. It is noticed from the figure that the whole flow field is divided into three sub-domains, viz. entrance section ($L_1$), test section ($L_2$), and exit section ($L_3$). The length of the different parts, as shown in Fig. 2, such as $L_1$, $L_2$, and $L_3$ are 0.245 m, 0.280 m, and 0.115 m, respectively These dimensions are chosen according to the ASHRAE 93–2003 standards [56]. The height(H) and width(W) of the SAH duct are taken as 0.02 m and 0.1 m, respectively. Based on the general di- mensions of the duct, the hydraulic diameter ($D_h$) is calculated as 0.0333 m, and the aspect ratio of the duct is 5, which is kept constant [31]. The entrance region and exit region are also called as guard section. as it protects the test region from both ends. The test region is subjected to a constant and uniform heat flux of 1000 W/m2 on the collector plate with a proper arrangement of an electric heater. In the present analysis, the quarter-circular sectioned ribs are arranged transversely to the flow direction in three ways (type-1, type-2, and type-3), as shown in Fig. 3. The ongoing investigation is intended to analyze the influence of quarter-circular rib roughened SAH on thermo-hydraulic performance characteristics. Also, a comprehensive study of various relevant pa- rameters, viz. inlet flow velocity, the temperature in the flow domain, pressure difference due to fluid friction, turbulent kinetic energy in the flow filed, and turbulent intensity of the flow for various relative roughness pitch and Reynolds number is carried out here. A rectangular duct, as suggested by Yadav and Bhagoria [44], is considered for the numerical study. As per the required specifications for

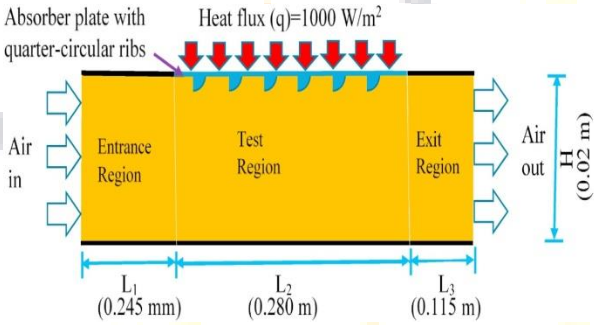
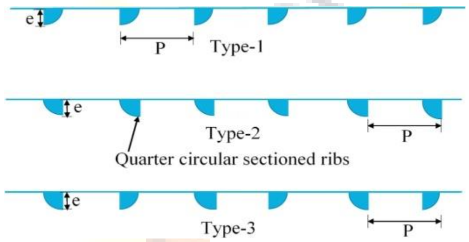


**Fig. 2.**Pictorial illustration of the two-dimensional flow domain.

**Fig. 3.**Schematic diagram of various types of absorber plate considered for the present study.



the current study, there are four values of pitch (*P*) taken for the simulation, i.e., 0.010 m, 0.015 m, 0.02 m, and 0.025 m, such that the relative roughness pitch (*P/e*) varies from 7.14 to 17.86. Six distinct Reynolds number (*Re*) values are selected in the turbulence flow regime, i.e., 3800 to 18000, by changing the air velocity at the entry. The height of the ribs is considered to be constant, i.e., 1.4 10 −3 m with a relative roughness height ($e/D_h$) of 0.042, which has a vital role in the breaking of viscous sub-layers. As per the parameters considered and arrangement of ribs (type-1, type-2, and type-3), 72 cases are found to study the performance characteristics of the quarter-circular rib roughened SAH.

## III. The objectives of the present investigation are as follows:

i. To evaluate the impact of roughness pitch and Reynolds number on thermo-hydraulic performance in SAH with quarterly ribs.

ii. To visualize the flow of water, temperature, pressure, and turbulence factors to translate the flow path and heat transfer.

iii. To find the rib geometry adjusted to the investigated range of parameters.

iv. Improving the Nusselt number and friction factor correlations as a function of the parameters of the geometric ribs and the number of Reynolds.

## IV Numerical procedure

In the present study, fluid flows to SAH with quarter-circular ribs in place of the hot aluminum collection plate. The only fluid base considered for imitation is negligence, loss of convection and radiation, and loss due to light and distribution. A two-dimensional computer domain is selected for this study. This category includes geometry, grid layout, mathematical modeling, governing dimensions, boundary conditions, and numerical solutions. The following considerations are taken from the current calculation.

i. Double-sided, fully developed, stable, and moving flow in the calculation area is considered.

ii. Imitation effects are obtained by separating the fluid domain only.

iii. Permanent thermo-hydraulic features of the absorber plate, air, and enclosed walls are considered in this study.

iv. The thermal conductivity of the hot aluminum plate and the closed walls of the duct are considered independent of the temperature.

v. The effect of radiation is ignored.

