HEAT TRANSFER ENHANCEMENT OF WAVY FINNED SOLAR AIR HEATER

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Abstract : Fossil fuels have become the part and parcel of our lives, which are the major source of energy. Among the different renewable energy resources, solar energy is the most important due to its quantitative abundance. One of the applications of solar energy to convert it into thermal energy is Solar air heater. Solar air heater is simple, cheap and most widely used collection devices of solar energy. A simple solar air heater has a low thermal performance as it has lower heat transfer coefficient between absorber plate and the carrier fluid(air). So, extended surface is attached to the absorber plate to overcome the lower thermal performance. Our aim of is to improve the efficiency of a solar flat plate collector by using wavy fins attached to the absorber plate. It mainly focuses on the heat augmentation and increase in efficiency with fins. In order to increase the heat transfer rate and efficiency, wavy fins are used. By varying air mass flow rates from 250 kg/hr to 350 kg/hr it is found that effective heat transfer coefficient is maximum for highest for 350 kg/hr . In addition the friction factors are lowest and pressure drops are highest with largest Reynolds number. The thermal performance of conventional Solar Air Heater and wavy fin Solar Air Heater are done analytically and the results were compared and the best configuration of Solar Air Heater is suggested for drying applications.

***IndexTerms* – Solar Air Heater,Wavy fins,mass flow rate,Efficiency,Pressure drop.**

I. INTRODUCTION

Energy is the most important factor in man's dominance over nature and is a significant factor in boosting economic development of a region and its availability is considered more important as that eventually leads to self-sufficiency in energy requirement. The reserves of natural gas, petroleum and coal will be exhausted in the very near future. Energy crisis has made us aware that our total dependence only on one form of energy is not a wise step. The ultimate solution of the world energy crisis will be the alternate sources which are non-conventional, non-polluting and practically inexhaustible in nature. India has a vast potential of renewable energy sources and a number of technologies have been developed to harness them. Renewable energy technologies, as well as energy conservation strategies, offer alternatives to fossil fuel use, which not only has constraints in terms of resource availability, but also is always accompanied by environmental deterioration. A simple solar flat plate collector consists of an absorber plate,transparent cover,air duct. This the simplest and most commonly used type since it is integrated with one or two glassing over a flat plate absorber, using low thermal conductivity insulation materials. The solar radiations pass through the transparent cover or covers and impinge on the blackened absorber plate and then transfer to the air flowing beneath the absorber plate. The air flow path may either be above or at a lower place or both above and below the absorber plate. These have found several applications including space heating,crop drying,ventilation.The heat transfer co-efficient is increased by using fins attached to the absorber plate, and in certain designs, the surface is made directionally selective. The fin configurations are louvered, offset Strip, perforated,rectangular,wavy,triangular fins. The Solar energy is more effective for food drying because it is diffuse in nature and provides low grade heat. This characteristic of solar energy is good for drying at low temperature,high flow rates with low temperature rise.

Yeh and Hou [1] conducted theoretical and experimental investigations to evaluate the effect of fins on either sides of the absorber plate with double pass arrangement. The authors have developed a mathematical model based on energy balance criteria to predict the thermal efficiency. They also concluded that the use of fins on a double pass air heater system had negligible effect on the pressure drop across the air duct and hence was an economically feasible option for heat transfer enhancement.
Alta et al. [2] investigated experimentally three different types of solar air heaters; two having fins and the other without fins, one of the heaters with a fin had single glass cover and the other had double glass covers. Based on the energy and exergy output rates, they concluded that, the heater with double glass covers and fins is more effective and the difference between the input and output air temperature is higher than others.
Priyam and Chand [3] have shown that the wavy fins can be very effective in enhancing heat transfer in a solar air heater..The authors found that the wavy finned collector provides higher thermal performance relative to the smooth duct. The maximum increase in thermal efficiency and effective efficiency due to wavy fins was found to be about 63.41 % and 35.83 % respectively relative to the smooth duct.

Naphon [4] developed mathematical models to predict the thermal characteristics and entropy generation of double pass solar air heater fitted with longitudinal fins on both sides of the absorber plate for the flow rates ranging from 0.02 to 0.1 kg/s. The results showed that the thermal efficiency increases and entropy generation decreases with increasing number of fins and fin height.

