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CFD Analysis of Convex Shape Solar Air Heater with Ribs inside the Channel

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***Abstract*: Solar heater air heaters are mainly used to convert renewable solar energy in to useful energy. Solar heaters are mainly used for heating air and water, different types of design were proposed to increase heat transfer from the heater. This work mainly focusses on the enhancement of performance of natural convection solar air heater. The CFD analysis of convex shape solar air heater and calculates the value of Nusselt number for different heat flux was done using. It also includes the effect of use of ribs inside the convex shape solar heater and optimize the pitch in between two fins for increasing the heat transfer from the duct.**

***Keywords:* Solar heater, convex shape, ribs pitch ratio, heat transfer**

1. Introduction

Solar radiation received by sun is vast and can be converted into thermal energy as well as electrical energy. The primary component that initiates the conversion process is a solar collector. A solar collector is either flat or concentrating type based upon the end use of energy or temperature requirement. Thus a solar collector is a device which converts incident solar radiation into thermal energy via a heat transfer fluid (water or air). The heat obtained by solar collectors can fulfil energy demand directly or it may be stored. Performance enhancement of solar collector can encourage its use for power saving in low temperature heating applications. Instantaneous useful energy found by the collector is result of an energy balance on the solar collector components. To evaluate the amount of energy produced in a solar collector properly, it is necessary to consider the physical properties of the materials. Solar radiation, mostly short wavelength, passes through a transparent cover and strikes the energy receiver. Low iron glass has high transmissivity. Hence, it is commonly used as a glazing cover which also greatly reduces heat losses. Natural convection solar air heater mainly depends on heat flux available on absorber plate, from where air gain the energy and due to bouncy effect, it starts moving in the upward direction. In natural convection solar air heater, heat transfer mainly due to convection whereas heat transfer through radiation is avoided. With the used of chimney effect natural convection solar air heater performance get increase. For further improvement of performance in convex shape solar air heater, here in this work ribs are used inside the solar air heater. This work performs the effect of different pitch ratio on the performance of solar air heater and optimize the conditions on the basis of Nusselt number and heat transfer enhancement factor. It also analyzed the effect of different shapes of ribs on the performance of solar air heater. Effect of different heat flux at different geometric conditions was also analyzed.

2. Convex shaped solar air heater

After validating the CFD model of flat plate incline solar air heater, numerical analysis of curved shape solar air heater was performed. For constructing the solid model of convex shape solar heater, 50-degree curvature radius of convex shape profile was considered as considered by Singh et.al. Singh et.al analyzed the effect of convex and concave shape of solar air heater at different curvature radius and found that convex profile having 50-degree curvature shows the maximum heat transfer enhancement ratio. Due to this region 50-degree convex shape profile heater is used in this work. For validating the convex shape profile solar heater analysis, here it calculates the value of Nusselt number at different heat flux and then it is compared with the values of Nusselt number obtained by Singh et.al at same heat flux. The solid model of solar heater with convex shape profile is shown in the fig below.

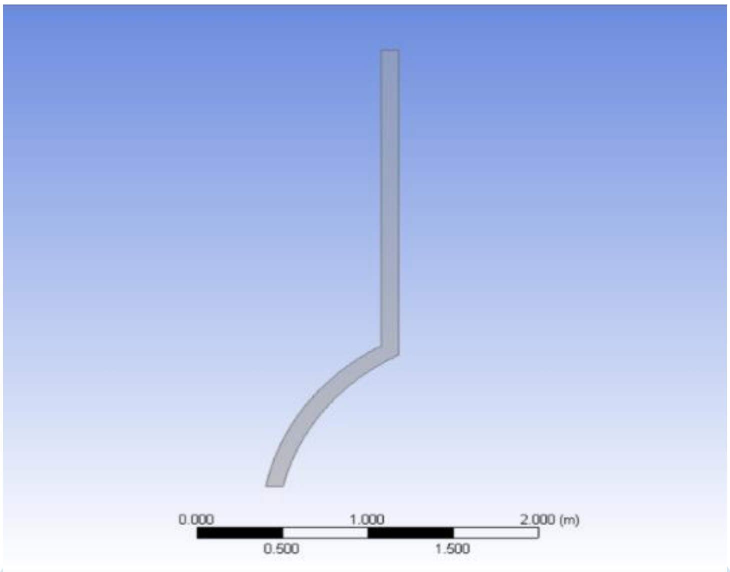


Fig.1 solid model of solar heater with convex profile

The value of Nusselt number for inclined flat plate collector at 500 W/m^2 heat flux. The velocity vector and pressure variation contours is shown in the fig below.

