Thermal and Effective Efficiency of V Shape Wire Ribs Solar Air Heater Duct

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Abstract— In the present work thermal and thermohydraulic efficiency analysis of v shape wire rib artificially roughened solar air heater (SAH) has been performed. The present result, different data, plots can be used for the design and analysis for v shape wire rib roughened SAH. The main results and conclusions of present investigation are as follows: Solar air heaters with V-shape roughness geometry with using different diameters wire ribs as roughness elements on the absorber plate are more efficient than conventional or flat plate type of solar air heaters. The highest thermal efficiency obtained for roughened SAH 78.7 % for e/D = 0.032, Re = 19970 and I = 800 W/m2.Thermal or energy efficiency as well as thermohydraulic or effective efficiency of roughened SAHs strongly depends on the operating, geometrical and flow parameters.

Key words: Thermal Efficiency, Effective Efficiency, V Shape Roughness

I. Introduction

The energy having important role due to, increasing and to fulfil needs of present societies along with withstand vastly economic and industrial growth worldwide. There are limited renewable energy resources, rapid utilization, and degradation of conventional energy sources have made a need to think in the direction to uses of various Non-renewable energy sources i.e. wind, geo-thermal, hydro-power and Solar etc as shown in The present available energy resources can be categorised into, mainly two group's i.e. primary conventional energy sources like: fossil fuels, coal, crude-oil, and other Petroleum products etc. & secondary energy resources like: coke, biodiesel, wood logs (described in Fig.1). The key and huge percentage demands of energy needs are fulfilled by these primary and secondary sources.

Figure 1, depicts the various losses like conversion, distribution, consumer etc. For increased various commercial and domestic need of energy attributed in growth and increase of industries in the all countries of wide-world, energy has a significant aspect in that cognizance.

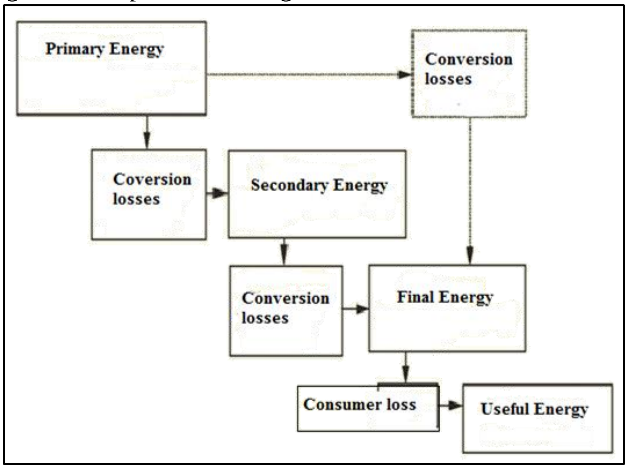

Fig. 1: Energy resources and its conversion chain.

II. Solar Energy

Solar energy is one of the auspicious and simply convertible forms of renewable energy available in plenty on earth. At present the investigators is to make solar energy as the primary source of energy world-wide.

Over the other energy resources solar energy have many benefits which make it most important like availability. It is the freely available and inexpensive source of energy, Non-damage and pollution to the atmosphere etc. The quantity of solar energy, which is reached on the earth's surface, is more than in several times over the energy consumption by all devices on the earth put composed.

A. *Conventional Solar Air Heater*

Conventional solar air heater is a heat exchange device that with smooth absorber plate which traps the incident solar radiation energy on its absorber plate surface area which is used to capture the sun's radiation through the transparent glass cover. Solar air heaters are widely employed and used due to its simplicity and low manufacturing cost. It is mostly used in the area where low moderate temperature is needed. The thermal efficiency of solar air heaters has Low because of low heat transfer capability between the absorber plate and air flowing in the duct of solar air heater.[1-2]

Solar air heaters are used for moderate temperature applications up to perhaps 100°C above ambient temperature. The major applications of these units are in solar air heating, buildings, Space heating, Crop drying, Timber seasoning and in some industrial applications.