Karim and Hawlader [5] experimentally investigated the thermal performance characteristics of solar air heater fitted with V-corrugated absorber plate used for drying applications.The analysis shows that the V-corrugations provide 12% higher efficiency than a flat plate absorber. The flow rate of 0.035 kg/m2s was recommended for drying applications at which the efficiency and outlet temperature of air were at higher levels.

M Charishma Brunda[6] numerically investigated the thermal performance of wavy finned solar air heater for drying applications. The analysis shows that effective heat transfer coefficient is maximum for mass flow rate of 350 kg/hr . In addition the friction factors are lowest and pressure drops are highest with largest Reynolds number.

Eshan Kumar Nashine,P.S.Kishore[7] numerically investigated the compound parabolic collector for the application of process steam generation.The performance analysis of the system shows potential of improving the thermal efficiency upto 75%.The analysis has done taking two cities i.e., Visakhapatnam and Mumbai.

Sunkaranam Revathi,P.S.Kishore[8] in their study,an Air based Photovoltaic Thermal Collector with a MonoCrystalline Photovoltaic Module was designed for the climatic conditions of Banglore, India and its electrical and Thermal performance are analyzed with the experimental results.Based on the climatic data,the Experiment has been carried and the results indicated the thermal and Electrical Efficiencies from the month of January to December on average were 43% and 11% respectively.

Gade Bhavani Shankar,P.S.Kishore[9] in their study investigated the thermal performance of Conventional solar air heater under varying solar and ambient conditions in different months.A parametric study was done for 10 months for Climatic conditions of Visakhapatnam.The effect of change in the tilt angle and mass flow rate on the temperature of collector has been studied. The thermal efficiency range shows from 31% to 47%.

