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Comparative Study of Thermal Efficiency of Artificially Roughened Solar Air Heaters

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Abstract: **The use of an artificial Roughness element on a surface is an effective technique to enhance the heat transfer from the collector plate to the air in a solar air heater duct. Thus it is imperative to design more efficient heat exchanger. The use of artificial roughness in different form shape and size is the most common and effective way to improve the performance of a solar air heater.**

Several studies have been carried out to determine the effect of different roughness element geometries on heat transfer and in solar air heaters. This paper presents a comparison of thermal performance of solar air heater having different types of geometries of roughness element on absorber plate. Thermal efficiency has been computed by using the correlations for the heat transfer and friction factor developed by various investigation within the investigated range of operating and system parameters. the investigation encompassed the Reynolds no. (Re), range from 4000 to 20000

Relative roughness pitch (P/e) = 5 to 20

Relative roughness height (e/D) : 0.015 to 0.040

1. INTRODUCTION

A solar collector is a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. Generally, these are of two types i.e. concentrating (focusing) and flat-plate collector.

PERFORMANCE OF A CONVENTIONAL SOLAR AIR HEATER

Thermal performance of a conventional solar air heater can be described by an energy balance that indicates the distribution of incident solar energy into useful energy gain and various heat losses from top, bottom and edges of the solar collector.

2. LITERATURE REVIEW

METHODOLOGY OF ARTIFICIAL ROUGHNESS

Solar air heaters have been observed to have generally poor convective heat transfer coefficient from absorber plate to the air. This low heat transfer coefficient result in relatively higher absorber plate temperature leading to higher thermal losses to the environment and hence lower thermal efficiency. It has been found that the main thermal resistance to the convective heat transfer is due to the formation of laminar sub layer in boundary layer on the heat-transferring surface. Efforts for enhancing heat transfer have been directed towards artificially destroying or disturbing this laminar sub layer in boundary layer. Artificial roughness on the absorber plate has been used to create artificial turbulence near the wall or to break the laminar sub layer. Thus, artificial roughness employed for the enhancement of heat transfer coefficient between the absorber plate and air has improved the thermal performance of solar air heater appreciably.

However, excessive power is required to make flow of air through the roughened duct. Therefore, turbulence must be created only in the region very close to the heat transferring surface i.e. in the laminar sub-layer only where heat exchange takes place and flow should not be unduly disturbed so as to avoid excessive friction losses. It can be achieved by keeping height of the roughness element small in comparison with the duct dimension. Many investigators have attempted to design roughness element, which can enhance convective heat transfer with minimum increase in friction loss.Although there are several parameters that characterize arrangement and important parameters. These parameters are usually specified in dimensionless form like relative roughness height (e/D) and relative roughness pitch (p/e).

Many investigators have attempted to design roughness element, which can enhance convective heat transfer with minimum increase in friction loss. Experimental analysis has been reported in the literature showing the performance analysis of smooth and roughened duct of solar air heaters.

PROBLEM-FORMULATION: It is revealed from the literature review that artificial roughness is a good technique to enhance heat transfer coefficient between absorber plate and flowing air. Methodology of creating artificial roughness on the surface of absorber plate is considered to be an effective technique for enhancing heat transfer coefficient in order to increase heat transfer rate between absorber plate and air flowing through the duct. As discussed, artificial roughness on the surface of absorber plate can be produced by several methods such as by wire fixation in the form of transverse continuous ribs, transverse broken ribs, inclined and V-shaped or staggered ribs, rib formation by machining process in the form of chamfered ribs, wedge shaped ribs, combination of different integral rib roughness elements, expanded metal mesh ribs and by formation of dimple /protrusionon surface of absorber plate. Formation of dimples/protrusions on surface of absorber plate is 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 produced augmented surface heat transfer levels as compare to channels with smooth surfaces and at par with other artificial roughness geometries. On the other hand pressure drop or friction loss usually does not increase appreciably as compare to other rough channels. Very little work is reported in the literature to use this type of roughness geometry for solar air heaters. It has also been observed that conducting experimental investigation is also tedious task similar to creating artificial roughness. Experimental analysis of different types of roughness geometries have been reported in literature. Experimental work requires good set up with good calibrated instruments. It requires a lot of human effort in setting up and analyzes the result. Due to the difficulties associated with experimental work to evaluate different roughness geometries one need to study performance of artificial roughened air heater numerically, which not only reduces human effort but also is less time consuming and these results can be validated with experimental results

THERMAL EFFICIENCY

Here work is done in three stages:

1. First we found the values of Nusselt No.(Nu) and friction factor (f) using the correlation for different geometries. These values are given in table.

