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Enhancement of Heat Transfer Rate and Thermal Efficiency of Solar Air Heater by Using Flow Turbulators'-A Review

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ABSTRACT: Heat energy plays most important role in the field of power generation which involves the heat transfer in domestic as well as industrial purposes. Literature shows the heat transfer coefficient between heat transferring surface and air is low which leads to lower thermal efficiency of the system. Therefore it is important to increase heat transfer coefficient between heat transferring surface and air. The most promising technique to enhance heat transfer coefficient is artificial roughness on heat transfer field. Artificial roughness applied on the absorber plate is the most acclaimed method to improve thermal performance of solar air heaters at the cost of low to moderate friction penalty. Experimental investigations pertinent to distinct roughness geometries unfolds that the enhancement in heat transfer is accompanied by considerable rise in pumping power. In view of the fact, a designer needs to carefully examine shape and orientation of roughness elements in order to choose the best fit roughness geometry for intended application.
This dissertation work will cover the types of technique used in enhancing the heat transfer coefficient in field of heat transfer and thermal efficiency.

KEYWORDS: Artificial roughness, Solar air heater, Roughness geometry, thermal performance.

I. INTRODUCTION

Energy plays an important role for economic and social development. Demand for energy has been rising rapidly with growing population, transportation and industrialization. Due to continuous use of fossil fuels, not only the energy starvation is felt at global level but another serious problem of environment degradation has also been resulted. The rapid depletion of conventional energy sources has necessitated search for alternative energy sources to meet the energy demand of immediate future and for generations to come.

The simplest and the most efficient way to utilize solar energy is to convert it into thermal energy for heating applications by using solar collectors. Solar air heaters, because of their inherent simplicity are cheap and most widely used collector devices. Solar air heaters are being used for many applications at low and moderate temperatures. Some of these are crop drying, timber seasoning, space heating, cooking etc.

Renewable energy sources that meet domestic energy requirements have the potential to provide energy service with zero or almost zero emission of both air pollutants and greenhouse gases. Renewable energy system development wil make it possible to resolve the presently most crucial tasks like improving energy supply reliability and organic fuel economy. Harvesting the renewable energy in decentralized manner is one of the options to meet the rural and small scale energy needs in a reliable, affordable and environmentally sustainable way.

Solar collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat and transfers this heat to a fluid(usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot

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water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night and/or cloud days.

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same are for intercepting and for absorbing solar radiation, whereas a sun-tracking concentration solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiver area, thereby increasing the radiation flux. A large number of solar collectors are available in the market. A comprehensive list is shown in table below.

Table 1. Solar energy collectors

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat plate collector (FPC)	Flat	1	30-80
	Evacuated tube collector (ETC)	Flat	1	50-200
	Compound parabolic collector (CPC)	Tubular	1-5	60-240
Single-axis tracking	Linear Fresnel reflector (LFR)	Tubular	10-40	60-250
	Parabolic trough collector(PTC)	Tubular	15-45	60-300
	Cylinder trough collector (CTC)	Tubular	10-50	60-300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100-100	100-500
	Heliostat field collector (HFC)	Point	100-1500	150-2000

The efficiency of conversion of incident solar radiation to useful heat energy greatly depends upon effectiveness with which absorber surface transfers the heat to the working fluid. The efficiency of solar air heaters is found to be low because of low convection heat transfer coefficient of the flowing air inside the duct. The absorber radiation energy by the absorber plate is not completely utilized by the air and leads to energy loss.

One of the most promising and economical method of increasing the heat transfer rate is providing the artificial roughness on the absorber plate, which creates turbulence in the flowing air. It has been found that the artificial roughness applied on the heat transferring surfaces breaks the viscous sub-layer, which reduces thermal resistance and promotes turbulence in a region close to artificially roughened surface RajkumarAhirwar and A.R. Jaurker[1]investigated heat transfer characteristics in solar air heater duct having three surfaces are smooth and top surface which absorb and transfer the heat is roughened by artificial roughness in V- shaped. The experimental parameters involve Reynolds number (Re) ranges from 2000 to 14000, Relative roughness pitch (p/e) 6 to12, for a fixed parameter relative roughness height (e/Dh) 0.036 and angle of attack of flow (α) 60°. The experiment conducted for four different roughened duct and smooth duct under similar geometrical and flow parameters. The experimental results show that the heat transfer increases with increasing the Reynolds number for smooth and roughened absorber plates, because of the higher turbulences. The presence of artificial roughness in the form of ribs gives higher heat transfer rate as compared to smooth duct. The maximum enhancement of heat transfer as compared to smooth is found on the relative roughness pitch (p/e) 10 in the range of present parameters under investigation Santosh B. Bopche and Madhukar S. Tandale [2] investigated heat transfer and frictional characteristics of a turbulator roughened solar air heater duct. Enhancement in the heat transfer and friction factor by 2.82 and 3.72 times, were reported respectively in the turbulator roughened duct. It is shown that maximum heat transfer enhancement can be achieved at affordable friction price.