II.DESCRIPTION AND WORKING OF WAVY FINNED SOLAR AIR HEATER

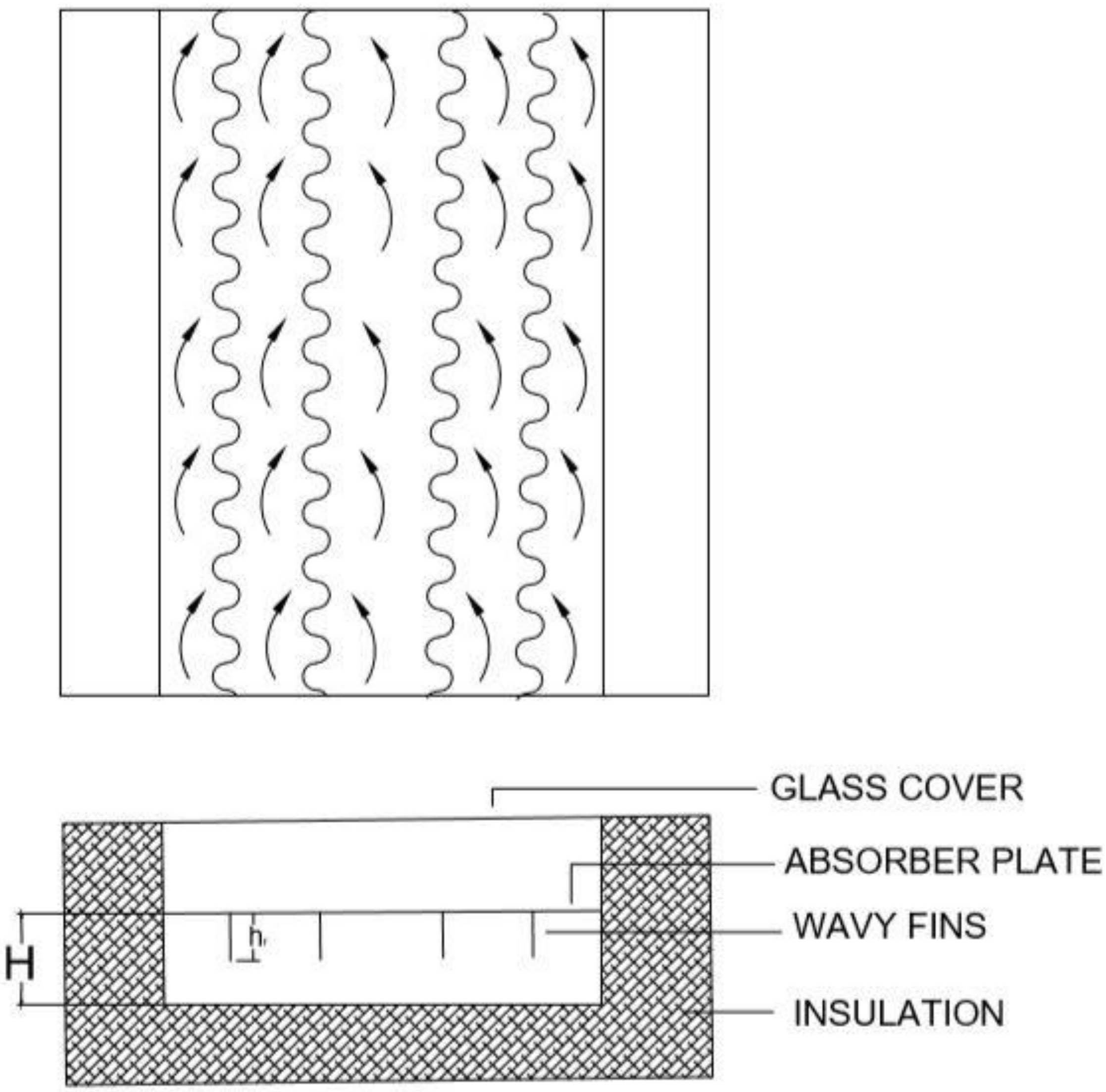

Fig1: Wavy finned Solar Air Heater

Fig.(1 shows the representation of wavy finned solar air heater. It consists of transparent glass cover, absorber plate attached with wavy fins placed on its topside. In this system air is used as a working fluid.

In this system the sunlight hits the transparent cover and next on to the absorber plate. The absorber plate is a thin rectangular shaped sheet with its top surface typically painted black for maximum solar radiation absorption. The absorber plate is usually made of aluminium or copper to ensure higher thermal conductance characteristics. The fan sucks the cold air into the duct and as it passes the heat which strikes the plate heats up the fluid and is blown into the space using blower (centrifugal fan).The air flows in the zigzag manner it creates the turbulence in the duct there by improving the thermal and hydraulic performance of solar air heater. The air duct is provided with insulation packing on the two side surfaces as well as on bottom surfaces to prevent heat losses from the air duct. The air flow through the duct is maintained either by natural circulation or by using an air blower for forced circulation depending on application.

III. ANALYSIS OF WAVY FINNED SOLAR AIR HEATER

1.Geometry of flat plate collector

Equivalent diameter(D_e)=$\frac{2(w-\delta_f)h_f}{[(w-\delta_f)+h_f]}$

where w = Wavy fin spacing, cm.

δ_f =Thickness of fin, cm.

h_f= Height of fin, m.

Number of fins (n) = $\frac{W}{w}$

where W = Width of absorber plate, m.

$$V=\frac{\dot{m}}{\rho\ An}$$

where V= Velocity, m/s.

$\dot{m}$ = Mass flow rate, kg/hr.

ρ = Density, kg/m^3.

A= Area between the absorber and bottom plate, m^2.

$$Re = \frac{\rho VDe}{\mu}$$

where Re= Reynolds number.

μ= Dynamic viscosity,Ns/m^2.

2.Heat transfer coefficients

For calculating the Nusselt number, the correlation of the Colburn factor (j) is recommended by Junqi et al. (2007) and used for wavy fin.

$$j=0.0836Re^{-0.2309}\left(\frac{w}{h_f}\right)^{0.1284}\left(\frac{w}{2amp}\right)^{-0.153}\left(\frac{L}{\lambda}\right)^{-0.326}$$

where j= Colburn j-factor.

amp = Amplitude of wavy fin, mm.

λ = Wavelength of wavy fin, mm.

L=Length of Absorber plate,m

where $j = \frac{Nu}{Re*Pr^{1/3}}$

$$Nu=\frac{hDe}{K_a}$$

where Nu= Nusselts number.

Pr= Prandtl number.

$h=h_{fp}=h_{fb}$=heat transfer coefficient of air, W/m^2-K.

K_a= Thermal conductivity of Air, W/m-K.

From that we obtain the values of h,h_{fp},h_{fb}. The values of h,h_{fp},h_{fb} are equal since the properties are evaluate at mean fluid temperature.

