Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

Thermal Efficiency of Solar Air Heater Having Transverse Rib Roughness Solar Air

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***Abstract*— Conventional (Flat plate) air heaters are found to have low thermal efficiency due to the low convective heat transfer coefficient (h) between the absorber plate and the flowing fluid (air), which leads into higher plate temperature and enhance the thermal losses hence its efficiency is lowered. Use of artificial roughness over the absorber plate of air heater duct is one of the important techniques to achieve this objective. In roughened solar air heaters , rib produces the turbulent in the flow as well as breaking the laminar-sublayer which is present in the flow then heat transfer coefficient increased between air and the absorber plate hence the overall performance of the duct increases as compared to smooth plate solar air heater duct. In the present work thermal and effective (thermohydraulic) efficiency analysis of transverse rib roughened solar air heater has been performed. A mathematical model was developed to compute the performance analytically; the programme codes are developed in MATLAB. Based on the computed results a suitable design or selection of geometrical, operating and flow parameters.**

Keywords*— Solar Air Heater, Solar Energy, Artificial Roughness, Efficiency

1. INTRODUCTION

For commercial & and domestic demands of energy attributed in growth and expansion of industries in the all countries of wide-world, energy plays a significant aspect in that cognizance. Therefore demand for energy resources is increasing day by day.

It becomes necessary to give importance to attain focus on utilization of continual energy (Non-conventional sources of energy) which turns in reduces the percentage of consumption of Non-conventional energy sources and fossil fuels up-to great extent.

Heat transfer coefficient of flat solar air heater can be increased by several ways like providing wire mesh as packing material, fins, artificial roughness in the form of small diameter wire on the absorber Plate, at air flow side as transverse direction with respect to the flow [1-2]. Kays [3] suggested that by using small diameter protrusion wires vertical to flow direction on surface of absorber plate may help to break laminar sub-layer.

Prasad and Mullick [4] applied and carried out an experimental study in order to- improve the thermal performance by using transverse rib on solar air heater duct. They found due to this wires improve plate efficiency factor from 0.63 to 0.72, which result in 14% improvement in thermal performance. Similarly Prasad and Saini [5] investigated the effect of transverse wire ribs on the heat absorber surface (absorber plate) in the form of small diameter wires of a solar heater duct.

Gupta et al. [6] investigated the thermo-hydraulic performance of solar air heater with inclined continious rib roughness surface by using the heat transfer and friction factor correlation developed by them.

An outdoor experimental investigation is performed by Verma and Prasad [7] for thermal and thermo-hydraulic performance of the transverse rib roughness and flow parameters for Reynolds number (Re) value of 5000–20,000.Relative roughness pitch (P/e) range of 10–40 and relative roughness height (e/D) value range of 0.01–0.03.

Momin et al. [8] used V-shaped roughness geometry as artificial roughness in their investigation and found that the V-shaped ribs having relative roughness height (e/D) of 0.034 and angle of attack (α) of 60o brought out 1.14 and 2.30 times enhancement in Nusselt number over the inclined smooth plate at Reynolds number (Re) value of 17,034. Similarly Karwa et al. [9] using chamfered rib, and Jaurker et al. [10] for rib-groove roughness on the absorber plate of solar air heater duct .Form the above literature survey it can be stated that the use of thin wire is used to create artificial roughness in the absorber plate of solar air heater duct which positively increase the thermal performance of solar air heater.

The different geometry is used by the different authors in terms of relative roughness height (e/D), relative roughness pitch (P/e), angle of attack (α) etc. in order to get maximum enhancement in thermal performance of roughened solar air heater.

The Present Work Has Been Taken Up With The Following Major Objectives:Development Of Analytical Or Mathematical Model For Artificially Roughened Solar Air Heater With Transverse Rib Roughness (Shown In Fig.1) Order To Find The Thermal And Themo-Hydraulic Performance.

To Study The Parametric Analysis And Its Effects Like Effect Of Reynolds Number (Re), Solar -Radiation (I), Wind Speed (Vw,) Relative Roughness Height (E/D), Relative Roughness Pitch (P/E), Duct Height (H) Etc. On Effective As Well Thermal Efficiency Of Roughened And Smooth Solar Air Heater.

