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Heat and Flow Analysis for Air through Porous Receiver of Parabolic Dish Collector

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Abstract— **The main objective of this work is to assess alternative materials for the volumetric porous media receiver. In this work air is used as fluid which is passed through fluid inlet surface of porous media receiver. The finite Volume method (FVM) is used to carry out the numerical simulation. The Local Thermal Non Equilibrium model is used for the energy equation (LTNE). The behaviour of different materials like aluminium oxide (Al_2O_3), steel balls, brass and mild steel is studied for constant wall temperature condition. It is observed that the efficiency of material is dependent upon the thermo physical properties of the material such as thermal conductivity, specific heat along with the flow conditions such as Reynolds Number, Prandtl Number, heat transfer coefficient between fluid phase and solid phase. The variation of temperature, pressure and velocity of fluid as well as temperature of porous material inside the porous zone is investigated to determine the flow and heat transfer rate of these materials under different operating conditions. The effect of change in porosity, velocity and particle diameter on pressure, temperature and velocity distribution inside the porous region is investigated. To determine the amount of pressure drop, average temperature rise inside the porous region and average outlet temperature of air outside the porous region. The study of materials like Brass, Al_2O_3, mild steel and steel balls under different operating conditions is done. Due to space limitation only results of Al_2O_3 for particle diameter of 10 mm and steel balls for particle diameter of 4.75 mm have been explained in this paper.**

Index Terms—**Porous Media, Heat Transfer, Finite Volume Method, LTNE**

I. INTRODUCTION

Porous media receiver is used in concentrating type of collector. It is placed on the focal plane of the collector .The material inside the receiver absorbs the concentrated solar radiation and gets heated. Air is then passed through the fluid inlet surface of this receiver as the air gets enough time inside the receiver due to resistance offered by the material against the flow. The air absorbs the heat of the material and gets heated later on this hot air can be used for various applications.

II. BACKGROUND OF THE PROJECT

A 10 m^2 solar thermal unit available in institute is a parabolic dish type collector. The porous media receiver is placed at the focal plane of the collector and is filled with oxidized copper material. This porous material acts as heat storage and release medium. The incident radiations from sunlight falls on the fluid inlet surface of the porous media receiver which gets heated due to continuous heat flux reflected from the dish surface. Air is then passed through this receiver. As the air gets enough time inside the receiver it gets heated. This hot air is then passed through the heat exchanger which is nothing but shell and tube type heat exchanger in which the air flows through the shell side and fluid flows inside the tubes. A blower attached at the outlet of the heat exchanger sucks air from the receiver and releases to the atmosphere.

III. AIM AND PURPOSE

The problem with the existing setup is that the oxidised copper material which is used as the porous material does not withstand the temperature greater than 500 ^{0}C and starts disintegrating. The main aim of this project is to assess alternative materials to be used as heat storage material in the receiver. Prospective materials should sustain high temperature and it should have good thermo physical properties even at high temperatures as well as which can give optimum heat transfer rate.

IV. SOLUTION METHODOLOGY

A Computational Fluid Dynamics (CFD) approach is used to solve this problem. To solve any problem by CFD the standard method is divided into three parts pre-processing, solver and post- processing. Pre-processing consists of the problem definition, creation of model in CAD software and Grid generation. Solver consists of the choice of models, Boundary conditions and flow field computation. Post processing consists of analysis of results. FVM method is used to carry out the simulation. The k-ε model with Enhanced wall treatment is used as turbulent model to calculate the pressure drop and change of velocity inside the porous region. The physical velocity formulation is used to determine the effect of change in velocity inside the porous region. The LTNE model is used for the energy equation. This model is used when there is a temperature difference between the solid phase and fluid phase. The pressure based solver is used for this work. The second order upwind scheme is used for both momentum and energy equation and a coupled scheme is used for pressure velocity coupling.