3.Radiative heat transfer coefficient

$$h_r = \frac{4\sigma Tav^3}{[\left(\frac{1}{\varepsilon_p}\right)+\left(\frac{1}{\varepsilon_b}\right)-1]}$$

where σ = Stefan-Boltzmann constant(5.67x 10^{-8}), W/m^2-K$^{4.}$

T_{av} = Average mean fluid temperature, K.

ε_p ,ε_b= Emissivity of Absorber, Bottom plates(0.95).

4. Effective heat transfer coefficient(h_e)

$$mh_f=\sqrt{\frac{2h_{ff}}{k_f\delta_f}}*h_f$$

where k_f = Thermal conductivity of fin material, W/m^2-K.

Fin Efficiency (φ_f) = $\frac{\tanh(mh_f)}{mh_f}$

$$\theta = \frac{\text{Heat transfer area of wavy fins}}{\text{Heat transfer area of plane rectangular fins}} = \frac{(w-\delta_f)h_f}{[wL_1-\delta_f h_f]}$$

where θ= Area enhancement Factor.

L_1= Length of the Collector, m.

$$h_e=h_{fb}+\frac{2h_f\varphi_f\theta h_{ff}}{w}+\frac{h_r h_{fb}}{h_r+h_{fb}}$$

5. Top loss coefficient (U_t)

Klein has developed the following empirical relations for calculating top loss coefficient.

The convective heat transfer coefficient(h_w) at the top cover is often referred to as the wind heat transfer coefficient. It has generally been calculated from the following empirical correlation suggested by McAdams

$$h_w=5.7+3.8V_w$$

where V_w= Velocity of wind, m/s.

$$f = (1-0.04h_w+0.0005h_w^2)(1+0.091M)$$

where M= No. of glass covers.

$C = 365.9(1-0.00883\beta+0.0001298\beta^2)$

where β =Latitude angle

$$U_t = \left[\frac{M}{\left(\frac{C}{T_{pm}}\right)\left(\frac{T_{pm}-T_a}{M+f}\right)^{0.03}} + \frac{1}{h_w}\right]^{-1} + \left[\frac{\sigma(T_{pm}^2+T_a^2)(T_{pm}+T_a)}{\frac{1}{\varepsilon_p+0.05M(1-\varepsilon_p)}+\frac{(2M+f-1)}{\varepsilon_c}-M}\right]$$

where T_{pm}=mean plate temperature, K.

T_a=Ambient temperature, K.

ε_c=Emissivity of Glass cover(0.88).

6. Bottom loss coefficient (U_b)

$$U_b=\frac{ki}{\delta_b}$$

where k_i= Thermal conductivity of insulation material, W/m^2-K.

δ_b = Back insulation thickness, cm.

7. Overall loss coefficient (U_l)

$$U_l = U_t+U_b$$

8. Collector Efficiency Factor (F^1)

$$F^1=[1+\frac{U_l}{he}]^{-1}$$

9. Collector Heat removal Factor (F_R)

$$F_R= \frac{\dot{m}Cp}{U_lAp}\ [1-\exp\{-\frac{F^1U_lAp}{\dot{m}Cp}\}]$$

where C_p =Specific heat of air, KJ/Kg-K.

A_p = Area of the absorber plate, m^2.

10.Useful Heat Gain Rate (q_u)

$$q_u=F_RA_p[S-U_l(T_{fi}-T_a)]$$

where $S= I_T(\tau\alpha)_e$

S= incident solar flux, W/m^2.

T_{fi} = Inlet temperature, °C.

I_T = Solar radiation intensity, W/m^2

$(\tau\alpha)_e$ = Transmittivity-Absorptivity product(0.84).

11.Outlet temperature (T_{fo})

$$q_u=\dot{m}C_p(T_{fo}-T_{fi})$$

where T_{fo} = Outlet temperature, °C.

12. Instantaneous Efficiency (η_i)

$$\eta_i=\frac{q_u}{A_c\,I_T}$$

where A_c= Area of the Collector, m^2.

I_T=Solar radiation intensity, W/m^2

L_2=Width of the Collector,m

.13. Pressure Drop(ΔP)

The fanning friction factor which is responsible for pressure drop is given as (Junqi et al., 2007)

$$f=1.16Re^{-0.309}\left(\frac{w}{h_f}\right)^{0.3703}\left(\frac{w}{2amp}\right)^{-0.25}\left(\frac{L_1}{\lambda}\right)^{-0.1152}$$

$$\Delta P= \frac{4f\rho LV^2}{2D_e}$$

Where L_1= Length of the Collector, m.

