CFD analysis on the effect of radiation and inlet gas temperature on porous media solar heater

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Abstract. The effect of porosity on flow and thermal characteristics is significant. Fluid flow through porous media has many practical relevance such as agriculture, engineering, bio-medical, etc. applications. In the present study, flow of gas and through solar heater is simulated and the heat transfer characteristics are studied. Two-dimensional numerical simulations are carried using ANSYS-Fluent. Velocity of gas at the inlet is varied from 0.005 to 0.5 m/s and passed through the porous media with porosity value of 0.7. Results are presented in the form of pressure variation, velocity variation and temperature variation.

1. Introduction

With increase in the demand of clean energy and the effect of fossil fuels on the environment and depletion, solar power is one of the best source of energy available to us. Proper utilization of this energy is always a great concern to the researchers, various techniques are used to utilize this energy various researcher worked on the utilization of this energy, **Torabi et al.** [1] The interest in second law analyses of porous thermal and thermochemical systems has increased a good deal of attention has been paid to the LTNE model of porous media, as this model will a lot of accurately present the energetic and energetics performances of the system. These often include those systems that feature extra physicochemical effects, the effects of magnetic field and radiation heat transfer have not been considered in conjunction of LTNE model. There has been additionally very limited work on entropy generation investigation in with chemicals reactive porous media. **Wang Fuqiang et al.** [2] Author studied the heat transfer performance by combining MCRT methodology and Fluent .The MCRT methodology is used to get the heat flux distribution on the fluid entrance surface of porous solar collector. He used P1 and Rossel approach in fluent to find the performance of the solar reactor. From his paper it can be concluded that the maximum solid phase and fluid part temperature for P1 approximation is above that of rossel conditions disappears at high optical thickness with high fluid temperature. **Tan Jianyu at al**. [3] studied numerically heat transfer of porous medium receiver with quartz window. The temperature distribution of porous medium receiver model with flow inlet set at the aspect wall is compared. He concluded with the introduction of the quartz wall heat flux on porous media front decreases, the pressure and temperature distribution is totally different from the inlet set at porous front. **Fuqiang Wang at al** [4]**.** In this paper LNTE model with rossel approximation was used to get the temperature distribution, the following can be concluded, heat flux has a robust impact on the temperature distribution most nonuniform heat flux distribution was at 1372 K and the most uniform heat distribution was at 1287 K. Radiation heat loss cannot be neglected, maximum temperature of solid section and thickness of thermal nonequilibrium will increase with body increasing. **Wu et al.** [5]describe the temperature drop observed in the gas outlet region as ascribed to the heat loss and the effect of water-cooled system. The gas inlet velocity has significant effects on the temperature distribution in the solar thermochemical reactor as the velocity increase the temperature increases. **Wang et al.** [6] studied different transport and thermophysical models for the thermal and physical behavior of the porous media in the simple cylinder cavity structure without any optimization.

The effect of inlet velocity and the inlet fluid temperature on the solar reactor is studied and effect of radiation temperature on the fluid thermophysical property is studied with the porosity of the system remains constant. The temperature difference, pressure distribution and velocity through the porous medium is studied if the pressure is high more pumping force will need to have efficient flow.

2. Problem Statement
Porous media solar heater has been numerically studied with objective to understand the effect of various operating parameters on performance of the heater. The operating parameters considered in the present study are flow velocity and radiation intensity in terms of temperature. Porosity and permeability of the porous media are selected based on the literature study. The computational domain is shown in Figure1.

3. Computational Domain
A convergent structure solar reactor is made to absorb the solar energy and utilize it for different application. Solar quartz glass receiver is of 100 mm diameter and the convergent at the length of 40 mm with 45º convergent angle. Then it diverged and is connected to a porous medium of length 60 mm and 50 mm diameter, again it converges and connected to 8 mm uniform diameter tube. [7]