2. From the values of friction factor (f) and (Nu) we found the values of heat transfer coefficient (h) and pressure drop. (ΔP)

   The relation is given below:

$$Nu = \frac{hD_h}{k}.$$

$$f = \frac{2\Delta P D_h}{4\rho L v^2}.$$

3. From the value of coefficient of heat transfer and pressure drop value of thermal efficiency found using a program in C++ .

4. Finally the graph are plotted for Re vs n_{th} to show variation of thermal efficiency

Thermal efficiency

As per ASHRAE recommendations the thermal efficiency of a solar collector can be expressed by the following equation

$$\eta = F_R\left[(\tau\alpha) - U_L\left(\frac{t_i - t_a}{I}\right)\right]. \quad (1)$$

where FR is the 'collector heat removal factor' defined as the ratio of the actual heat transfer to the maximum possible rate.

The relation between the collector efficiency factors F0 and heat removal factor FR is given as

$$F_R = \frac{mC_p}{A_C U_L}[1 - \mathrm{Exp}(-A_C U_L F'/mC_p)]. \quad (2)$$

In a particular case of a solar air heater without recycling and where the inlet air temperature coincides the ambient.

Eq. (1) reduces to $h = F_R(\tau\alpha)$

This expression of efficiency does not allow the real operative temperature to be shown and it, therefore, results less efficacious. In view of these limitations Biondi et al. [9] proposed the following equation for efficiency of solar air heaters:

$$\eta = F_o\left[(\tau\alpha) - U_L\left(\frac{t_o - t_i}{I}\right)\right] \quad (3)$$

whereFo is the heat removal factor referred to the outlet temperature and can be expressed as

$$F_o = \frac{GC_p}{U_L}[\mathrm{Exp}(U_L F'/GC_p) - 1]. \quad (4)$$

Comparing Eq. (3) with **Y=mx+c** indicates that a plot of efficiency against $[(t_o - t_i)/I]$ will result in a straight line whose slope is $F_o U_L$ and ordinate axis intercept is $F_o(\tau\alpha)$,

If F_o, U_L and $(\tau\alpha)$ are not very strong functions of operating parameters like mass flow rate, intensity of solar radiation, ambient temperature and wind velocity variations. Further, thermal performance can be expressed based on temperature gain produced by the collector and expressed as

$$\eta = \frac{GC_p(t_o - t_i)}{I}$$

4.2 Thermal performance prediction

The thermal performance of a solar air heater can also be predicted on the basis of detailed consideration of heat transfer processes in the system. Using the correlations for heat transfer coefficient and friction factor developed, and the performance parameters, namely overall heat loss coefficient, heat removal factor and other relevant factors can then be evaluated. For this purpose a step-by-step procedure has to be followed. In order to compute the values of loss coefficient and heat removal factor plate are assumed and an iterative process followed to match the values of total energy gain. Subsequently, the value of effective efficiency of solar air heater can be determined. A computer program of calculation in C++ has been developed. Various steps involved in the iterative process have been explained below.

Step 1: An initial estimate for the mean absorber plate temperature Tp is made by using the approximation **tp =ta = ti.**

Step 2: Using this plate temperature, top loss coefficient, Ut, and then overall loss coefficient, UL, is computed using the following equations. The top loss coefficient Ut can be computed using the relationship proposed by Klien [10] as given below:

$$U_t = \left[\frac{N}{(349/t_p)[(t_p - t_a)/(N+\delta)]^{0.33}} + \frac{1}{h_w}\right]^{-1} + \frac{\sigma(t_p - t_a)(t_p^2 + t_a^2)}{[\varepsilon_p + 0.05N(1-\varepsilon_p)]^{-1} + [(2N+\delta-1)/\varepsilon_g] - N}$$

Where

$$\delta = (1 - 0.04h_w + 0.005h_w^2)(1 + 0.091N).$$

Using this value of top loss coefficient, the overall loss coefficient can be determined from

$$U_L = U_t + \frac{k_i}{t},$$

whereki is the thermal conductivity and t is the thickness of insulating material.