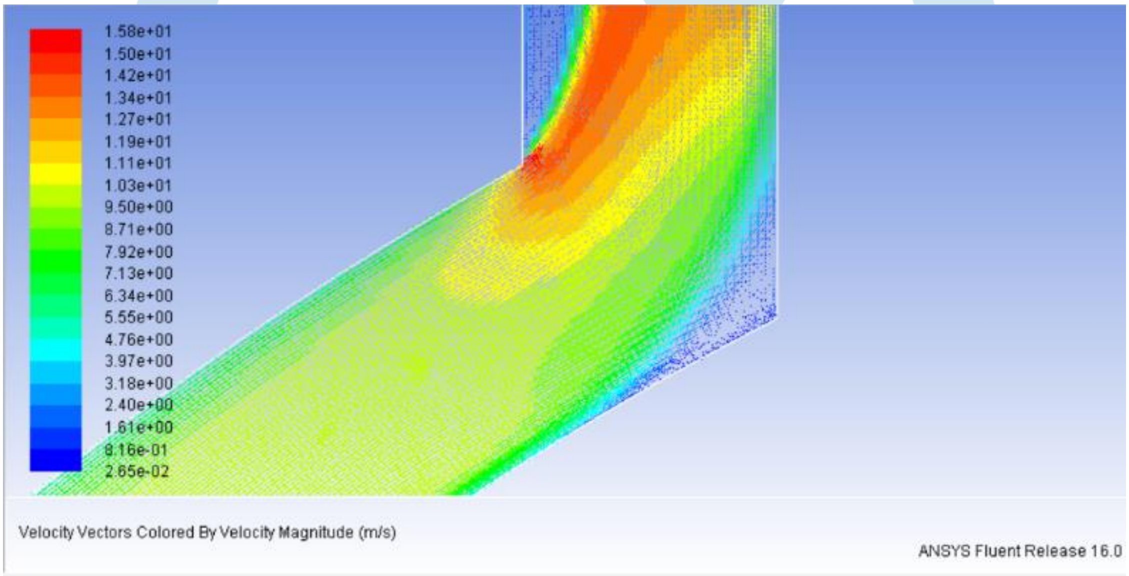
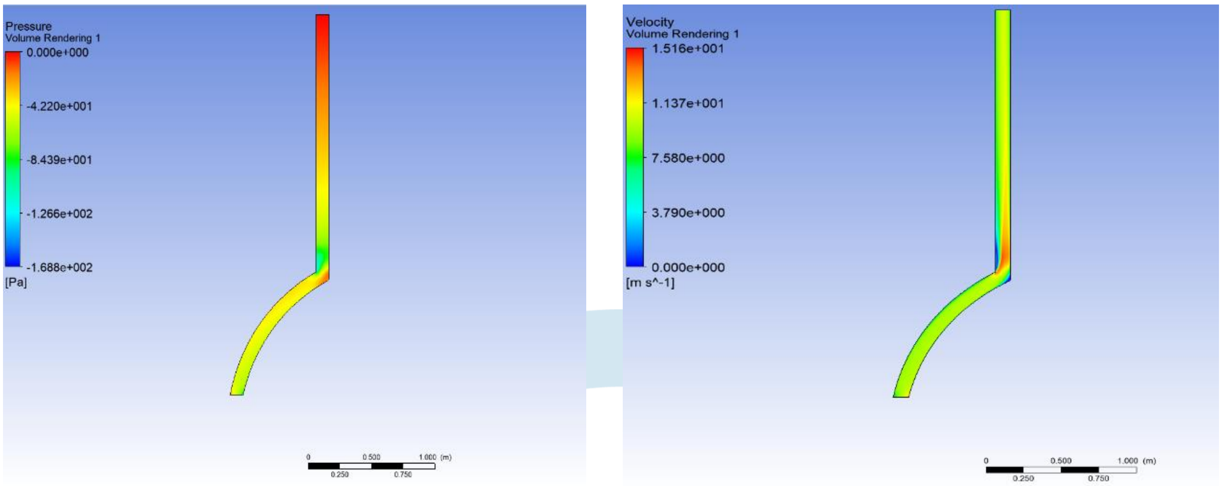


