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Thermal Analysis of Vertical Flow of Steam Through a Porous Media

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ABSTRACT: The heat, mass, and flow transfer through mixing area of fluid with porous materials used in many applications like heating of pipe, production engineering, materials isolation, and building envelope. Chiefly the slip impact at the interface between the porous media and fluid which has been important in the fluid flow, mass, and heat transfer. In this paper, thermal simulation and numerical to analyze the flows of fluid within porous material as porous media is achieved. Results were obtained for different flow velocity (Reynolds number) of steam ranged of (37374, 42315, 47275, and 52070) with inlet temperature of 400 K. The increase in Reynolds number (flow velocity) increases the pressure distribution along the porous zone segment. Velocity of steam is higher at inlet and outlet and be lower at the porous zone, so the increase in steam flow velocity increases velocity distribution. Steam temperature enter at high value at the inlet (400 K) and reduces along the segment distance (Z/L). The increase in steam flow velocity increases temperature along the section.

KEYWORDS: Thermal analysis; high turbulent flow; porous material; numerical simulation

INTRODUCTION

The systems of flow by porous material widely used in separation processes, civil and mechanical engineering, etc. One of interest by mechanical engineering is micro heat exchanger, pneumatic, catalytic reactors all of them with porous media. For the heat exchanger, the fluid is cooled or heated by cross section available for flow with walls of porous. The behavior of porous systems as heat exchanger doing by fluid motion around area of porous section. Regarding to sinuous fashion, the heat will developed because of in uniform fluid motion. Due to its features, the mass and heat transfer via the porous system has been widely elaborated. Vafai and Tien [1] applied the technique the averaging of volume to imitate the fluid flow and heat flux through porous media and studied the inertia and boundary effects. Masuoka and takatsu [2] revealed the high velocity of flow through the porous systems and assessed the model of zero-equation for fluid and heat flux. Lu et al. [3] discussed numerically the overall heat coefficient and pressure gradient in the open-celled metallic system as porous media with structured cell zone. Calmidi and Mahajan [4, 5] presented numerically and experimentally the heat transfer and thermal conductivity behavior in highly-porosity open-celled porous media heat exchanger. Asaad [6] presented a CFD simulation of flowing gas through a packed bed at low and high particle Reynolds number. The runs were done over a 0.9 m column length using k-ε model. Asaad and Farhan [7] studied the effect of multi size media on fluid behavior at Darcy flow region as differences in the sizes and weight of porous media. Rafael et al. [8] presented an educational code by using a Stokes flow simulation in the porous system to find absolute permeability for heterogeneous matters in conditions of periodic boundary. Angirasa [9] the equations of volume-averaged eddy transport has been study numerically within porous media. Boomsma and Poulikakos [10] and Boomsma et al. [11] presented by experiments the performance and characterization of porous heat exchanger. The computational fluid dynamics depend on the governing equations, by which the detailed fluid flow and heat transfer through the porous media is unobtainable. For presenting the microscopic view of the flow through the porous media, Krishnan et al.

[12] Built the open-cell framework and studied the effects of permeability and porosity on the Nusselt number and friction factor using finite volume scheme. Ochoa-Tapia and Whitaker [13] the effective viscosity of fluid was recommend in the system of porous media at condition of Shear Stress Jump to solve the equation of volume integral transfer. Kuznetsov [14] state the conditions of shear jump effects on the flow rate of free-flowing zone. It has been found that influence viscous dynamic factors and the shear lag can affect the distribution of the fluid flow velocity. Chandesris and Jamet [15] studied the deriving of interface boundary condition by identical method

and found that the pressure gradient is related to the condition of shear boundary. Silva and Lemos [16] analyzed the effect of physical properties for the porous regime in the mixed region flow to velocity distribution by using the mathematical model founded during the jump condition. Vafai and Kim [17] found that the single-region method gives accuracy in the fluid properties changes when analyze it. Many researchers [18,19] developed a general model which including the method of single region to estimate state of velocity profiles in the mixed area by applying experiments on the single region method.

The present work involves simulation of thermal analysis and flow of steam through vertical segment of porous media using computational fluid dynamics to find the behavior of pressure, velocity, stream lines, and temperature through the porous zone.

FLUID PROPERTIES

The physical and thermal properties of the steam (at 400 K) used in the present work are listed in table (1). These properties were entered as inlet boundary conditions in the set up process stage.

