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Design and Testing of Experimental setup for Determining Performance of High Temperature Solar Power Absorber

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ABSTRACT

Ceramic foam solar absorber has been intensively studied in the recent years as the increasing problems of CO_2 emissions and energy security concerns have strengthened interest in alternative nonpetroleum-based sources of energy. Solar radiation is first converted into thermal energy by passing high temperature fluids like air, molten salts etc, through the concentrated solar power absorber element and then at a later stage this thermal energy is converted into electricity in thermal power plant. This necessitates the consideration of high temperature selective material for solar absorber. Ceramic foam consists of a porous material that absorbs concentrated radiation inside the volume of a structure and transfers the absorbed heat to a fluid passing through the structure. Material used for ceramic foam will be silicon carbide as it has good thermal conductivity. Main objective of this project work is to design and fabricate test set up and conduct experiments to determine pressure drop across the porous media, heat transfer coefficient of SiC ceramic foams with 10ppi and 20 ppi at different Reynolds number. The single-blow method will be used, in which, the fluid temperature varies with time and convective heat transfer becomes time-dependent. Based on the experimental data variation of heat transfer coefficient between fluid and foam solid surface at different temperatures and Reynolds number will be presented.

Keywords— **Concentrated solar power (CSP), porous, silicon carbide, heat transfer coefficient, pores per inch (ppi), single-blow method.**

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I. INTRODUCTION

Engineering applications in which porous materials are widely utilized include concentrated solar power, thermal energy storage, geophysical fluid engineering, thermal insulation, heat transfer enhancement, and heat exchangers. Such materials are promoted because they produce high thermal performance and low pressure drop. In concentrated solar power a porous material absorbs concentrated radiation inside the volume of a structure and transfers the absorbed heat to a fluid passing through the structure. Using air as heat transfer fluid for electricity generation offers some significant advantages for the development of Concentrated Solar Power (CSP) such as high conversion efficiency, low environmental impact and being used in deserts or other areas scarce of water resources. Thermal efficiency of a concentrated solar power plant depends on the temperature of fluid coming out of the foam and higher temperature is achieved by increasing the heat transfer area of the receiver. Silicon carbide ceramic foams have the characteristics of light weight, high strength, large specific surface areas, high porosity, excellent thermal shock resistance performance which make them particularly fit for absorber material in CSP. In CSP a central receiver is stationed on the top of a tower at the focus of an array of heliostats, which reflect concentrated radiation into it, and water/steam, molten salt, liquid metal and air have been used as heat transfer fluid in solar receivers. The process flow diagram of CSP plant is summarized in Fig.1

To develop and modify the design of such advanced devices, it is necessary to know the convective heat transfer coefficient and pressure drop data between a fluid and a solid material in a porous medium. In present work measurement of heat transfer coefficient between air and porous silicon carbide foam, and pressure drop measurement across the SiC foam will be obtained and comparative study of 10 and 20 ppiSiC foam will be presented.

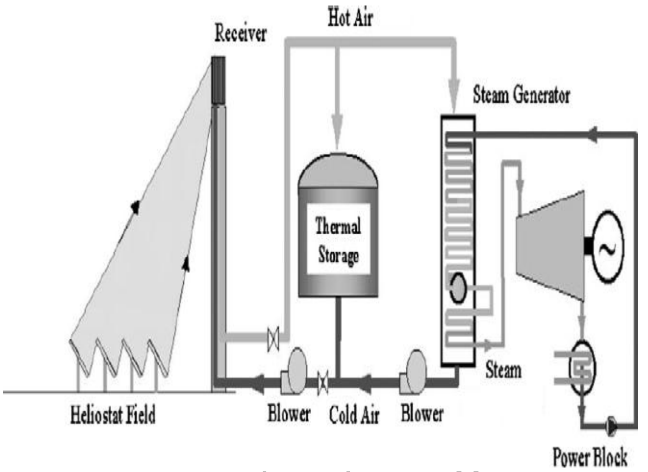


Fig.1 Schematic plant concept.[5]

II. LITERATURE SURVEY

Ja Hyun Cho, et al. [1] experimentally investigated characteristics of heat transfer and pressure loss of fills for solar volumetric air receivers. The solar volumetric air receiver considered in this paper consists of a ceramic tube and fills inserted in the ceramic tube. Two materials, honeycomb and laminated mesh were considered as the fills. The results showed that the heat transfer and pressure loss characteristics of the laminated mesh were superior to those of the honeycomb.