A. Model description

A computational domain is a cylindrical pipe which is 1800 mm in length and 200 mm in diameter in which first 300 mm is inlet section from which air enters in to the domain next 300 mm is porous material region and rest 1200 mm is outlet region. The wall of the porous material is assigned the constant temperature value and it is made as adiabatic wall so that there is no heat loss to the surrounding and the wall

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temperature is constant thought the simulation. The material inside the porous zone is initially set at a value same as the wall temperature with an assumption that material has been heated uniformly at a temperature equal to wall temperature. The heat transfer coefficient and the interfacial area density (1/m) is calculated from the model given by Amiri and Vafai (1994). The inertial and viscous resistance coefficient along the flow direction is calculated from the Ergun's equation. As the fluid is flows along the x direction the resistances in y and z are assumed as infinite. As the properties of the material and air such as specific heat, thermal conductivity, density and viscosity and air are different at different temperature there values at different temperatures are calculated and the trend of the curve obtained at various temperature values is plotted and the constants for polynomial are investigated from the equation of the curve obtained and set as a input while defining material properties in fluent for both material as well as air. As the air is passed through the material which is at higher temperature the air takes heat from the material by convection due to this the material temperature will reduce and it starts taking heat from the wall by conduction. As porous material offers the resistance to the flow of air which results in drop in pressure of air and air gets enough time inside the zone to absorb more heat from the material. In this work the effect of change in porosity of material and change in velocity of air in terms of pressure, Temperature and velocity variation inside the porous region are investigated

B. *Boundary Conditions*

Inlet BC's: A uniform velocity with negligible compressible effect is prescribed at the inlet boundary. At x =0, u = u_0.

Outlet BC's: A pressure outlet boundary condition is given at the outlet surface and constant wall temperature condition is given for the wall of the porous zone.

No slip BC's: The walls of the three zone such as inlet ,porous and outlet zone are assigned as stationary walls with no slip boundary condition.

C. *Cell zone conditions*

The inputs required in this zone such as direction vectors, inertial and viscous resistance coefficient, heat transfer coefficient and interfacial are density are given as input value for this zone to solve the governing equation.

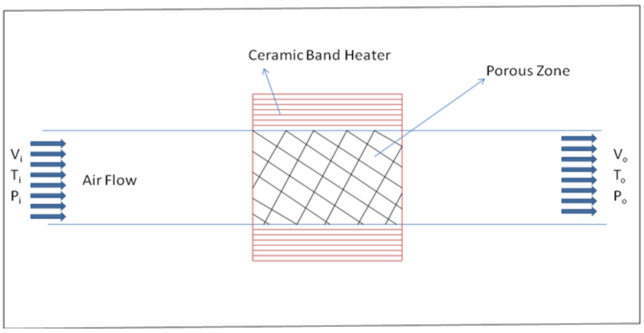


Fig. 4.1 Schematic of Air Flow and heat transfer in porous media receiver

V. GOVERNING EQUATIONS

A. *Continuity equation*

Based on the physical velocity formulation the continuity equation for the isotropic porous media is given by [5]

$$\frac{\partial(\varepsilon\rho u)}{\partial t} + \nabla.(\varepsilon\rho\bar{v}u) = 0 \tag{1}$$

Where ε is porosity, u is the velocity in x direction

B. *Momentum equation*

The momentum equation for the porous media follow the extended Darcy-forchheimer extended equation which is given as follows [2]

$$\frac{\rho_f}{\varepsilon}\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = \left(-\frac{\partial P}{\partial x}\right) + \mu_{f,eff}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \left(\frac{\varepsilon^2\mu}{\alpha}u + \frac{\varepsilon^3 C_2}{2}\rho uu\right) \tag{2}$$

Where ρ_f is the fluid density, $\mu_{f,eff}$ is the effective viscosity of the fluid which is calculated by $\mu_{f,eff} = \mu_f * \varepsilon$ and α and C_2 are the inertial and viscous resistance coefficients which are calculated from Ergun's equation as follows [4]

$$\alpha = \frac{d_p^2}{150} * \frac{\varepsilon^3}{(1-\varepsilon)} \tag{3}$$

$$C_2 = \frac{3.5}{d_p} * \frac{1-\varepsilon}{\varepsilon^3} \tag{4}$$

Where d_p= particle diameter in mm

C. *Energy equation*

In the local thermal non equilibrium model there is a temperature difference between solid zone and fluid zone for simulations in which the porous medium and fluid flow are not assumed to be in thermal equilibrium, a dual cell approach is used. In such an approach, a solid zone that is spatially coincident with the porous fluid zone is defined, and this solid zone only interacts with the fluid with regard to heat transfer. The conservation equations for energy are solved separately for the fluid and solid zones. For the fluid phase the equation is given as follows [1]

$$\rho C_{pf}\left(u\frac{\partial T_f}{\partial x} + v\frac{\partial T_f}{\partial y}\right) = k_{feff} \tag{5}$$

$$k_{feff} = \left(\frac{\partial^2 T_f}{\partial x^2} + \frac{\partial^2 T_f}{\partial y^2}\right) + h_{sf}\alpha_{sf}(T_s - T_f) \tag{6}$$

