Influence of number of gaps created in a arc shaped roughened absorber plate used in solar air-heaters

Navneet Kumar Pandey1*, Vijay Kumar Bajpai2 and Sanjay Yadav3
1 MED, JSSATE, Noida (UP), India
2 MED, NIT Kurukshetra (Haryana), India
3 MED, ITS Engineering College, Gr. Noida (UP), India
*Corresponding Author Email: nkpandey@jssaten.ac.in Contact: 9871177812

Experimental investigation to study the influence of number of gaps in arc shaped roughness elements on heat transfer (Nu) and friction penalty (f) used in solar air-heaters (SAHs) was performed. A heating source of 1000 W/m² was provided on the top of the surface to simulate the radiant energy of the sun. Experimentation was done to ascertain the influence of gaps with 36 set of test results. The result shows that the highest value of Nu was obtained for roughness element which is having number of gaps equal to 2.

Keywords: Rectangular duct, Friction Penalty, Nusselt Number,

1. Introduction

Sun’s radiant energy is an unlimited source of energy capable of fulfilling the energy requirements of the world. Increasing population is putting a lot of pressure on the energy sector with ever increasing demands. Solar energy being prime amongst them has attracted the attention of human race to the maximum [1-3]. An effective and widely used heat exchange medium used is solar air-heater where radiant heat is exchanged between two surfaces by means of air flowing through the system. This warm air can be utilized in a variety of applications like drying and heating. Air in the heater gets heated upon contact with the heated absorber plate getting heated by solar radiation received from the sun. The formation of laminar sub-layer in the heated plate has made the efficiency of these systems very poor [4-6]. The turbulence created due to detachment and its subsequent reattachment of flow may be enhanced by creating artificial rib roughness across the absorber plates which also significantly leads to the enhancement of heat transfer from the surface [7-11].

In this article experimental analysis has been performed to estimate the friction factor and heat transfer for arc shaped rib roughened roughness elements having gaps. This study has carried out to see the influence of gaps on friction factor and heat transfer.

2. System Description

ASHRAE standards have been used to fix the system and operating parameters [5-8]. The duct has dimensions of 250 and 25 mm for width and height respectively as shown in figure 2. A heater above the absorber plate has been provided to simulate the solar irradiation and to supply a constant radiant heat supply. Rib height is of thickness of the laminar sub-layer. Its height has been kept constant as shown in figure 1. The various operating and fixed parameters are enlisted in Table 1.
The study is done on twelve configurations of a rectangular cross-sectioned channel having arc shaped ribs with single and multiple vents used as roughness elements on the absorber plate. Lastly, four different set of value of Reynolds number were also considered and this makes in total of 36 sets of experimentation. The purpose of the present study is intended to predict Friction factor (f) and Nusselt number (Nu). Ambient air conditions are taken to be constant at a temperature of 300 K.
Figure 3: Schematic representation of Gaps created on the absorber plate (a) Single Gap (b) Double Gap (c) Triple Gap

Table 1: List of fixed and variable operating characteristics

| S. No. | Parameters            | Range                             |
|--------|-----------------------|-----------------------------------|
| 1      | Roughness height, $e$ (mm) | 2 (fixed)                        |
| 2      | Reynolds number, $Re$     | 12000,16000 and 20000              |
| 3      | $g/e$                   | 1 (fixed)                         |
| 4      | $p$ (mm)                | 8, 12, 16                         |
| 5      | Number of gap ($Ng$)     | 1, 2 and 3                        |
| 6      | Hydraulic diameter $D$ (mm) | 45.45 (fixed)                    |
| 7      | Heat Flux $I$ (W/m$^2$) | 1000 (fixed)                      |
| 8      | Duct aspect ratio, $W/H$ | 10 (fixed)                        |
| 9      | Arc angle, $\alpha$ ($^\circ$) | 60 (fixed)                      |
3. Results and Discussions

The results from experimentation of smooth duct were also compared with the results from Chaube et al. [16]. It shows good agreement between these two results as shown in figure 4. The adopted methodology showed agreement with the results and the variation observed between experimental and numerical results was found to be less than 5%.

![Figure 4](image.png)

Figure 4: Friction Factor and Nusselt number results and its validation with Chaube et al. [28].

3.1 Heat Transfer

The ribs used for creating roughness geometries were employed to change the flow characteristics and heat transfer properties. Roughness not only increases the Nu but on the contrary also shows an increase in the friction penalty. Nu is low in proximity of the ribs. This could be attributed to the fact that the heat-transfer around the ribs takes place due to conduction only. High values of Nu have been observed [12-14].

3.1.1 Influence of number of gaps

Figure 5 shows the influence on Nu with changing values of Re for various values of number of gaps keeping p/e and δ constant. It was evident that Nu increases for number of gaps (N_g) until 2 thereafter a decrease is observed. This could be due to the fact that the arc shaped rib geometry produces secondary flow travelling along the entire rib length. The gaps created in the arc shaped roughness elements breaks down the flow enabling mixing of the secondary flow fluid and main flow through the gap leading to increase in turbulence augmenting heat transfer. Developed flow in the entry length produces the main flow with a thick boundary layer consisting of various sub-layers resulting in energising of the retarded boundary layer flow along the surface resulting in an augmentation of
Nusselt Number which means an increase of Nu through the gap width area. Low levels of secondary flow have been observed which is not sufficient to excite flow passing through the gaps if the gaps are produced close to the leading edge [15]. The effect of gap distance is not so significant as it does not show any significant increase in Nu when the number of gaps have been increased to 3.