Table 1. Fluid properties

Property	Value	Units
Density	0.554	Kg/m^3
Thermal conductivity	0.0261	w/m.k
Dynamic viscosity	$1.34x10^{-5}$	Kg/ m.s
Heat capacity	2014	j/ kg.k
Molecular weight	18.015	Kg/kgmol.

FLUID FLOW MODELLING

THE EQUATION OF CHANGE FOR ISOTHERMAL SYSTEM

i) This equation represents the motion equation for incompressible fluid with constant density and viscosity. The Navier-Stokes equation can be written in simplified form when it is reduced to x,y components equation by assuming that the fluid is flowing only in the axial direction [20, 21, 22].

ii) For incompressible Newtonian fluid with turbulent flow(Newtonian resistance) , the rate of viscous dissipation will integral over the volume of entire flow, so the growing in the kinetic energy (ε) will appear due to rising of inertial forces. [23, 24, 25, 26].

CFD MODELLING

ANSYS-Fluent is one of a Packages analysis of CFD which used to simulate fluid motion and steams in porous systems. ANSYS-Fluent software has general parts of to analyze the regime which starts with the pre-processor, post-processor and gives the final result with part of the solver. All of data will provides for the porous system under isothermal condition, steam velocity, etc. by Fluent software, to solve the equations of change and porous condition model [24]. In this paper, simulate the upward flow of steam through the vertical segment of porous media using ANSYS Fluent v.16 with steady state turbulent flow condition. The boundary conditions involves of turbulent flow model with inlet velocity raged from 22.6 to 31.6 m/s and inlet steam temperature of 400 K assuming isothermal condition. After the simulation is iterated to steady value, the results of the system appear as contours gradients, results were obtained through the solver that can be shows the details of output like to velocity, pressure, streamlines, and temperature.

MODEL DESCRIPTION AND MESHING

The analysis of a porous media segment used with ANSYS-Fluent v.16 to simulate numerically the he upward flow of steam in the regime. The geometry of model was done with hexahedral grids of 13079 quadrilateral cells and 14661 nodes as shown in figure (1). The geometrical model was built with 0.040 m in a diameter for inlet and outlet section, and 0.100 m in a diameter of porous zone, length of inlet and outlet section is 0.030 m, and length of porous zone is 0.400 m.

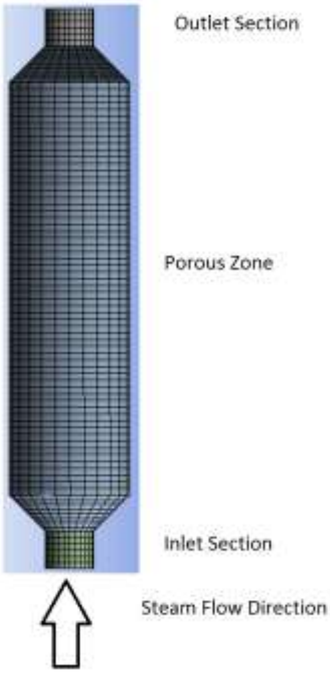

Figure 1. Meshing the test section

MODELS OF POROUS MEDIA

According to Darcy's law, a linear relationship of the pressure change and flow is suggested [25]:

$$\frac{\Delta p}{L} = \frac{\mu u}{k} + \rho k_F u^2 = \alpha u + \beta u^2 \quad (1)$$

Where k_F is the resistant force existing at low Reynolds number, while β is the coefficient of the internal resistance in the permeable material per unit length at high flow velocity [25].

Furnas [24] developed a correlation between the porosity in packed and the diameter of a particle and bed:

$$\varepsilon = 0.375 + 0.34\ \frac{d}{D} \quad (2)$$

By using CFD modeling depending on solving Navier-Stokes equation for pressure and velocity according to specific boundary conditions, values of equation (1) could be determined.

