Augmentation in Heat transfer and friction factor of SAH duct using artificial coarseness

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Abstract. The augmentation of heat transfer in case of SAH with smooth collector plate is very low. In this experimental study, an attempt has been made to see the consequences of using artificial coarseness to the underside of the collector plate of SAH. Ribs have been fixed to the collector plate to create roughness at $\alpha$ of 60° and $e/D$ of 0.021 which have been used to provide artificial roughness. The range of RE varies from 4000 to 27000 and $p/e$ from 8 to 16. Nu and f have been evaluated for various roughness parameters. It has also been compared to the polished collector plate for the augmentation in heat transfer and f.

1. Introduction

As the global population rises, energy demand is growing day by day. There are many sources through which we can develop energy like fossil fuels, non-conventional energy resources. Generation of energy through fossil fuel creates lot of pollution as well as it is harmful for earth creatures as it generates lot of poisonous gases. Therefore, non-conventional energy sources are better as compare to fossil fuels for generation of energy as it does not create hazardous gases. Of all non-conventional energy resources, the main one is solar energy [1]. Solar energy can be utilised by absorbing it through a collector plate and this solar power is taken away by the fluid running below the collector plate. Such type of equipment is called as SAH in which air is used as fluid which helps in its operation. The performance of SAH is very low because of less heat transfer capability of air and less heat transfer rate among collector plate and flow to the underside of the duct. Artificial coarseness is generated to the underside of the collector plate which creates the disturbances in the flow, hence augment the heat transfer rate. It also enhances pumping power needed to produce flow through ducts.

Several studies have been probed by number of researchers on variety of duct using various coarseness geometries. Hong and Hsieh [2] have been developed the correlation for Nu and f for developing and fully developed flow in short square and rectangular channel with staggered and In-line ribs. Saini and Verma [3] have developed the correlations for the rectangular duct having the dimple shape artificial coarseness for SAH. Aharwal et.al. [4] used the inclined discrete as the coarseness and found that discrete ribs have better thermal efficiency than continuous inclined rib arrangement. Ahn and Son [5] done an experiment to study the fully developed turbulent flow in the horizontal triangular duct. They have also seen the consequence of square ribs on the heat transfer and f. The laminar hydrodynamically completely defined flow ratio for a uniform wall temperature condition in isosceles triangular ducts with an apex angle of 30 ° to 120 ° has been stated by Zhang [6]. Leung and Probert [7] have established the correlation for the convective heat transfer and Nu in the horizontal, uniformly heated electrically, equilateral triangular duct. They also concluded that rate of heat transfer is slightly increased by rounding off the apex angle of the duct. Varun et al. [8] probed...
an experimental study of heat transfer and friction characteristic of a collector plate having combination of inclined and transverse ribs as the coarseness element. Altemani and Sparrow [9] have been performed an experiment over a sharp cornered equilateral triangular duct and determined the heat transfer characteristics at both entrance and fully developed region. They kept one wall of the duct thermally insulated and the other two were uniformly heated per unit axial length. An investigation by Braga and Saboya [10] was carried out to identify heat transfer and pressure drop inside an internal finned equilateral triangular duct in a turbulent, fully developed area. Luo et al. [11] examined the consequence of using square ribs on the internal top of equilateral triangular duct. They found that by taking coarseness and operating variables into account, the heat transfer coefficient and f for a fully formed turbulent flow were calculated. Rajneesh et al. [12] have been carried out a detail review of various coarseness geometries used in solar air heaters. They also reviewed the relations developed for the Nu and f by various investigators. Rajneesh et. al. [13] done a study of SAH using CFD and various operating parameter taken into consideration. They have used elliptical rib coarseness under this study. Rajneesh et al. [14] have carried out consequence of apex angle variation on thermohydraulic characteristics of roughened triangular duct. Bharadwaj et al. [15] developed correlation for Nusselt number and friction factor for coarseness used in equilateral triangular duct. Bharadwaj et. al. [16] examined the effect of doping Graphene in PCM in thermal energy storage system.

The current investigational study determines the consequences of P/e on the characteristics of heat transfer and friction in an equilateral triangular SAH duct in which the coarseness is created by circular ribs of different sizes, maintaining a constant e/D and α.

2. Roughness configuration and span of variables

Fig. 1 represents the pattern in which the circular ribs are glued on the top of the collector plate to create the artificial coarseness. The cross section of artificial coarseness has been described by rib height e, rib pitch P, α. These variables have been presented in terms of the following dimensionless coarseness variables:

(i) P/e.
(ii) e/D.
(iii) α.

Based on practical considerations, the span of variables for this investigation has been set and is shown in Table 1.