IV. RESULTS AND DISCUSSIONS

A Conventional Solar Air Heater was analysed and the results are compared with that of wavy finned solar air heater. By varying mass flow rates, different results are plotted for wavy finned solar air heater based on different parameters such as effective heat transfer coefficient, fin efficiency, useful heat gain rate, instantaneous efficiency, collector heat removal factor, collector efficiency factor and friction factor.The following values are used for numerical calculations:
I_T=1000W/m^2,L=1.8m,W=0.9m,L_1=2m,L_2=1m,w=2.25cm,h_f=1.55cm,,δ_f=0.2cm,k_i=0.0372W/m-K,$(\tau\alpha)_e$=0.84, δ_b=4cm amp=7.5mm,λ = 70mm,T_{fi}=35°C,V_w=3m/s,T_a=26°C.For the mass flow rates of 250-350 kg/hr,the various graphs are plotted.

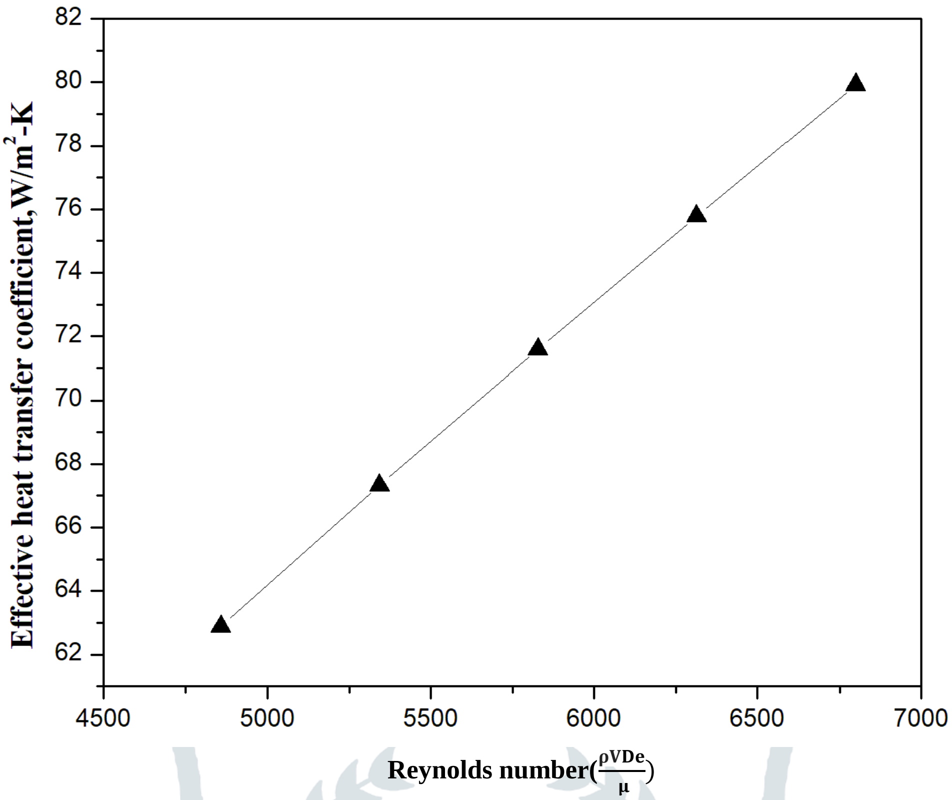

Fig 2. Variation of Effective heat transfer coefficient with Reynolds number

Fig 2. shows the variation of Effective heat transfer coefficient with Reynolds number at mass flow rates of 250,275,300,325 and 350kg/hr. From the results thus obtained we can infer that Re,h_e increases for different mass flow rates. Overall there is an increase in Effective heat transfer coefficient of 6.18% for different mass flow rates.

