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THERMOHYDRAULIC PERFORMANCE ENHANCEMENT OF A TRIANGULAR DUCT SOLAR AIR HEATER USING ARTIFICIAL ROUGHNESS: A STATE-OF-THE-ART REVIEW

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Abstract – *Solar energy is the most dependable alternative energy source that is currently accessible. It can be used by a variety of solar thermal systems that are compatible. One of these systems for heating air is the triangular duct solar air heater (TDSAH). Innovatively designed, TDSAH can absorb irradiance, transform it into thermal energy at the absorbing surface, and then transfer this energy to moving air via the triangular channel. Duct geometry is the primary factor determining heat transfer in laminar and turbulent flows. Numerous investigations are carried out to comprehend the performance of ducts with non-circular shapes. This article reviews the various triangular duct studies that have been carried out. A comparative study of natural and forced convection is presented in this article using experimental and numerical approaches. Each roughness geometry incorporated in the absorber plate enhances the heat transfer rate. The data acquired are then utilized to compare the performances with conventional SAH, and correlations are established for different geometry. It has been found that rounded corners with artificial roughness having an apex angle of 60^0 gave the better thermohydraulic performance.*

Keywords: *Triangular duct, Thermohydraulic performance, Artificial roughness.*

1. INTRODUCTION

Energy is a key component of economic growth and industrialization. It plays an important role in everyone's life. Aside from the population growth, there is a daily rise in the demand for energy. The continued usage of fossil fuels for energy production has caused the depletion of fossil fuels to begin. On the other side, the production of energy via fossil fuels results in significant pollution, which worsens the Earth's life cycle. Energy production is accelerated by advancements in renewable energy sources. When used to generate energy, renewable energy sources are pollution-free.

The sun is the most dominant natural resource among all those that are renewable. The process of converting solar energy into thermal energy using a solar collector is the simplest way to utilize solar energy properly. These solar collectors are an element of solar water heaters and SAH, which heat water and air respectively. Due to its compact size, SAH are quite simple to construct (see fig.1). Additionally, because SAH require less material than solar water heaters, they are less expensive. SAH can be used for a variety of purposes, including the drying of crops, space heating, wood seasoning, and industrial product curing.

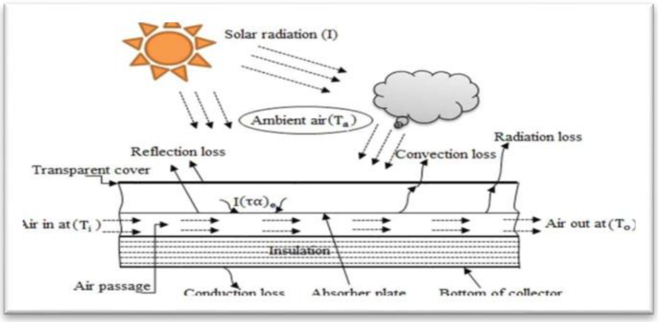

Fig. 1: Conventional SAH [1]

Due to the low specific heat of air and the slow heat transfer rate between the absorber plate and the air passing through the duct, SAH have poor efficiency. Therefore, increasing the rate of heat transfer is required to make SAH efficient. Heat is transferred more efficiently between the air and the absorber surface when artificial roughness is added to the flow. The laminar sublayer region, or the region next to the wall, is broken by the roughness created in this technique. There are numerous ways to artificially roughen the absorber plate. There is always an increase in frictional losses associated with any technique used to enhance heat transfer. Therefore, the thermohydraulic parameter must be analysed to determine the amount of power required to push air through the duct.

2. PERFORMANCE PARAMETERS

Table 1 gives detailed thermal performance parameters of a SAH.

Table 1. Thermal and thermo-hydraulic performance parameters for SAH

Useful heat gain	$\boldsymbol{Q_u = \dot{m}C_p(T_o - T_i)}$
Thermal efficiency	$\boldsymbol{\eta_{th} = \frac{\dot{m}C_p(T_o - T_i)}{A_c I_T}}$
Thermo-hydraulic efficiency or effective efficiency[2].	$\boldsymbol{\eta_{th-hyd} = \frac{Q_u - \left(\frac{Q_p}{C}\right)}{I_T A_p}}$
C is the conversion factor [3] Taken as 0.18	$\boldsymbol{C = \eta_F \eta_E (1 - \xi_t)\chi_c}$
Pumping power Q_p	$\boldsymbol{Q_p = \frac{\dot{m}}{\rho_a}\Delta p}$
Thermohydraulic enhancement parameter (TPP)	$\boldsymbol{TPP = \frac{Nu_e/Nu_s}{\left(f_e/f_s\right)^{1/3}}}$

