

Numerical Study of Jet Plate Solar Air Heater for Heat Transfer Augmentation

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ABSTRACT: Flat plate solar air heaters are typically associated with low heat transfer efficiency owing to higher energy losses and poor thermal characteristics of air, which is the working fluid. In this paper, a two dimensional numerical analysis of flat plate solar collector fitted with jet plate is carried out to determine its performance enhancement capability using the available CFD code. The design parameters considered in the analysis are the jet plate hole diameter, the length of the jet plate, the spacing of the jet plate below the absorber plate and the pitch of the holes in the jet plate. The nozzle diameter and nozzle hole pitch are fixed at 2.5 mm and 42.5 mm respectively. The spacing of the nozzle plate is varied as 5 and 15mm. The jet plate length ratio is varied in the range of 0.25-1 and the mass flow rate is varied corresponding to the Reynolds number range of 4000 to 20,000. It is found that the jet plate with spacing of 15mm and jet plate length ratio less than 0.5 provides improved thermal performance and the highest enhancement in Nusselt number is found to be about 22% as compared the smooth duct.

KEYWORDS: Jet plate, CFD, Solar air heater, Nusselt number

I. INTRODUCTION

Solar air heater with a flat absorber plate is effectively a heat exchanger that collects and transfers solar heat energy to the air flowing through the duct. Solar air collectors are employed in many applications requiring low to moderate temperatures, such as process heating and space heating applications, most particularly in agricultural production drying. The chief advantage of a flat plate collector is its simplicity in design and ease of operation and low maintenance. However, the air stream which is the working fluid has poor heat transfer characteristics. In addition, flat plate collectors are typically associated with high heat losses which results in lower thermal efficiency. If the projected area of absorber plate for heat transfer is greater than the absorber plate area, the absorber becomes unnecessarily hot which in turn leads to higher heat loss [2, 3]. Hence, there is a need to improve the thermal performance of these collectors. Many researchers have adopted various techniques to improve the thermal efficiency of flat plate solar air heaters in the past. Choudhury and Garg et al [2] introduced the concept of impinging jet plate solar air heater which makes use of, essentially, a perforated plate termed jet plate placed in the air duct. High velocity jet of air is produced that impinges on the bottom surface of the absorber plate creating greater cooling effect. They showed that the thermal efficiency increased by about 20%. However, the pressure drop was reported to be significantly high. Belusko et al [4] conducted a parametric experimental study on jet plate collector used in an unglazed solar air collector. Brideau et al [5] developed a theoretical model for a PV/T collector using jet plate technique and experimentally validated the results. Vinson Adidhrama Audwinto et al [13] conducted an experimental analysis on impinging jet solar air heater using various geometries and size for jet holes and found that 6mm hole diameter performed better as compared to 10mm hole diameter [13].

However, from the literature it is found that the use of Computational Fluid Dynamics (CFD) to study the performance of jet plate solar air heater is lacking. CFD had gained importance in the area of fluid flow and heat transfer owing to the advent of high end computers in the last decade and can greatly reduce the time and effort of testing the performance. Application of CFD to solar air heaters helps to develop numerous techniques to improve thermal performance. Hence, in

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this paper, a two dimensional CFD analysis of jet plate solar air heater is carried out to determine the effect of jet plate and its design parameters on the performance enhancement of flat plate solar air heater.

II. CFD ANALYSIS

A. Collector Configuration

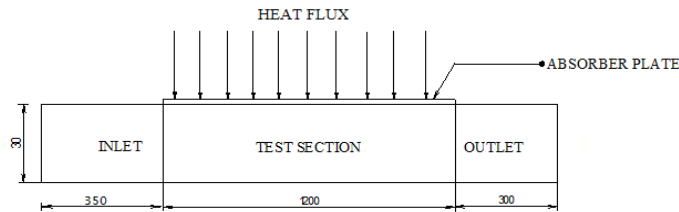


Fig 1(a) Computational domain of the solar air heater

The computational domain of the solar air heater is shown in the Fig.1 (a). It consists of inlet section, test section and outlet section. The length of the test section is 1.2m. The height of the duct is 30mm. The absorber plate in the test section has 0.5mm thickness and is made of aluminum. The length of inlet and exit sections is fixed at 350mm and 300mm respectively as per the ASHRAE guidelines [13].