### *Boundary conditions*

The fluid base of the SAH pipe is closed on four sides, between which two sides (above and below) are walls, and the left side is given a speed entry point, and the pressure exit position is applied to the right of the flow base, as shown in Fig. 4. The state of the equilibrium speed limit is set at the point of entry of the air flow, and at the pressure point of the exit boundary is set as the pressure may be considered as ambient pressure in that area. Six identical speeds from 1.64 m / s to 7.89 m / s were selected for comparison, and speed values were calculated from the specified Reynolds number. At the entry of the liquid into the computation center, the fluid temperature is considered to be ambient, i.e., 300 K. Fixed values are expected in thermophysical properties working fluid, i.e., air, and those properties are calculated at the average bulk temperature. At the adiabatic walls of the SAH, no-slip and no- penetration conditions are implemented, and a constant uniform heat flux of 1000 W/m2 is applied at the collector plate. Thermo-physical properties such as density ($\rho$), thermal conductivity ($k$), specific heat ($C_p$) and viscosity($\mu$) of the air and aluminum plate is considered

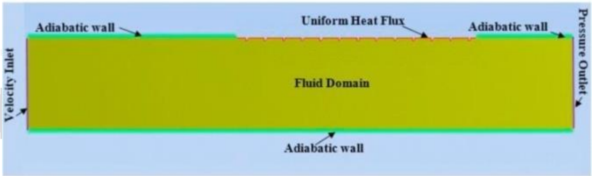
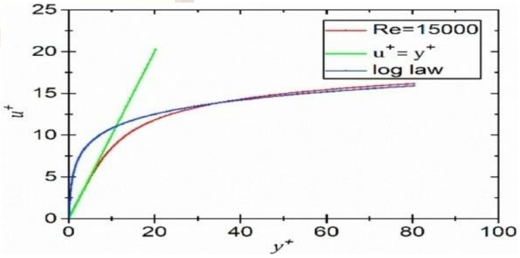


**Fig. 4.**Diagrammatic representation of the flow domain with bound- ary conditions.

### *Numerical scheme*



In the ongoing analysis, numerical simulations of the continuity and momentum equation, along with the energy balance equation, are conducted for a two-dimensional computational domain using the FVM technique (finite volume method). The SIMPLE algorithm proposed by Patankar [57] is implemented to make the coupling between pressure and velocity. For the convective terms involved in the momentum and energy equation, the second-order upwind scheme is implemented. In contrast, the central difference scheme is adopted for the diffusive terms. Absolute convergence criteria of $10^{-6}$ are taken for all equations to have higher accuracy in the results.

***Important relations***

There are some well-established empirical correlations such as Dittus-Boelter and Blasius correlations available for smooth duct for calculation of dimensionless parameters like average Nusselt number and average friction factor, respectively, and mathematically repre- sented as follows.

$$Nu_s = 0.023 Re^{0.8} Pr^{0.4} \qquad (1)$$

$$f_s = 0.0791 Re^{-0.25} \qquad (2)$$

The present study is meant for a thorough survey of flow and heat transfer characteristics of the quarter-circular ribbed SAH duct for the turbulent flow regime.

The amount of heat extracted from the absorber plate is given by

**fig .Nusselt number verses Reynolds number plot for various *P/e* values of (a)Type-1 (b) Type-2 (c) Type-3 collector plate with *e/Dh* =0.042.**