3. INFLUENCE OF DUCT CROSS-SECTIONAL ON HEAT TRANSFER AND FRICTION FACTOR

Fig.2 shows triangular duct SAH (TDSAH) with artificial roughness. To investigate the impact of duct shape on the thermal performance of a SAH, Satyendra Singh conducted analytical and numerical methods. Semi-circular and triangular cross sections of geometry were taken into consideration. The semi-circular duct achieved a 70% greater pressure drop than the triangle duct, and it had a 3-5% higher thermal and thermohydraulic efficiency than the triangle duct. Cebeci and Bradshaw, conducted studies on the effect of duct cross-section on the efficiency of SAH. Here, several cross sections are taken in the form of rectangles, squares, ellipses, circles, and triangles. It is revealed that triangular cross sections yield the lowest friction factor. Experimental analysis was carried out by C.W. Leung et al. to investigate the impact of the apex angle on the performance of the TDSAH. Three rib roughness values on the surfaces and five various apex angles (30°, 45°, 60°, 75°, and 90°) were taken into consideration. It was noted that ducts with an apex angle of 60° function remarkably well in terms of thermal performance. Experimental investigation was conducted by (Campbell and Perkns, 1968) [4] to determine the impact of rounding the triangle duct's all corners. Although the heat transfer coefficient was decreasing, the friction factor was rising, which increases the pumping power. (Shah, 1975) [5] carried out a numerical analysis to determine the influence of duct shape on the performance of the SAH. Different shapes of ducts can be used, including triangles, rectangles, trapezoidal ducts, triangular ducts with rounded corners, sine shapes, and rhombic shapes. In addition to showing the impact of rounding the corners of the triangle duct, this study presents a wide range of outcomes dependent on height to base ratio. It was determined that as the triangular duct's corners were rounded further, heat transfer rises. S. Ray et al. investigated the impact of corner radius on square and triangular ducts, numerically. Corner radii could range from zero to their greatest value. It was established that when the rounding radius rises, the variation in the local hear transfer coefficient also increases. The efficacy of the rounded part similarly grows with rounding radius and reaches its greatest value at 0.325. For a rounded triangular duct, the friction factor increases with radius, reaching its highest value at a radius of 0.35.

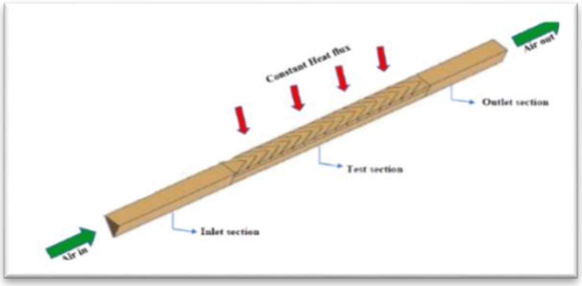

Fig. 2: Triangular duct SAH with artificial roughness [6]

4. INFLUENCE OF ARTIFICIAL ROUGHNESS ON PERFORMANCE OF SAH

Many investigators used artificial roughness such as ribs, fins, and vortex generators (VG) on the absorber surface to enhance the heat transfer by breaking the laminar sub layer.

(Ahmed et al., 2015)[7] carried an experimental as well as numerical study on TDSAH with nanofluids and delta VG. When VG and nanofluids were utilised concurrently, the highest heat transfer augmentation attained was around 31.87% and 33.22% for Al_2O_3 and SiO_2 nanofluids, respectively. (Goel et al., 2017) [8] studied the influence of apex angle on performance of TDSAH. The apex angle value increases from 30° to 60°, rising the friction factor (f) and Nusselt number(Nu), however further increasing the apex angle value causes a drop in both quantities. The dimple-shaped roughness element significantly improves Nu and f values. (Kumar et al., 2017) [9] investigated the flow and heat transfer enhancement using rectangular rib TDSAH numerically. Variations in rib aspect ratio (e/w) values between 0.25 and 4.0 led to a noticeable change in f and Nu. At a Reynolds number (Re) of 15,000, the maximum value of the TPP was found to be 1.89. (Kumar et al., 2018) [10] studied the performance of TDSAH has been examined using