ApurbaLayek J.S. Saini S.C. Solanki[3] investigated heat and fluid flow characteristics of fully developed turbulent flow in a rectangular duct having repeated integral transverse chamfered rib-groove roughness on one broad wall has been carried out. Experiments encompassed the Reynolds number range of 3000–21,000; relative roughness pitch of 4.5–10, chamfer angle of 5–30,relative groove position of 0.3–0.6 and relative roughness height of 0.022–0.04. The effect of roughness parameters on Nusselt number and friction factor have been discussed and the results are compared with the results of square rib-grooved and smooth duct under similar flow conditions. The conditions for the best performance have been determined. Correlations for the Nusselt number and friction factor have been developed as a function of roughness parameters and flow Reynolds number.

R.P. Saini and JitendraVerma [4] developed heat transfer and friction factor correlations for a duct having dimple shape artificial roughness on the underside of the absorber surface. The maximum value of Nusselt number has been found corresponds to relative roughness height (e/Dh) of 0.0379 and relative pitch (p/e) of 10. While minimum value of friction factor has been found correspond to relative roughness height (e/Dh) of 0.0289 and relative pitch (p/e) of 10. It is therefore suggested that, roughness parameters of the geometry are to be selected by considering the net heat gain and corresponding power required to force the air through the duct Sahu and Bhagoria [5] have investigated the effect of 90° broken wire ribs on heat transfer coefficient of a solar air heater duct. A pitch of 20 mm gives the highest thermal efficiency of 83.5% for and element height of 1.5 mm and reported heat transfer coefficient of roughened duct is 1.25 to 1.4 times compared to smooth duct under similar operating conditions at higher Reynolds number.

S. W. Ahn [6], made a comparison of fully developed heat transfer and friction factor characteristics has been madein rectangular ducts with ones roughened by five different shapes. The effects of rib shape geometries and Reynolds numbers are examined. The rib height-to-duct hydraulic diameter, pitch-to-height ratio, and aspect ratio of channel width to height are fixed at e/De =0.0476,P/e=8, and W/H=2.33, respectively. To understand the mechanisms of the heat transfer enhancements, the measurements of the friction factors are also conducted in the smooth and rough channels. The data indicates that the triangular type rib has a substantially higher heat transfer performance than any other ones in the range we studied.

S.V. Karmare, A.N. Tikekar[7] experimentally investigated the heat transfer to the airflow in the rectangular duct of an aspect ratio 10:1. The top wall surface is made rough with metal ribs of circular cross section in staggered manner to form defined grid. The roughened wall is uniformly heated and the other walls are insulated. This geometry of duct closely corresponds to that used in solar air heaters. The effect of grit geometry [i.e., relative roughness height of grid (e/Dh), relative roughness pitch of grit (p/e), relative length of grit (l/s)] on the heat transfer coefficient and friction factor is investigated. The range of variation of system parameters and operating parameters is investigated within the limits, as e/Dh: 0.035 to 0.044, p/e: 12.5–36 and l/s: 1.72–1, against variation of Reynolds number: 4000–17,000. It is observed that the plate of roughness parameters l/s = 1.72, e/Dh = 0.044, p/e = 17.5 shows optimum performance. Correlations for Nusselt number and friction factor in terms of above parameters are developed which reasonably correlate the experimental data.

