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# Solar Air Heater Performance enhancement using Perforated Plates: An Experimental Study

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***Abstract*— *In present study solar air heater duct performance is enhanced using perforated plate structure in it. In this study, simple rectangular array design is investigated experimentally and compared with simple solar air heater duct. Design is installed in two parallel installation combinations. Experimental setup has been fabricated to investigate the effects. Effect on Heat transfer has been investigated for 4 different mass flow rates. Arrangement has been tested for Mass Flow Rates of 0.05, 0.065, 0.08 and 0.095(all in kg/s)***

*It was found that due to Presence of Perforated Plates, heat transfer enhanced up to 3.3 times in comparison to smooth ducts.*

***Keywords*— *Experiment, Heat Transfer Coefficient, Perforated Plates, Solar Air Heater.***

***Nomenclature***

| | |
|---|---|
| $D_h$ | *Hydraulic Diameter (m)* |
| $A_h$ | *Heat Transfer Area ($m^2$)* |
| $L$ | *Length of Duct (m)* |
| $W$ | *Width of Duct (m)* |
| $H$ | *Height of Duct (m)* |
| $m$ | *Mass flow rate (kg/s)* |
| $c_p$ | *Specific Heat Capacity at Constant Pressure (J/kg-K)* |
| $h$ | *Heat Transfer Coefficient(W/$m^2$-K)* |
| $K$ | *Thermal Conductivity (W/m-K)* |
| $Q$ | *Heat Transfer Rate (J/s or W)* |
| $T_{in}$ | *Inlet Temperature (K)* |
| $T_{out}$ | *Outlet Temperature (K)* |
| $Nu$ | *Nusselt Number* |
| $Re$ | *Reynolds Number* |
| $V_{in}$ | *Inlet Velocity (m/s)* |
| $\rho$ | *Density (kg/$m^3$)* |
| $\mu$ | *Viscosity (kg/m-s)* |

## I. INTRODUCTION

Sunlight available freely as a direct and perennial source of energy provides a non-polluting reservoir of fuel. The simplest and the most efficient way to utilize solar energy is to convert it into thermal energy for heating applications by using solar collectors. Solar Air Heaters (SAH), because of their inherent simplicity are cheap and most widely used collection devices.

The main applications of SAHs are space heating, drying etc. Numerous SAHs devices have been developed and used experimentally. A glass or plastic cover is fixed above the absorber plate and the system is insulated thermally from back and from the sides. The main drawback of a SAH is that the heat transfer coefficient between the absorber plate and the air stream is low, which results in a lower thermal efficiency of the heater. However, different modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air.

Solar air heaters have higher thermal efficiency when the Reynolds number of air flow through their passage is 3000-21000 [4]. In this range, the duct flow is generally turbulent. Hence, the research work pertaining to the design of an effective solar air heater involves turbulent flow. Conventional solar air heaters usually have low efficiency.

Our interest lies in augmenting the heat transfer coefficient and the distribution of heat from plate to air. Extensive work has been done to enhance heat transfer rate using artificial roughness, use of fins and baffles but very less work has been done in the field of utilizing perforated plates in Solar air heaters for heat transfer augmentation. Experimental approach is an excellent method to understand the flow behavior under the presence of obstacles in solar air heaters.

### 1.1 INCORPORATION OF PERFORATED PLATES

Use of Perforated plate in Heat Exchangers was first invented in 1949 by McMohan et al.[1] and is used to provide a compact design for recuperative heat exchanger.

Perforated plates are generally oriented perpendicular to the flow. Different plates are used in an alternating sequence. Low conductivity spacers provide a high axial resistance and the perforated plates provide a high stream to stream conductance. [4]

### 1.2 AIM OF CURRECT STUDY

The performance of conventional solar air heaters is generally low. Their performance are greatly enhanced by

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changing parameters such as Mass flow rate of air and providing obstacles in the path of flow which prevent the fully developed hydrodynamic boundary layers to take place. Nusselt Number strongly depends on these parameters.

