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Parametric study of particle distribution in tube bundle heat exchanger

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ABSTRACT

Fluidized particles in liquid–solid fluidized bed exchangers are able to remove deposits from walls and thus are able to prevent fouling or scaling. Particle distribution is an important parameter for the performance of fouling prevention. In this paper, the Eulerian multiphase fluid model was adopted to simulate the particle distribution in the fluidized bed heat exchanger incorporating tube bundle arranged in parallel. The porous media model was applied in the zone of the tube bundle to analyze the pressure loss through the vertical tube. Factors influencing the particle distribution including the velocity, volume fraction of the solid phase and the property of the particle were discussed respectively. Particle distribution became more uniform in the high velocity due to the full fluidization of particle in each tube. With the increase in density or diameter of particle, particle maldistribution took place because the sedimentation velocity of these particles was so great that particles could not run into the tubes on both sides. With the increasing of volume fraction of solid phase, particle distribution became slightly more uniform. However increment of particle would bring about greater flow resistance and reduce the usage life of particle and devices. Therefore amount of injected particle should be adjusted according to parameters such as effect of fouling prevention, pressure drop etc. A comparison of the simulation results with the experimental measurements was carried out, showing good agreement.

1. Introduction

In heat transfer processes, the deposition of solids on heat exchanger walls can usually be formed by suspended particles that stick to the wall or by crystalline materials that crystallize on the wall due to the local super-saturation [1–3]. For both cases, fouling reduces overall heat transfer coefficients significantly and increases pressure drop. It was reported that a powdery fouling layer of a few millimeters thick could lead to a reduction in heat transfer coefficient of 25% [4]. In order to avoid excessive fouling, heat exchangers need to be periodically cleaned requiring costly maintenance stops.

A promising alternative to these conventional fouling control techniques is the liquid–solid fluidized bed heat exchanger [5–8]. In this technology, particles were added into the circulating fluidized bed to continuously impact on the wall and to avoid the deposits. Meanwhile the heat and mass transfer coefficients were enhanced up to eight times higher than for the case without particles [9]. Particle collision on the wall is important for the performance of fouling prevention and heat transfer in the heat exchanger. Pronk [1] reported that the scaling prevention was greatly dependent on the collision force and frequency of the particles on the wall. Li and Gu [9] proposed that improvement of the heat transfer was attributed to the increment of the nucleus of boiling, the destruction of layer and the collision of the particles on the wall in the gas–liquid–solid three phase flow. Tatjana [10] studied the solid circulation rate and particle collisions in quasi two-dimensional water fluidized beds of spherical particles. They concluded that majority of collisions in fluidized beds differed very much from the instantaneous collisions, and the overall particle circulation rate was much better measure of the bed dynamics than the frequency of collisions. Dario and Tadrist [11] summarized the two-phase flow distribution in parallel channels with macro and micro hydraulic diameters: main results, analyses, trends. They concluded that modifying the geometry by inserting specific devices into the header or the feeding tube was one promising approach to improve the two-phase flow distribution in parallel channels.

Numerical simulation, as a helpful tool, has been applied to study the flow, the heat transfer and the fouling prevention in the heat exchanger [12–14]. Han [3] investigated the fouling rate reduction for the gas–solid two phase flow in the heat exchanger. Continuum model and a discrete phase model for particle trajectory were used to study the parameters to affect the fouling rate as well as heat transfer. Morsi [15] numerically investigated the particle rebounding characteristics of a gas-particle flow over a cylindrical body and an in-line tube bundle arrangement.

As the prerequisite for the particle collision on the wall, uniformity of particle distribution is crucial to obtain high performance