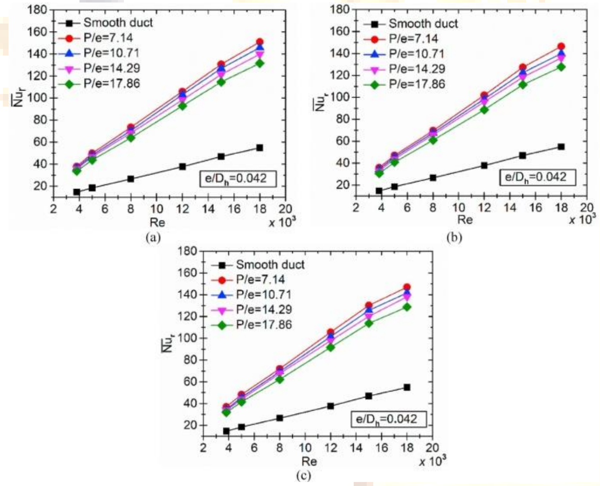


**Fig. .**Variation of *u* + with *y*+ for smooth channel flow.

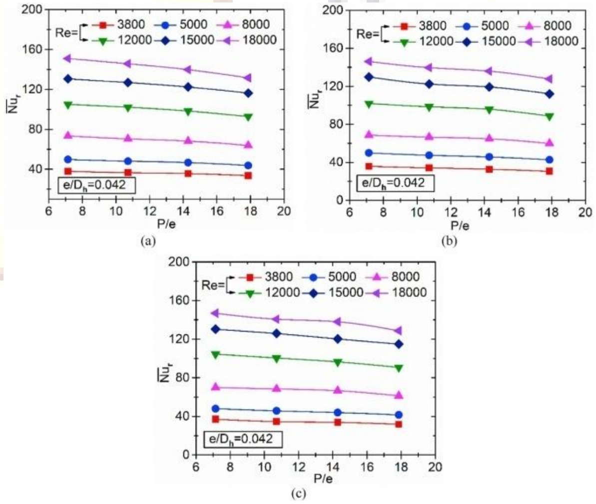
results of Yadav and Bhagoria. In contrast, the Nusselt numerical variance of the current result has a total deviation of less than 9% and that of the experimental results obtained by Gawande et al .. In contrast, the friction factor values obtained in the current calculation are available. lying about a complete deviation of less than 2% and 3% and that of Yadav and Bhagoria and Gawande et al. respectively. Current numerical schemes are also verified by a roughed route by comparing Nusselt's median number obtained with the current SAH-shaped distortion-L and Gawande et al. and shown in Fig. 8 (c). Statistics show that the Nusselt number obtained from the current calculation using the RNG k-ϵ model with advanced wall treatment has a very satisfactory agreement with the available test results and numbers. The current Nusselt computer number has a completely divergent rate of 6.5% and 2.8% with test results and numbers This comparison provides evidence of acceptance of the numerical operating system.

## V.Results and discussion

SAH thermo-hydraulic features of the quarter-circular vein are analyzed in this section, that is, this section introduces a summary of the calculation results. Nusselt number, friction factor, and TER variant with different speed parameters are calculated for SAH in three types (type 1, type 2, type 3) absorption plate. Average of performance for the present study with previous results is illustrated here.

The use of quarterly round ribs on a hot aluminum collection plate significantly enhances SAH heat transfer significantly. When the ribs are connected to the SAH aluminum plate, the convection heat transfer decreases, and the convection heat transfer increases; this is because the surface area of the convection increases with the addition of ribs. Moreover, this is a condition of forced convection heat transfer, and the growth of the boundary layer is an enemy of heat transfer. Therefore, the provision of ribs in the flow of water helps to break the boundary layer and improve the rate of heat transfer.

**Fig. Plot of average Nusselt number versus relative roughness pitch for various Reynolds number for SAH duct with (a)Type-1 (b) Type-2 (c) Type-3 plate with *e/ Dh* =0.042.**



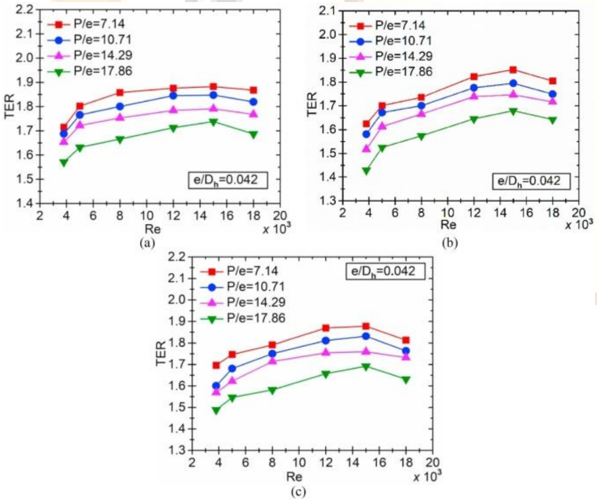
*Variation of Nusselt number with Reynolds number*

Figure 9 represents the approximate area of the Nusselt number compared to the Reynolds number of the P / di variety of the three types of absorption plate which is considered to be the average length (e / Dh 0.042). Here, the uniform and constant speed at the entrance to the pipeline is used to calculate the Reynolds number. The Nusselt value ratio is the variable heat transfer rate in the heat transfer holding surface over the hot aluminum plate. In SAH with a given geometric adjustment, the Nusselt number can only differ if the coefficent variable heat transfer is changed. Just as heat transfer is due to forced conversion, so too the heat transfer coefficient increases with increasing Reynolds number or flow rate. As the flow rate increases, the number of Reynolds also increases, which causes the flow to become more chaotic. Therefore, the liquid packets may move several layers which leads to excessive mixing in the flow, which can transfer the maximum amount of heat from the suction plate. That is why the number of Nusselt is increasing

## VI. Conclusion

The numerical analysis of thermo-hydraulic characteristics of quarter-circular ribbed SAH is done taking a two-dimensional domain. The effect of various pertinent parameters, such as Reynolds number, relative roughness pitch, and relative roughness height on Nusslet number and friction factor is studied for a fixed relative roughness height. The provision of ribs on the collector plate of the SAH results in appreciable heat transfer enhancement. Few crucial conclusions of the

**Fig.** .Plot of TER versus Reynolds number for different relative roughness pitch of a SAH with (a) type-1, (b) type-2, and (c) type-3 absorber plate.



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