Solar air heater duct having triangular protrusions As roughness elements on absorber plate

A. Nagaraju[1], B. Chnadramohan Reddy[2]
[1,2]Department of Mechanical Engineering,
Jawaharlal Nehru Technological University, Anantapur, A.P.
Corresponding author E-mail: arekantiraju@gmail.com

Abstract— In the present paper Artificial roughness in the form of triangular protrusions of varying numbers is placed on smooth aluminum plate for enhancement of thermal performance of solar air heaters. The apex angle of 45º triangular protrusions is common for different aluminum plates of varying number of triangular protrusions viz. 198,216,234 and 252. The mass flow rate is maintained between 0.017-0.0182 kg/sec, the rate of air flow corresponds to Reynolds number (Re) ranging from 10300-12000, Nusselt number range is 50-110 and friction factor is 4.5-6.7x$10^{-3.}$ The heat transfer rate is found to be maximum at 234 numbers of triangular protrusions of aluminum plate is 107.

Keywords-**component: solar air heater, varying number of protrusions, Nusselt number, friction factor, heat transfer enhancement**

I. INTRODUCTION

In recent years there has been increasing effort to promote renewable energy resources in mounting countries. Solar air heater is one of the most widely used device in various industrial areas, such as for drying of agricultural products, seasoning of wood, space heating, curing of industrial products. Convective heat transfer coefficient can be increased by creating turbulence at heat transfer surface by providing artificial roughness on the underside of the absorber plate. Various roughness geometries with heat transfer and friction factor correlation developed by various investigators are reported in this paper. The thermal efficiency of solar air heater is low due to: 1.low thermal capacity of air 2. Low heat transfer co-efficient between the absorber plate and air flow through duct.

Several investigators have attempted to design a roughness element, which can enhance convective heat transfer with minimum pumping losses. Saini et al.[3] and gupta et al.[16] investigated the effect of artificial roughness and different shapes of protrusions on heat transfer enhancement. However, in case of solar air heaters, the roughness element has to be considered only under side of one broad wall, which receives solar radiation. So solar air heater modeled as a rectangular channel having one rough wall and three smooth walls is considered. The flow Reynolds number in solar air heaters ranges as 10000<Re<12500. By the different shapes of protrusions the heat transfer rate is enhanced. Karmare et al.[8], lanjewar et al.[9] and sachin choudary et al. investigated on metal grits ribs, w-shaped ribs and m-shaped ribs roughness on absorber plate. B.N. Prasad and J.S. Saini [2] investigated effect of artificial roughness on heat transfer enhancement and friction factor in a solar air heater. Jaurker et al.[7] made the heat transfer and friction characteristics of rectangular solar air heater duct using rib-grooved artificial roughness. Anil Kumar et al. [14] investigated the heat and fluid flow characteristics of roughened solar air heater ducts. Saini et al.[3] studied the effect of roughness and operating parameters on heat transfer and friction factor in a roughened duct provided with dimple shape roughness geometry for the range of Reynolds number(Re) from 2000 to 12,000, relative roughness height (e/d) from 0.018 to 0.0379 .

In view of the above, it can be stated that roughness in different shapes of protrusions makes maximum heat transfer. The present investigation is therefore taken up to determine the optimum number of protrusions that are required to enhance the heat transfer rate. In the present work, experimental investigation is done on the performance of solar air heater ducts of having varying numbers of triangular protrusions of apex angle 45^0. The mass flow rate is maintained between 0.017-0.0182 kg/sec, Nusselt number range is 50-110 and friction factor is $4.5\text{-}6.7\text{x}10^{-3}$. The varying numbers of triangular protrusions have been evaluated to examine the thermo-hydraulic performance of the solar air heater.

II. EXPERIMENTAL PROGRAM

An experimental test facility has been designed and fabricated to study the effect of varying number of triangular protrusions for heat transfer enhancement. A schematic diagram of experimental set-up is shown in fig 1. A rectangular fly wood duct with interior dimensions of $2400\text{x}150\text{x}15\text{mm}^3$ is virtually divided into three sections.

Fig.1Actual experimental set-up

They are entry section, test section, exit section, transition section, a flow measuring orifice-meter and centrifugal blower with control valve. The entry, exit sections with length 800,600mm are more than the ASHRAE designated minimum standards i.e., 5√WH, and 2.5√WH respectively and the test section with length 1000mm. The aspect ratio of the duct is chosen to be 10. A by-pass valve is attached between the duct and the centrifugal blower for the purpose of changing the mass flow rate. A digital micro voltmeter is used to indicate the output of the thermocouples. An electric heater made of nichrome wire and asbestos sheet acts as a substitute to solar energy. A centrifugal blower is coupled with the shaft of single phase induction motor which runs at 2800rpm.