Fig.2 shows the velocity vector at 500 W/m^2 heat flux

Above fig. shows the variation of velocity inside the solar heater channel, through contours it is found that there is a constant and linear variation of velocity. While moving away from the absorber plate velocity of air get increases which is mainly due to natural convection. Air coming inside the solar heater and gain energy from the absorber plate and mode towards the chimney. The variation of pressure inside the solar air heater.

Fig.3 shows the pressure and velocity variation inside the solar air heater



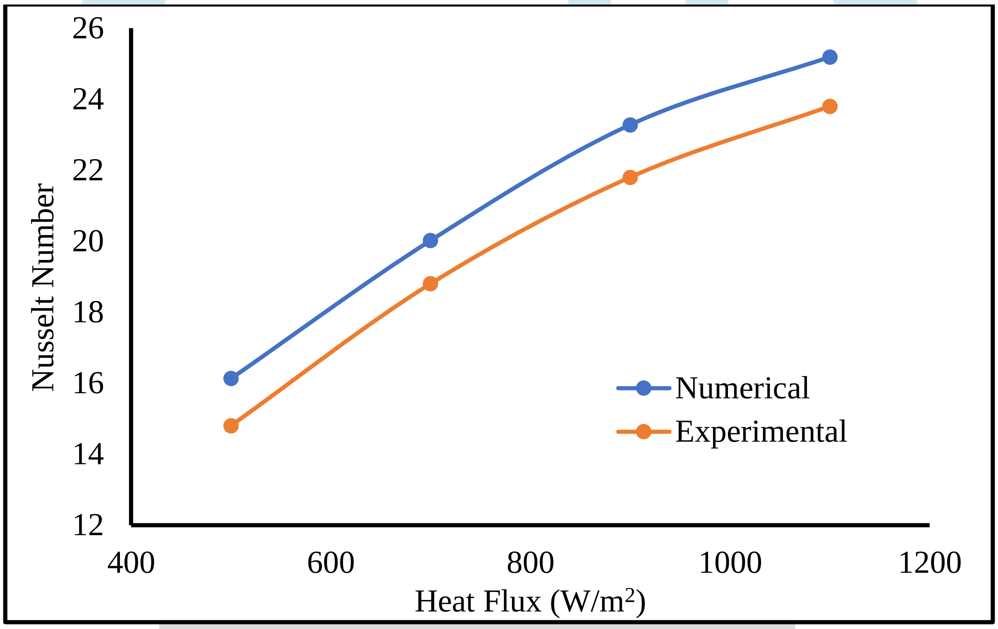


Fig.4 comparison of value of Nusselt number for convex shape solar air heater

From above graph it is found that the value of Nusselt number calculated through CFD analysis for convex shaped solar air heater is close to the value calculated by Singh et.al. The percentage error is also under permissible limit; hence it can say that the CFD analysis of convex shaped solar air heater is correct. So, after validating the numerical model for inclined and convex shaped solar air heater, effect of different pitch ratio and different shape of ribs was analyzed and calculated the heat transfer enchantment factor for each case of analysis.

3. Effect of Different pitch Ratio

For increasing the heat transfer rate from the convex shape solar air heater, here in this work ribs are used inside the solar duct. For analyzing the effect of ribs at different pitch ratio, rectangular shape ribs having 0.03 m width and 0.02 m height is used. This work considered four different pitch ratios that is 0.1, 0.075, 0.05 and 0.025 m, and calculate the value of Nusselt number for different pitch ratio geometry at different heat flux.