Step 3: Using this estimated loss coefficient UL, the efficiency factor F', and heat removal factor Fo are computed using the following equations. The heat removal factor, Fo, is given by

$$F_o = \frac{GC_p}{U_L}\left[\text{Exp}\left(\frac{U_L F'}{GC_p}\right) - 1\right]$$

where F', the collector efficiency factor can be computed from the following relation:

$$F' = \frac{h}{h + U_L}$$

The heat transfer coefficient h can be determined from the correlation developed

$$h = 0.0006 \times Re^{1.213} \times (p/e)^{0.0104}\,\frac{k}{D_h}$$

Net thermal energy gain is then computed using the following equation:

$$q_u = A_c[I(\tau\alpha) - U_L(t_p - t_a)]$$

The temperature rise is computed using the equation given below:

$$(t_o - t_i) = \frac{q_u}{mC_p}$$

Step 4: These estimates for heat removal factor Fo, loss coefficient UL, heat energy gain qu, and temperature rise $(t_o - t_i)$ are then used in the following equation to compute the new mean plate temperature:

$$t_p = t_a + F_o I(\tau\alpha)\left[\frac{1 - F_o}{F_o U_L} + \frac{t_o - t_i}{I(\tau\alpha)}\right]$$

Step: 5 This new mean plate temperature is compared with the previous value and the difference decides the further course of calculations. If difference is within acceptable limits, the process is terminated while if the difference is outside the tolerance limits the calculated value of tp is used as revised value.

Step 6: Using this revised value of mean plate temperature the above steps (1–5) are repeated till new and old values of mean plate temperature agree within specified limits.

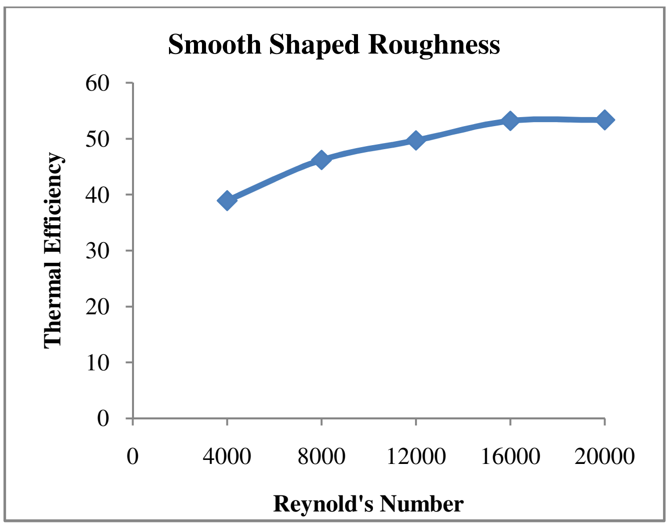
Step 7: When the correct plate temperature has been determined from this iterative procedure, the thermal efficiency of solar air heater is calculated by using the following expression:

$$\eta = F_0 \left[(\tau\alpha) - U_L \left(\frac{t_o - t_i}{I} \right) \right]$$

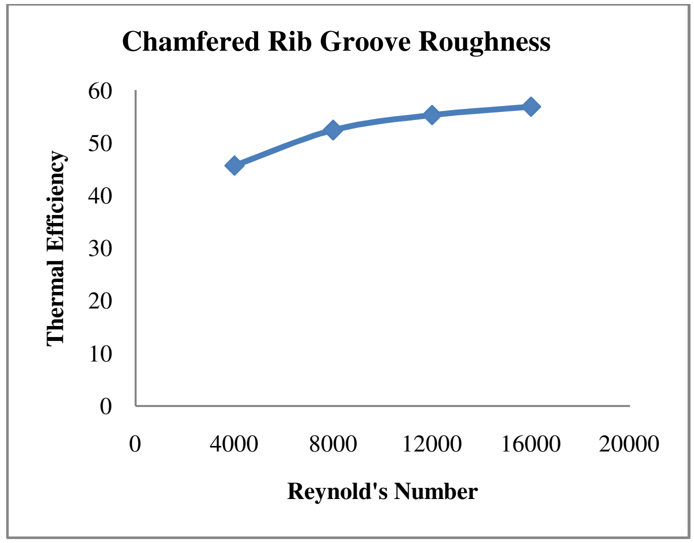
By using this procedure the thermal efficiency is estimated and compared the results with the experimental data is obtained.