ROUGHNESS

Formations of dimples/protrusions on surface of absorber plate are also considered to be a simple and economical methodology to create artificial roughness. It is a subject of many recent experimental investigations. Use of dimple shape roughness produce augmented surface heat transfer levels as compared to channels with smooth surfaces and par with other artificial roughness geometries. On the other hand pressure drop or friction loss usually does not increase appreciably as compare to other roughness channels.

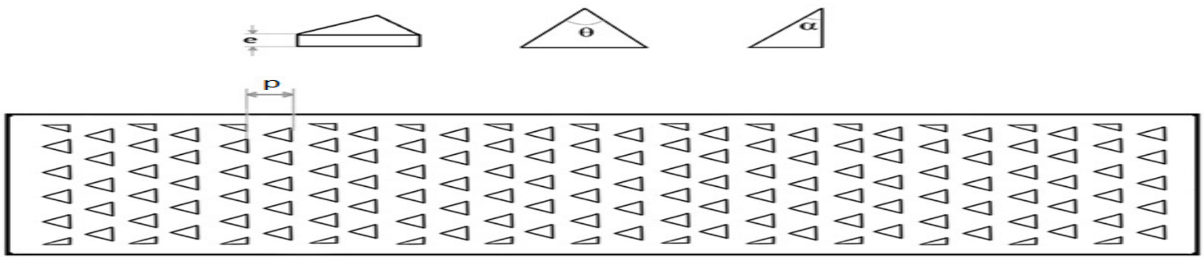


Fig.2 Absorber plate with triangular protrusions

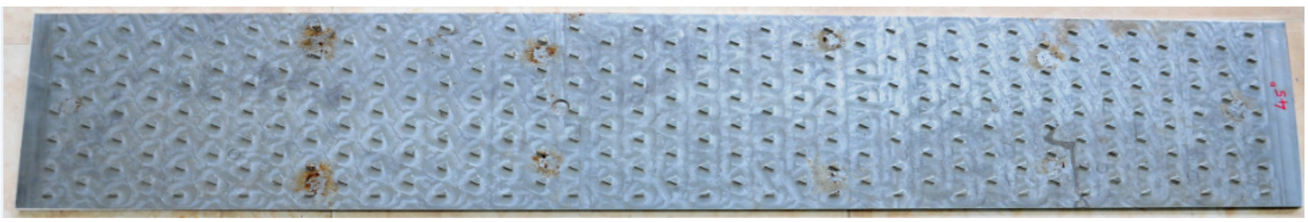


Fig.3 Roughness plate with 45^0apex angles

III. EXPEREMENTATION

Before starting the experiment, all the thermo couples were checked carefully so that they indicate room temperature and all the pressure tapings were checked for leakage. The blower is then switched on and joints have been checked for leakage. Flow control valve is adjusted to give a predetermined rate of air flow to the test section on switching on the blower. The test runs were conducted under steady state conditions to collect relevant heat transfer and flow friction data. For each set it takes 2-3hrs to reach a steady state. The Steady state was assumed to have been attained when no considerable variation in plate temperature and outlet air temperature was observed over a period of 10min.The parameters recorded for each set of experiments were inlet air temperature, outlet air temperature at two points in the span-wise direction of the duct, temperature of the heated plate at 10 locations, pressure drop across the orifice plate, and pressure drop across the test section.

TABLE-1 EXPERIMENTAL CONDITION

Parameter		Values
Reynolds Number (Re)		10300 – 12000
Roughness height (e)		3 mm
Relative roughness height		0.11
(e/D_h)		1000 W/m^2
Heat Flux (1)		Aluminium
Plate Material		plate
Thickness of Plate		6 mm
Channel Aspect ratio (W/H)		10
Test Length		1000mm
Hydraulic Diameter		40mm

A. VALIDATION TEST

Nusselt number and Friction factor determined from the experimental data and smooth duct were compared with those obtained from the modified Dittus-Boelter equation (1) and modified Blasius equation (2) for Nusselt number and friction factor respectively and found satisfactory.