3.1 For 0.075 m pitch ratio

Here in this case, 0.075 m pitch ratio was considered during the analysis, pitch ratio denotes the intermediate distance of ribs. The solid model of solar air heater with 0.075 m pitch ratio is shown in the below figure. It calculates he Nusselt number and also determines the velocity vector of air near to the ribs on which the turbulence depends.

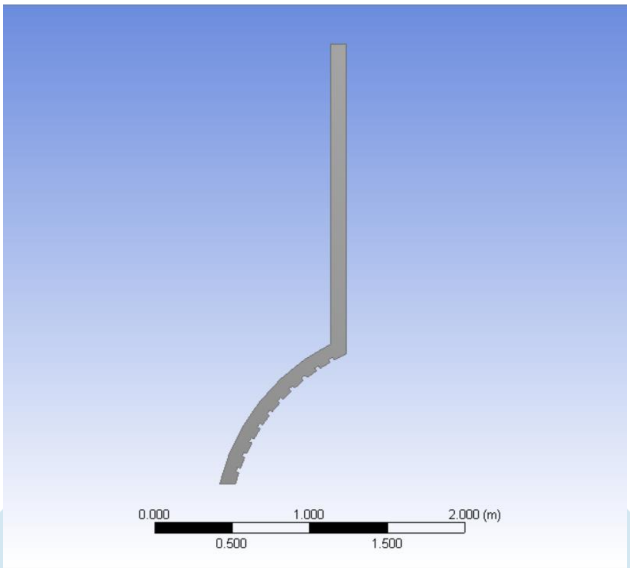


Fig.5 solid model of solar air heater having rectangular ribs with 0.075 m pitch ratio

3.1.1 For 500 W/m^2 heat flux:

In this case of analysis 500 W/m^2 heat flux was applied on the 0.075 m pitch ratio ribs of absorber plate. Through analysis it is found that the value of Nusselt number for rectangular ribs having 0.075 m pitch ratio is significantly higher than the plane inclined and convex shape solar air heater. The value of Nusselt number for 0.075 m pitch ratio is higher than 0.1 m pitch ratio. The velocity and pressure variation is also shown in the fig below.

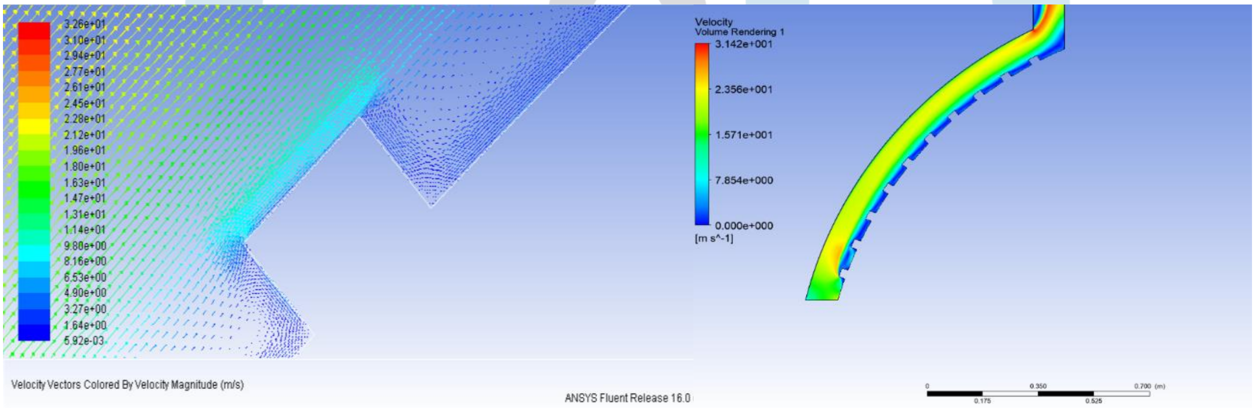


Fig.6 variation and flow behavior of velocity vectors

4. Comparison of different pitch ratio

After evaluating the effect of different pitch ratio on the heat transfer at different flux, comparison was made. The comparison of value of Nusselt number for different pitch ratio is shown in the table below.