Our Primary aim of current work is to enhance the heat transfer rate between fluid (in our case Air) and absorber plate by using Perforated and to give validation to the results obtained from Experimental setup.

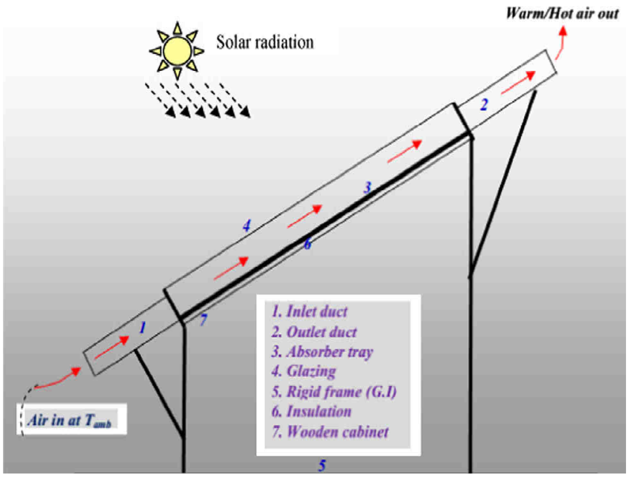


*Fig.1.1 : Components of Solar Air Heater[6]*

## II. LITERATURE REVIEW

**McMohan et al.[1]** first introduced Perforated Plates in Heat Exchangers in 1949, and called this arrangement as Matrix Heat Exchangers. It was aimed mainly to be fabricated commercially for use in production of liquid Oxygen. They expected that his invention can be used for large scale air separation but due to the unavailability of reliable brazed aluminium plate fin exchangers, it was not materialized. Their design consisted of a series of perforated aluminium plates separated by thin, die cut neoprene gaskets, which served as channels to separate the fluid streams. The whole package, together with a cast aluminium header at each end, was held together by means of steel tie rods.

**Nilles et al.[2]** compared diffusion bonding and vacuum brazing methods of fabrication and summarized the advantages of diffusion bonding over vacuum brazing as a) Heat Exchanger assembly is simplified . b) Bond Strength is greater. c) No sharp boundary between pieces. d)Less chance of plugging the exchanger since there is no liquid – phase brazing materials to contaminate the passages of the exchanger. e) No extra materials(braze or solder) to add to the exchanger. f) Diffusion bonding can be used for copper/stainless steel pairs up to 800 $^{o}$C.

**Tingwei et al.[3]** experimentally studied the effect of geometric size change of holes in a perforated plate on its heat transfer characteristics, and the total average heat transfer coefficients of the working surface for different hole length to diameter ratios. They performed the experiment on the basis of two parameters viz. hole length to diameter ratio and per hole Reynolds No. They studied the influence of no. of diversion plates on the heat transfer characteristics by placing three and five plates in front of the test plate. They used 78 round holes having triangular pitch. They found that Sherwood No. as function of Reynolds no. was same for three upward diversion plates and five upward diversion plates having less than 1% error. They concluded that length to diameter ratio in the range of 0.5 to 1.1 had little influence on the heat transfer coefficients of a perforated plate.

**Bayajit et. al[4]** investigated the use of numerical simulation and experimental results to validate the choice of turbulence model. They investigated a broad study of flow characteristics of perforated plates which are situated perpendicular to a uniform oncoming free stream flow. They used two patterns of perforated holes viz. Square and Staggered Array structure to validate the simulation. For Laminar region, they concluded that Pressure drop varies linearly with Reynolds Number and the staggered hole pattern gives rise to a higher pressure drop than does the square hole pattern, and higher porosities lead to lower pressure drops. For, the turbulent region, they found that pressure drop depended upon the square of the Reynolds number, which indicated the dominance of momentum-based losses. Also, in this case the hole distribution was found to be of minor significance, and the magnitude of pressure drop correlated inversely with the porosity.