Ergun proposed the following equation [26]:

$$\frac{p_{o-}p_l}{L} = 150\left(\frac{\mu\, u}{d^2}\right)\frac{(1-\varepsilon)^2}{\varepsilon^3} + 1.75\left(\frac{\rho u^2}{d}\right)\frac{(1-\varepsilon)}{\varepsilon^3} \quad (3)$$

RESULTS AND DISCUSSION

For different flow velocity of steam through vertical porous media segment gives different pressure distribution, the pressure drop can be calculated by the difference between the pressure value at bottom and top of the segment, the pressure distribution contours have been simulated using ANSYS-Fluent 16.0 over the Reynolds numbers range of (37374, 42315, 47275, and 52070) as shown in Fig. (2). Pressure decrease along the porous zone because of the strong inertial forces of the porous media material, the increase in Reynolds number (flow velocity) increases the pressure distribution along the porous zone segment, this behavior shown clearly in fig.(6). Actual reason for decreasing in the pressure gradients coming from Navier-Stokes equation, when the flow upward is extremely slow and the equation at this case called stokes flow equation with the resistant force existing at L of porous media segment [27-35].

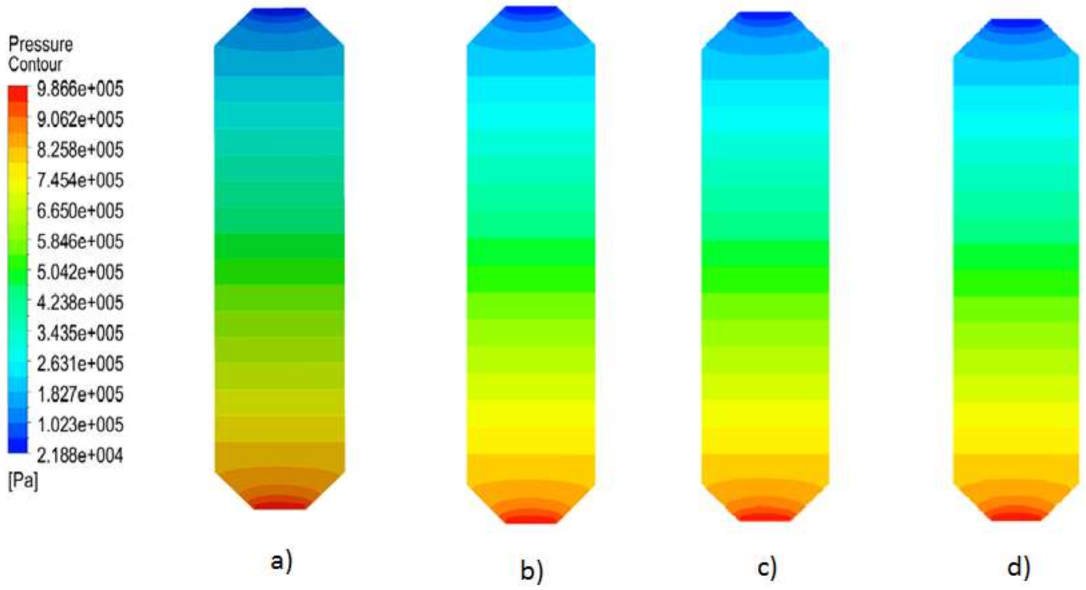

Figure 2. Pressure contour through porous zone for different inlet Reynolds number (a: 37375, b: 42315, c: 47275, d: 52070)

Fig.(3) illustrates the contours of velocity distribution along the porous zone segment for different flow velocity (Reynolds number), velocity of steam is higher at inlet and outlet and be lower at the porous zone, so the increase in steam flow velocity increases velocity distribution as shown in fig.(8). Fig.(4) reveals the velocity stream line of flowing the steam through the segment for different flow velocity, different flow velocities give different steam flow behavior. According to the highly turbulent flow in the porous media zone, the velocity flow approach to the square.