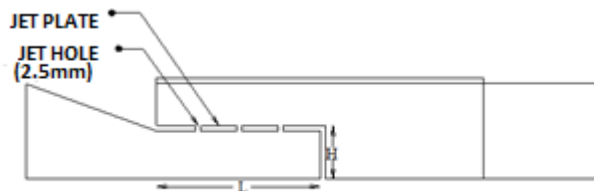


Fig 1(b) Solar air heater model with jet plate

Fig.1 (b) shows the details of collector plate with jet plate. In this model, sloping inlet with impinging jets are placed at a specified distance over a given length which is then blocked by a barrier plate. The sloping inlet is of taper 30 in 350. The diameter of the nozzle hole is 2.5mm placed at a pitch of 42.5mm each. The spacing of the nozzle plate is varied as 5 and 15mm. The length of the nozzle plate is varied in steps of 25%, 50%, 75%, and 100% of the absorber plate length which corresponds to the jet plate length ratio (X_j) of 0.25, 0.5, 0.75 and 1 respectively. The mass flow rate is varied corresponding to Reynolds number range of 4000 to 20,000.

III. NUMERICAL ANALYSIS

A. Numerical Model

The mesh of the computational domain for base model and jet plate model is shown in Fig.3 and Fig.4. At the inlet a known mass flow rate was specified and at the exit pressure outlet boundary condition is used. A constant heat flux input of 1000 W/m² is specified on the absorber plate.

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B. Material Properties

Air is the working fluid flowing through the duct and the absorber plate is taken to be made of aluminum. The thermo-physical properties of air and aluminum are given in Table 1 below.

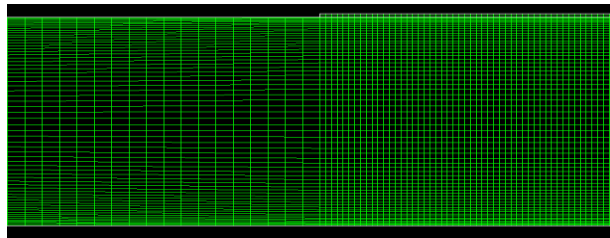


Fig.2: Mesh of the computational domain for base model.

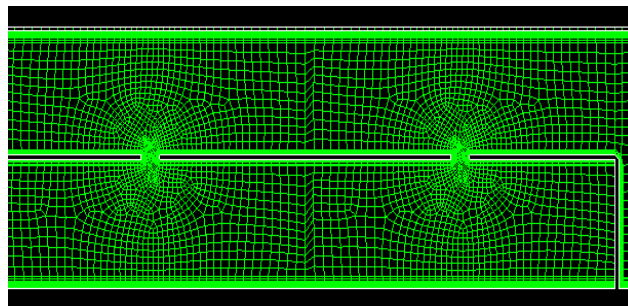


Fig.3: Mesh of computational domain for jet plate collector.

TABLE 1. MATERIAL PROPERTIES

Air	Conductivity(W/m-K)	k	1.225
	Heat Capacity(J/kg-K)	C _p	1006.43
	Density(kg/m ³)	ρ	0.0242
	Viscosity(kg/m-s)	μ	1.7894e-05
Aluminum	Conductivity(W/m-K)	k	202.4
	Heat Capacity(J/kg-K)	C _p	871
	Density(kg/m ³)	ρ	2719

C. Numerical Scheme

A two dimensional steady state analysis is carried out. SIMPLE algorithm was used for coupling of pressure and velocity and second order upwind scheme was used for spatial discretization. The convergence was considered when the residuals of all the variables in the computational domain fall below 10^{-5} . SST k- ω model was used to solve the turbulence equations.

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IV. RESULTS AND DISCUSSIONS

Two-dimensional steady state numerical analysis is carried out at different mass flow rate conditions and varying spacing of the jet plate below the absorber plate to determine the effect of jet plate and its design parameters on the performance of the flat plate solar air heater. The analysis is carried out at constant heat flux input at 1000 W/m^2 .

Fig.5 shows the Nusselt number variation at different mass flow rate conditions and varying length of the nozzle plate. It is found that in general the Nusselt number increases with the increase in mass flow rate and the jet plate models exhibit a trend similar to the base model.