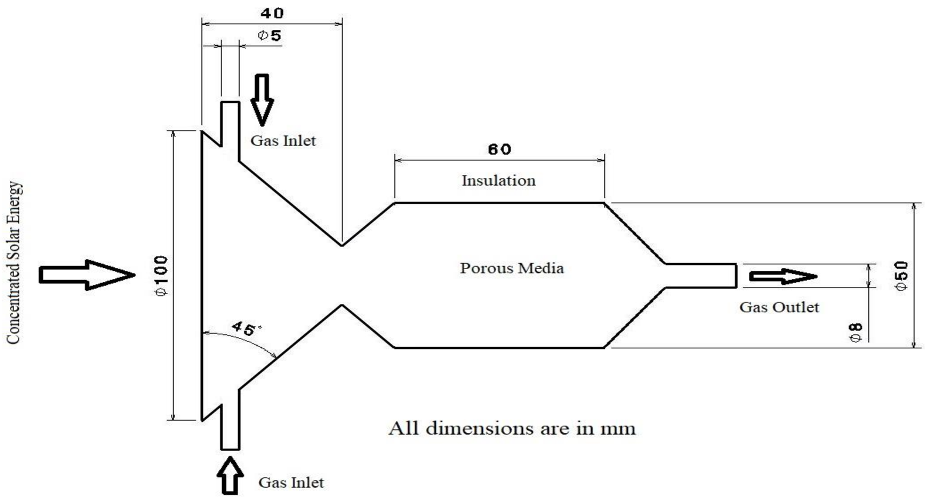

Figure 1: Computational Domain

The solar emission temperature varies from 500K to 1600K depending on the sun intensity and the flow rate of the fluid is changed from 0.005 m/s to 0.5 m/s. with operating temperature as 300 K and 1 atm pressure.

4. Governing Equations
The momentum(1), energy(3) and continuity(2) equations are used in a steady laminar flow of fluid, the flowing other equations are used for the calculations.

$$\frac{1}{r}\frac{\partial}{\partial r}(\rho r v) + \frac{1}{r}\frac{\partial}{\partial \theta}(\rho u) + \frac{\partial}{\partial z}(\rho w) = 0 \tag{1}$$

$$\rho(\vec{V}.\nabla\vec{V}) = -\nabla p + \nabla.(\mu\nabla\vec{V}) \tag{2}$$

$$\rho C_p(\bar{V},\nabla T) = k\nabla^2 T \tag{3}$$

$$\mathrm{k} = \frac{{d_m}^2}{180}\frac{(1-\emptyset)^2}{\emptyset^3} \tag{4}$$

where Ø=porosity and d_m=mean diameter of the molecule in porous zone.

5. Computational Setup and Boundary Conditions

The problem is solved using P1 Radiation approximation with steady state laminar flow with energy equation.P1 approximation is simple and compatible with standard method for the solution of general CFD equations The inlet velocity is given as 0.005 m/s with operating temperature 300K and 1 atmospheric pressure, the radiation temperature is taken as 1600K with internal emissivity 0.92 and outer wall emissivity 0.3.The porosity is 0.7 and permeability as $4.737091e^{-9}$. The outlet pressure is kept at 1 atmospheric temperature. The second order upwind equation is used for the calculation of pressure and energy. [7]

6. Results and Discussion

The variation of the pressure, velocity and temperature variation along the axis at the center of the plane.

The temperature changes drastically from convergent to divergent, the temperature remains constant at porous region and then again decreases till the exit. The pressure remains constant at the convergent and divergent section it uniformly decreases at the porous section and again its uniform at the exit. The velocity at the convergent section increases and then decreases at divergent section the is constant at the porous region with some positive value and the velocity drastically increases after the exit of the porous medium remains constant for a while and decreases drastically.