III. Literature Survey

Performance of flat solar air heater can be increased by providing artificial roughness in the form of fine diameter wire on the absorber Plate at air flow side as transverse direction with respect to the flow. The wires can be attached on the absorber plate by the means of gluing materials or by soldering. The thin wire on the absorber plate break the laminar Sub-layer and create turbulence adjacent to the wall and create vortices which result in increased the heat transfer between the fluid (air) and the absorber plate and hence heat transfer coefficient get enhanced then it leads to overall increased in thermal performance of Solar air heaters.

Prasad and Mullick [3] applied and carried out an experimental study in order to- improve the thermal performance of solar air heater duct. The experimental study was conducted using relative roughness height (e/D) value of 0.019 and relative roughness pitch (P/e) value of 12.7. They found due to this wires improve plate efficiency factor from 0.63 to 0.72, which result in 14% improvement in thermal performance.

Fig. 2, Shows the geometry of the transverse rib roughness.

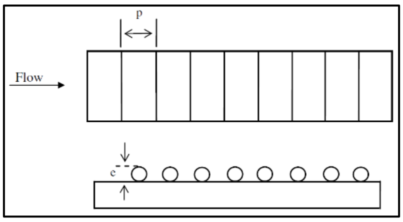

Fig. 2: Transverse rib roughness

Gupta et al. [4] investigated the thermo-hydraulic (through analytical investigation) performance in terms of effective efficiency (Cortes and Piacentini 1990 [5] of solar air heater with inclined continious rib roughness surface by using the heat transfer and friction factor correlation developed by them. The parameters relative roughness height (e/D) value range of 0.023-0.05, Reynolds number (Re) value range of 4,000-18,000, solar intensity (I) value range of 400–1300 W/m2 ,angle of attack (α) value of 60°.

Fig. 2, shows the geometry of the inclined rib roughness.

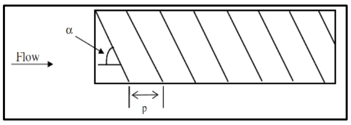

Fig. 2: Inclined rib roughness.

Momin et al. [6] 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. Fig. 3. Shows, the geometry of the V-shaped wire rib roughness.

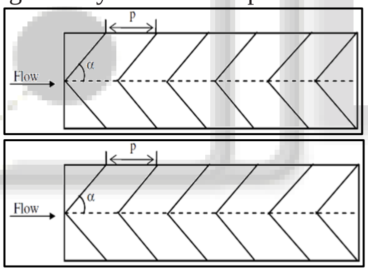

Fig. 3: Geometry of V-shaped rib roughness.

Aharwal et al. [7] explored the effect of gap in continious inclined ribs in rectangular solar air heater duct. The improvement in Nusselt number and friction factor was found in the range of 1.48–2.59 times and 2.26–2.9 times over the smooth duct respectively for the range of Reynolds number (Re) from 3000 to 18,000. Corresponding to a relative gap width (g/e) value of 1.0 and relative gap position (d/W) value of 0.25, the heat transfer, friction factor ratio (f/fs) and thermo hydraulic performance parameters were found supreme.

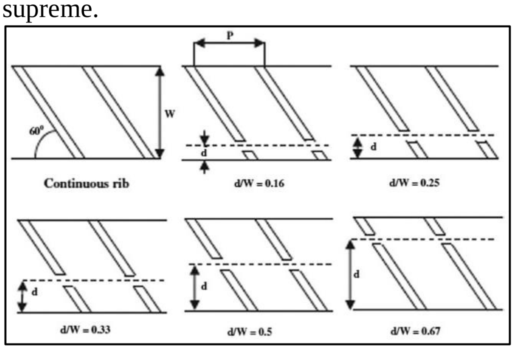

Fig. 4: Inclined rib with gap roughness geometry

Fig.4. shows the inclined rib with gap roughness geometry.