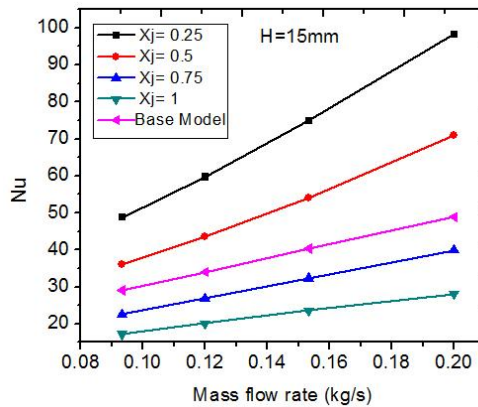


Fig.5: Comparison of Nusselt number at different mass flow rates

This is due to the fact that as the mass flow rate increases the rate of heat transfer from the absorber plate increases resulting in higher values of Nusselt number. This is further validated by the variation of the absorber plate temperature at different air flow rate conditions as shown in Fig.6. It is clear that the absorber plate temperature decreases with increase in the mass flow rate of air owing to increased heat transfer.

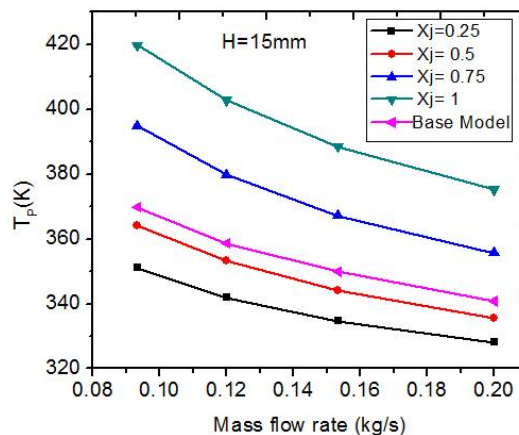


Fig. 6: Comparison of absorber plate temperatures at different mass flow rates.

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A. Effect of jet plate length

The jet plate has numerous holes in it which leads to the generation of high velocity jet of air impinging onto the bottom surface of the absorbing plate. This impinging action results in increased cooling effect on the absorber plate and leads to improved heat transfer to the flowing air. For $X_j < 0.5$, the jet plate creates high velocity air jet that impinge on the absorber plate and continue to flow at relatively higher velocity below the absorber plate which results in higher heat transfer coefficient and hence higher Nusselt number. However at $X_j > 0.5$, the jet plate length is longer entering through the first set of jet holes gets heated up gradually and as it moves towards the exit in the gap between the absorber plate and jet plate, the hot air mixes rigorously with the incoming jet of air and exchange heat thereby increasing the temperature of air. Thus, the temperature of air in the gap will be relatively higher and the impinging air jet will have lesser cooling effect on the absorber plate and hence reduced heat transfer which leads to lower values of Nusselt number as shown in Fig.5. This in turn leads to higher temperature of the absorber plate as shown in Fig.6 for all cases with $X_j > 0.5$ and compared to the base model and models with $X_j \leq 0.5$. For cases with $X_j < 0.5$, since the jet plate length is lower, the mixing of hot air with the impinging jet is far minimized. Also, as the air flows out of the space between the jet plate and the absorber plate, the air flows at relatively higher velocity which results in increased heat transfer and hence higher Nusselt number.

B. Effect of the jet plate spacing

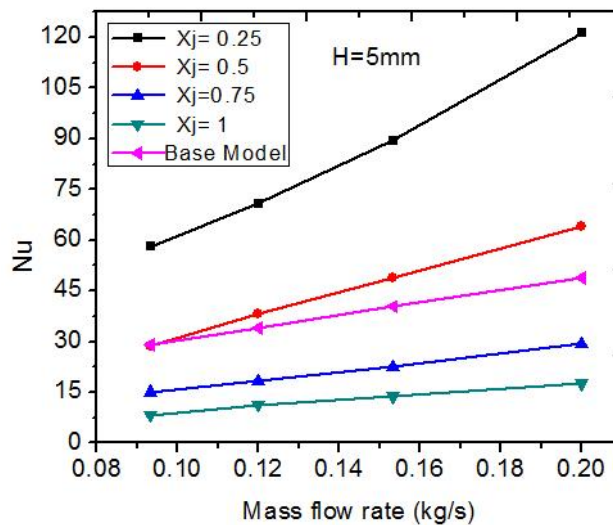


Fig.7 Comparison of Nusselt number at H=5mm

The spacing between the absorber plate and the jet plate is varied as 5 and 15 mm measured from the absorber plate. Fig.7 and Fig.8 shows the variation of Nu and T_p at different mass flow rate conditions for the jet plate spacing of 5mm and is found to have the same trend as explained for Fig.5 and Fig.6.