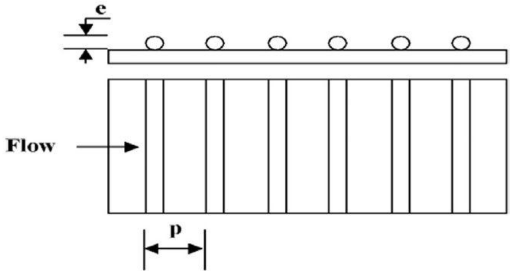

Fig.1. Transverse rib roughness.

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2. COMPUTATIONAL ANALYSIS

Effective efficiency is calculated by

$$\eta_{eff} = \frac{Q_u - \left(\frac{Wp}{C}\right)}{I \times A_c} \qquad 1$$

The rate of useful thermal energy gain and mechanical power (P) spent has been obtained by:

$$Qu = [I(\tau\alpha) - U_l(T_{pm} - T_a)/2]A_cF_R \qquad 2$$

F_R ,is the heat removal factor of the solar air heater , which is calculated as;

$$F_R = \frac{mC_p}{A_cU_l}\left[1 - \exp\left[\frac{F'U_lA_c}{mC_p}\right]\right] \qquad 3$$

F´ is the collector efficiency factor which is calculated as;

$$F' = \frac{h}{h + U_l} \qquad 4$$

The thermal efficiency of solar air heater is calculated as:

$$\eta_{th} = \frac{Q_u}{IA_c} \qquad 5$$

Mechanical power (WP) is calculated as:

$$W_P = VA_c\Delta P \qquad 6$$

The Value of pressure drop across the collector is calculated as:

$$\Delta P = \frac{2fLV^2\rho}{D} \qquad 7$$

The values of heat transfer coefficient, (h) and friction factor, (f) for smooth solar air heaters have been evaluated by [7];

$$Nu_s = 0.024\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \qquad 8$$

Friction factor, (fs) for smooth solar air heaters is calculated by;

$$f_s = 0.085\,\mathrm{Re}^{-0.25} \qquad 9$$

The values of heat transfer coefficient, (h) for transverse rib roughened solar air heaters have been determined by the correlations developed for heat transfer by [7] which is given by;

$$Nu_r = 0.08596\left(\frac{P}{e}\right)^{-0.054}\left(\frac{e}{D}\right)^{0.072}\mathrm{Re}^{0.723} \qquad 10$$

For $e^+ \leq 24$

$$Nu_r = 0.02954\left(\frac{P}{e}\right)^{-0.016}\left(\frac{e}{D}\right)^{0.021}\mathrm{Re}^{0.802}$$

For $e^+ > 24$

Friction factor, (f) for transverse rib roughened solar air heaters have been determined by the correlations developed by [7] which is given by;

$$f = 0.245\left(\frac{P}{e}\right)^{-0.206}\left(\frac{e}{D}\right)^{0.0243}(\mathrm{Re})^{-1.25} \qquad 11$$

2. SOLAR AIR HEATER AND DIFFERENT PARAMETERS FOR ANALYSIS

The values of parameters considered under the present investigation are:

Table. 1. The values of parameters considered under the present investigation are:

Parameters	Symbol	Value /Range	Unit
System parameters			
Collector length	L	1.5	m
Collector width	W	0.8	m
Height of Duct	H	0.04	m
Thickness of insulation		0.05	m
Thermal conductivity of insulation	Ki	0.037	W/m K
Number of glass covers	N	1	W/m K
Emissivity of absorber plate	ε_p	0.9	
Emissivity of glass cover	ε_g	0.88	
Transmittance-absorptance product	$\tau\alpha$	0.80	
Angle of attack	α	90°	
Relative rib height	e/D	0.0145-0.0220	
Relative roughness pitch	p/e	10-40	
Overall heat loss coefficient	U_l	4-10	W/m² K
Operating parameters			
Ambient air temperature	T_a	310	K
Intensity of solar radiations	I	9000-1200	W/m2
Variable parameters			
Temperature rise parameter	$\Delta T /$	0.002-0.02	K/m2 W
Reynolds number	Re	8000 – 28,000	

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4. RESULTS AND DISCUSSIONS

Below Figs. show the plot of thermal efficiency (η_{th}) verses temperature rise parameter (ΔT/I) with varying relative roughness height (e/D). The fixed parameter is insolation (I) and relative roughness pitch at (P/e=10), P/e is keeping 10, because at this value heat transfer coefficient is maximum reported by authors [7].