A. *Literature Survey and Research Gap*

A lot of work has been done in the field of solar air heater through experimental investigation. Few researchers have worked on the different roughness geometries for the aim to enhance the efficiency of conventional solar air heater. Still there is large scope of work in this field. Sufficient parametric analysis has not been done to predict the effect of geometrical parameters on the performance of solar air heater provided with transverse rib artificial roughness. No work has been done to predict the performance by varying the relative roughness height (e/D), relative roughness pitch (P/e), Reynolds number (Re), Mass velocity of air (G), and effect of Insolation (I) collectively. Codes have been developed in MATLAB and generated data's are recast and used to generate graphs for the graphical representation and analysis.

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 V-shaped wire Rib roughness in 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,) etc

B. *Solution Procedure*

The effective efficiency takes in account the fan work (Wp) by minus the equivalent thermal energy from useful heat gain (Qu) by air heater to obtain net thermal energy gain. The effective efficiency [5] is evaluated as ratio of thermal energy gain of solar air heater to the falling incident solar radiation on the absorber plate.

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

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

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

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

$$F_R = \frac{mC_p}{A_c U_l}\left[1 - \exp\left[\frac{F'U_l A_c}{mC_p}\right]\right] \quad (3)$$

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

$$F' = \frac{h}{h + U_l} \quad (4)$$

The thermal performance of solar air heater is calculated as [8]

$$\eta_{th} = \frac{Q_u}{IA_c} \quad (5)$$

C. *Mechanical and Pressure Drop*

Mechanical power (W_P) is calculated as:

$$W_P = VA_c\Delta P \quad (6)$$

The Value of pressure drop (ΔP) in the duct is calculated as:

$$\Delta P = \frac{2fLV^2\rho}{D} \quad (7)$$

Where hydraulic diameter (D) of the duct and is calculated by:

$$D = \frac{2(W \times H)}{W + H} \quad (8)$$

D. Heat Transfer Coefficient and Friction Factor

The values of heat transfer coefficient, (h) and friction factor, (f) for smooth solar air heaters have been evaluated by [1-2];

$$Nu_s = 0.024\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \quad (9)$$

Therefore

$$h = \frac{Nu_s k}{D} \quad (10)$$

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

$$f_s = 0.085\,\mathrm{Re}^{-0.25} \quad (11)$$

The values of heat transfer coefficient, (h) for v shaped rib roughened solar air heaters have been determined by the correlations developed by [6] which is given by;

$$Nu_r = 0.067\left(\frac{e}{D}\right)^{0.424}\left(\frac{\alpha}{60}\right)^{-0.077} \quad (12)$$

$$.\exp[-0.782(\ln\alpha/60)^2]\,\mathrm{Re}^{0.888}$$

The heat transfer coefficient (h) for roughened solar air heater is calculated as;

$$h = \frac{Nu_r k}{D} \quad (13)$$

Friction factor, (f) for v shaped rib roughened solar air heaters have been determined by the correlations developed by [6] which is given by;

$$f = 6.266.(\mathrm{Re})^{0.425}\left(\frac{e}{D}\right)^{0.565}\left(\frac{\alpha}{60}\right)^{-0.093} \exp[-0.719(\ln\alpha/60)^2] \quad (14)$$

Reynolds number evaluated by using the equation;

$$\mathrm{Re} = \frac{mD}{\mu W H} \quad (15)$$

Where, μ is the dynamic viscosity of air (N s/m²)

E. System Parameters

Parameters	Symbol	Value and Range	Unit
System parameters			
Collector length	L	1.5	m
Collector width	W	1.0	m
Height of Duct	H	0.030	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	0.90	
Emissivity of glass cover	ε_g	0.85	
Transmittance-absorptance product	$\tau\alpha$	0.85	
Angle of attack	α	30-90	
Relative rib height	e/D	0.020-0.034	
Relative roughness pitch	P/e	10	
Overall heat loss coefficient	U_l	4-10	W/m² K
Operating Parameters Fixed			
Ambient air temperature	Ta	301	K
Intensity of solar radiations	I	900-1200	W/m²
Variable Parameters			
Temperature rise Parameter	$\Delta T/I$	0.0061-0.061	K/m² W
Reynolds Number	Re	1600 - 20,000	