B. MODIFIED DITTUS BOELTER EQUATION

$$Nu_s = 0.023 \,.\, \mathrm{Re}^{0.8} \,.\, \mathrm{Pr}^{0.4} \,.\left(\frac{2R_{av}}{D_h}\right)^{-0.2} \quad (1)$$

Where $\left(\frac{2R_{av}}{D_h}\right)$ = (1.156+H/W-1)/(H/W)

C. MODIFIED BLASIUS EQUATION

$$f_s = 0.085.\mathrm{Re}^{-0.25}$$

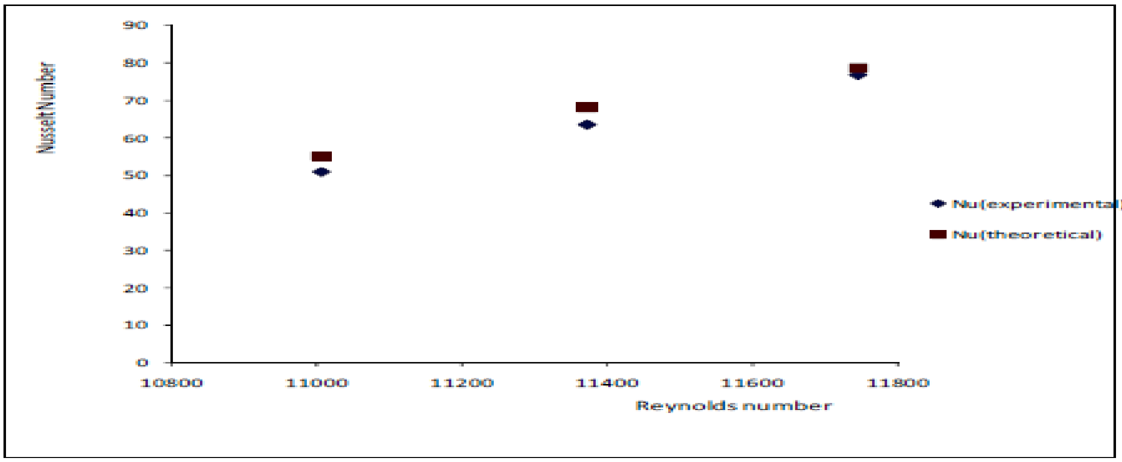


Fig.4 Comparision of experimental and predicted values of Nusselt Number for smooth duct

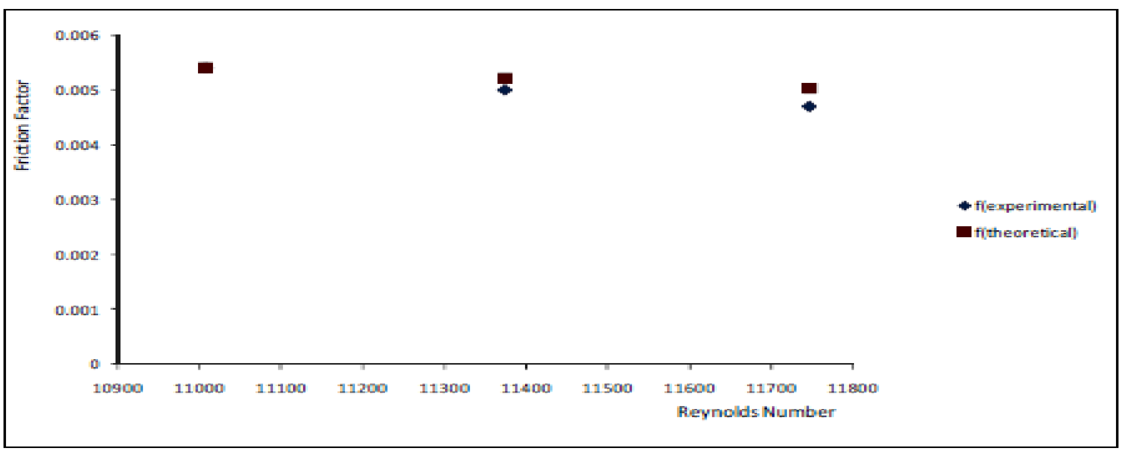
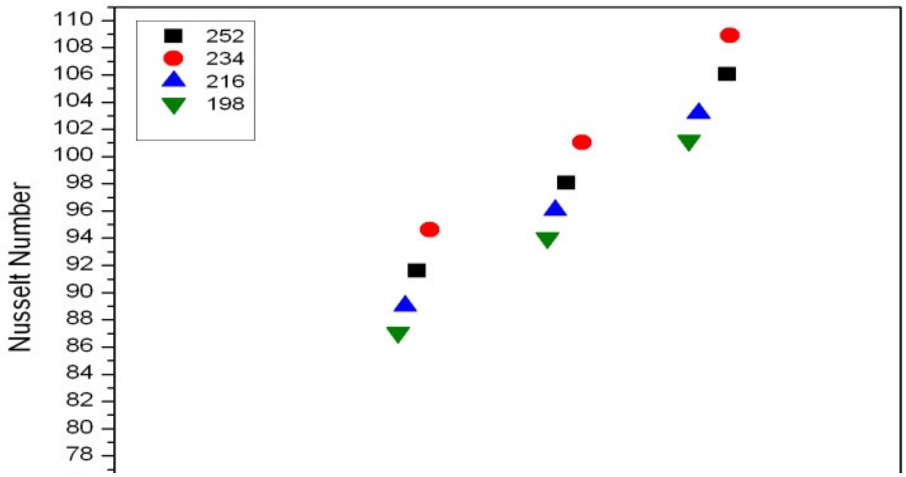


