



Modeling and Numerical Analysis of Sphere Packed Beds for Cooling a Fusion Reactor Core

A. Rabiee, A. H. Kamalinia*, K. Hadad

Department of Mechanical Engineering, University of Shiraz, Shiraz, Iran

ABSTRACT: A vital challenge in fusion nuclear reactors is the heat removal through the embedded channels. Various methods have been employed to improve the reactor core cooling systems. One of the methods in this context is creating turbulence in the flow field by using sphere packed beds. In present study, heat transfer in channels filled with spheres, as a technique to enhance the heat transfer coefficient, is investigated through numerical modeling. The spheres in the channel are assumed as a continuous porous media and domain coefficients are obtained by using the Ergun and momentum conservation equations. Wall effect in porous media modeling is considered by employing the modified k-ε turbulent model. In comparison with the conventional numerical methods that require high number of unstructured grid generation, the porous media numerical simulation demonstrates acceptable accuracy in obtaining flow field parameters including pressure drop and heat transfer coefficient. Meanwhile, it is concluded that a reduction of porosity results in an increase in pressure drop and heat transfer coefficient.

Review History:

Received: 2 August 2015
Revised: 6 March 2016
Accepted: 9 May 2016
Available Online: 8 November 2016

Keywords:

Spherical packed bed pipe
Porous media
CFD
Turbulent flow

1- Introduction

One of the methods to optimize the heat transfer process is developing turbulent flow by embedding the spheres in the tube. In this way, effect of ratio of the tube diameter to sphere diameter is experimentally investigated by Seto et. al. [1]. Results showed that by increasing the Reynolds number, pressure loss and the heat transfer coefficient increase, correspondingly. Various investigations have been done which report enhancement of heat transfer coefficient due to the Reynolds number and pressure loss [2-5]. Transition of flow from laminar to turbulent has been investigated by Bue et. al. [5] and k-ε model has been compared with experimental data. It showed that sources for k and ε are necessary to improve the capability of the model in order to predict the flow parameters [6-9]. Nakayama et. al. [10] and Chandris et. al [11] investigated general effects of turbulent flow in porous media and reported that the complexity of the packed bed in numerical analysis can be simplified by using porous media. Investigations show that limited studies have been accomplished in order to simulate and analysis the sphere packed bed pipe with porous media. In current research, flow field parameters such as pressure drop and heat transfer coefficient have been analyzed.

2- Equations and boundary conditions

Reynolds averaged Navier-Stokes equations have been used in order to simulate flow field in the porous media.

• **Continuity**

$$\frac{\partial(\gamma\rho)}{\partial t} + \nabla \cdot (\rho\vec{v}) = 0 \quad (1)$$

• **Momentum equations**

$$\frac{\partial(\gamma\rho\vec{v})}{\partial t} + \nabla \cdot (\rho\vec{v}\vec{v}) = -\nabla P + \nabla \cdot \overline{\tau} + \rho\vec{g} + S_i \quad (2)$$

• **Energy equations**

$$\frac{\partial}{\partial t}(\gamma\rho_f E_f + (1-\gamma)\rho_s E_s) + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla k_{eff} \left[\nabla T + \left(\overline{\tau} \cdot \vec{v} \right) \right] + S_f^h \quad (3)$$

Porosity (γ) is calculated through the ratio of tube diameter to the sphere diameter (D/d) [5].

3- Description of turbulent flow field

Available CFD code assumes that porous media wall does not have any effect on flow turbulency. This assumption can be true in the cases that either permeability of porous media is high or flow velocity is low. Therefore, in current problem it is necessary to use sources to optimize the turbulent equations [11].

4- Heat transfer coefficient

Local heat transfer coefficient has been calculated within average temperature of fluid in every section:

$$h_i = \frac{q}{(T_{w_i} - T_b)} \quad (4)$$

$$T_b = T_i + (T_o - T_i) \frac{x}{L} \quad (5)$$

T_i is inlet temperature, T_o is outlet temperature of the and L is

Corresponding author, E-mail: rabiee@shirazu.ac.ir

the length of porous media.

5- Description of the problem

Four different configurations have been studied in this study. Fig. 1 depicts the sphere configurations in the heat transfer tube.

In this research, sphere packed bed simulation as a porous media with different porosity according to reference [5] is conducted. Water has been used as a working fluid.

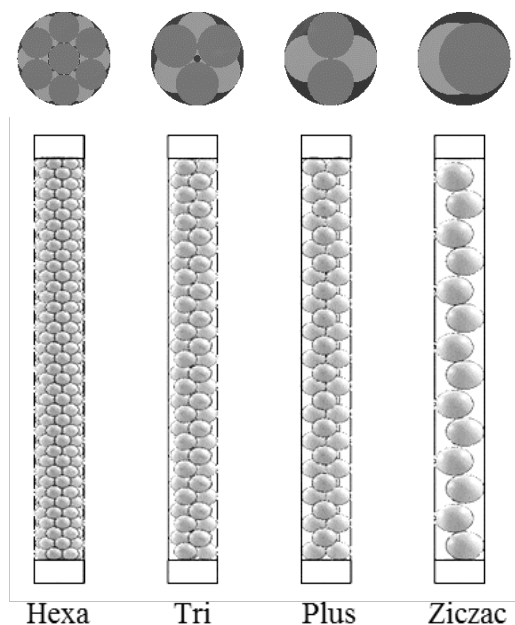


Figure 1. Sphere arrangements

6- Results

Figures 2 and 3 depict comparison of the pressure drop and heat transfer coefficient in different Reynolds number, respectively.