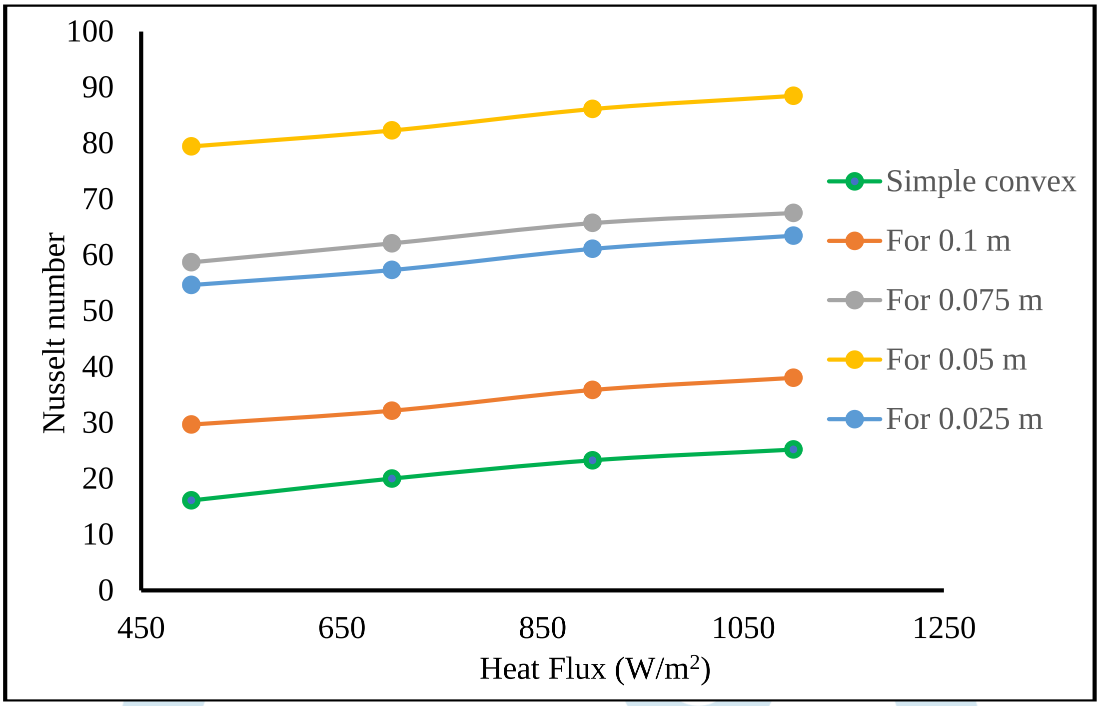


Fig.7 comparison of value of Nusselt number for different pitch ratio

From figure above it is found that, with the use of ribs inside the solar air heater, heat transfer rate gets increased. The Nusselt number of convex shape solar air heater having ribs is higher than the simple convex shape solar heater. From above graph it is found that for 0.05 m pitch ratio, heat transfer from solar heater is maximum as compared to other pitch ratio. There is very marginal difference in between 0.075 and 0.025 pitch ratio. Through graph it is concluded that convex shape solar air heater having rectangular ribs with 0.05 m pitch ratio shows the maximum heat transfer. For calculating the heat transfer enhancement by using ribs inside the convex shape solar air heater with respect to simple convex shape solar heater, heat transfer enhancement factor (HTEF) was calculated.

For calculating the HTEF following calculation was done

$$HTER = \frac{Nu_{Pitch\ ratio}}{Nu_{simple\ convex}} \quad \text{.....(a)}$$

$Nu_{pitch\ ratio}$ is the Nusselt number for different pitch ratio geometry, whereas $Nu_{simple\ convex}$ is the value of Nusselt number for simple convex shapes solar air heater. The value of HTER for different pitch ratio geometry at different heat flux value is mention in the table below.