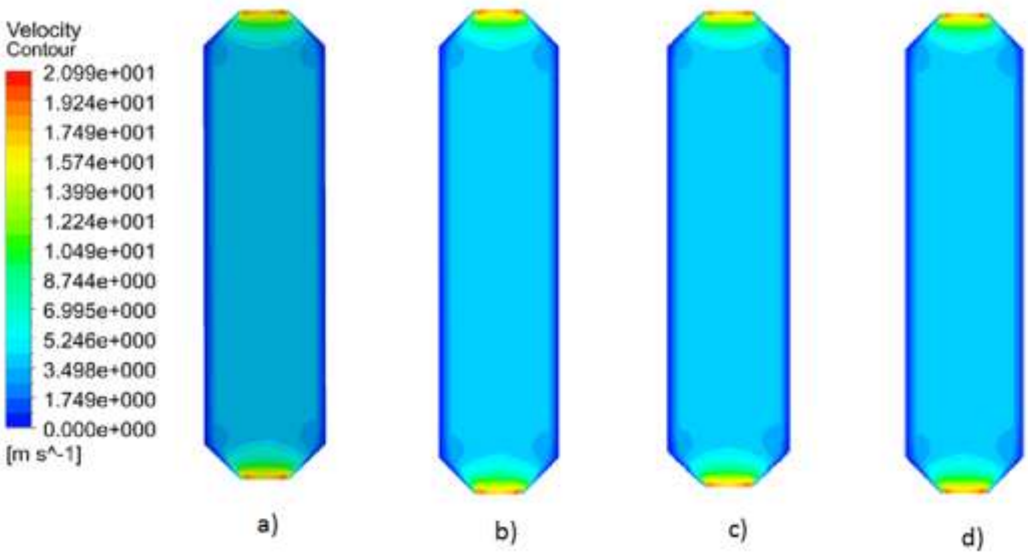

Figure 3. Velocity contour through porous zone for different inlet Reynolds number (a: 37375, b: 42315, c: 47275, d: 52070)

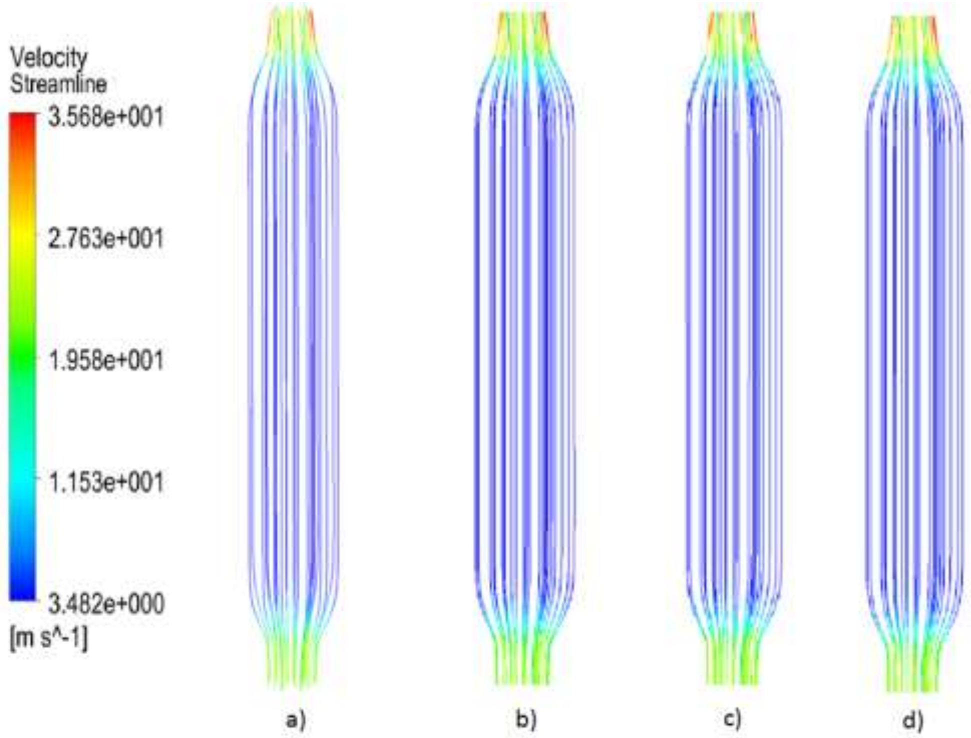

Figure 4. Velocity streamline contour through porous zone for different inlet Reynolds number (a: 37375, b: 42315, c: 47275, d: 52070)