Table 1: The Values of Parameters Considered for the Present Investigation:

IV. RESULT AND DISCUSSION

A. Effect of relative roughness height

Effect of temperature rise parameter (ΔT/I) on thermal efficiency (Ƞth) of rough as well as smooth plate solar air heater is shown in Fig.5. The fixed parameter is insolation (I) and relative roughness pitch as P/e = 10, angle of attack α = 60°.

It can be seen from; Fig.5 that thermal efficiency of V- shape rib roughened solar air heater is higher than the smooth plate solar air heater for all the values of temperature rise parameter.

It also can be seen that thermal efficiency is decreases with increase in temperature rise parameter for all the values of relative roughness height.

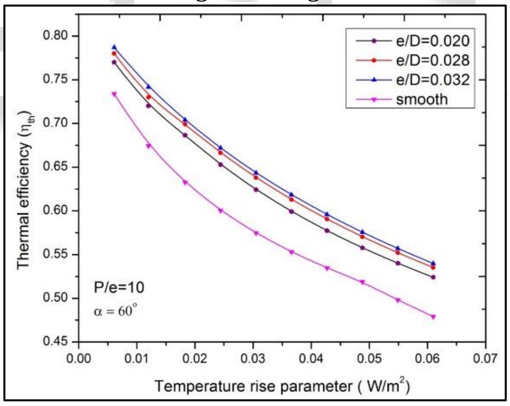

Fig. 5: Thermal efficiency as a function of temperature rise parameter and relative roughness height (e/D)

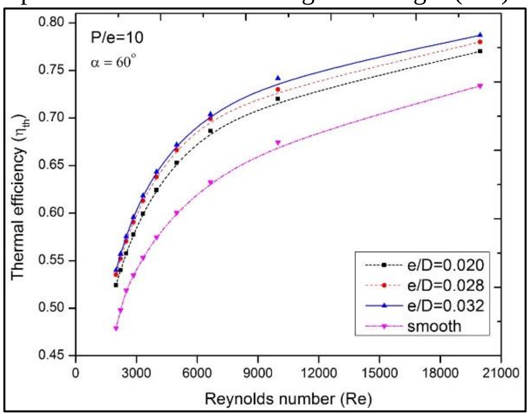

Fig. 6: Thermal efficiency as a function of Reynolds number (Re) with different relative roughness height (e/D) for I= 800 W/m².

Fig.6 shows the design plot of effect of e/D on thermal efficiency (Ƞth) with Reynold number (Re). The fixed parameter is insolation (I), relative roughness pitch P/e, relative angle of attack α, are shown in the Fig. At these values authors reported maximum enhancement.

It can be seen from; Fig.6 that thermal efficiency of v shape roughness solar air heater is higher as compared to the flat plate solar air heater for all the values of Reynolds number.

B. Effect of angle of flow attack

At the last model summery table have also been presented which shows the 98.04 % of R2 which shows the accuracy of the present model results.

Fig.7. shows the plot of thermal efficiency (Ƞth) verses temperature rise parameter (ΔT/I) with different values of angle of flow attack (α). The fixed parameter is insolation I = 800 W/m2, relative roughness height at e/D = 0.020, relative roughness Pitch P/e = 10.

The angle of attack values are taken as three different values of 30, 45 and 60°.