CFD to determine the impact of forward facing chamfered rectangular ribs (FCRR). The Nu_{enh} and $f_{penalty}$ was 2.64 and 3.14 times the without rib SAH, respectively, and it reaches highest for e/w value of 1.5. (Kumar et al., 2019a) [11] simulated TDSAH with square rib roughness to augment heat transfer. The RNG k-ε turbulence model more nearly satisfies the Dittus-Boelter correlation among the various turbulence models. Furthermore, the TPP was determined, and its greatest value was 1.97 at Re of 17900. (Nidhul et al., 2020) [12] studied the effect of secondary flow on the performance of TDSAH with V-rib numerically. For similar input conditions, this TDSAH design outperforms ribbed rectangular duct SAH in terms of performance. Therefore, a V-ribbed TDSAH was preferable to a ribbed rectangular duct SAH for applications which require compact heat exchangers, particularly for higher mass flow rates. Using the simulation and experimental studies, (Akhbari et al., 2020) [13] evaluated the effect of the U-turn air movement arrangement on the flow path temperature. Under typical conditions and a constant air flow rate, a U-turn airflow arrangement TDSAH had a surface area that was 25% less than a conventional SAH. (Misra et al., 2020) [14] examined the thermo-hydraulic performance of a TDSAH with V-down ribs with several gaps and turbulence promoters numerically. Because there was more interaction between the fluid particles, this artificial roughness enhances both heat transfer and fluid flow behaviour. (Goel et al., 2021) [15] investigated performance enhancement of TDSAH with hemi spherical dimple roughness on absorber plate numerically. The results revealed that, the heat transfer was larger at the training edge than the leading edge of the dimple due to the considerable variations in the flow-structure on the absorber plate. (Faujdar and Agrawal, 2021) [6] studied the heat and friction behaviour of the working medium of a TDSAH with perforated baffles with V down arrangement numerically. Turbulent kinetic energy was found to be highest due to the creation of swirls and the increased level of mixing of primary flow with jets issuing from holes. (Kumar and Goel, 2021) [16] conducted a numerical study to examine the influence of different shaped roughness on heat transfer augmentation as well as frictional consequence in the TDSAH under the impact of constant roughness parameters. The chamfered edge of the roughness helps the main flow more effectively mix with the interrupted viscous sub-layers by directing the flow toward the centre of the TDSAH. The lack of a pointed end causes the air to flow easily through semi-circular (SCR) and circular (CR) rib elements without even noticeably altering the flow field, resulting in weak local turbulence intensity. The circular rib, therefore had the worst normalized Nu in comparison with other shaped roughness. (Mahanand and Senapati, 2022) [17] investigated the heat and frictional behaviour of the TDSAH equipped with pentagonal ribs, numerically. The highest TPP achieved was 1.46. (Karwa, 2022) [18] studied the heat transfer augmentation using TDSAH with inclined fins. The results revealed that, this design enhances heat transfer without increasing pressure loss or pumping power penalty.

Table 2 gives Nu and f correlations developed by various researchers using TDSAH with roughness.(see in page no.8)

5. COMPARISON OF DIFFERENT ROUGHNESS GEOMETRY

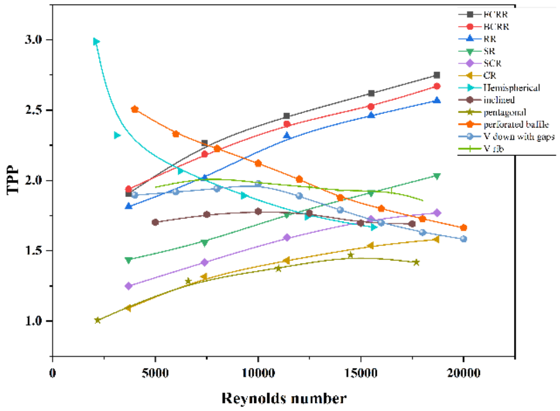

Fig. 3: Plot of TPP Vs. Re for different roughness

Fig. 3 shows the TPP variation for various shape rough surfaces with Re. According to the study, TPP tends to rise as Re rises and this pattern held true for majority of the roughness geometries considered. The best TPP value, 2.75, was found for FCRR at Re of 18700, but as the roughness-geometry changes, the maximum TPP reduces to 2.68, 2.57, 2.06, 1.79, and 1.60 for BCRR , RR , SR, SCR, and CR, respectively. In case of hemispherical rib and perforated baffles type TDSAH , TPP value was highest for low Re. the pentagonal rib TDSAH gave lowest TPP value compared to other geometries.

6. CONCLUSION

The following conclusions are reached after conducting a literature review on triangle ducts.

1. In comparison to other non-circular cross-sectional ducts, the triangle cross-sectional duct has the lowest friction factor.
2. In addition, the friction factor increased dramatically with the value of the rounded corner of the triangle duct, and the effectiveness of rounded parts increased with a radius of curvature of curvature (maximum Rc=0.35).
3. Maximum heat transfer was noted in the case of an equilateral triangular having an apex angle of 60^0.
4. Apex angle has a large influence on the friction factor and Nusselt number.
5. The triangular duct's narrow apex had a reduced turbulent flow. Therefore, the narrow apex zone has laminar flow even when there is turbulent flow.
6. In fully developed regions, friction factor becomes independent of flow direction and inversely proportional to Reynolds number.

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