Thomas Fend et al. [2] performed experiments and observed that there is improved volumetric receiver system, a Sic fiber mesh has been compared to a combined version consisting of a mesh plus a Sic parallel channel monolith. At air outlet temperatures of 300^{o}C - 550^{o}C the system reaches efficiencies of 75 - 92 %. This is mainly caused by excellent absorption properties and an enormous amount of specific surface. Three metallic catalyst carriers have been compared similar to the fiber mesh, flow predominantly penetrates through the colder parts of the receiver, a fact which is enhanced by the linear pressure drop characteristics of the material. To avoid peak temperatures over 1000, the average air outlet temperature had to be limited to 400^{o}C with the 800 and 1600 cpsi (cells per square inch) material. Due to its higher specific surface, which leads to lower front temperatures, 1600 cpsi material achieved 2 - 3% higher efficiencies. The average air outlet temperatures achieved were a little higher due to a more homogeneous temperature distribution.

K. Ando, H. Hirai and Y. Sano [3] carried out exhaustive experimental investigation for accurate determination of interstitial heat transfer coefficients of ceramic foams in forced convective flows. The single-blow method was used, in which, the fluid temperature varies with time and convective heat transfer becomes time-dependent.

Younis and Viskanta [4] experimentally investigated heat transfer by forced convection of air through porous ceramic foams using a single-blow transient technique. Employing a two temperature model and implementing a step-change in the inlet air stream temperature, they obtained heat transfer coefficient correlations for a variety of foam specifications.

G. shrinivasarao et.al [8] has developed Experimental test rig for packed bed to determine the heat transfer of a packed bed system with Schumann Model. It is assumed that the temperature of the bed is uniform.

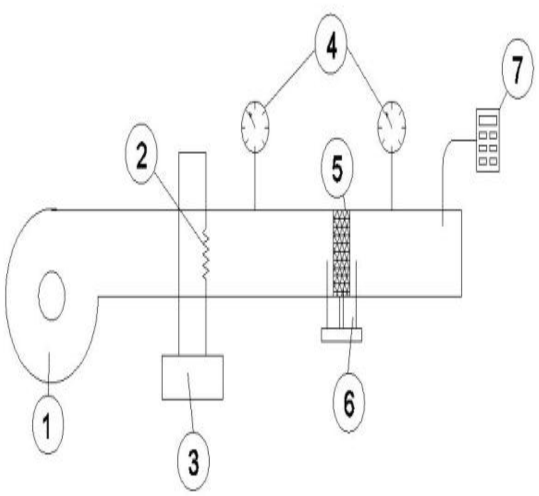
Variation of heat transfer coefficient with non dimensional axial distance along the bed length at 400^{o}C for minimum and maximum flow rates for water and nano fluid at two different concentrations for the two particles. The heat transfer coefficient increase with increasing flow rate and concentration of the nano fluid. Variation of heat transfer coefficient for 6mm, 14.56 mm particles for different operating conditions such as for flow rate of 150 LPH at 400 ^{o}C for water and nano fluids at different concentration, the heat transfer coefficient increased with decreasing particle diameter. At higher flow rates and temperatures, the heat transfer coefficient is greater, for 6mm compared to 14.56 mm particle size. The heat transfer coefficient is higher with 6mm particles due to larger surface area and the number of particles. Similarly, the heat transfer coefficient is greater at higher concentrations of the nano fluid. With an increase in volume concentration, the heat transfer is more and increases with the flow rate and inlet fluid temperature. The enhancement in heat transfer coefficient with nano fluids than base fluid lies between 10 to 15% due to higher values of thermal conductivity. The values from Schumann model agree with the experimental data for the two bead sizes of 6.0 and 14.56mm. The deviation between the two is less than 10%.

III.EXPERIMENTAL SETUP

The experimental set-up used in this study is schematically shown in figure.3.The whole system consists of a blower, a receiver, an electric heater, a thermostat, pressure gauges, thermocouples and an anemometer.