**Skullong et al.[5]** experimented on a solar air heater incorporated with thin ribs(ribs of high aspect ratios). The range of Reynolds number was 5000-24000. The channel aspect ratio was 10 and the complete length of the duct was 2000 mm including a test portion length of 440 mm. They attempted to present a comparison of thermo-hydrodynamic performance between transverse thin and square ribs (ribs of low aspect ratios) arranged in three patterns viz. single ribbed wall, staggered and in-line pattern on the lower and upper walls. As a result, six different configurations were achieved viz. single square rib, single thin ribs, staggered square ribs, staggered thin ribs, in-line square ribs and in-line thin ribs. Heat flux was given only on the upper wall of the rectangular duct test section, while the remaining surfaces remained insulated. They found that the presence of ribs or disturbances had a strong influence on enhancing the friction factor as well as the convective heat transfer coefficient. The average Darcy's friction and average heat transfer characteristics were observed to be maximum for in-line thin ribs and minimum for single square ribs. They

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developed a set of correlations that could be used to calculate average friction factor and average Nusselt number values, when Prandtl's number, Reynolds number, rib blockage ratio and relative pitch are the input parameters.

**Saxena et al.[6]** presented an excellent review of the developments that has followed round the globe in various aspects of solar air heating systems since 1877 up to publication time. They reviewed more than 300 research paper to report various methods that are used to improve the thermal performance of SAHs e.g. optimization of dimensions of air heater construction elements, use of extended surfaces with different shapes and dimensions, use of sensible or latent storage media, use of concentrators to augment the available solar radiation, integrating photovoltaic elements with the heaters etc.

## III. EXPERIMENTAL FABRICATION

The experimental study on Solar Air Heater consisting of Perforated Plates is performed to know the effect of perforated plates in the augmentation of heat transfer coefficient and Nusselt number. Air is taken as the fluid while Aluminium as Absorber Plate.

Experimental Setup consists of a wooden rectangular duct 1000 mm × 500 mm × 50 mm in size fitted with MS pipe and blower fan. The duct length is provided with an entrance section, a test section and an exit section of lengths 300 mm, 400 mm and 300 mm respectively. A transition section having V Shape of 250 mm length has been provided on both sides in order to supply the air from the blower to the entrance section smoothly and exit of air from test section to atmosphere. Transition section is fitted with MS Pipe of 50 mm diameter. A constant heat flux is given to the Absorber plate using Halogen Light. Aluminium is used as the metal to fabricate Absorber Plate. Temperature of $70^0$ C is maintained to carry out the experimental work. Glass is attached to the top of duct with thermocol sheet in order to minimize heat losses from topside of the heater assembly. Two Straight rectangular aluminium blocks were attached to the absorber plate by use of super glue. Thickness of blocks is taken as 5 mm because blocks of small thickness are more advantageous. Four thermocouples were used in the Test rig to measure temperatures at different places. One thermocouple is used at Exit section of Duct to measure Outlet Temperature of air. One thermocouple is attached to Absorber plate to measure the temperature of Absorber Plate. Two thermocouples is used at Two Perforated plates and In the Test Section to measure the temperature of Air at different places. Velocity of air from blower is measured with the help of anemometer which in turn helps in measuring Mass Flow Rate.

*Fig.3.1 : Experimental Setup*

### 3.1. VALIDATION OF EXPERIMENTAL SETUP

Before incorporating Perforated Plates in Solar Air Heater smooth duct and collecting data, a validity test was conducted to validate our experiment. Complete experiment was carried out on Smooth Duct and data was collected and Nusselt Number and Friction factor is calculated from collected data. Calculated values of Nusselt number and friction factor were then compared to values obtained from Dittus Boelter (D-B) Correlation and Modified Blasius Equation for Nusselt Number and Friction Factor. These correlations are given as:

**D-B Correlation**: $Nu = 0.023\ Re^{0.8}\ Pr^{0.3}$

**Modified Blasius Equation**: $f = 0.085\ .\ Re^{-0.25}$

The comparison between values obtained by above two correlations and values obtained by experimental data are shown in Nu vs. Re graph as shown in below.

