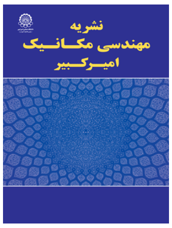

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Performance Evaluation of a Fluidized Bed Reactor by Studying the Hydrodynamics and Thermal Properties of Different Solid Particles

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ABSTRACT: High heat transfer rate as one of the important advantages of fluidized bed reactors is attributed to hydrodynamic mechanisms. In this research the important hydrodynamic parameters such as minimum fluidization velocity, pressure drop, bed height, bubble formation and flow regime were investigated experimentally and numerically. The two-fluid model coupled with the kinetic theory of granular flow and two different drag models of Gidaspow and Syamlal-O'Brien were applied in the present simulation. The results showed that by using the Gidaspow drag model in numerical solution, the minimum fluidization velocity with an approximate error of 13.8% and the bed height with an average error of 9% are predictable in comparison with the experiments. In order to investigate the effects of particles properties on temperature distribution of a bubbling fluidized bed, several solid particles with different densities and thermal diffusivities were investigated. Finally, to demonstrate the advantages of fluidized beds to receive the required hot air in industrial units, temperature distribution and required height of a bubbling fluidized bed reactor were compared with a similar constant surface temperature simple channel. The results showed that the outlet air temperature of a bubbling fluidized bed is about 28 degrees Celsius higher than a similar simple channel.

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1. Introduction

Fluidized bed reactors are widely used in many chemical and power industries, because of the proper mixing of phases, high heat transfer rate and uniform temperature distribution [1]. High heat transfer rate in fluidized beds is attributed to complex hydrodynamic and heat transfer mechanisms. Therefore, parameters related to these mechanisms should be studied.

Hamzehei and Rahimzadeh [2] studied the particle size effect on heat transfer and hydrodynamics of a gas-solid bubbling fluidized bed experimentally and computationally. Abdelmotalib et al. [3] studied wall-to-bed heat transfer and hydrodynamic characteristics of a conical fluidized bed reactor by applying two-fluid model and Kinetic Theory of Granular Flow (KTGF). Ostermeier et al. [4] studied the heat transfer coefficient around the horizontal tubes immersed in a bubbling fluidized bed experimentally and numerically.

In this research, minimum fluidization velocity, pressure drop, and bed height as three important parameters that directly influence the optimal design and performance of fluidized beds are investigated experimentally and numerically. The two-fluid model and two different drag models of Gidaspow [5] and Syamlal and O'Brien [6] are applied in the present simulation. Increasing the heat transfer rate is one of the challenges facing the industry. Therefore, the effect of solid particles properties such as density and thermal diffusivity on heat transfer rate is also investigated. Subsequently, to evaluate the advantages of fluidized bed reactors, temperature distribution and required height of a bubbling fluidized bed are compared with a similar constant surface temperature simple channel.

2. Experimental Procedure

In this experiment, the air was injected into the bed at a volumetric flow rate of 1.2 liters per second. After sufficient time for the proper mixing of phases, the pressure drop and the bed height after expansion were reported. Afterward, the inlet air flow was reduced step-by-step. By drawing the pressure drop diagram in terms of the inlet air velocity, it was shown that the pressure drop in the bed does not change when the weight of the whole particles begins to be thoroughly supported by the air. The certain inlet gas velocity which the drag and buoyancy forces balance the gravitational force is called the minimum fluidization velocity. All steps were repeated with the incremental trend for volumetric flow rate. In addition, for more accurate investigations, the minimum fluidization velocity results were validated by some of the existing empirical correlations.

3. Numerical Method

In the two-fluid model, gas and solid phases are described as interpenetrating continua. The mass, momentum and energy conservation equations are solved for each phase separately with interaction terms representing the coupling between the phases. By using the KTGF, the solid particles properties are

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described as a function of the granular temperature [7] .The gas and solid phase conservation equations are described as following [8,9]:

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g\right)+\nabla\cdot\left(\varepsilon_g \rho_g \overrightarrow{u_g}\right)=0 \tag{1}$$

$$\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s\right)+\nabla\cdot\left(\varepsilon_s \rho_s \overrightarrow{u_s}\right)=0 \tag{2}$$

$$\begin{aligned}&\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g \overrightarrow{u_g}\right)+\nabla\cdot\left(\varepsilon_g \rho_g \overrightarrow{u_g}\overrightarrow{u_g}\right)=-\varepsilon_g \nabla P+\\&\nabla\cdot(\overline{\overline{\tau}}_g-\varepsilon_g \rho_g \overline{\overrightarrow{u_g'}\overrightarrow{u_g'}})+\varepsilon_g \rho_g \vec{g}+\beta\left(\overrightarrow{u_s}-\overrightarrow{u_g}\right)\end{aligned} \tag{3}$$