The requirement for a good volumetric receiver which should be considered while selecting the receiver material are high strength, large specific surface areas, high thermal conductivity, high thermal shock resistance, corrosive resistant. As per literature review it has been found that many people studied and analysed the performance of different material out of which Silicon carbide and ceramic foam are the most promising material for volumetric receiver material for concentrating type of solar collectors. Thus as shown in figure.2, test specimens used in this study are silicon carbide foams with 10 and 20 ppi (90mm diameter, 50mm length). In order to apply heat to the receiver, the electric heater with a capacity of 2kw will be installed across the receiver and a constant heat flux will be supplied by using the thermostat. The pressure drop across the foam will be measured by using the pressure gauges having the range from 0 to 6000mm of water column. The temperature of the foam and the air at the windward and the leeward side will be measured by using K-type thermocouples having the range of -200^{o}C to 1350^{o}C, and an anemometer will be installed to measure the air flow velocity to calculate the air flow rate.

Figure.2.Silicon carbide ceramic foam (20ppi)



1. Blower, 2.Heater, 3.Rheostat, 4.Pressure gauge, 5. Test specimen, 6.Thermocouples, 7. Anemometer
Fig. 3.Experimental set-up.

IV. PROPOSED METHOD

In this experimentation the receiver will be heated up to a temperature range of 300 to 400^{o}C for 2 to 3 hours until the steady state has been reached. Then the air will be supplied by the blower through the receiver and pressure drop can be determined directly by taking the difference of the two pressure gauge readings at several flow rates with velocity ranging from 1 to 3m/s.

Heat transfer coefficient of the receiver material can be calculated as follows:
Heat Gain by Air = Heat convected to fluid by receiver material
Heat Gain by Air = m $C_p\,\Delta T$ (1)
Heat convected to fluid = h A_s (T_s- T_{fm}) (2)
Where surface area of porous material $A_s = A_v$. V. The model proposed by Gibson and Ashby [6] allows the determination of the specific surface area Av of foams by measuring the porosity ε and the mean pore size dm.

$$A_v = \frac{12.979[1-0.971(1-\varepsilon)^{0.5}]}{d_m(1-\varepsilon)^{-0.5}} \quad (3)$$

The pore size level quantity dm (pore diameter,) porosity ε are determined using the following equations. [2]

$$d_m = \frac{0.0254}{PPI}\sqrt{\frac{4\varepsilon}{\pi}} \quad (4)$$

$$\varepsilon = 1 - \frac{\rho_b}{\rho_s} \quad (5)$$

ρ_b = bulk density

ρ_s = Standard density of material

Reynolds numbers are calculated from pore diameter d_m velocity v, viscosity μ, density ρ by

$$Re_{dm} = \frac{\rho v d_m}{\mu} \quad (6)$$

Similarly from the calculated value of heat transfer coefficient h_v, and thermal conductivity of air k_f the Nusselt number can be determined by

$$Nu_v = \frac{h_v d_m^2}{k_f} \quad (7)$$

The analytical study for 20PPI foam is carried out as shown in Table No.1 in which the Nusselt number is determined by the correlation[2]

$$Nu_v = 0.342 Re_{dm}^{0.8} \quad (8)$$

ANALYTICAL STUDY AT ε=0.7 AND d_m=1.2mm				
Velocity m/s	Re	Hv W/m^{3}K	Nu	H W/m^{2}K
5.00417	400	775174.5	41.27377	59.18718
5.629691	450	851768.4	45.35197	65.03538
6.255213	500	926675.1	49.34034	70.75476
6.880734	550	1000096	53.24959	76.36069
7.506255	600	1072192	57.0883	81.86545

Table No. 1 Anayltical Result

V.CONCLUSION

In compliance with the design, the fabrication & procurement of instruments is done as per specifications mentioned above. Finally installation of the setup is to be completed, and after which commencement of the experimental work will be done, and we would be able to perform some experiments on the test set up for checking material performance in terms of heat transfer properties, pressure drop, temperature drop of air etc.
Based on the experimental data obtained for different combination of porosities of material several graphs can be plotted viz. Reynolds number vsNusselt number, Reynolds number vs pressure drop, velocity and temperature variation

across the porous zone. And correspondingly more efficient material will be suggested. With the help of the same setup we can also experimentally investigate various materials with different porosities as a means for achieving best possible material useful in solar tower technology, which will offer the potential for a more effective and reliable operation in comparison with the ongoing volumetric receiver technology.

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