A. R. Jaurker, J. S. Saini, B. K. Gandhi [8], experimentally investigated the heat transfer and friction characteristics of rib-grooved artificial roughness on one broad heated wall of a large aspect ratio duct shows that Nusselt number can be further enhanced beyond that of ribbed duct while keeping the friction factor enhancement low. The experimental investigation encompassed the Reynolds number range from 3000 to 21,000; relative roughness height 0.0181-0.0363; relative roughness pitch 4.5-10.0, and groove position to pitch ratio 0.3-0.7. the effect of important parameters on the heat transfer coefficient and frictio factor has been discussed and the results are compared with the results of ribbed and smooth duct under similar flow conditions. The investigation clearly demonstrates that the heat transfer cooffecient for rib-grooved arrangement as compared to that of rectangular transverse ribs of similar rib height and rib spacing. Correlations for Nusselt number and friction factor have been developed that predicts the value within reasonable limits.

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II. OBJECTIVES

To investigate experimentally the effect of wire geometry of thin circular wire used as artificial roughness as shown in figure 4.1on heat transfer coefficient and friction factor in solar air ducts.To investigate experimentally the effect of arcs with varying arc diameter (w/W)as artificial roughness on heat transfer coefficient and friction factor in solar air ducts as shown in figure 1 to 2. To investigate experimentally the effect of relative roughness pitch(p/e) 10 to 40, for a fixed parameter relative roughness height (e/D_h) 0.0243 and Reynolds number(Re) range from 3000 to 8000 for above roughness shapes. To develop correlations for heat transfer coefficient and friction factor in terms of roughness and operating parameters. To compare the above results with that of the smooth duct

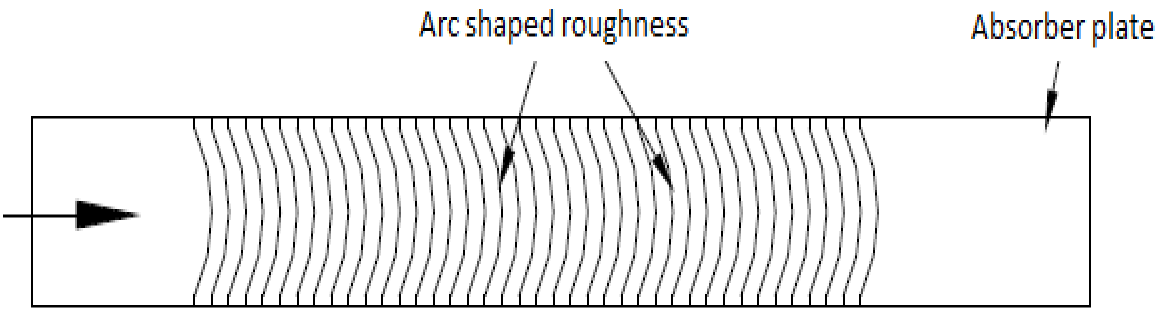

Fig.1.Arc shaped artificial roughness on absorber plate

Fig.1. shows the arc shaped artificial roughness for the creating turbulence in the air flow direction hence we can increase the heat transfer rate and thermal efficiency of the surface.

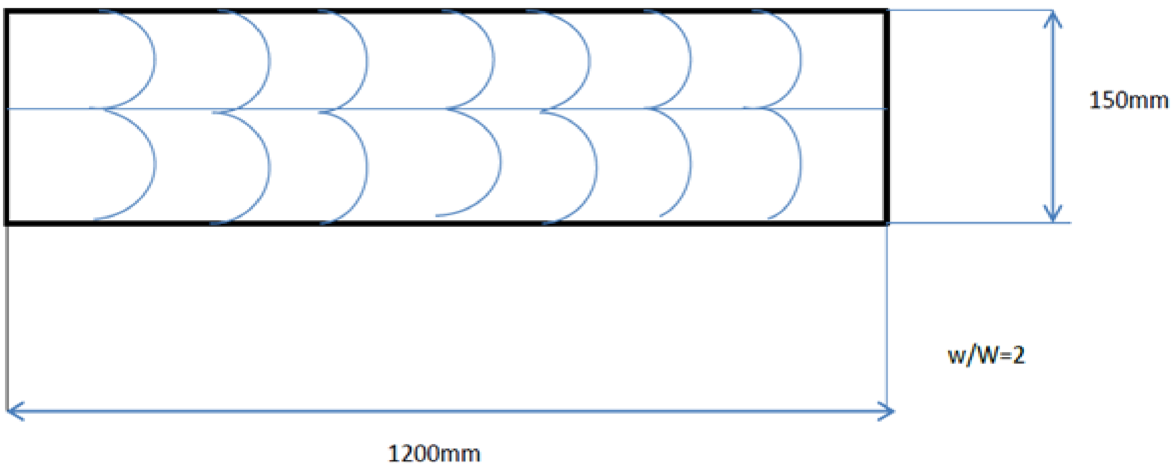

Fig.2. Arc shaped artificial roughness (w/W=2)

The experimental work carried out in the present study is based on creating artificial roughness on absorber plate to enhance the heat transfer coefficient between air flowing in the duct having one side as absorber plate. The indoor test facility has been designed and fabricated to generate heat transfer data at different airflow rates for a range of roughness parameters in rectangular duct. The range of parameters considered under the experimental study is as given in Table.