$$\begin{aligned}&\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s \overrightarrow{u_s}\right)+\nabla\cdot\left(\varepsilon_s \rho_s \overrightarrow{u_s}\overrightarrow{u_s}\right)=-\varepsilon_s \nabla P-\nabla P_s+\\&\nabla\cdot(\overline{\overline{\tau}}_s-\varepsilon_s \rho_s \overline{\overrightarrow{u_s'}\overrightarrow{u_s'}})+\varepsilon_s \rho_s \vec{g}+\beta\left(\overrightarrow{u_g}-\overrightarrow{u_s}\right)\end{aligned} \tag{4}$$

$$\begin{aligned}&\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g H_g\right)+\nabla\cdot\left(\varepsilon_g \rho_g \overrightarrow{u_g} H_g\right)=\varepsilon_g\left(\frac{\partial P}{\partial t}+\overrightarrow{u_g}\cdot\nabla P\right)+\\&\nabla\cdot\left(\varepsilon_g k_g \nabla T_g-\varepsilon_g \rho_g c_{p,g}\overline{\overrightarrow{u_g'}T_g'}\right)+\alpha(T_s-T_g)+\overline{\overline{\tau}}_g\cdot\nabla\cdot\overrightarrow{u_g}\end{aligned} \tag{5}$$

$$\begin{aligned}&\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s H_s\right)+\nabla\cdot\left(\varepsilon_s \rho_s \overrightarrow{u_s} H_s\right)=\varepsilon_s\left(\frac{\partial P}{\partial t}+\overrightarrow{u_s}\cdot\nabla P\right)+\\&\nabla\cdot\left(\varepsilon_s k_s \nabla T_s-\varepsilon_s \rho_s c_{p,s}\overline{\overrightarrow{u_s'}T_s'}\right)+\alpha(T_g-T_s)+\overline{\overline{\tau}}_s\cdot\nabla\cdot\overrightarrow{u_s}\end{aligned} \tag{6}$$

4. Results and Discussion

4.1 Minimum fluidization velocity and bed height

The minimum fluidization velocity was studied numerically and experimentally. Table 1 shows the results of U_{mf} for alumina particles.

Since the maximum bed height determines the height of the reactor and the need for cyclone separator installation, this parameter was also studied experimentally and numerically. Table 2 summarizes these results.

Table 1. Minimum fluidization velocity

Calculation approach	U_{mf} (m/s)
Experiment	0.058
Numerical result (Gidaspow [5])	0.05
Numerical result (Syamlal and O'Brien [6])	0.069
Wen and Yu correlation [10]	0.045
Davies and Richardson correlation [11]	0.05

Table 2. The bed height investigation

Velocity (m/s)	Experimental bed height (cm)	Numerical bed height (cm)
0.04	8.4	8.2
0.052	8.5	8.4
0.084	8.7	10
0.139	9.8	11

4.2 The influence of solid particles properties

In order to investigate the effects of particles properties on temperature distribution of a bubbling fluidized bed, first solid particles with the same density and different thermal diffusivities, and then particles with equal thermal diffusivity and different densities were investigated as shown in Fig. 1. Based on Fig. 1, Particles with different densities and almost identical thermal diffusivity represent the same temperature distribution in the bubbling flow regime.

4.3 Comparison of the height and temperature distribution of a fluidized bed and a simple channel

To demonstrate the advantages of fluidized beds, the temperature distribution in a bubbling fluidized bed was compared with a similar simple channel. The results showed that the outlet air temperature of a bubbling fluidized bed is about 28 degrees Celsius higher than the air temperature in a similar simple channel. It also provides higher temperatures over a shorter height of the reactor.

5. Conclusions

The minimum fluidization velocity with an approximate error of 13.8% and the bed height with an average error of 9% are predictable in comparison with the experiment. The beds with alumina and aluminum alloys particles increase the air temperature more than the bed particles with the same density and lower thermal diffusivity coefficient. The outlet air temperature of a bubbling fluidized bed is about 28 degrees Celsius higher than the air temperature in a similar simple channel.

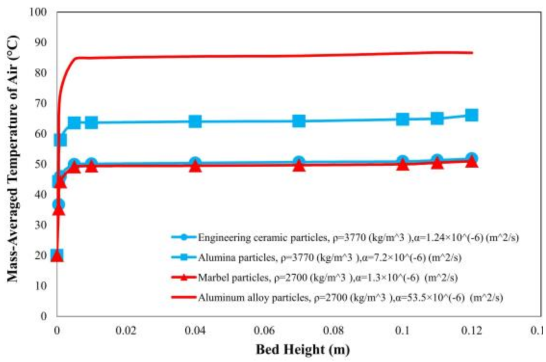

Fig. 1. Effects of solid particles properties on temperature distribution of a bubbling fluidized bed

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