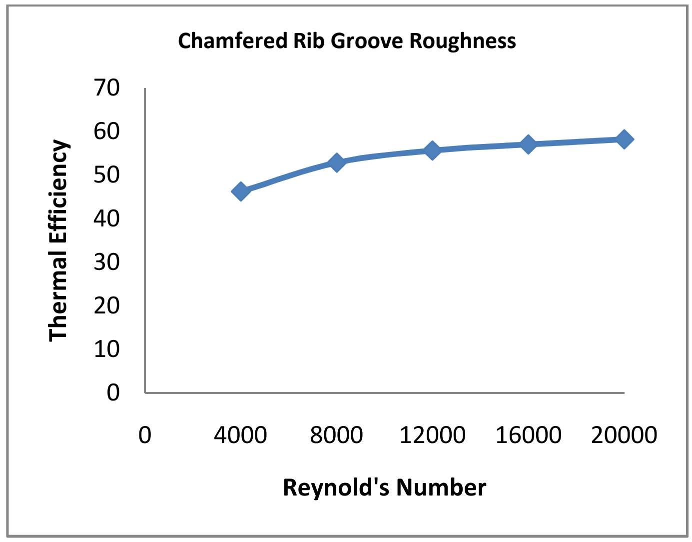
3. RESULTS AND DISCUSSIONS

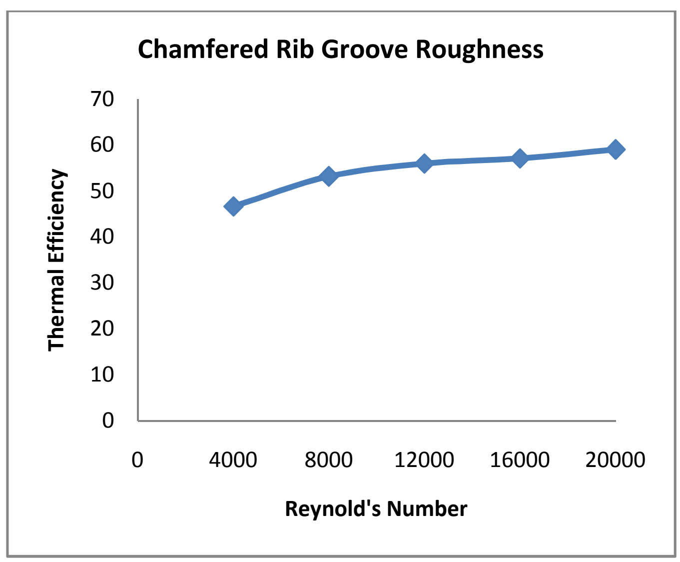
The efficiency for solar air heaters with different roughness and operating parameters have been evaluated and presented.

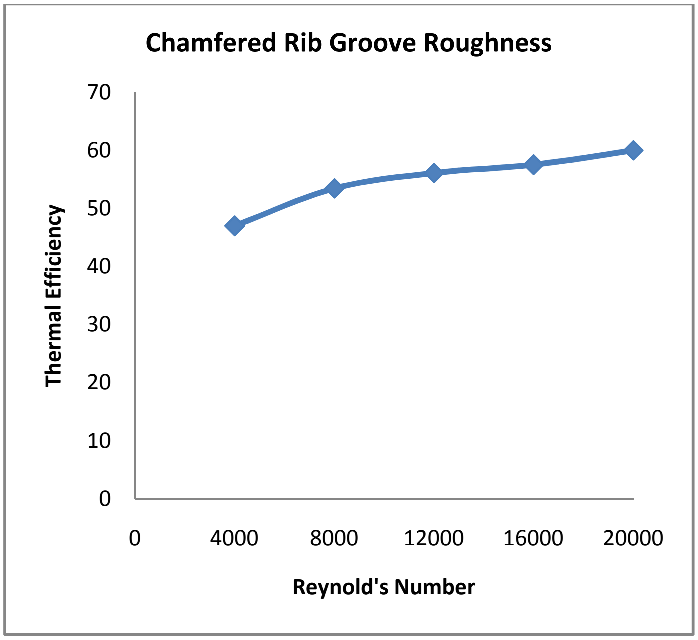


CHAMFERED RIB GROOVE ROUGHNESS
LAYEK ET AT(2007)
P/e=4.5
e/D=0.025(for 1st plot)
=0.03(for 2nd plot)
=0.035(for 3rd plot)
=0.04(for 4th plot)
g/p=0.45
phi=20 deg