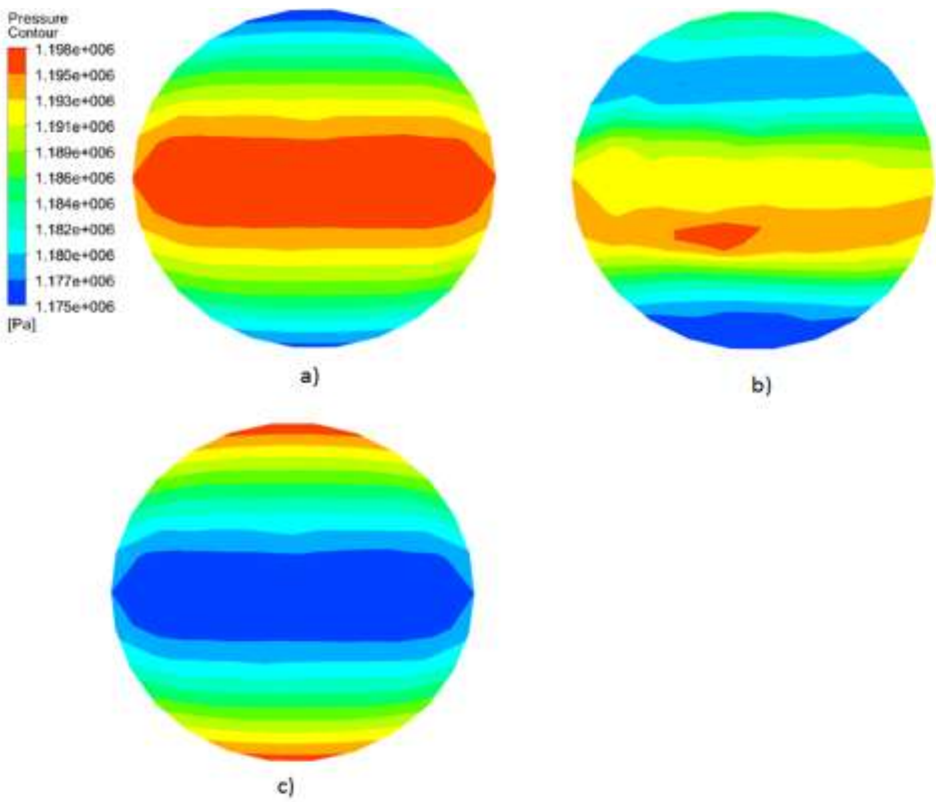

Figure 5. Pressure contour through porous zone at different location (a: inlet , b: mid, c: exit,)

Fig.(5) present pressure contour at different location (Z/L) of porous zone, pressure be at high value at the inlet and decreases gradually to the end. Fig.(6) shows pressure contour at different location (Z/L) of porous zone, it can be seen that flow velocity be at high value at the inlet and decreases gradually to the end. Fig.(8) reveals temperature distribution along the porous zone segment, steam temperature enter at high value at the inlet (400 K) and reduces along the segment distance (Z/L), because of heat loss through porous body. The increase in steam flow velocity increases temperature along the section. Fig.(9) presents the pressure decrease across the porous zone for different inlet steam flow Reynolds number. The values of pressure drop obtained from the current CFD model were in consistence with that values found from Ergun model with relative error of (1.3-2.4)%. At the inlet part zone, the simulation shows the second part in the equation (3) along the porous segment to the mid zone (z/L). The first part form equation (3) appear in the out let section porous zone because of the flow becomes creeping [36-41].