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Table 2. Range of parameters.

SI No	Parameters	Range
1.	Reynolds number(Re)	3000-8000
2.	Duct aspect ratio (W/B)	5
3.	Test-section length, L (mm)	1200
4.	Roughness height, wire diameter, e (mm)	1.219
5.	Hydraulic diameter of duct, D (mm)	50
6.	Relative roughness height, e/D	0.0243
7.	Relative roughness pitch, p/e	10 to 40
8.	Relative arc diameter, w/W	1,2,4,6

III. EXPERIMENTAL SETUP

The experimental setup is shown in Figure 5.1. The setup consists of smooth entrance section, roughened entrance section, test section, an exit section, mixing chamber, a flow meter and an air blower. The duct is of size 2600mm × 150mm × 30mm made of wooden panels. Test section is of length 1200mm. The length of smooth entrance section and exit section are 800mm and 600mm respectively. An electric heater is used to provide a uniform heat flux up to a maximum of 1500 W/m^2 to the absorber plate. The power supply to the heater is controlled through an AC variac.U-tube manometer is used to measure the flow rate of air using orifice meter. The duct is insulated from the three sides to ensure that all the heat flux which is supplied from the heater plate is transferred to the duct and also to minimize the losses to the surroundings. The other end of the duct is connected to a circular pipe via a rectangular to circular transition section. Calibrated chromel–alumel thermocouples are used to measure air and plate temperatures at various locations. Micrometer is used to measure the pressure drop in the test section.

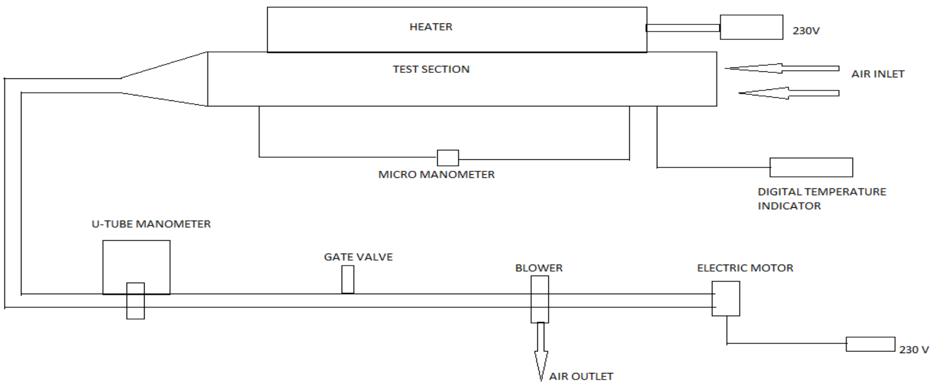

Fig.5.1. Experimental setup

IV. CONCLUSION

1. Use of artificial roughened surface with different type of roughness geometries is found to be the most effective technique to enhance the heat transfer rates from the heated surface to flowing fluid at the cost of moderate rise in fluid friction
2. In the entire range of Reynolds Number it is found that Nusselt number increases and friction factor decreases with an increase of Reynolds number in all the cases, Nusselt number and friction factor are significantly higher as

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compared to those obtained for smooth absorber plates. This is due to the distinct change in the fluid flow characteristics as a result of roughness that causes flow separation, reattachment and the generation of secondary flows.

3. For all the three roughness geometries (transverse, single arc, double arc) it was found that the Nusselt number increases as Reynold number increases, the maximum value of Nusselt number is found corresponding to relative roughness pitch (p/e) of 10, while the minimum value of Nusselt number corresponds to relative roughness pitch (p/e) of 40. The friction factor decrease as the Reynolds number is increased for all the relative roughness pitch (p/e) value, it is found to be maximum for relative roughness pitch (p/e) of 10 and minimum for (p/e) of 40.

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