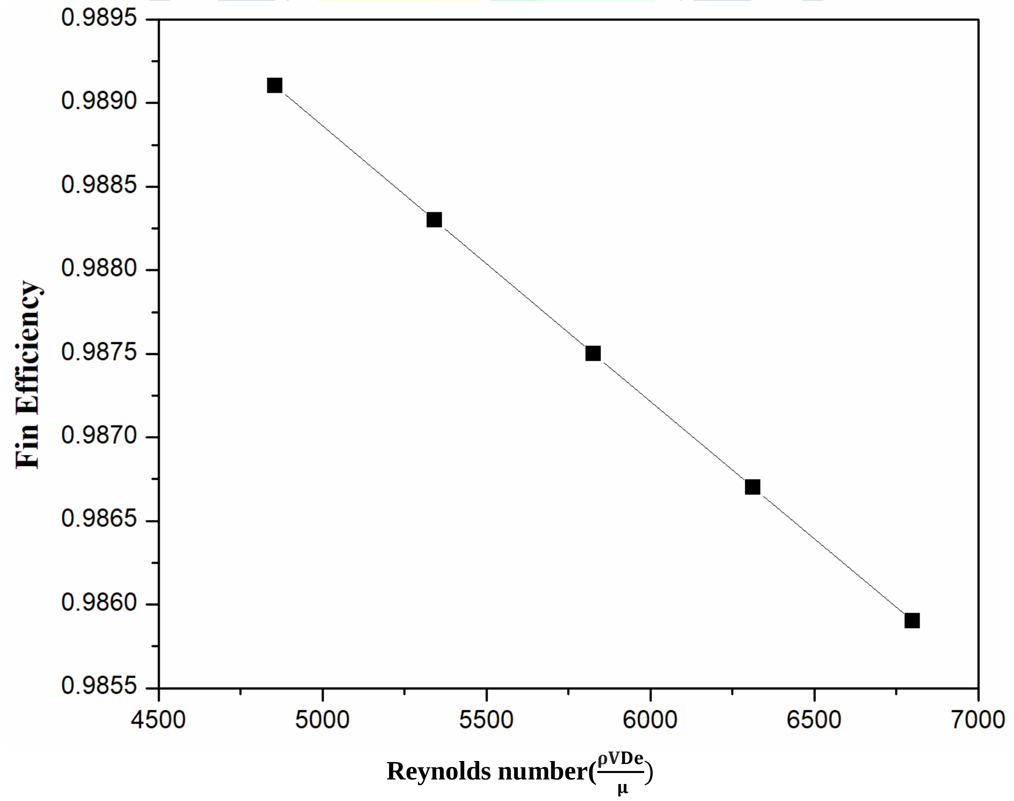

Fig 3. Variation of Fin efficiency with Reynolds number

Fig 3. shows the variation of Fin efficiency with Reynolds number. As the mass flow rate increases from 250kg/hr to 350kg/hr, the Reynolds number increases and Fin efficiency decreases. From the above graph we can conclude that Fin efficiency decreases varies linearly with Re.