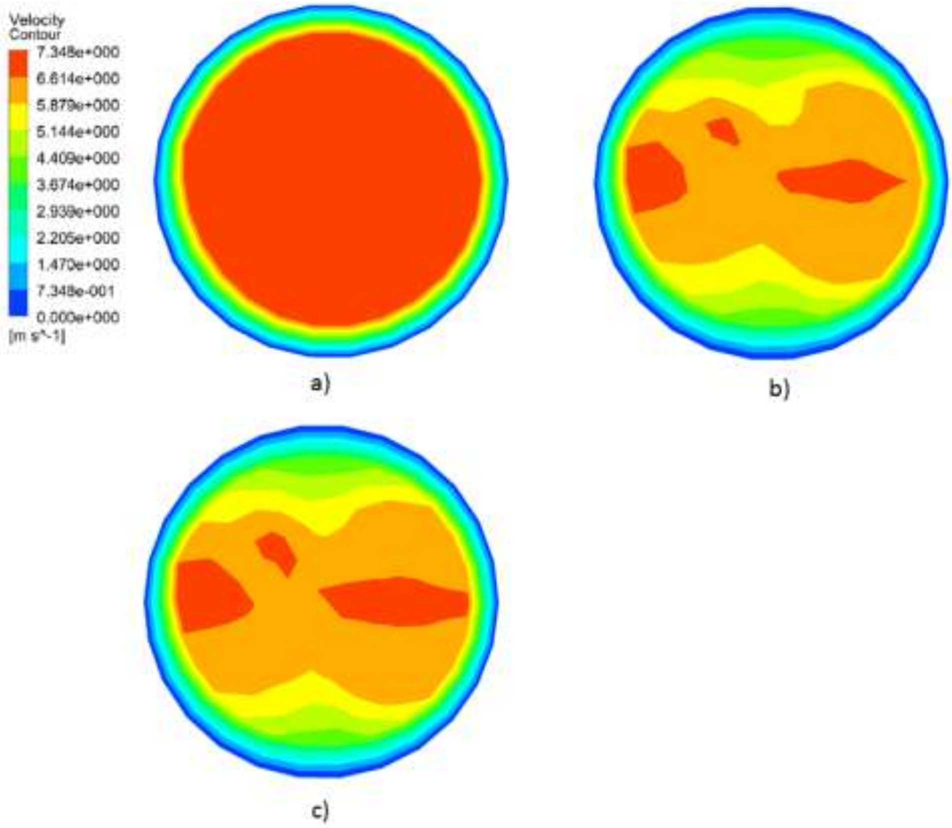

Figure 6. Velocity contour through porous zone at different location (a: inlet, b: mid, c: exit)

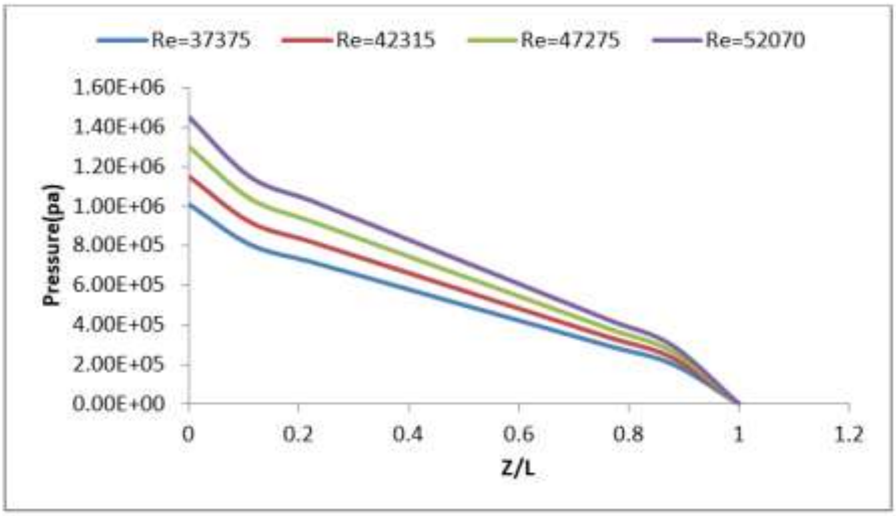

Figure 7. Pressure distribution through porous zone for different Reynolds number

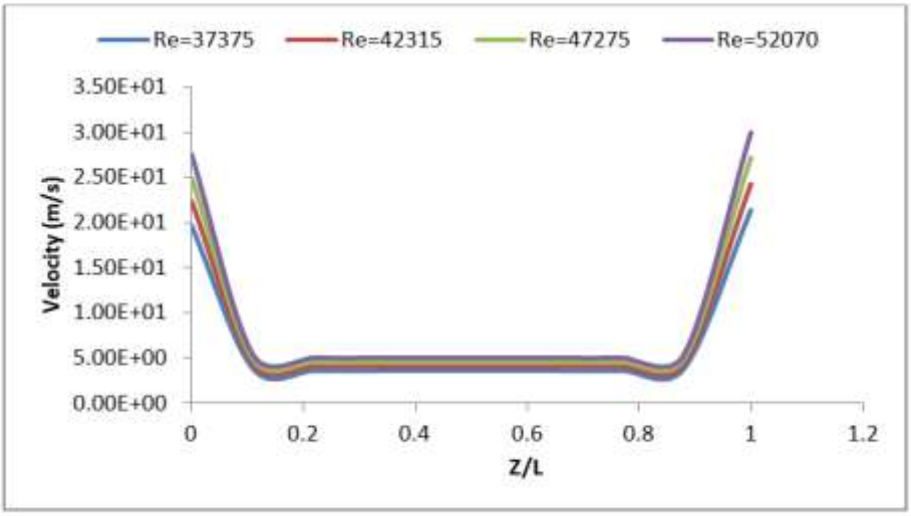

Figure 8. Velocity distribution through porous zone for different Reynolds number