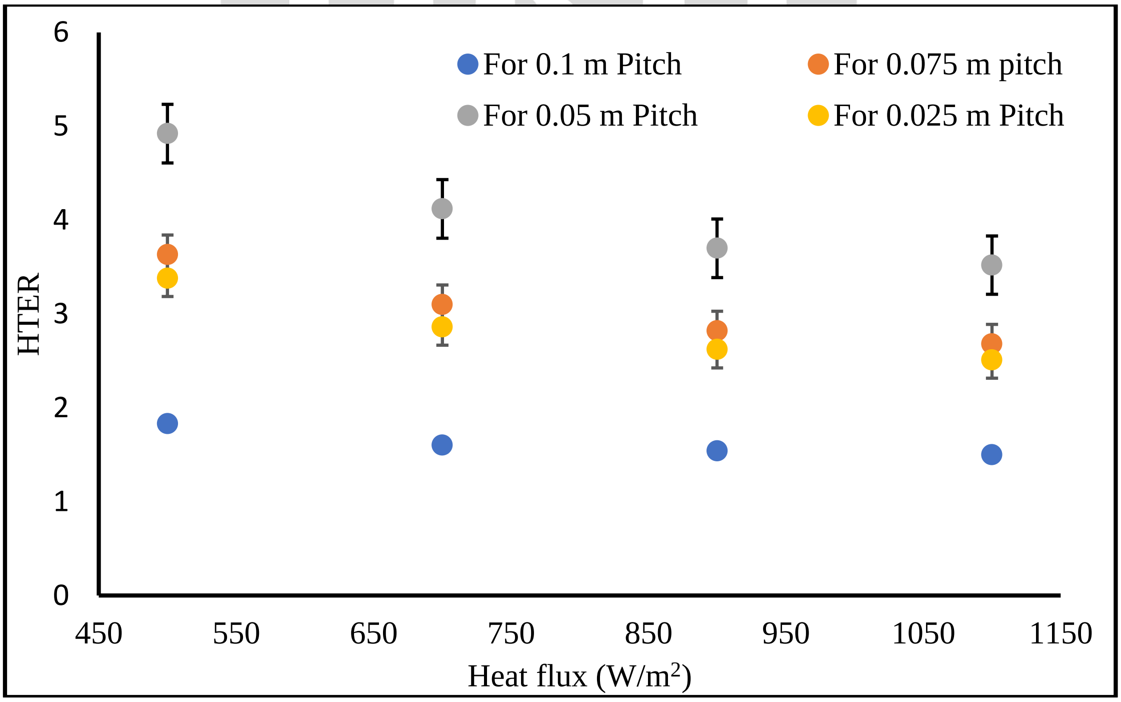


Fig.8 value of heat transfer enhancement factor for different pitch ratio

From above graph it is found that heat transfer enhancement ratio is higher for 0.05 m pitch ratio as compared to other pitch. Through analysis it can say that with 0.05 pitch ratio rectangular rib solar air heater work more efficiently than the other pitch ratio. From above figure it is also seen that the HTEF for 0.075 and 0.025 m pitch is very close to each other, whereas 0.1 and 0.05 m pitch ratio values is far away from each other.

Conclusion

By CFD analysis it is revealed that with 0.05 m pitch ratio, value of Nusselt number of solar air heater is significantly higher than the other pitch ratio of ribs, which means that heat transfer rate is more in case of solar air heater having 0.05 m pitch ratio. As compared to simple convex shape profile solar heater, convex solar heater with ribs have much higher heat transfer capacity. With the use of ribs, heat transfer rate gets increase to 4-5 times higher than the simple convex shape solar air heater. The turbulence in between to ribs is more intense in case of 0.05 m pitch ratio as compared to other ratios which is mainly responsible for increasing the heat transfer. For CFD analysis it is concluded that solar air heater with 0.05 m pitch ratio geometry is the optimum value for maximum heat transfer from duct.

6. Future work

The effect of different height of ribs using the solar duct to increase heat transfer can be analysed.

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