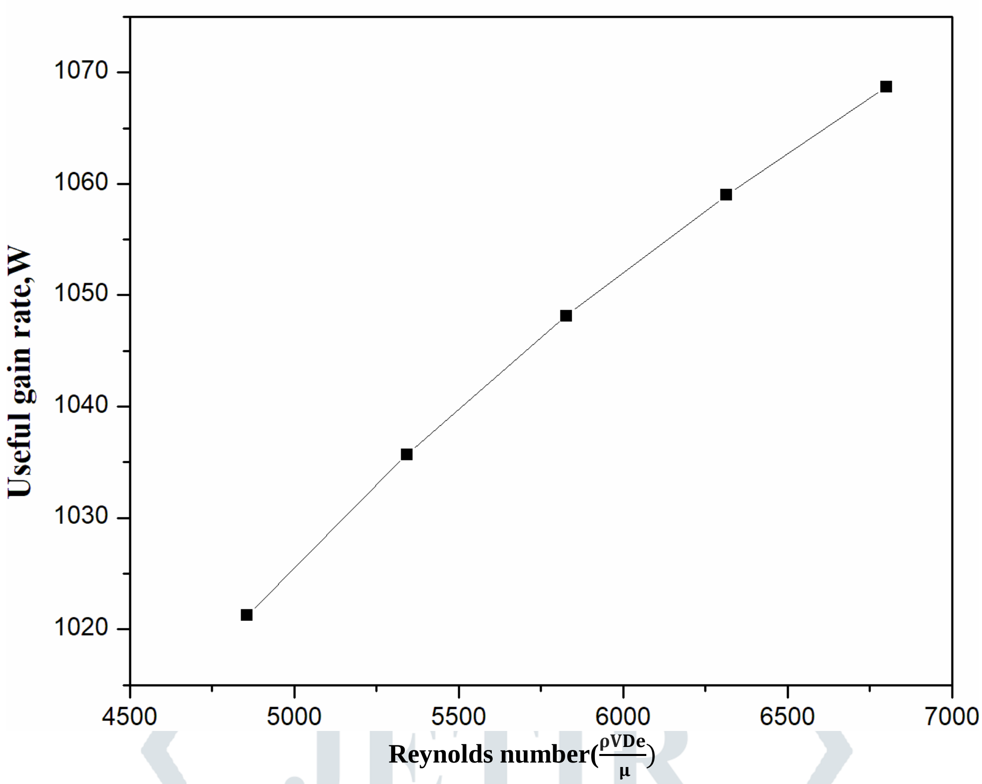

Fig 4. Variation of useful heat gain rate with Reynolds number

Fig 4. shows the variation of useful heat gain rate with Reynolds number at mass flow rates of 250,275,300,325 and 350kg/hr. From the results thus obtained we can infer that maximum useful heat gain rate is high at 350kg/hr. Overall there is an increase of 1.14% in the useful heat gain rate for change in mass flow rates.

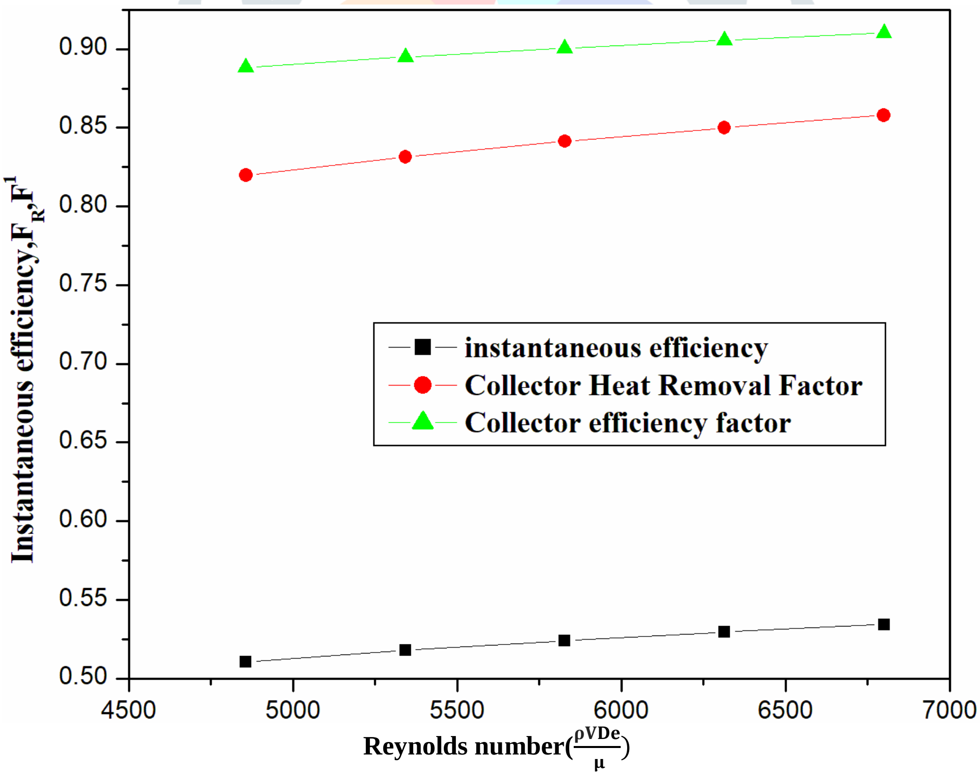

Fig 5. Variation of η_i, F_R, F^1 with Reynolds number

Fig 5. shows the variation of η_i, F_R, F^1 with Reynolds number at mass flow rates of 250,275,300,325 and 350kg/hr. From the results thus obtained we can infer that collector heat removal factor, maximum efficiency, collector efficiency factor is high at 350kg/hr . Overall there is an increase in efficiency of 1.14% different mass flow rates.