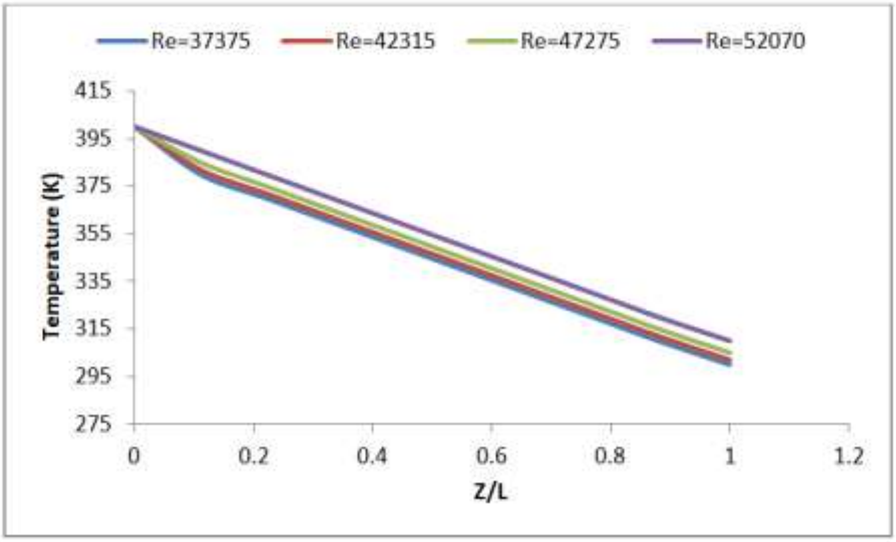

Figure 9. Temperature distribution through porous zone for different Reynolds number

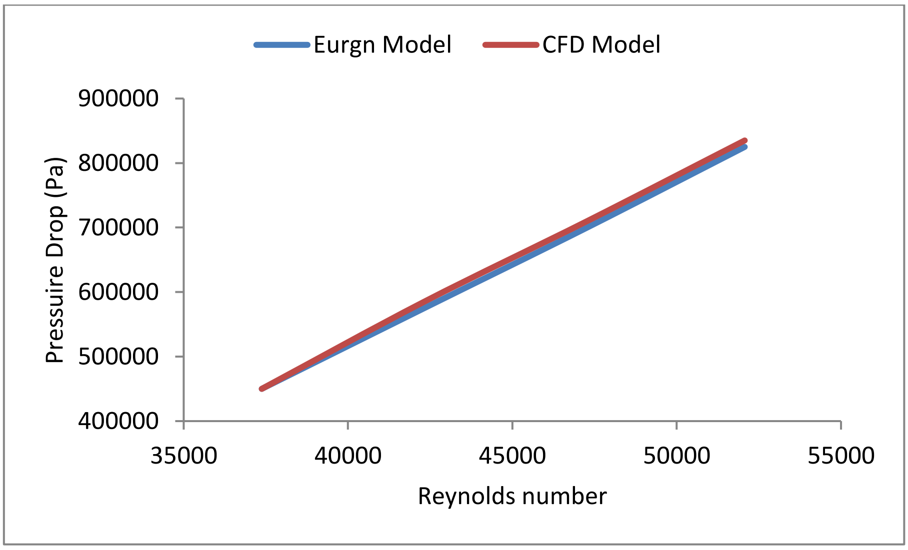

Figure 10. Pressure decreasing through the porous section for different inlet gas velocity

CONCLUSIONS

The present work studied the effect of varying steam flow velocity on some parameters for flow of steam vertically through a segment of porous media, the following conclusion can be obtained:

1. The increase in Reynolds number (flow velocity) increases the pressure distribution along the porous zone segment.

2. Velocity of steam is higher at inlet and outlet and be lower at the porous zone, so the increase in steam flow velocity increases velocity distribution.

3. Steam temperatures enter at high value at the inlet (400 K) and reduces along the segment distance (Z/L). The increase in steam flow velocity increases temperature along the section.

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