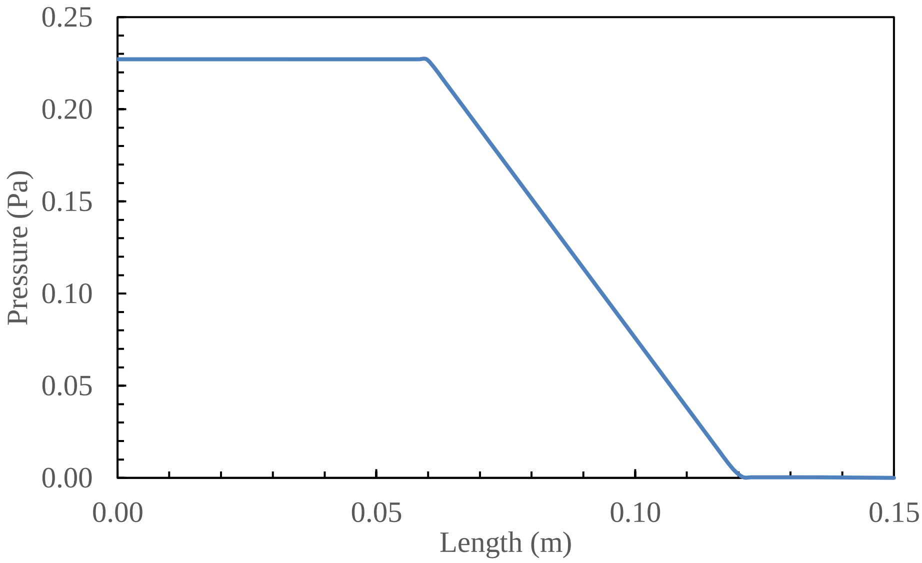

Figure 2: Variation of pressure along the centre axis of the domain with velocity 0.005 m/s and 1600K radiation temperature.

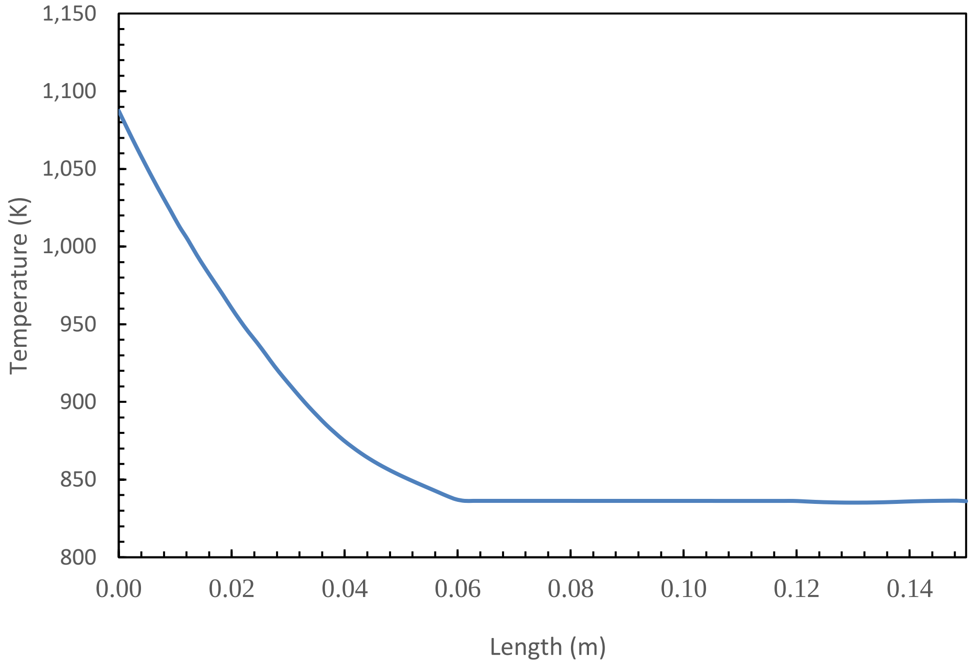

Figure 3: Variation of temperature along the centre axis of the domain at 0.005 m/s velocity and 1600K radiation temperature.