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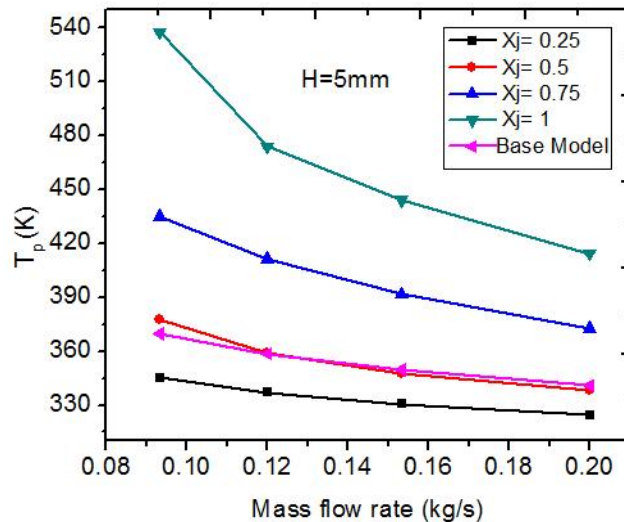


Fig.8 Comparison of absorber plate temperature at H=5mm

Fig.9 shows the variation of the Nusselt number for two cases of jet plate spacing having 5mm and 15mm for a mass flow rate of 0.0933kg/s. It is found that the spacing of 15mm produces relatively improved thermal performance as compared to jet plate at all $X_j \geq 0.5$.

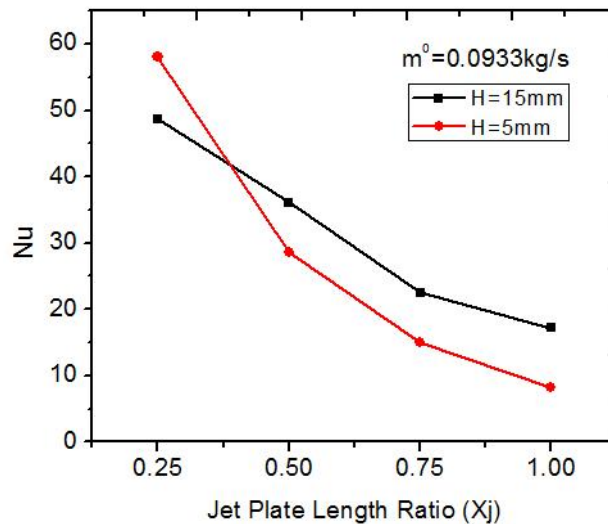


Fig.9 Nusselt number variation at jet plate spacing of 5mm and 15mm for a mass flow rate of 0.0933kg/s.

This can be due to the fact that at 5mm spacing, the air flowing in the gap between the absorber plate and the jet plate is relatively at higher temperature as it flows too close to the absorber plate. This results in reduced heat transfer from the absorber plate and hence relatively higher absorber plate temperature as shown in Fig.10.

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However, at $X_j = 0.25$, it is interesting to note that the 5mm spacing produces better thermal performance as compared to the 15mm spacing as shown in Fig.9. This can be due to relatively higher velocity of air flowing below the absorber plate as it exits the space between the jet plate and the absorber plate. The same trend is observed at all mass flow rates considered in the analysis and is shown in Fig.11, Fig.12 and Fig.13.

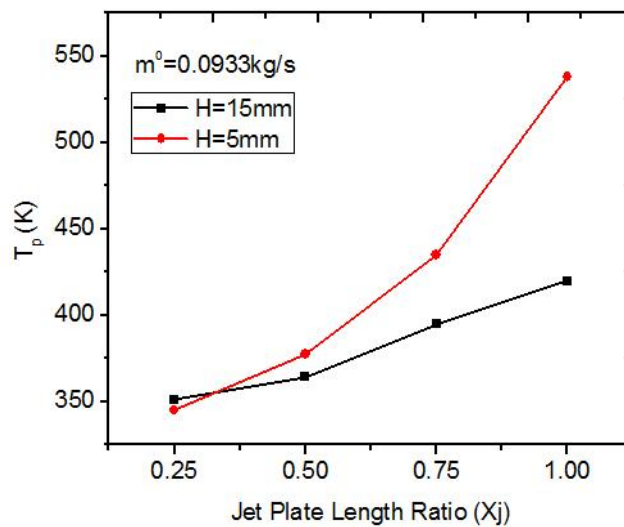


Fig.10 Absorber Plate Temperature Variation at jet plate spacing of 5mm and 15mm for a mass flow rate of 0.0933kg/s.

