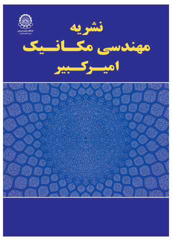

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Modeling and Numerical Analysis of Sphere Packed Beds for Cooling a Fusion Reactor Core

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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.

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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**

$$\frac{\partial(\gamma\rho)}{\partial t}+\nabla.\left(\rho\vec{v}\right)=0 \tag{1}$$

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- **Momentum equations**

$$\frac{\partial\left(\gamma\rho v\right)}{\partial t}+\nabla.\left(\rho\vec{v}\vec{v}\right)=-\nabla P+\nabla.\overline{\overline{\tau}}+\rho\vec{g}+S_i \tag{2}$$

- **Energy equations**

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

Porosity (γ) is calculated through the ratio of tube dimeter 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:

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

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

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

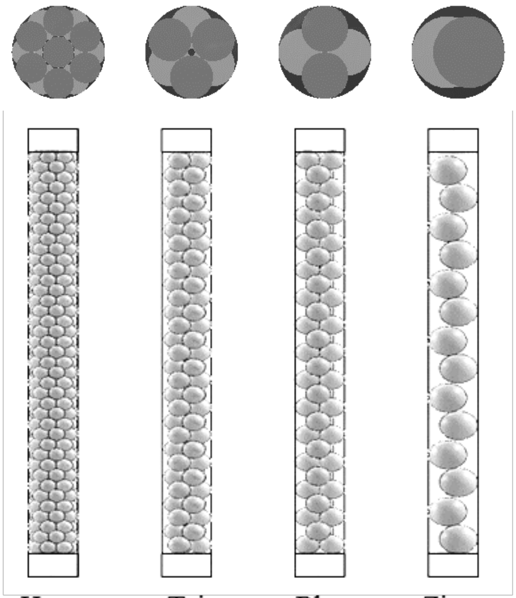

Figure 1. Sphere arrangements

6- Results

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

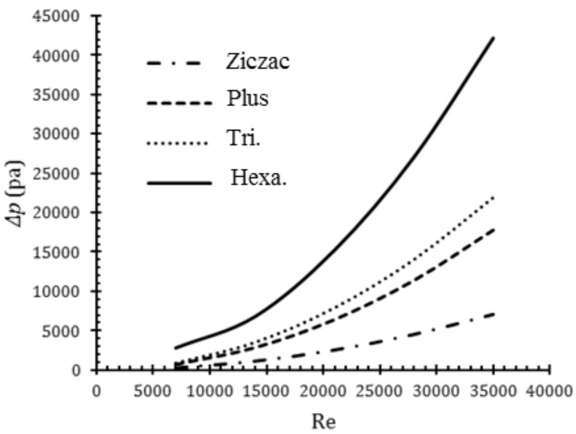

Figure 2. Pressure loss in different sphere configurations

7- Conclusion

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

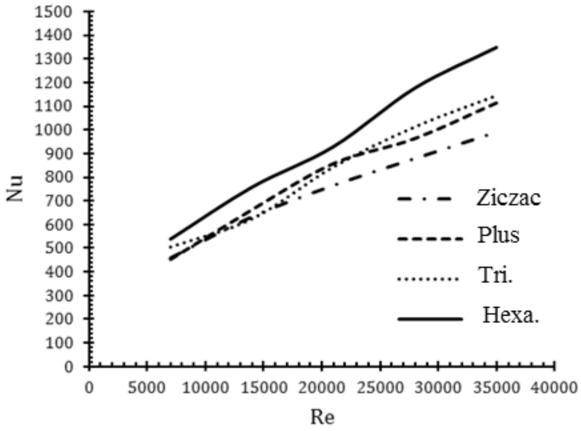

Figure 3. Nusselt number in different sphere configurations

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

The results show that, heat transfer coefficients in hexagonal arrangement have highest value and lowest in the Zickzack arrangement for similar Reynolds number.

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 number are about 5 to 16 %.

Porous media model reduces the complexity of the numerical analysis and leads to more accurate results compared to the experimental results.

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