Fig.5 Comparision of experimental and predicted values of friction factor for smooth duct



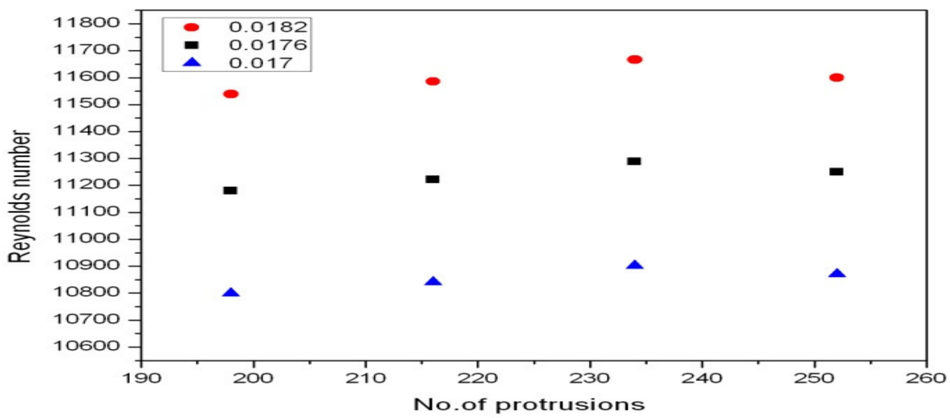
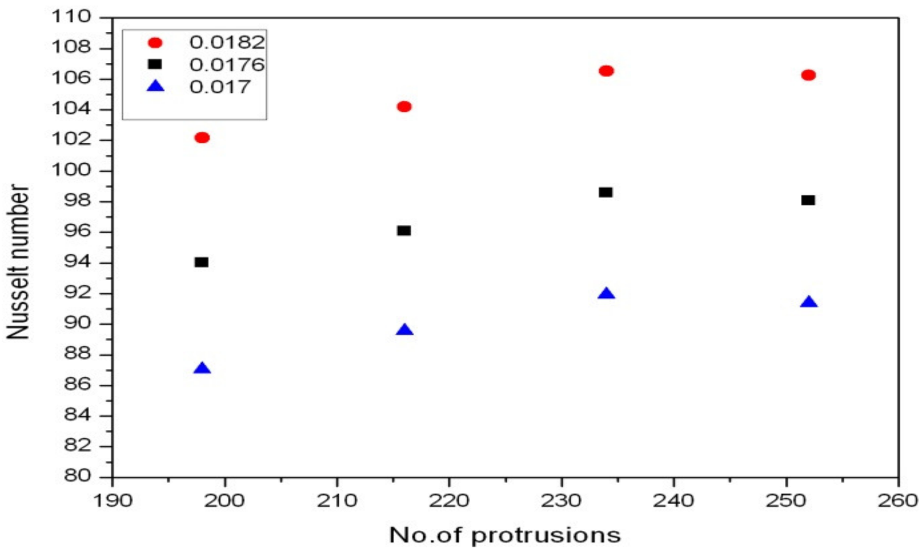
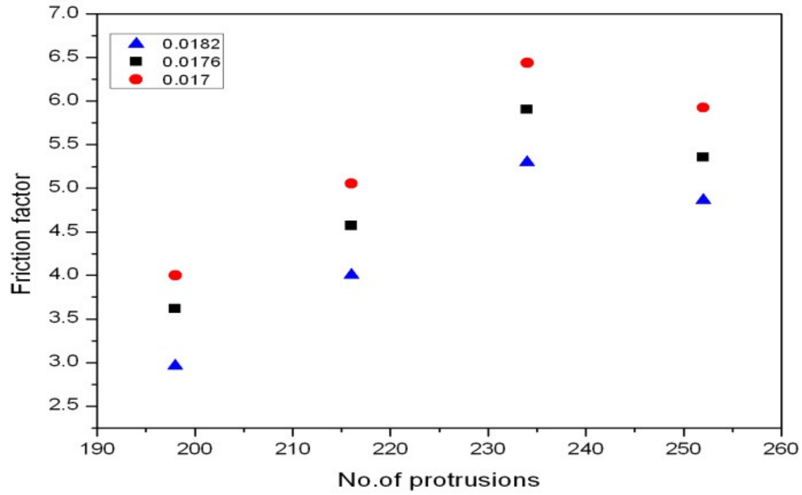