It is seen from; Fig.2 that thermal efficiency of transverse rib roughened solar air heater is superior then the smooth plate solar air heater for all the values of temperature rise parameter. It is also can be seen that thermal efficiency is decreases with increase in temperature rise parameter for all the values of relative roughness height.

For all the values of relative roughness height, e/D=0.0220 shows the highest value of thermal efficiency which is used for the present investigation, it happens due to, increase in the value of relative roughness height enhance the barrier to the flow and hence more vortices and turbulent is occurred, which increases the heat transfer coefficient (h) between the air and absorber plate, so there is increase in overall thermal performance of the roughened solar air heater. The fixed parameter is taken as P/e = 10 and Intensity or radiation is 900 W/m^2.

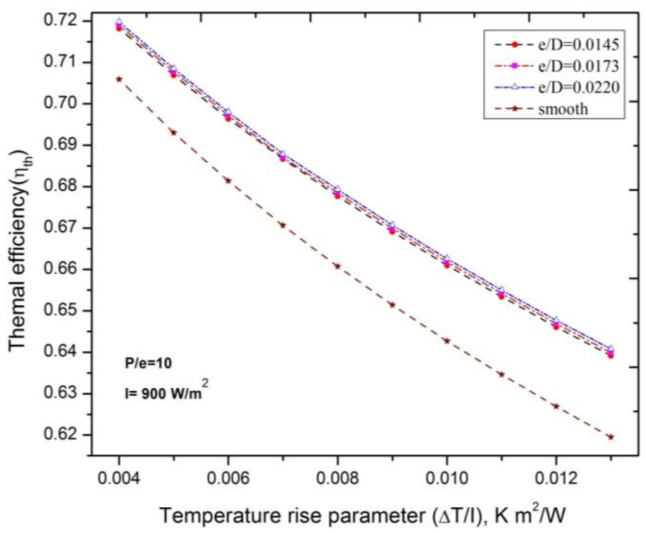

Fig.2. Thermal efficiency as a function of temperature rise parameter and relative roughness height (e/D)

Fig.3 shows the plot of thermal efficiency (η_{th}) verses Reynold number (Re) with varying relative roughness height (e/D). The fixed parameter is insolation (I) and relative roughness pitch at (P/e=10), P/e is keeping 10, because at this value heat transfer coefficient is maximum reported by authors [6].

It can be seen from; Fig.3 that thermal efficiency of roughened solar air heater is higher over the flat plate solar air heater for all the values of Reynolds number. The thermal efficiency is increases with increase in Reynolds number (Re). At higher Reynolds number more turbulent flow is occurred or produced which results in more increase in heat transfer coefficient, hence thermal efficiency is enhances.

For all the values of relative roughness height, e/D=0.0220 shows the highest value of thermal efficiency among the all which is used for the analysis.

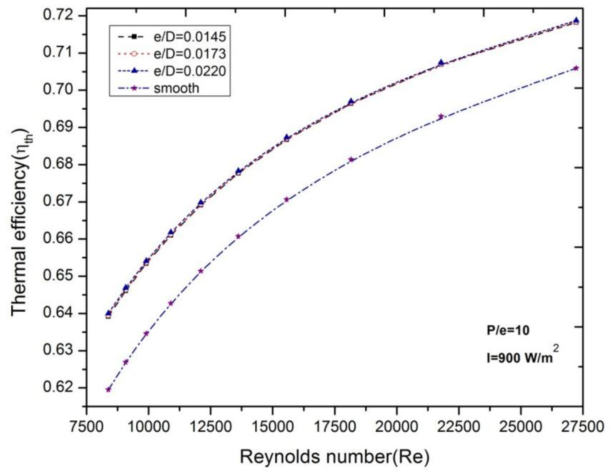

Fig.3. Thermal efficiency as a function of Reynolds number and relative roughness height (e/D)

Fig.4. shows the plot of thermal efficiency (η_{th}) verses temperature rise parameter (ΔT/I) with varying relative roughness pitch (P/e). The fixed parameter is insolation (I = 900 W/m^2) and relative roughness height at (e/D=0.0220), e/D is having 0.0220, because at this value heat transfer coefficient is maximum reported by authors [7].