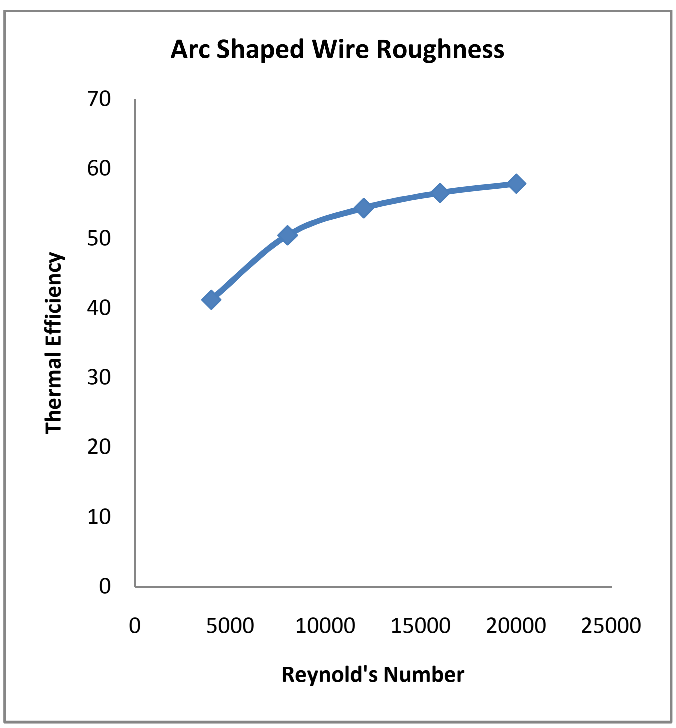


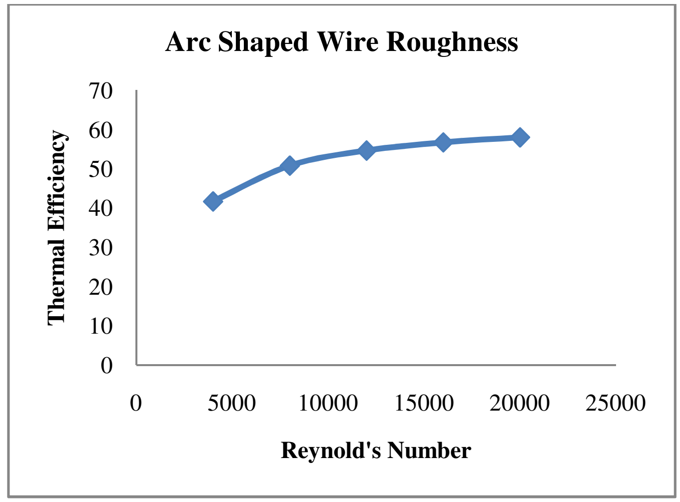


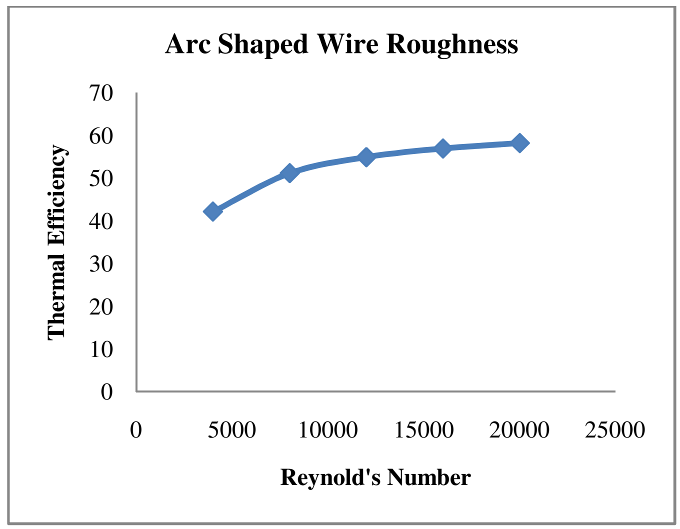


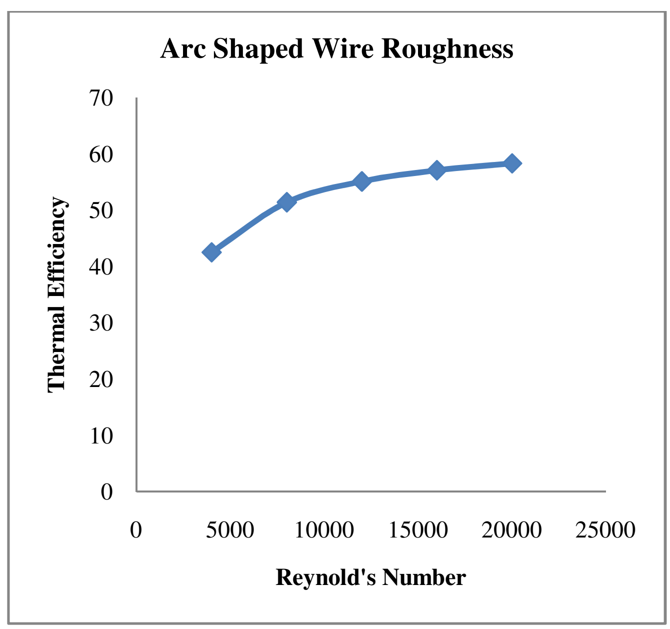


ARC-SHAPED WIRE ROUGHNESS
SAINI AND SAINI(2008)
e/D=0.025(for 1st plot)
=0.03(for 2nd plot)
=0.035(for 3rd plot)
=0.04(for 4th plot)
Phi=30 deg