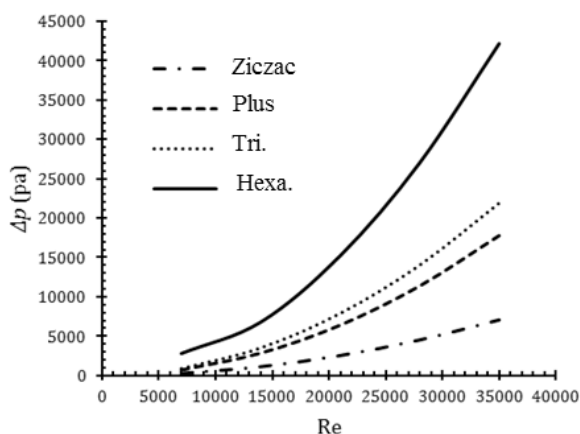


Figure 2. Pressure loss in different sphere configurations

7- Conclusion

In this research, a CFD simulation has been performed for four different configurations of spheres that have been embedded in the tube. Comparison with the experimental results showed that decreasing the porosity leads to an increase in pressure loss and heat transfer coefficient, correspondingly.

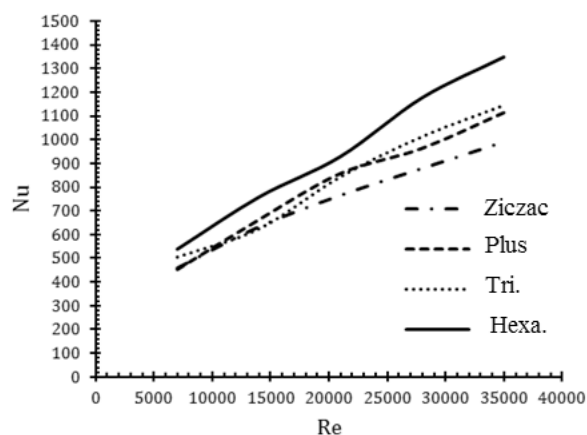


Figure 3. Nusselt number in different sphere configurations

It was observed that in all mentioned patterns, the averaged heat transfer coefficient is reasonably increased with the Reynolds number.

The results show that heat transfer coefficients in hexagonal arrangements have the highest value and the lowest in the Zigzag arrangement for similar Reynolds numbers.

It is noteworthy to say that by using sphere arrangements in the tube compared to the simple tube, the heat transfer enhancement in different Reynolds numbers is about 5 to 16%.

Porous media models reduce the complexity of the numerical analysis and lead to more accurate results compared to experimental results.

References

- [1] Seto, N., K. Yuki, H. Hashizume and A. Sagara, "Heat Transfer Enhancement in Sphere-Packed Pipes under High Reynolds Number Condition", *Fusion Engineering and Design*, October (2008): 1102-1107.
- [2] Chiba, S., M. Omae, K. Yuki, H. Hashizume, S. Toda and A. Sagara, "Experimental Research on Molten Salt Thermofluid Technology Using a High-Temperature Molten Salt Loop Applied for a Fusion Reactor Flibe Blanket", *Fusion Engineering and Design*, 2002.
- [3] Varahasamy, M. and R.M. Fand, "Heat Transfer by Forced Convection with Porous Media whose Matrices are Composed of Spheres", *Heat mass transfer*, (1996): 3931-3947.
- [4] Okumura, M., K. Yuki, H. Hashizume and A. Sagara, "Evaluation of Flow Structure in Packed-Bed Tube by Visualizing Experiment", *Fusion science Technology*, (2005): 1089-1093.
- [5] Bu, S., J. Yang, Q. Dong and Q. Wang, "Experimental study of flow transitions in structured packed beds of spheres with electrochemical technique", *Experimental Thermal and Fluid Science*, 60 (2015): 106-114.
- [6] Guardo, A., M. Coussirat, M.A. Larrayoz, F. Recasens and E. Egusquiza, "Influence of the turbulence model in CFD modeling of wall-to-fluid heat transfer in packed beds", *Chemical Engineering Science*, 60 (2005): 1733-1742.
- [7] Guardo, A., M. Coussirat, M.A. Larrayoz, F. Recasens and E. Egusquiza, "Influence of the turbulence model in CFD modeling of wall-to-fluid heat transfer in packed

- beds”, *Chemical Engineering Science*, 60 (2005): 1733 – 1742.
- [8] Fand, R. M. and R. Thinakaran, “The Influence of the Wall on Flow Through Pipes Packed With Spheres”, *Heat mass transfer*, 112 (1990).
- [9] Bua, S.S., J. Yanga, M. Zhoua, S.Y. Lia, Q.W. Wanga and Z.X. Guob, “On contact point modifications for forced convective heat transfer analysis in a structured packed bed of spheres”, *Nuclear Engineering and Design* , 270.15 (2014): 21–33.
- [10] Nakayama, A. and F. Kuwahara, “Turbulence Model for Flows in Packed Beds, Channels, Pipes, and Rod Bundles”, *Journal of Fluids Engineering*, 130 (2008).
- [11] Chandesris, M., G. Serre and P. Sagaut, “A macroscopic turbulence model for flow in porous media suited for channel, pipe and rod bundle flows”, *International Journal of Heat and Mass Transfer*, 49 (2006): 2739–2750.

برای ارجاع به این مقاله از عبارت زیر استفاده کنید:

Please cite this article using:

A. Rabiee, A. H. Kamalinia, K. Hadad, “Modeling and Numerical Analysis of Sphere Packed Beds for Cooling a Fusion Reactor Core”, *Amirkabir J. Mech. Eng.*, 49(1) (2017) 127-136.

DOI: 10.22060/mej.2016.714