For the solid phase [1]

$$k_{s,eff}\left(\frac{\partial^2 T_s}{\partial x^2} + \frac{\partial^2 T_s}{\partial y^2}\right) = h_{fs}\alpha_{sf}(T_s - T_f) \tag{7}$$

In the above equations Ts and Tf are the solid phase and fluid phase temperature, $k_{s,eff}$ and k_{feff} are the fluid phase and solid phase effective thermal conductivity, where $k_{feff}=\varepsilon k_f$ and $k_{s,eff}= 1-\varepsilon\ k_s$, h_{fs} is the heat transfer coefficient between the fluid phase and solid phase in [W/m^{2}K]. αsf Is the specific surface are per unit volume in [1/m]. According to heat transfer model developed by Amiri and Vafai these two coefficients are given by [3]

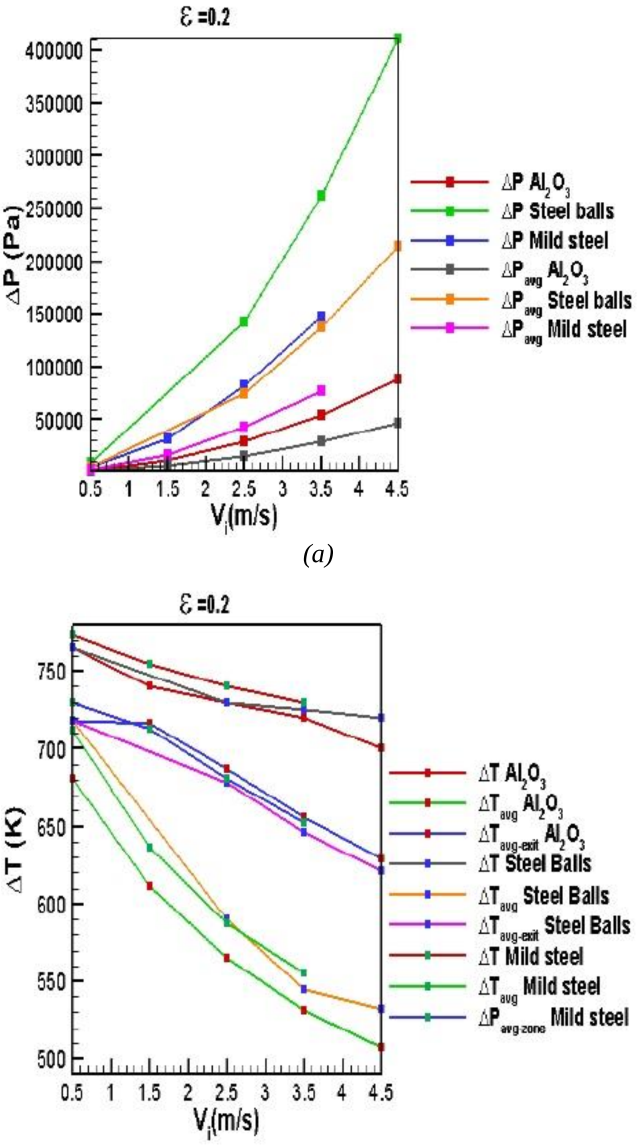
$$h_{fs} = \left(\frac{\lambda_f}{d_p}\right)\left(2 + 1.1\mathrm{Pr}^{1/3}\mathrm{Re}^{0.6}\right) \tag{8}$$

$$\alpha_{sf} = \frac{6(1-\varepsilon)}{d_p} \tag{9}$$

Where λ_f = thermal conductivity of fluid, Re and Pr are the Reynolds number and Prandtl number of air flowing through the porous region.

