A Review on Augmentation in Thermal Performance of Solar Air Heater

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Abstract. Low thermal efficiency is the remarkable drawback of solar air heaters. They have remarkable importance for low temperature applications. In a solar air heater due to formation of laminar sublayer between absorber plate and the flowing air convection coefficient of heat transfer is small. The laminar sublayer form on the absorber plate can be braked by applying the rib roughness of distinct shape and sizes due to which turbulence in the flowing air increases tremendously due to which friction factor increases between absorber plate and flowing air, resulting in increment in the convection coefficient of heat transfer and pressure drop. Design considerations of solar air heater, rib roughness geometries, fluid flow conditions and their effect on the turbulence, absorber plate temperature, convection coefficient of heat transfer and other thermo-hydraulic augmentation parameters have been minutely discussed. In this review, ongoing research and development on thermo-physical properties of solar air heater and effect of distinct roughness’s over absorber plate on heat transfer augmentation is summarized and to provide viewpoint for future research and development.

Keywords: Thermal properties, Solar air heater, Rib, Nusselt number, Absorber plate, Friction factor, Augmentation.

1. Introduction

Solar air heaters are widely used in space heating and ventilation, herbal medicines, timber seasoning, leather drying, crop drying, food packaging, clothing and in other industrial and household applications. The classification of solar air heater is shown in fig.1. The thermal performance of a solar air heater is
small due to formation of laminar sublayer between absorber plate and the flowing air the convection coefficient of heat transfer is small due to which heat losses to the surrounding environment is higher that finally leads to low thermal efficiency. The laminar sublayer form on the absorber plate can be braked by using the rib roughness of distinct shapes and sizes because of that the turbulence in the flowing air increases tremendously due to which friction factor between absorber plate and flowing air increases, resulting in increment in the convection coefficient of heat transfer and pressure drop. A conventional solar air heater is shown in fig. 2. They have remarkable importance for low temperature applications. The rate of heat transfer can be augmented by using roughness of distinct shapes and sizes on the absorber plate. The thermal performance of solar air heaters can be enhanced by increasing the convection coefficient of heat transfer in between the absorber plate and working fluid. [34-38] The performance can also be enhanced with the application of nanofluids.

**Nomenclature**

- e/D- Relative roughness height.
- P/e- Relative roughness pitch.
- r/e- Relative staggered rib size
- d/x- Relative gap position
2. Methodology and Experimental Investigations

The rib-roughened duct with distinct roughness along the direction of flow of working fluid has been suggested for augment the heat transfer in numerous engineering devices such as heat exchangers, nuclear reactors, combustors and electronic devices etc. [1, 4] studied that the heat transfer surface roughened by oblique ribs is the best augmented technique. The rate of heat transfer greatly augmented due to roughness on the absorber plate at same Reynolds number. [2] Experimentally and theoretically studied heat transfer and flow-friction performance of solar air heater by applying delta shaped roughness (fig.3) at an aspect ratio of 6:1 for Reynolds number ranges from 2100 to 30000.

Fig. 2. Conventional Solar air Heater [6, 7]

Fig. 3. Delta shape roughness over absorber plate [2].

The performance of air duct affect strongly by the longitudinal pitch of roughness and the duct shows maximum performance at longitudinal pitch of 3/2. [3] Numerically investigated the effect of equilateral triangular sectioned rib roughness over the absorber plate for Reynolds number 3800 to 18000. They show that the performance of solar air heater strongly depends on the Reynolds number.
and roughness height and width. The Nusselt number is enhanced by 3.073 times at a Reynolds number of 15000 for

\[ \text{Fig. 4. Increment in Nusselt number and friction factor [12].} \]

\( \frac{P}{e} \) and \( \frac{e}{D} \) of 7.14 and 0.042 respectively. The effect of roughness pith ratio and relative roughness height on the flow pattern is shown in fig.5 and fig.6 respectively. and [9, 10, 32, 33] The heat transfer coefficients increase definitely by increasing friction in the flow with the help of roughness. [11] The performance of collector has been increased by using roughness on every side of the absorbing plate and have maximum value at \( \frac{r}{e}=2.5 \). [12] Experimentally and theoretically studied the performance of three side roughened solar air heater and surface in double pass solar air heater. Nusselt number
Fig. 5. Flow pattern for different roughness pitch ratio (P/e) [8].

Fig. 6 Impact of relative roughness height effect on flow pattern [8].

and frictional losses both has better performance for Reynolds number between 5000 to 13000. The increment in heat transfer factor lies between 0.378 to 0.487. the variation in Nusselt number and friction factor with respect to Reynolds number is shown in fig.4. [13] They studied comparative analysis of heat transfer dispersal over absorber plate by applying computational method and liquid crystal thermography for circular rib turbulators. The flow pattern has excellent result at P/e = 10 for circular rib turbulators. The Nusselt number is excessive by a factor of 1.97 as comparison to smooth surface. [14] Experimentally studied the thermo-hydraulic performance of solar air heater by applying multiple arc type rib turbulators on underside of absorber plate. The Nusselt number increases by 49% for value of d/x ranges from 0.3 to 0.6 and decreases by 18% for value of d/x ranges from 0.6 to 0.9. [15] Theoretically investigate that the thermal performance of solar air heater is augmented by 8 to 10% by applying arc type of rib roughness. [16] Experimentally investigate the effect of novel type rib roughness in the form of reverse NACA 0040 profile rib for thermal performance of solar air heater. The increment in Nusselt number and friction factor ranges from 97.56% to 193.12% and 54.90% to 64.71% respectively. The maximum value of Nusselt number is at Reynolds number of
18000. Experimentally investigate the thermal performance of a solar air heater by applying winglet type of rib roughness which has small hole on the tip just above the absorber plate. The Nusselt number is augmented by 2.85 and friction factor by 2.84 times respectively with respect to smooth absorber plate.