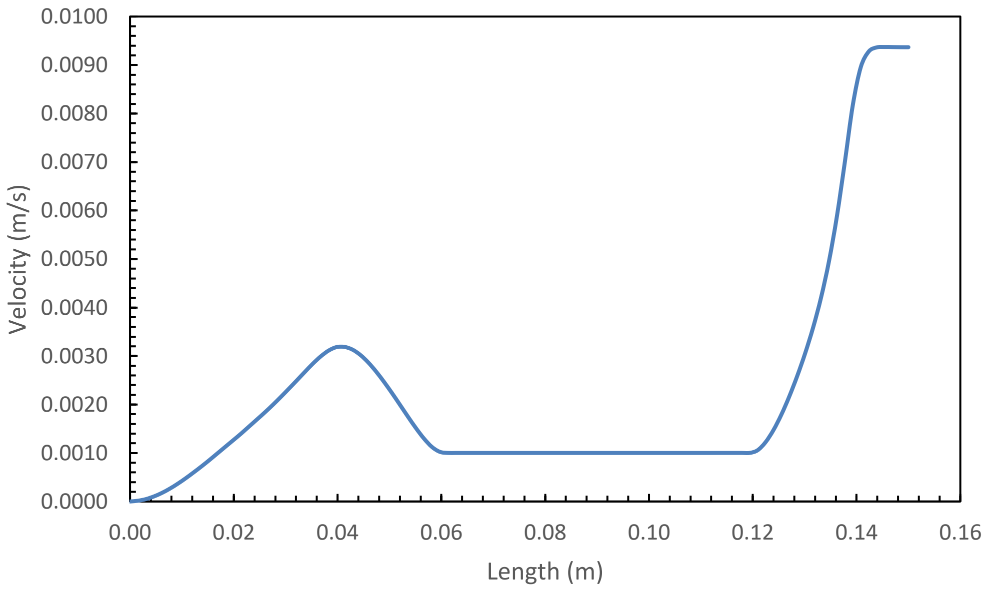

Figure 4:Variation of velocity at the centre axis of the domain with inlet velocity 0.005m/s and radiation temperature 1600K.

The Temperature, Pressure and Velocity variation contours at the mid plane.

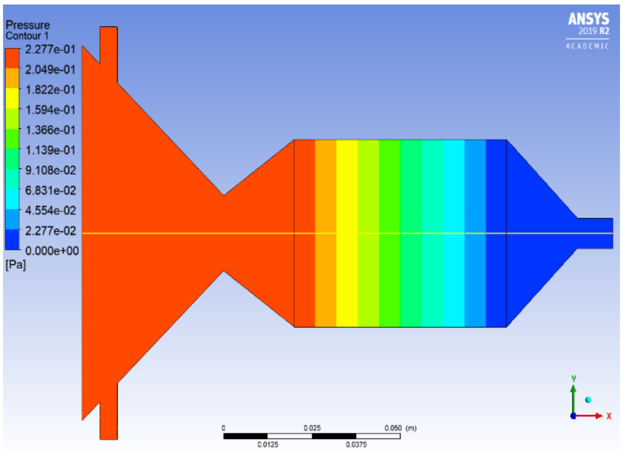

Figure 5: Pressure Contour.

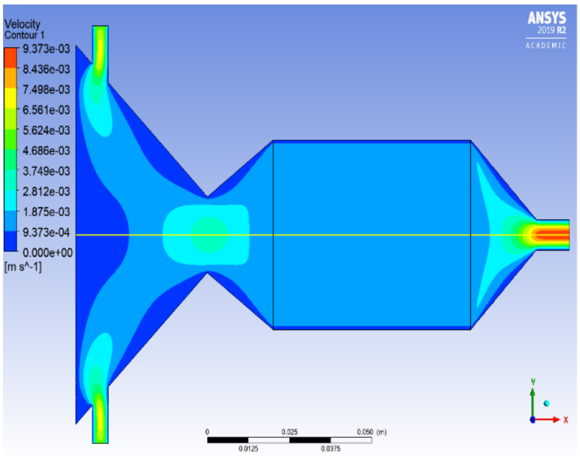

Figure 6: Velocity Contour.

Effect of Velocity Variation: The inlet velocity is varied from 0.005 to 0.05 to find its effect on the average pressure on the surface, as the velocity increases the average pressure increases keeping porosity and radiation temperature constant. The average temperature increases but has very little variation in the temperature. As the velocity increase there is increase in the pressure with variation in temperature so optimum temperature and pressure combination should be maintained to get maximum variation.

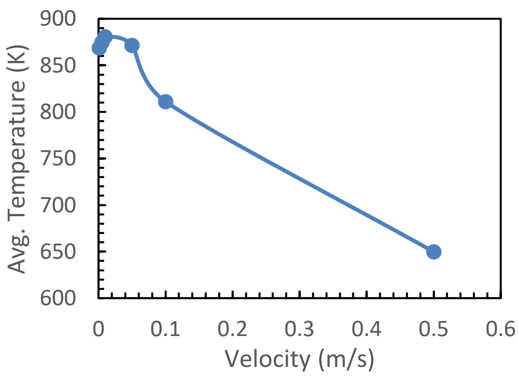

Figure 7: Variation of average surface temperature with change in input Velocity.

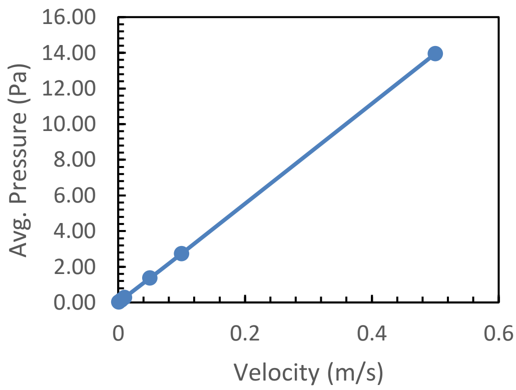

Figure 8: Variation of average surface pressure with change in input Velocity.