VI. RESULTS AND DISCUSSION

In this section the results obtained for the material Al2O3, Steel balls and mild steel are explained in detail. The results obtained in terms of Pressure, Temperature and velocity variation of air inside the porous zone is estimated. The variation of material Temperature inside the porous zone is also estimated. The results obtained for different porosity value and for different mass flow rate for each porosity value, for wall temperature of 500 ^{0}C which is applied at the wall of the porous zone is given as follows:



(a)

(b)

Fig.6.1 Temperature and Pressure variation for ε = 0.2

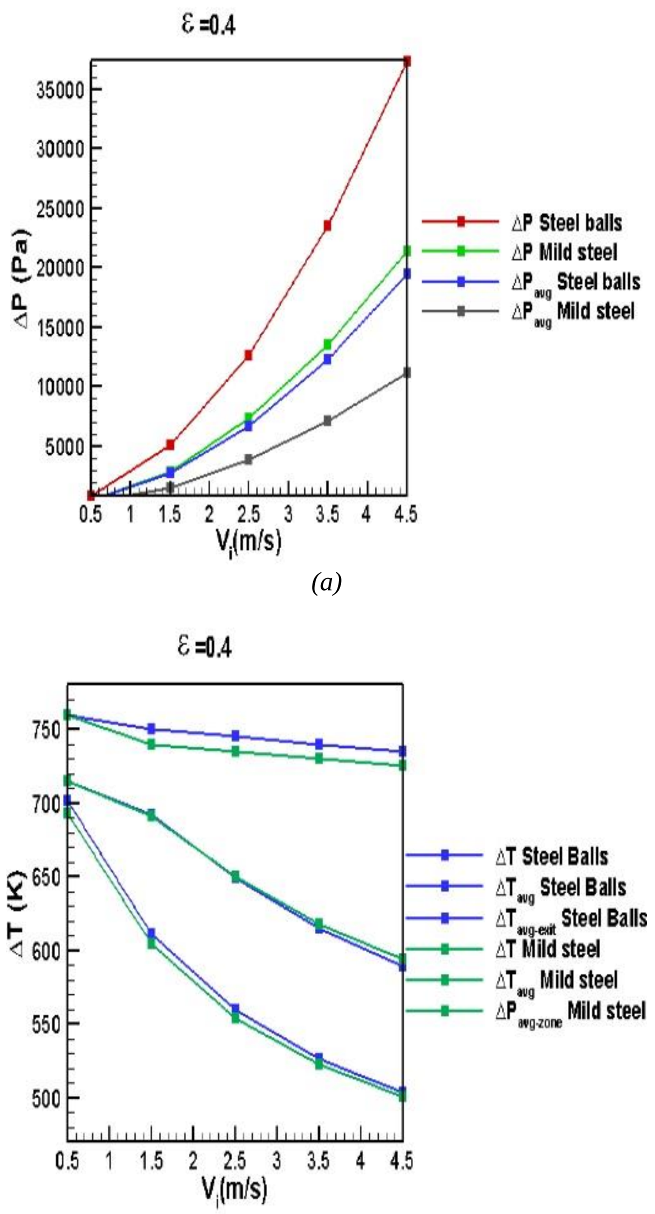


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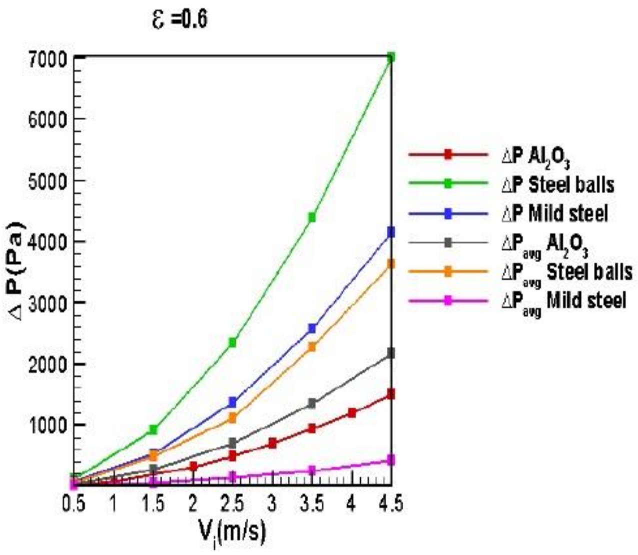
Fig.6.2 Temperature and Pressure variation for ε = 0.4