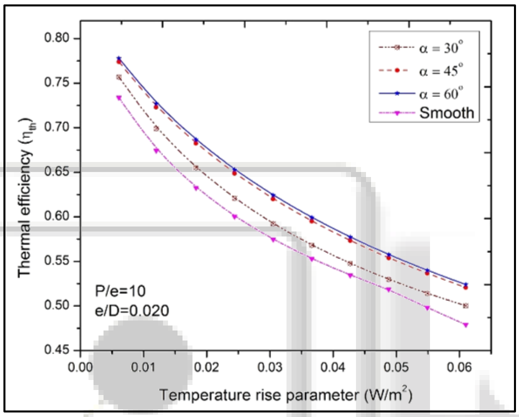

Fig. 7: Thermal efficiency as a function of temperature rise parameter and relative angle of attack (α).

It is cleared from Fig 7 that thermal efficiency is decreases with increase in temperature rise parameter and increases with increase in the value of angle of attack. For all the values of relative angle of attack (α) = 60° shows the highest value of thermal efficiency over the other two values of relative angle of attack (α).

It can be clear from Fig. 7 that, thermal efficiency of rough solar air heater is higher than the smooth plate solar air heater for all the values of angle of attack (α). Also it can be concluded that thermal efficiency increases with increase in Reynolds number (Re)

For all the values of relative angle of attack, α = 60° shows the highest value of thermal efficiency 78 % (approx.) over the other values of relative angle of attack.

V. MECHANICAL POWER ANALYSIS

Fig. 8 shows the effect of different relative roughness height (e/D) on Mechanical power of the blower fan. The fixed parameter is insolation (I) and other parameters are shown in Fig. 9.

Fig. 9 shows the graph of Mechanical power consumption (Pm) as a function of Reynolds number (Re) with different values of relative angle of attack (α). The fixed parameter is insolation (I), e/D and P/e are shown in Fig. 9.

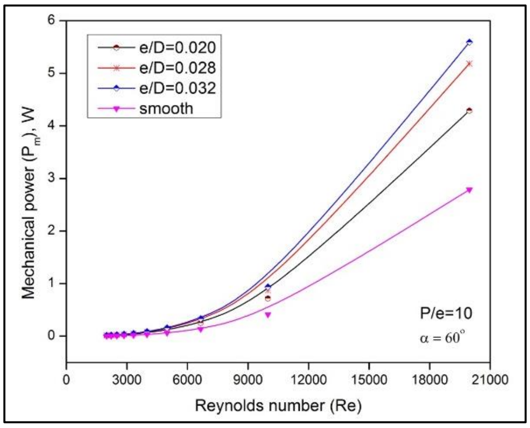

Fig. 8: Plot of Mechanical power as a function of Reynolds number with different relative roughness height (e/D).

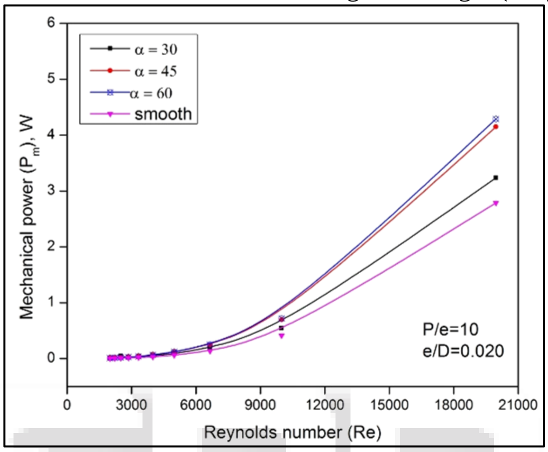

Fig. 9: Plot of mechanical power as a function of Reynolds number with different relative angle of attack (α).

It can be seen from Fig.9 that, Mechanical power consumption, of present roughness geometry having α = 60 ° is higher as compared to other values of α and smooth plate SAH.

VI. EFFECTIVE EFFICIENCY ANALYSIS

In previous section we have seen that e/D = 0.032 and α = 60° have the highest thermal efficiency and also Mechanical power so in that case we should have one factor upon which we can decide that which roughness configuration have also economically feasible. Cortes and Piacentini [5] gave the performance criteria which include the both factors i.e. Thermal energy gain and Mechanical power simultaneously.