Fig.7 No. of protrusions vs. Reynolds





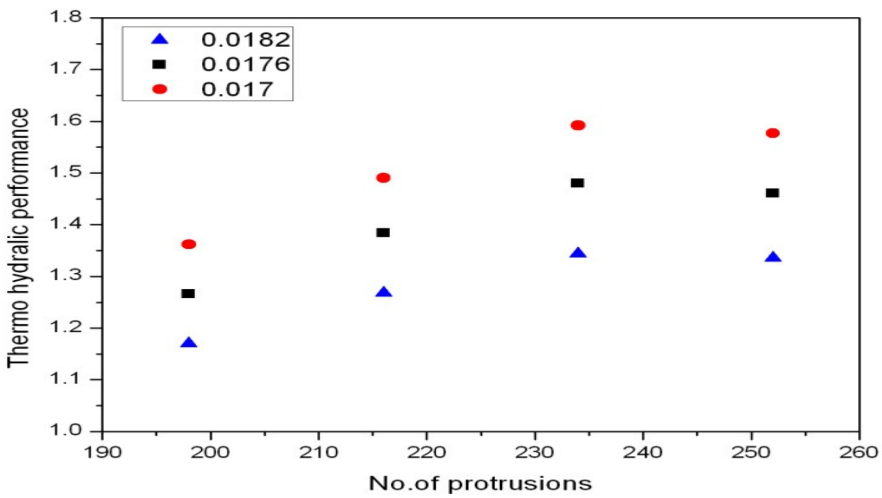


Fig.10 No. of protrusions vs Thermal hydraulic performance

Fig.4 and 6 plots show that the Reynolds number and Nusselt number increases from 198 to 234 numbers of triangular protrusions and then slightly decreases. The Reynolds number and Nusselt number is maximum at 234 numbers of triangular protrusions roughness plate. This roughness plate having mass flow rate of 0.0182 kg/sec. The Reynolds number for protrusions greater than 234 is greater than 12000 so Nusselt number decreases slightly thereafter.

Fig.7 and8 Graph says that Nusselt number increases with increase in Reynolds number. The 234 triangular protrusions of 45^0 apex angle plate is having higher Nusselt number as compared to 198,216 and 252 triangular protrusions plates. As the flow rate increases turbulent kinetic energy also increases and thereby heat transfer coefficient is increases. But for roughened surfaces Nusselt number decreases slightly when Reynolds number reaches above 12000.

Fig.5 and 9 This graph concluded that friction factor is maximum for less mass flow rate, so friction factor increases up to 234 numbers of triangular protrusions and decrease slightly from 234 to 252 number of triangular protrusions. It determines the friction factor is optimum at 234 triangular protrusions.

Fig.10 The thermo hydraulic performance is enhanced form 198 to 234 numbers of triangular protrusions and then it is decreases. In this plot thermo hydraulic performance is maximum for 234 numbers of triangular protrusions.

V. CONCLUSION

- From the experimental result, it is found that 234 numbers of triangular protrusions has maximum heat transfer rate compared to198, 216 and 252 numbers of triangular protrusions.
- The maximum Nusselt number is obtained for the 234 number of triangular protrusions which is 107
- The maximum value of friction factor is obtained for the 234 numbers of triangular protrusions which is $6.7x10^{-3}$.
- The Thermo-hydraulic performance value for 234 numbers of triangular protrusions is maximum that is 1.73 and minimum for the 198 numbers of triangular protrusions plate which is 1.2.

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