Effect of variation of inlet fluid temperature As the inlet operating temperature increases the average surface temperature remains constant from 300 to 400 K after that it increases till 500 K. The increase in inlet temperature effects the overall surface temperature it can also be used in specific thermal reaction if required for specific application. While the pressure remains constant even after changing the inlet temperature. While the inlet velocity is kept as same 0.005m/s for the process throughout.

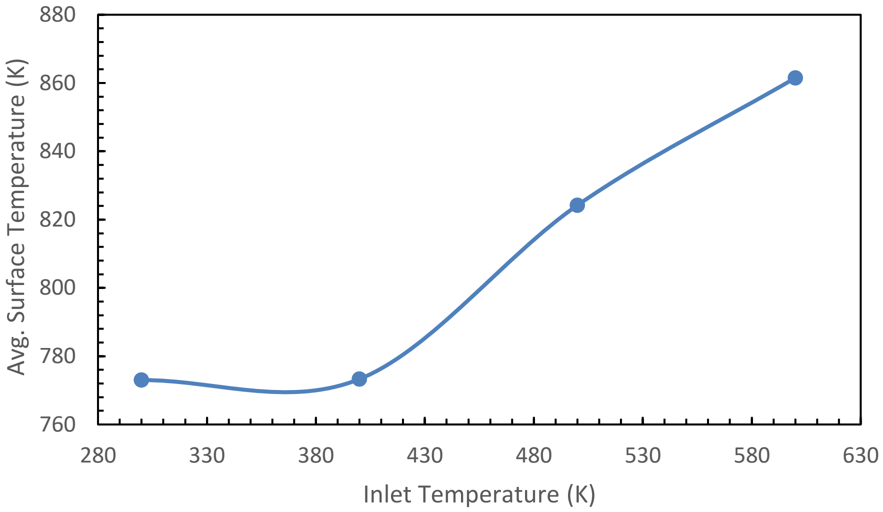

Figure 9:Variation of average surface temperature at mid plane with variation of inlet fluid temperature.

Effect of Radiation temperature as solar power is not constant throughout the day so the variation of radiation temperature is also a parameter to find the ability of the solar reactor, as the radiation temperature at the central axis increase temperature increases.

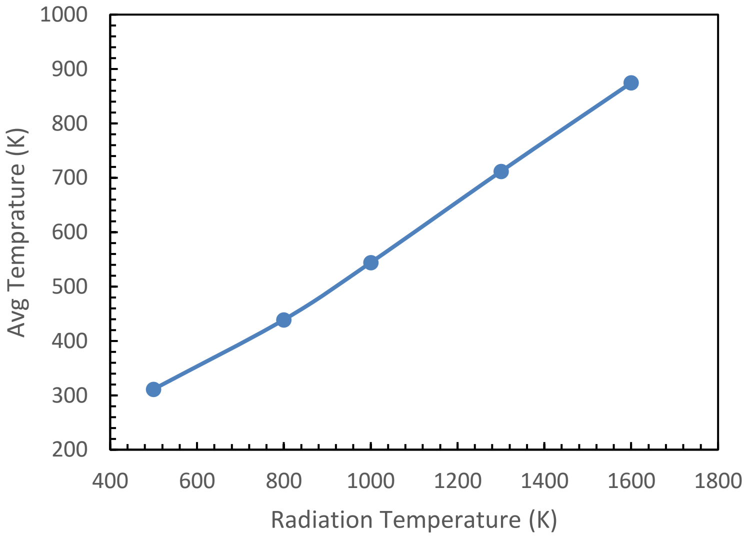

Figure 10:Variation of temperature along the axial length of the domain.

7. Conclusion

Thermal transport and fluid flow in porous media solar heater is studied using ANSYS Fluent 2019 R2 (Academic Version). Pressure drop due to the porous media is analyzed and reported. Porous media provides better flow distribution, therefore uniform temperature in the region is observed. Also heat transfer enhancement is possible with porous media. Average pressure at the central axis increases with velocity. On the other hand, average temperature decreases with increasing velocity, due to enhance heat transfer. Average surface temperature remains constant for at lower temperature of the inlet fluid. For moderate to higher temperature of the fluid inlet average surface temperature increases.

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