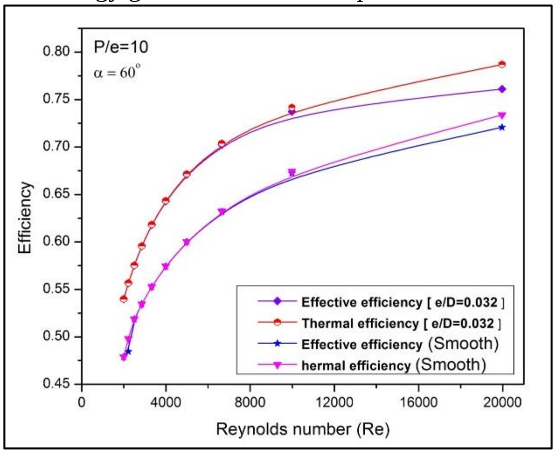

Fig. 10: Comparison of thermal and effective efficiency as a function of Reynolds number for rough and smooth SAH.

Fig 10 and 11 demonstrates that, the effective efficiency analysis of roughened SAH with Reynolds number as a function of relative roughness height (e/D) and relative angle of attack (α) respectively.

We can see from Fig. 9 that at higher value of Re > 10,000 effective efficiency is decreases for both i.e. rough and smooth SAH as compared to the thermal efficiency factor. It is also seen that effective efficiency is increases with increase in Reynolds number up to maximum value, after reaching its higher value it starts decreasing.

Fig.11 shows the plot effective efficiency (Ƞeff) and thermal efficiency with Reynolds number at highest values of relative angle of attack (α). The fixed parameter is insolation (I) and other parameters are shown in Fig.11

It also can be seen that at higher Re no. the highest effective efficiency is 75.7% at Re = 19,970 which is 2% (approximate) less than thermal efficiency at higher values of Re the gap may be increase more due to increase in Mechanical power loss.

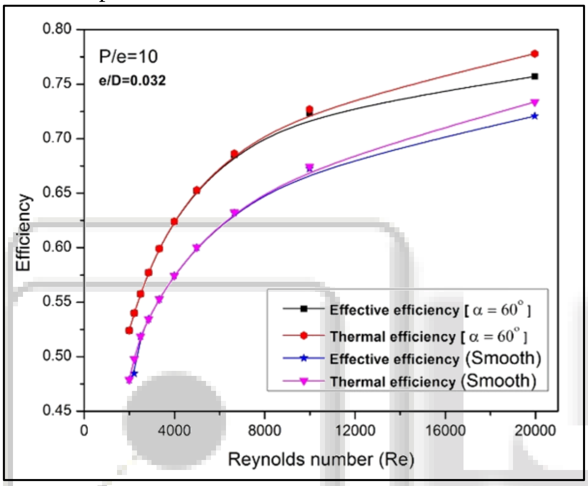

Fig. 11: Comparison of thermal and effective efficiency as a function of Reynolds number for rough and smooth SAH.

VII. Conclusion

Various detail parametric analyses, has been done to explore the effect of various parameters on thermal as well as thermohydraulic performance of v shape wire rib roughened solar air heater analytically with help of mathematical model. The following conclusions can be drawn from the present investigations:

The geometrical and flowing parameter of roughness i.e. relative roughness height (e/D), relative angle of attack (α), Reynolds number (Re) and mass flow rate (m) temperature rise parameter significantly affects the thermal and thermohydraulic performance.

Thermal efficiency performance enhances with increase in the Reynolds number due to more turbulence.

Thermohydraulic or effective efficiency increases with Reynolds number up to its supreme value, after that it decreasing with further increase in Reynolds number.

Effective efficiency value decreases at higher value of Re no. because at higher Re no. pumping power is increases significantly hence it lowered the thermal performance

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