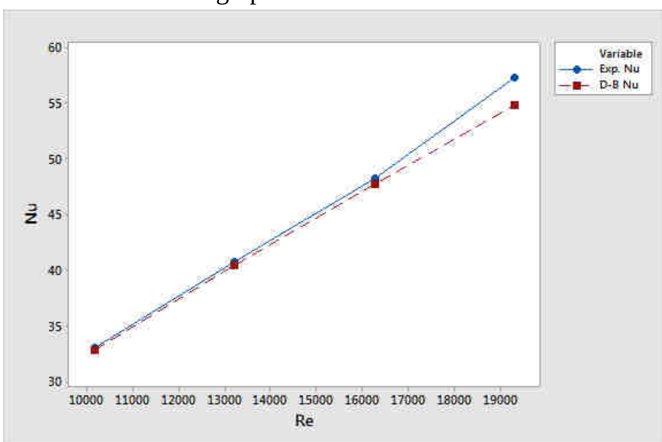


*Fig.3.2 : Nusselt Number Vs Reynolds Number Graph for Validation of Experiment*

CAD geometry of the experimental setup is shown in the fig. given below :

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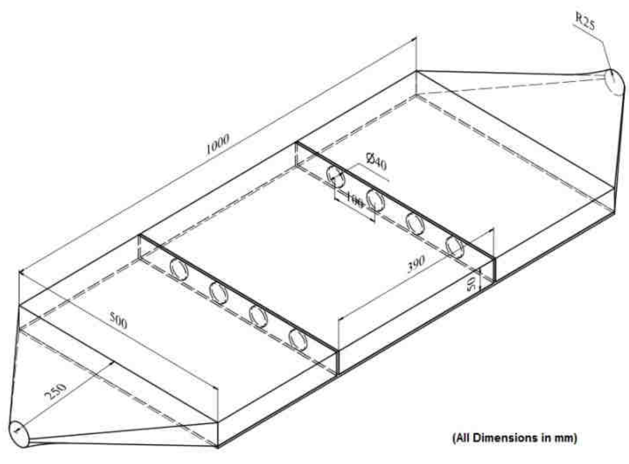


*Fig.3.3: CAD Geometry of Experimental Setup*

### 3.2 DATA REDUCTION

The parameters of key interest are Bulk Temperature, Wall Temperature along the axial direction. Nusselt number can be calculated with the help of these parameters.

Hydraulic Diameter

$$D_h = \frac{2.H.W}{(H+W)}$$

Reynolds Number

$$Re = \frac{\rho V_{in} D_h}{\mu_a}$$

Heat Transfer

$$Q = \dot{m} C_p (T_{out} - T_{in})$$

Local Heat Transfer Coefficient

$$h = \frac{Q}{A(T_{wall} - T_{bulk})}$$

Nusselt Number

$$Nu = \frac{h.D_h}{K_{air}}$$

## IV. RESULTS AND DISCUSSION

In present study, a experimental model was constructed to study and enhance a Solar Air Heater's thermal performance. This model consisted of Perforated Plates. This section presents detailed results of experiment and. All the experimental data is recorded by using various instruments. Temperature has been recorded using J-type thermocouples and to measure mass flow rate, Anemometer has been used.

Experimental data are given below in Table 4.1:

*Table.4.1: Experimental Data*

| MFR(kg/s) | Inlet Velocity(m/s) | Reynolds Number | Outlet Temperature(K) | Nusselt No. |
|---|---|---|---|---|
| 0.05 | 1.463 | 9104 | 310 | 99 |
| 0.065 | 1.938 | 12060 | 309 | 115 |
| 0.08 | 2.452 | 15259 | 308.6 | 124 |
| 0.095 | 2.894 | 18009 | 308 | 147 |

All the experiments have been carried out for 4 different mass flow rates and temperatures have been measured at Inlet and Outlet and 3 additional points on the plate. Validation error is less than 10% for most of the data. Fig. 4.1 shows the Comparison for Outlet Temperature of Solar Air Heater with Perforated Plates.