![Figure 5: Plot of Nusselt Number vs Reynolds Number at various Ng values and constant p/e = 8](image)

### 3.2 Friction factor

Friction factor as a variable of Reynolds number has been demonstrated in figure 6. The results clearly indicate that the phenomena of second flow which demonstrates a observable influence on the flow profile leading to an enhancement in the friction penalty as referred to rectangular ducts. Results indicated a decrease in friction penalty with an observed increase in Re for number of gaps as 2. This could be attributed to the reattachment as observed at p/e values of 8. With any change in p/e value an decrease in friction penalty is observed. Influence of Ng on friction penalty for various values of Reynolds number at constant various p/e=8 is shown in figure 6. Results have indicated a maximum friction penalty at a Ng value of 2.
Figure 6: Variation of friction factor with Reynolds number at different Ng values at p/e = 8

4. Conclusions

Influence of number of gaps, reynolds number and p/e on friction penalty and Nusselt number has been discussed. Results indicated a maximum enhancement of 4.25 and 0.276 times in $Nu$ and $f$ respectively for number of gaps as 2. It is found that as the number of gaps goes on increasing the Nusselt number decreases drastically making the roughness geometry insignificant for use. The parameters very well established in literature also conform to the justifications provided by experimentation. The exergy of the system has also decreased with increase of number of gaps beyond 2.

References

1. Pandey Navneet Kumar and Bajpai Vijay Kumar., Experimental Investigation of Heat transfer and Friction Characteristics of Arc-Shaped Roughness Elements Having Central Gaps on the Absorber Plate of Solar Air Heater, Journal of Solar Energy Engineering, 138, 2016, pp. 1-8
2. Pandey Navneet Kumar, Bajpai V K, Varun., Heat Transfer and Friction Factor Study of a Solar Air Heater Having Multiple Arcs with Gap-Shaped Roughness Element on Absorber Plate, Arab J Sci Eng Vol 41, (2016) pp. 4517–4530.
3. Pandey N K, Bajpai V K, Varun., Experimental investigation of heat transfer augmentation using multiple arcs with gap on absorber plate of solar air heater, Solar Energy, 134 (2016) pp. 314–326.
4. Pandey Navneet Kumar, Bajpai V K., Thermo-hydraulic performance enhancement of solar air heater (SAH)having multiple arcs with gap shaped roughness element on absorber plate, International Journal of Engineering, Science and Technology Vol. 8, No. 1, 2016, pp. 34-42
5. Ucar, A., Inal, M., Thermal and exergy analysis of solar air collectors with passive augmentation techniques,Int Commun Heat Mass Transf, 33 (2006), pp. 1281–90.
6. Kumar, A., Saini, RP., Saini, JS., A review of thermo hydraulic performance of artificially roughened solar air heaters, Renew Sustain Energy Rev, 37 (2014), pp. 100-22.
7. Sharma, SK., Kalamkar, VR., Thermo-hydraulic performance analysis of solar air heaters having artificial roughness a review, Renew Sustain Energy Rev, 41 (2015), pp. 413-435.
8. Yadav, AS., Thapak, MK., Artificially roughened solar air heater: experimental investigations, *Renew Sustain Energy Rev.* 36 (2014), pp. 370-411.
9. Prasad K., Mullick SC., Heat transfer characteristics of a solar air heater used for drying purposes, *Appl Energy* 13 (1983), pp. 83-93.
10. Kumar, S., Saini, RP., CFD based performance analysis of a solar air heater duct provided with artificial roughness, *Renew Energy* 34 (2009), pp. 1285-1291.
11. Jin D., Zhang M., Wang P., Xu S., Numerical investigation of heat transfer and fluid flow in a solar air heater duct with multi V-shaped ribs on the absorber plate, *Energy* 89 (2015), pp. 178-190.
12. Tanda G., Performance of solar air heater ducts with different types of ribs on the absorber plate, *Energy* 36 (2011), pp. 6651-6660.
13. Annamalai, A.S., Ramalingam, V., Experimental investigation and computational fluid analysis of an air cooler heat pump, *Thermal Sciences* 15 (2011), pp. 759-772.
14. Tu, J., Yeoh GH., Liu C., *Computational Fluid Dynamics*, 2nd Ed., Butterworth-Heinemann Elsevier, UK, 2013.
15. ASHRAE Standard 93–97, Method of Testing to Determine the Thermal Performance of Solar Collector, ASHRAE, New York, pp. 1-34, 1977.
16. Chaube A., Sahoo PK., Solanki SC., Analysis of heat transfer augmentation and flow characteristics due to rib roughness over absorber plate of a solar air heater, *Renew Energy* 31 (2006), pp. 317-331.
17. Lewis, MJ., Optimizing the thermo-hydraulic performance of rough surfaces, *Int J Heat and Mass Transfer* 18 (1975), 18:1243-1248.