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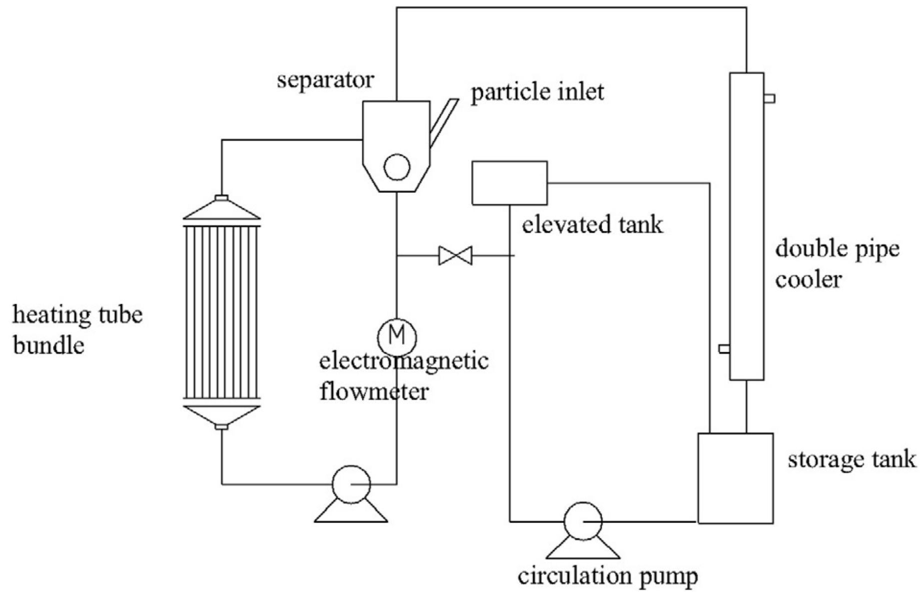

Fig. 1. Schematic diagram of the experimental setup.

of fouling prevention and improved heat transfer efficiency in fluidized bed heat exchanger. An experimental and numerical investigation was carried out for phase distribution and pressure drop in the two-phase offset strip fin type compact heat exchanger by Selma [16].

In this paper, a parameter study of the particle distribution in the tube bundle heat exchanger was undertaken using the commercial CFD code FLUENT. The simulation results were compared with the experimental one. Numerical simulation would be expected to provide an alternative way to optimize the industrial process for the fouling prevention.

2. Experimental setup

The details of the experimental setup and procedure were presented in our previous paper [17]. Here only an outline is provided. The schematic diagram of experimental system is shown in Fig. 1. It includes the vertical tube heat exchanger, separator and the circulation tube with 80 mm in diameter. The vertical tube heat exchanger is composed of five heated tubes made in the transparent glass with 1.1 m in height and 45 mm in diameter, and these tubes are arranged in parallel and shown in Fig. 2. The experiments were performed using water and the particle described in Table 1.

Particle maldistribution degree M was adopted to characterize the particle distribution, which was defined by the following:

$$M = \left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\varepsilon_i - \overline{\varepsilon}}{\overline{\varepsilon}}\right)^2\right]^{0.5} \quad (1)$$

where ε_i stood for holdup of solid phase along the axis direction of the ith tube, and $\overline{\varepsilon}$ represented the average holdup of solid phase along the axis direction of the five tubes which was expressed as follows:

$$\overline{\varepsilon} = \frac{1}{n}\sum_{i=1}^{n}\varepsilon_i. \quad (2)$$

3. Model description and numerical method

3.1. Physical model

A three dimensional and unsteady-state numerical simulation of the flow of liquid–solid two phase in the fluidized bed heat exchanger were conducted by using the commercial software FLUENT. The physical model of the heat exchanger was set up on basis of the experimental setup and shown in Fig. 3. Hexahedron cells were applied in the whole domain. The tube bundle of heat exchanger included five heating tubes with the diameter of 45 mm and the length of 1.1 m. It consisted of tap water and particles of 1, 2, 3 or 4 mm in diameters with the density of 1200, 1600, 2000 and 2300 kg·m^{-3}, respectively. Liquid and particle were upstream injected into the inlet.

3.2. Control equation

Tatjana [10] demonstrated that majority of particle collisions in fluidized beds differed very much from the instantaneous collisions, and the overall particle circulation rate was much better measure of the bed dynamics than the frequency of collisions.

According to the above analysis, the Eulerian multiphase model was employed to simulate the liquid–solid two phase flow in the fluidized bed heat exchanger in this paper. The effects of the inlet velocity, volume fraction of solid phase and particle property on the particle distribution in the tube bundle of heat exchanger were discussed respectively.

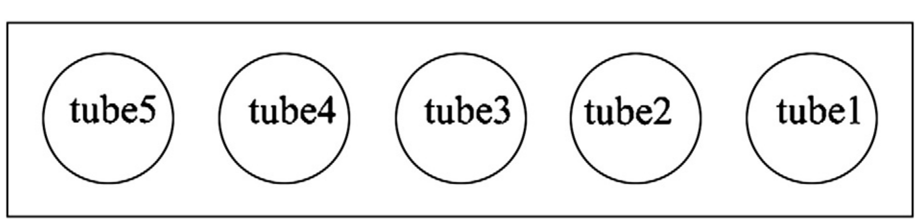

Fig. 2. Distribution of vertical tube bundle in the heat exchanger.