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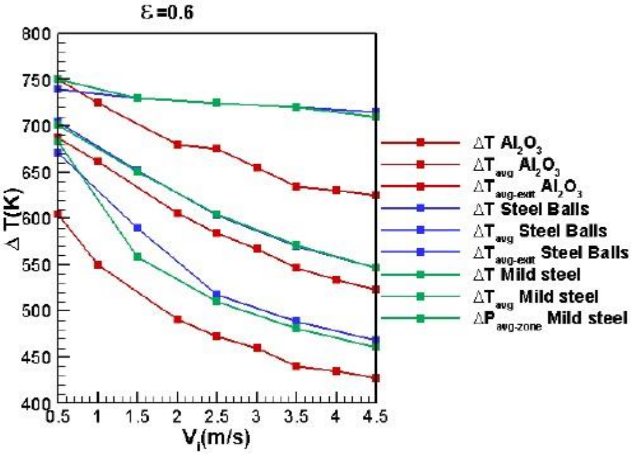

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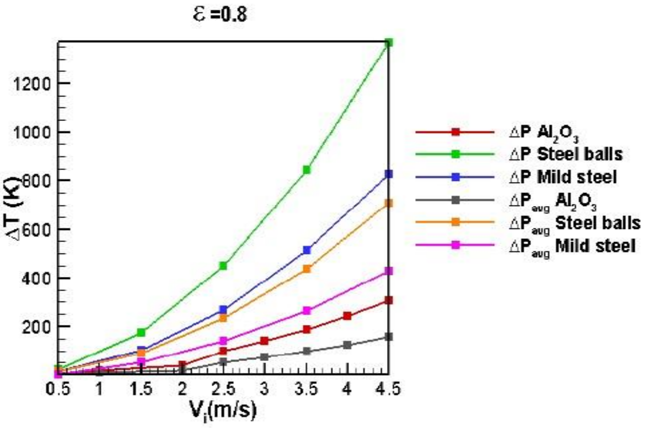
Fig.6.3 Temperature and Pressure variation for ε = 0.6



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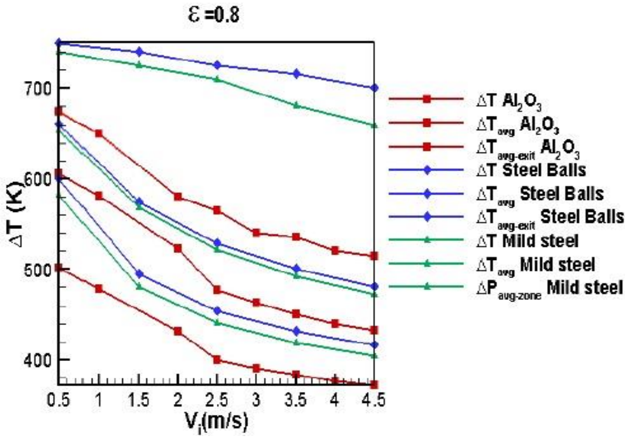

(b)

Fig.6.4 Temperature and Pressure variation for ε = 0.8

VII. CONCLUSION

In this work the heat transfer and fluid flow performance of different materials with change of porosity, particle diameter and velocity in terms of change in the value of pressure, Temperature and velocity are investigated. The heat transfer rate of these materials at different particle diameter, with variation of porosity in the range of 0.2 to 0.9 and with the change of velocity value in the range of 0.5 to 4.5 m/s for each porosity value and at a constant wall temperature of 773K is investigated. During this it is observed that the heat transfer ability of materials is depending upon the several factors such as thermo physical properties of the material as well as the fluid flow conditions. When the particle diameter is less the outlet temperature of air obtained is more but the pressure drop value is also more .As the value of porosity increases the pressure drop and the average outlet temperature of air is reduced. From the above results it can be concluded that the efficiency of materials at higher temperatures depend upon the porosity, diameter of the particles the variation of properties of the material with temperature, mass flow rate of air, interfacial area density and the heat transfer coefficient between fluid to solid interface.

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