Table 1: Operating variables span

| S.No | Operating variables        | Span         |
|------|---------------------------|--------------|
| 1.   | Reynolds Number (Re)      | 4000-27000   |
| 2.   | Dimensionless coarseness pitch (P/e) | 8-16         |
| 3.   | Dimensionless coarseness height (e/D) | 0.021        |
| 4.   | Angle of attack (α)       | 60°          |
3. Explanatory details
3.1. Practical setup
Diagram of practical setup with test section is presented in Fig. 2(a) and Fig. 2(b). The test section contains (a) an entry section, (b) an exit section, (c) a flowmeter (d) a blower. A 160 mm × 160 mm × 160 mm equilateral triangular duct having length of 2300 mm was fabricated. The aluminum ribs are fixed to the top of the collector plate which is also of aluminum having thickness 5mm and length 1000 mm. As shown in the Fig. 2, top of the test section is heated with the help of a heater and the other two sides of the duct is thermally insulated. The mass flow rate is determined by the Orifice meter and the flow rate is regulated by the assistance of control valves. Thermocouples have been used at different points to calculate temperature, as shown in Fig. 3.
3.2. Experimental Steps
The test was conducted to find out the data used to calculate f and Nu. The system was allowed to attain the quasi-steady state condition for different mass flow rate before data were recorded. It takes 2-3 hrs to attain steady state. The following variables were measured:
(i) Collector and test section temperature at various points.
(ii) Friction drop in test section.
(iii) Pressure change across the orifice plate.

4. Evaluation of data
Data collected in the 3.2. section is used to determine the various variable as follows:
Mass flow rate $m$ is determined by using following equation:

$$m = C_d A_T \left[ \frac{2 \rho A \sin \theta}{1 - \beta^2} \right]^{1/2}$$  \hspace{1cm} (1)

velocity of air $v$

$$v = \frac{m}{\rho A_c}$$  \hspace{1cm} (2)

heat supplied to the air $q$

$$q = m C_p (t_o - t_i)$$  \hspace{1cm} (3)

heat transfer coefficient $h$

$$h = \frac{m C_p (t_o - t_i)}{A_p (t_p - t_a)}$$  \hspace{1cm} (4)

where $t_p$ is temperature of collector plate and $t_a$ is temperature of fluid air.

The average Nusselt number was obtained by the use of convective heat transfer using the following expression:

$$Nu = \frac{h D}{\kappa}$$  \hspace{1cm} (5)

The $f$ was obtained using

$$f_r = \frac{2 \Delta P D}{\rho L v^2}$$  \hspace{1cm} (6)

5. Validity Test

The basic aim of validity test is to compare experimental heat transfer result through the smooth plate with the relations available for the heat transfer and friction factor ($f_r$) through smooth plate. The Nusselt number ($Nus$) assessed from experimental data is compared to the correlation between Dittus and Boelter, and the Karman-Nikuradse equation and the Modified Blasius equation are compared to the friction factor. The comparison is shown in Fig. 4 (a) and (b).

Dittus—Boelter equation : $Nus = 0.023 Re^{0.8} Pr^{0.4}$  \hspace{1cm} (7)

Karman—Nikuradse equation : $f_s = 0.046 Re^{-0.2}$  \hspace{1cm} (8)

Modified Blasius equation : $f_s = 0.085 Re^{-0.25}$  \hspace{1cm} (9)
Figure 4.(a) Comparison of experimental and predicted values of \( \text{Nu} \) for polished plate

Figure 4.(b) Comparison of experimental and predicted values of friction factor for smooth plate.

6. Result and Discussion
This section of the paper addresses the effect of p/e holding e/D fixed on Nu and f for air flow in the triangular duct. It can be seen from Fig.6 (a and (b) that with the increment in RE and f, the Nu grows with the drop in the value of RE. The laminar sublayer separates due to the growth in p/e and reattachment of the flow takes place, thereby increasing the heat transfer rate. Fig.5 (a) represents the augmentation in the Nu with the growth in the value of p/e from 4 to 12 where the value of e/D kept fixed as 0.021.
Figure 5 (a) Enhancement in the value of friction factor for different p/e and for fixed e/D.

![Friction Factor vs Reynolds Number](image)

Figure 5 (b) Enhancement in the value of Nusselt number for different p/e and for fixed e/D

Fig. 5 (b) represents that the increment in the value of f as the value of p/e increases from 8 to 12 and then starts decreasing, where the value of e/D kept fixed as 0.021.

7. Conclusions
Following are the concluding remarks for the above experiment study:
1. This experimental study represents that by providing the artificial coarseness Nu and f get augmented.
2. The consequence of p/e on the Nu and f has been researched.
3. This experimental study shows that at p/e of 12, maximum heat transfer and friction factor occur.

8. Future Scope
1. Same study can be carried out using CFD and variation in the results can be seen with respect to experimental results.
2. Other roughness and parameters can be used to see their effect on heat transfer.

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