Fig. 4.2 shows the comparison for Nusselt Number. Nusselt Number obtained from experiment is compared with Simple Air duct. It is seen that Nusselt number increased considerable up to 3 times.

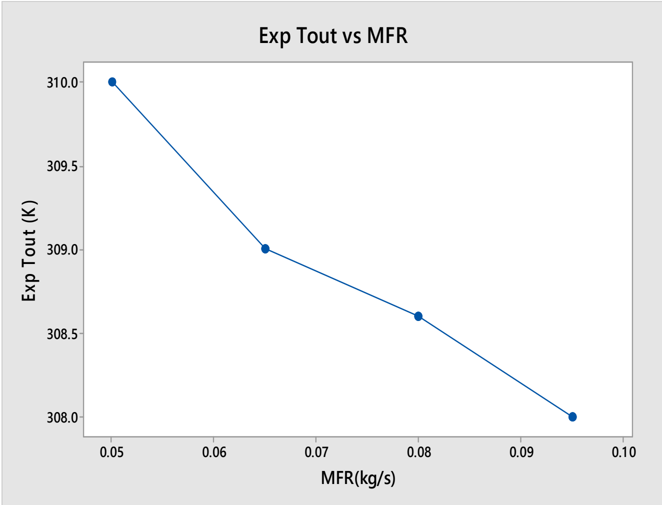


*Fig.4.1: Comparison on the basis of Outlet Temperature*

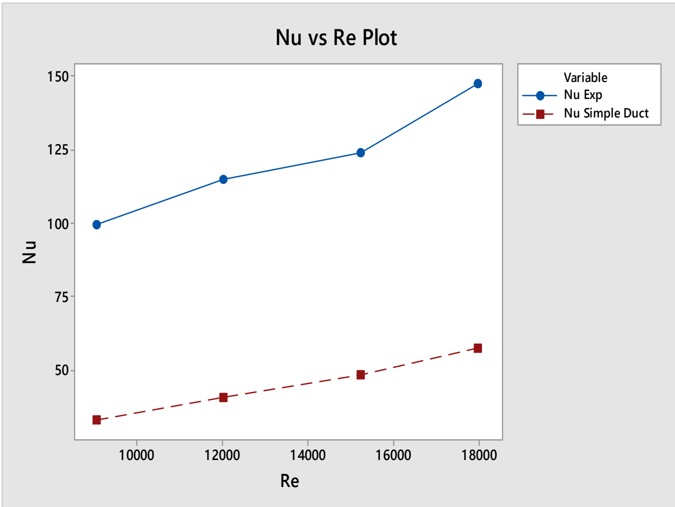


*Fig.4.2: Comparison of Experimental and Simple Air Heater Nusselt Number*

## V. CONCLUSION

In Present study, Heat transfer enhancement of Solar Air Heaters by incorporating Perforated Plates has been investigated using Experimental technique. Results have been and effect of different parameters viz. Mass flow

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rate, outlet temperature etc has been investigated. Optimized condition for Nusselt number was plotted against Reynolds number and mass flow rate. Following conclusions were drawn:

i) In comparison to simple solar air heaters, incorporation of Perforated plates resulted in considerable enhancement of Nusselt Number.
ii) Due to presence of perforated plates, Nusselt number rise up to 3 times in comparison to smooth duct as much as 147 at mass flow rate of 0.095 kg/s.

**Future Scopes:**

i) Different geometries of perforated plates can be incorporated. Here only circular holes have been considered.
ii) Materials of perforated plates can be varied.

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