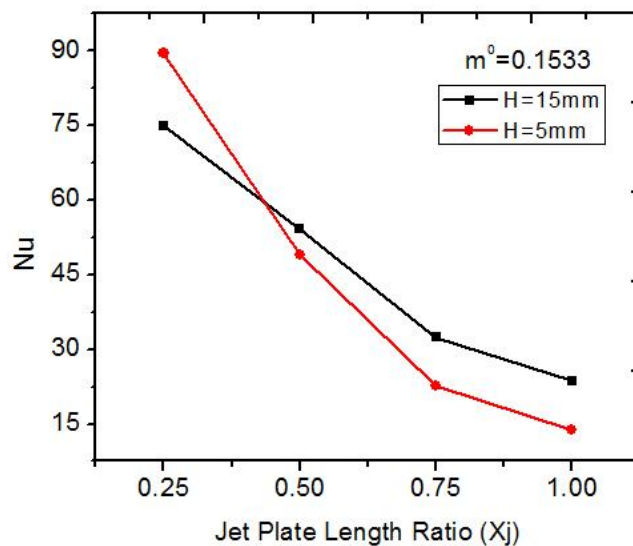


Fig.11. Nusselt number variation at jet plate spacing of 5mm and 15mm for a mass flow rate of 0.1533kg/s.

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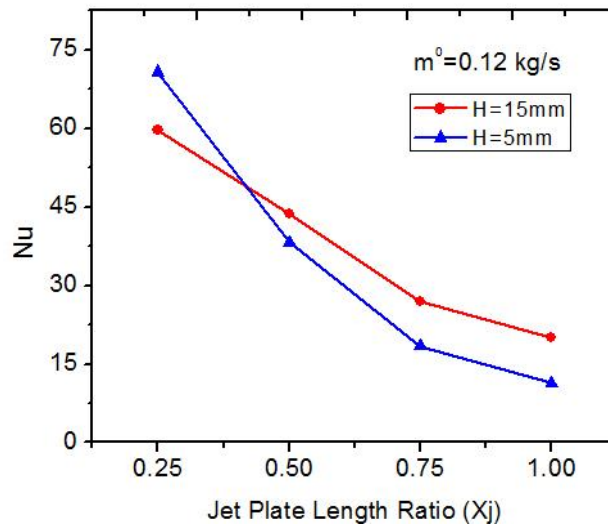


Fig.12. Nusselt number variation at jet plate spacing of 5mm and 15mm for mass flow rates 0.12kg/s.

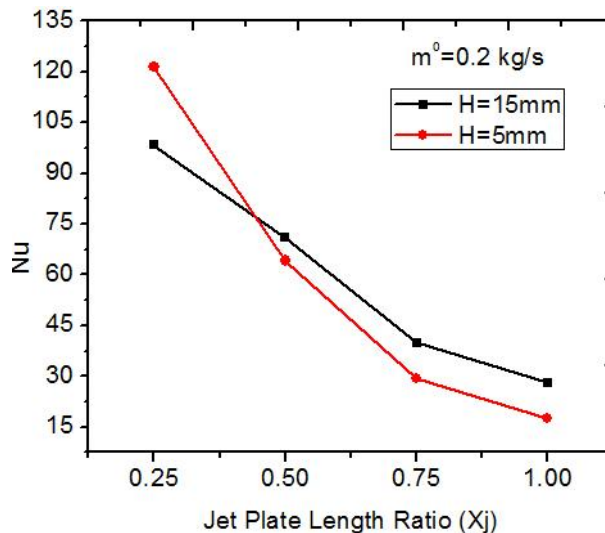


Fig.13. Nusselt number variation at jet plate spacing of 5mm and 15mm at mass flow rate of 0.2 kg/s

V. CONCLUSIONS

A two dimensional CFD analysis of jet plate solar air heater is carried out to determine the effect of jet plate and its design parameters on the performance enhancement of flat plate solar air heater. It is found that the jet plate length and its spacing in the duct as well as the flow rate has significant influence on the thermal performance of the collector. The highest enhancement in the Nusselt number was found to about 22% for the range of parameters and operating conditions considered in the analysis.

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