It can be seen (Fig.4.) that thermal efficiency is decreases with increase in temperature rise parameter. For all the values of relative roughness pitch, P/e=10 shows the highest value of thermal efficiency, due to increase in relative roughness pitch there is reduction in the reattachment points which decreases the heat transfer coefficient hence thermal performance of the roughened solar air heater decreases. The rough solar air heater has the higher value of thermal efficiency as compare to smooth plate positively.

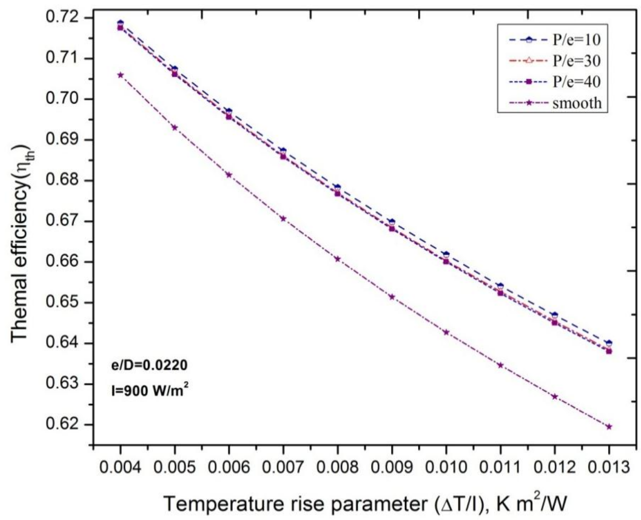

Fig.4. Thermal efficiency as a function of temperature rise parameter and relative roughness pitch (P/e)

Fig.5. shows the plot of thermal efficiency (η_{th}) as a function of Reynolds number (Re) with varying relative roughness pitch (P/e). The fixed parameter is insolation (I) and relative roughness height at (e/D=0.0220).It can be seen (Fig.5.) that thermal efficiency is higher than the smooth plate solar air heater for all the values of P/e.

Also it can be concluded that thermal efficiency increases with increase in Reynolds number (Re). For all the values of relative roughness pitch, P/e=10 shows the highest value of thermal efficiency over the other values of relative roughness pitch.

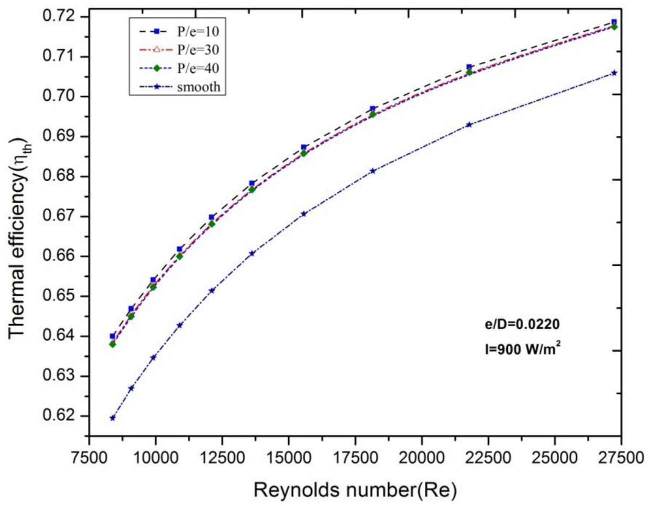

Fig.5. Thermal efficiency as a function of Reynold number and relative roughness pitch (P/e)

5. CONCLUSIONS AND FUTURE SCOPE

Various parametric analyses, has been done to know its effect on thermal as well as thermohydraulic performance of transvers rib roughened roughness solar air heater with help of mathematical modelling. The following conclusions can be drawn from the above investigations:

1. The geometrical and flowing parameter of roughness i.e relative roughness height (e/D), relative roughness pitch (P/e), angle of attack (α) and Reynolds number (Re) significantly affects the both (i.e. thermal and thermohydraulic) performance.
2. Thermal efficiency increases with increase in Reynolds number.
3. Thermal efficiency decreases with increase in temperature rise parameter.
4. The highest values of Thermal efficiency is reported corresponding to the relative roughness height (e/D) and relative roughness pitch (P/e) value of 0.0220 and 10 respectively, which is also reported by (Verma and Prasad 2000) through there experimental investigation hence it is the validation of the programme.

6. FUTURE SCOPE

1. Optimization of the various parameters collectively using Taguchi method and other optimization tools.
2. Exergy analysis of transverse roughened solar air heater.

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