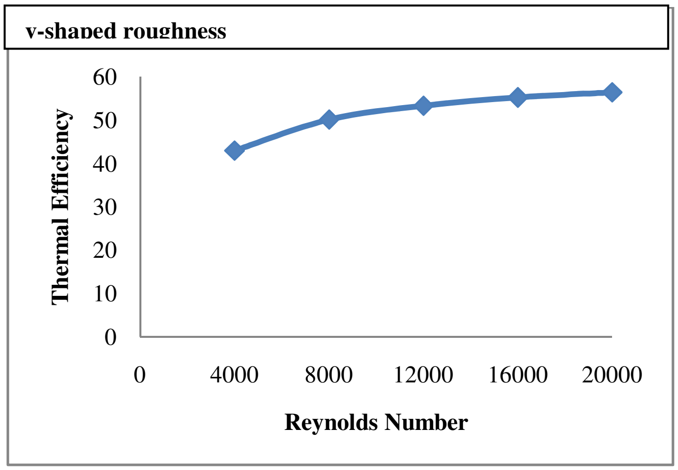


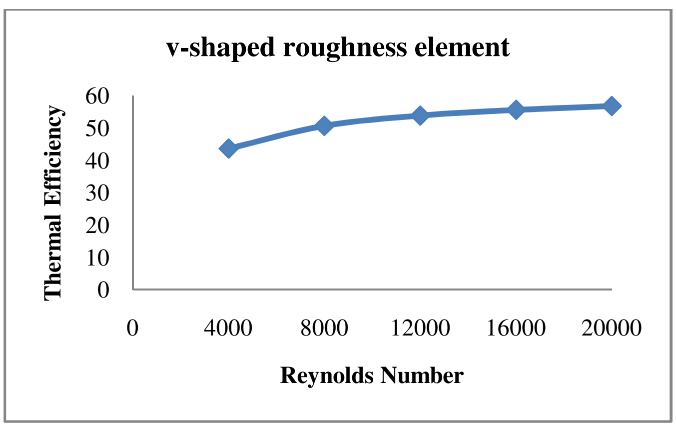


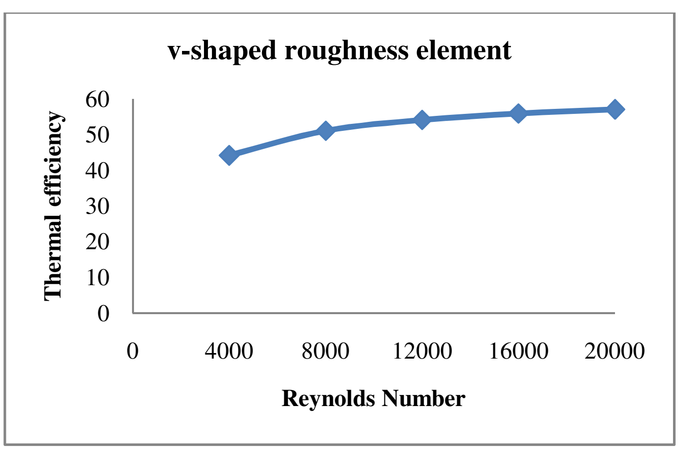


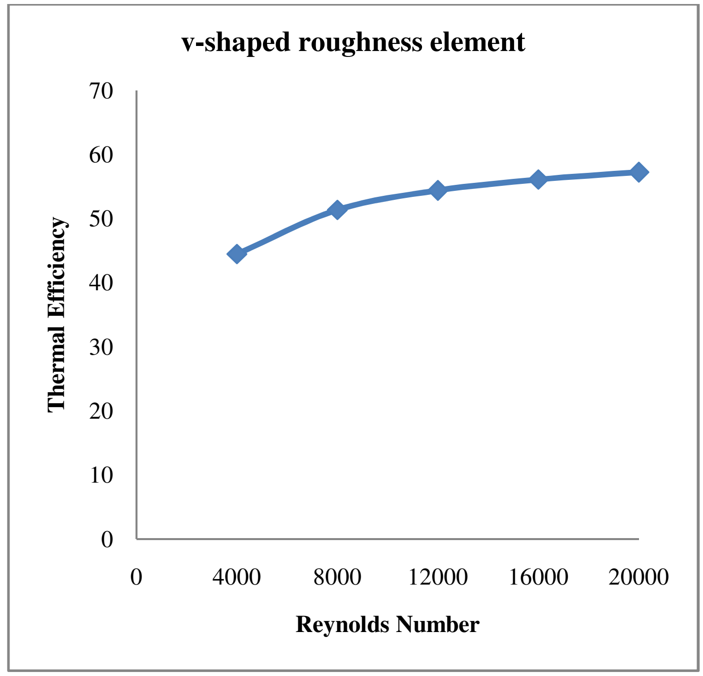


V-SHAPED ROUGHNESS
MOMIN ET AL(2002)
e/D=0.020(for 1st plot)
=0.025(for 2nd plot)
=0.030(for 3rd plot)
=0.034(for 4th plot)
Phi=60 deg