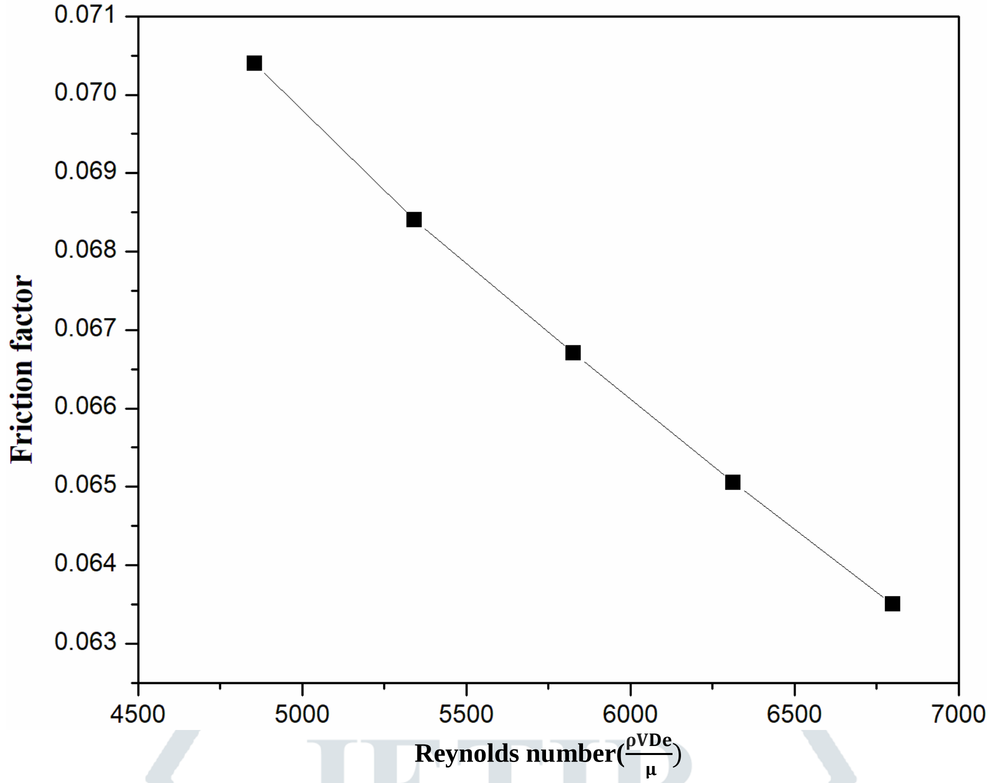

Fig 6. Variation of friction factor with Reynolds number

Fig 6. shows the variation of friction factor with Reynolds number at mass flow rates of 250,275,300,325 and 350kg/hr. From the results thus obtained we can infer that friction factor decreases and pressure drop increases for different mass flow rates. Overall there is an increase in pressure drop of 15.325% for different mass flow rates.

V.CONCLUSIONS

The performance of conventional as well as wavy finned solar air heater has been done analytically by varying mass flow rates. From the evaluation done it has been concluded that the wavy finned solar air heater gives more useful heat gain rate and instantaneous efficiency than the conventional solar air heater at different mass flow rates.

From the comparision of the performances of the conventional solar air heater and wavy finned solar air heater, the following conclusions are made:

1. For the same mass flow rate i.e.,250kg/hr , the wavy finned solar air heater shows an increase in efficiency and useful heat gain rate of 22.78% as compared to conventional solar air heater.
2. Nusselt number increases with Reynolds number at all mass flow rates from 250kg/hr to 350kg/hr at an overall increase of 6.6875%.
3. The effective heat transfer coefficient increases with mass flow rate from 250 to 350 kg/hr at an overall increase of 6.1725% for wavy fins.
4. Various parameters such as collector heat removal factor, collector efficiency factor increases linearly with increasing mass flow rates.
5. The useful heat gain rate increases and outlet temperature decreases as mass flow rate increases at an overall increase of 1.14% and decrease in 1.9175% from 250 kg/hr to 350 kg/hr .
6. The solar air heater with fins and without fins at a mass flow rate of 250kg/hr are found to be 41.588% and 51.061%.
7. The pressure drop across the collector increases for all mass flow rates from 250 kg/hr to 350kg/hr 13.21% .

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