**Table 1: Summary of different investigations**

| S.No | Investigators       | Type of method | Geometry of roughness                  | Reynolds number | P/ε | Summary of investigation               |
|------|---------------------|----------------|----------------------------------------|-----------------|-----|----------------------------------------|
| 1    | Bekele et al. [2]   | Experimental   | Delta shaped                           | 21000-30000     | 1.5-5.5 | Performance of air duct affect strongly by the longitudinal pitch of roughness |
| 2    | Tanda [1]           | Experimental   | Angled ribs, transverse, V shaped ribs | 9000-13000      | -   | Heat transfer from the heated surface greatly augmented due to roughness     |
| 3    | Ravi and Saini [11] | Experimental   | Multi V shaped                         | 2000-20000      | 10  | Thermal performance have maximum value at r/e=2.5.                          |
| 4    | Kumar and Layek [13]| Experimental   | circular                               | 8551-11149      | 10  | Nusselt number is higher by a factor of 1.97 as comparison to smooth surface |
|   | Authors [Ref] | Methodology | Geometry | Reynolds Number | Nusselt Number Increase | Observations |
|---|--------------|-------------|----------|----------------|------------------------|--------------|
| 6 | Behura et al. [12] | Experimental | - | 4000-20000 | 10-30 | Nusselt number and frictional losses has better performance for Reynolds number between 5000 to 13000 |
| 7 | Kumar et al. [14] | Experimental | Arc shaped | 11000-19000 | - | Increment in Nusselt number by 49% for value of d/x ranges from 0.3 to 0.6 and decrement by 18% for value of d/x ranges from 0.6 to 0.9 |
| 8 | Layek et al. [28] | Experimental | Chamfer rib | 3000-21000 | 10 | As the relative roughness height increases entropy generation decreases. |
| 9 | Saini and Saini [29] | Experimental | Arc shape rib | 2000-17000 | 10 | Nusselt number increased by 3.80 times. |
| 10 | Saini and Verma [30] | Experimental | Dimple-shape rib | 2000-12000 | 10 | Nusselt number have higher value for e/D = 0.0379 |
|   | Authors [Ref] | Type            | Description                    | Range  | Magnitude |
|---|--------------|----------------|--------------------------------|--------|-----------|
| 11 | Jaurker et al. [31] | Experimental | Rib groove | 3000-21000 | 4.5-10 | Rid-grove type of roughness arrangement has excellent thermal performance. |
| 12 | Layek et al. [17] | Experimental | Winglet type | 3000-22000 | 5-12 | Nusselt number augmented by 2.85 as compared to smoother absorber plate. |
| 13 | Prasad and Saini [20] | Experimental | Transverse rib | 5000-50000 | 10 | Due to increment in relative roughness height the heat transfer rate decreases. |
| 14 | Aharwal et al. [21] | Experimental | Inclined continuous ribs with gap | 3000-18000 | 10 | Nusselt number increased by 2.59 times as comparison to smooth absorber plate. |
| 15 | Sukhmeet et al. [22] | Experimental | Discrete V shape rib | 3000-15000 | 8 | Thermal performance is highest for $\alpha = 60^\circ$. |
| 16 | Patil et al. [23] | Experimental | Broken V-rib | 3000-17000 | 10 | Thermal performance is best for relative roughness gap position 0.6. |
The Nusselt number increases with the increase in Reynold’s number and friction factor decreases as Reynolds number increases. [18] The thermo-hydraulic performance of a solar air heater studies by using cylindrical fins with the help of theoretical and computational method. The staggered arrangement of cylindrical fins has high heat transfer rate as comparison to linear arrangement.[19] Thermo-hydraulic performance of solar air heater has been studies numerically and experimentally by changing the baffle position for Reynolds number varies from 2370 to 8340. The net value of the Nusselt number and friction factor at Reynolds number 8340 are 40 and 0.005 respectively. [39-43] the performance can also be enhanced by using phase change materials.

**Conclusion**

This paper shows recent development in the field of thermo-physical performances of solar air heater. On the basis of literature review the following conclusions are summarized below:

1. The Nusselt number increases with the increase in Reynold’s number and friction factor decreases as Reynolds number increases.[12]
2. The staggered arrangement of roughness turbulators has high heat transfer rate as comparison to linear arrangement.
3. Delta winglet type of roughness increases heat transfer without to much increase in the friction factor.
4. The gap produced between the ribs show higher heat transfer coefficient as comparison to continuous rib.
5. Perforated rib roughness has greater thermal performance as comparison to solid roughness elements.
6. The performance can also be enhanced by using nano-embedded phase change materials. [44-47]

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