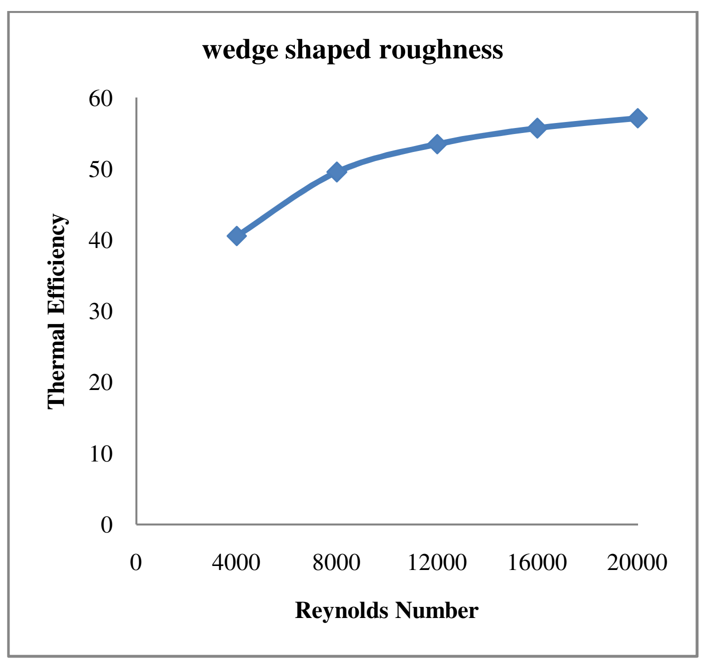


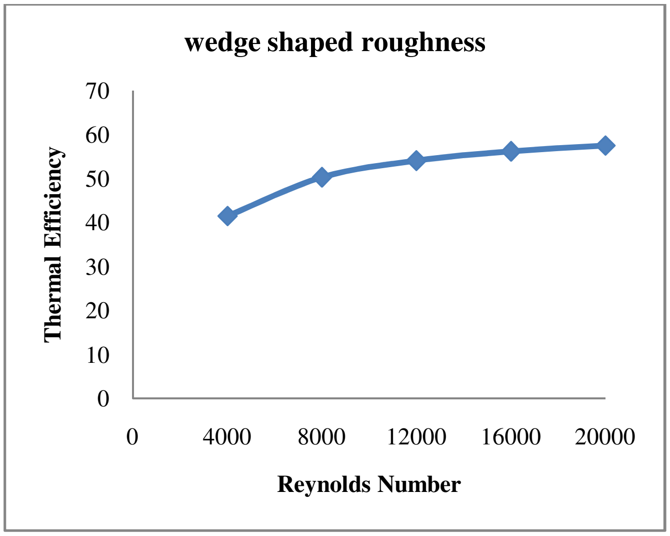


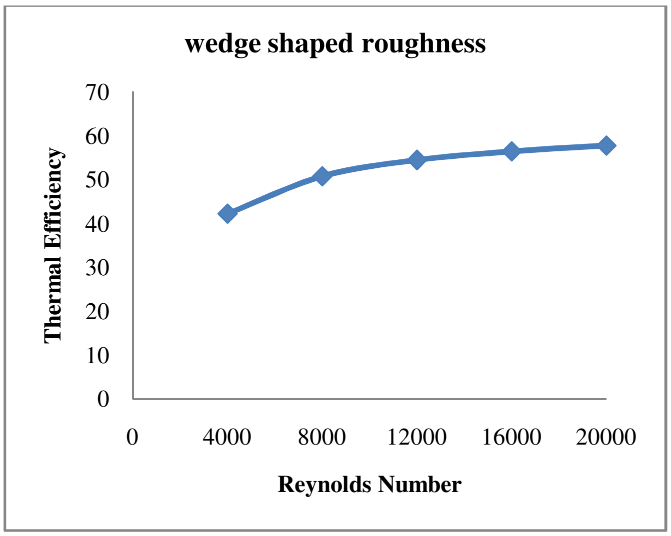


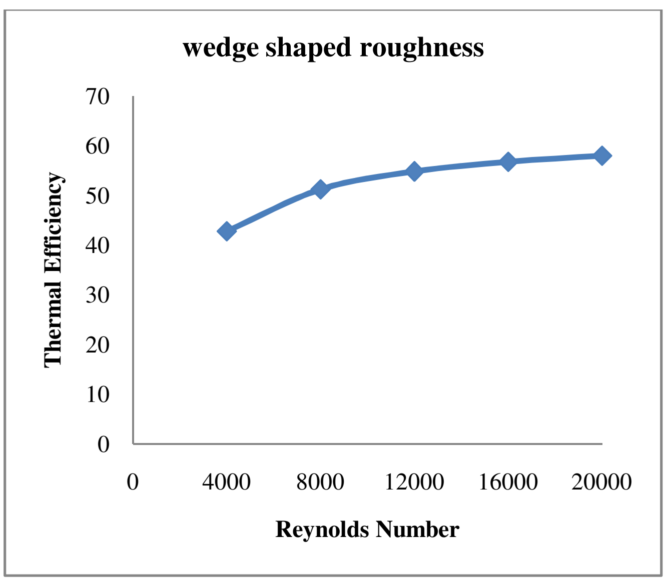


WEDGE SHAPED ROUGHNESS
BHAGORIA ET AL(2002)
e/D=0.020(for 1st plot)
=0.025(for 2nd plot)
=0.030(for 3rd plot)
=0.034(for 4th plot)
Phi=11.5 deg









4. CONCLUSION

From the above observation it can be clearly interpreted that the maximum obtainable thermal efficiency is for chamfered rib groove roughness (60 percent) at reynold's number of 20000 and e/D=0.040.Further these curves can be used for comparison of various roughness element and thus required can be used for better efficiency as per as requirement.

- The present work was undertaken with the objective of detailed investigation of roughness geometries that have a combination of different roughness elements.
- Results have been compared with those of a smooth duct under similar flow conditions to determine heat transfer coefficient and friction factor.
- It is concluded that the presence of roughness on the absorber plate yields considerable enhancement of heat transfer. Which ultimately results in higher thermal efficiency with higher values of Reynolds no.
- The selection of roughness geometry should be such that the heat transfer increases significantly but the increase in friction is to be very less.
- The thermal performance of roughened solar air heater is influenced by the roughness parameters and the best performance has been found for the roughness parameter that yield maximum heat transfer coefficient.

REFRENCE

[1] Karwa RK. Experimental studies of augmented heat transfer and friction in asymmetrically heated rectangular ducts with ribs on heated wall in transverse, inclined, v-continuous and v-discrete pattern. IntCommun Heat Mass

[2] Sahu MM, Bhagoria JL. Augmentation of heat transfer coefficient by using 908 broken transverse ribs on absorber plate of solar air heater. Renew Energy

[3] Sarac¸ BA, Bali T. An experimental study on heat transfer and pressure drop characteristics of decaying swirl flow through a circular pipe with a vortex generator. Exp Thermal Fluid Sci 2007;32:158–65.

[4] Lewis MJ. Optimizing the thermohydraulic performance of rough surfaces. Int J Heat Mass Transfer 1975;18:1243–8.

[5] Solar air heater by sukhatme

[6] Google.com