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Numerical investigation on prevention of fouling in the horizontal tube heat exchanger: Particle distribution and pressure drop

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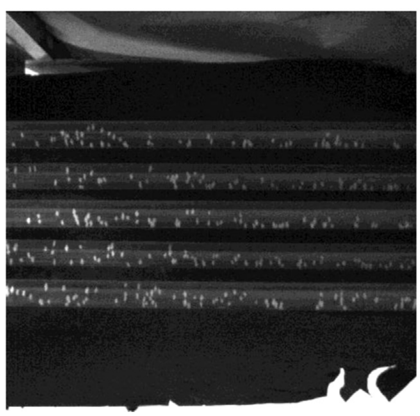
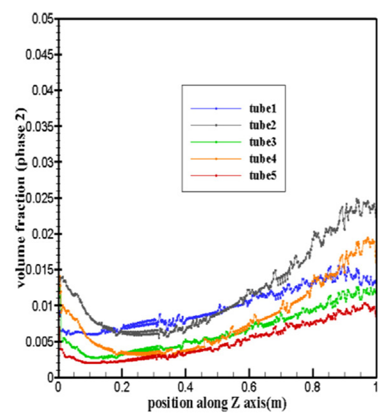
HIGHLIGHTS

• Adoption of Eulerian multiphase model for the simulation in the heat exchanger.

GRAPHICAL ABSTRACT

Uniformity of particle distribution was improved in high velocity and excellent performance of fouling prevention was obtained in the horizontal tube heat exchanger. What was observed in the experiment was compared with that in the simulation, showing good agreement.





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ABSTRACT

To improve the performance of fouling prevention in liquid–solid fluidized bed heat exchanger with the horizontal tube bundle, parametric study of particle distribution and pressure drop in the heat exchanger was numerically conducted. Eulerian multiphase fluid model was used to calculate the flow of liquid–solid two phase in heat exchanger by means of the commercial software Fluent. In the simulation result, it was demonstrated that more particles occurred in the lower tubes of the horizontal tube bundle in low velocity due to the lack of full fluidization. Relative to that in low velocity, uniformity distribution of particle was obtained in high velocity which was accompanied with greater dynamic pressure drop. The particle with the greater density and diameter was inclined to sediment in the lower tubes due to larger sediment velocity and difficulty in the realization of full fluidization. Meanwhile an increase in size and density of particle would bring about greater pressure drop originating from more particle kinetic energy consumed. Effect of volume fraction of solid phase on particle distribution and pressure was discussed. It showed that an increase in volume fraction of solid phase led to significant rise of pressure drop. It was because consumed kinetic energy and collision energy of particles were greatly amplified with the increasing volume fraction of solid phase. Therefore greater volume fraction of solid phase, especially for the particle with the greater diameter and density, would not be recommended in the performance of fouling prevention in the horizontal tube bundle heat exchanger.

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1. Introduction

Particulate fouling on the heat exchanger surfaces is a major problem in many fields, such as wastewater disposal in the pharmaceutical manufacture, condensation of traditional Chinese medicine, and evaporation of the salt solution, i.e., calcium chloride or lithium sulfate et al. [1–4]. Fouling can usually be formed by suspended particles that stick to the wall or by crystalline that crystallizes on the wall due to the local super-saturation. It was found that the layer formed by deposition of the solids could reduce the overall heat transfer coefficient by about 25%. In order to avoid excessive fouling, heat exchangers need to be periodically cleaned requiring costly maintenance stops [5,6].

The application of liquid–solid fluidized bed, as a green and energy-saving alternative, can prevent fouling effectively in many chemical processes [7,8]. In this technology, particles were added into the circulating fluidized bed to continuously impact on the wall and to avoid deposits.

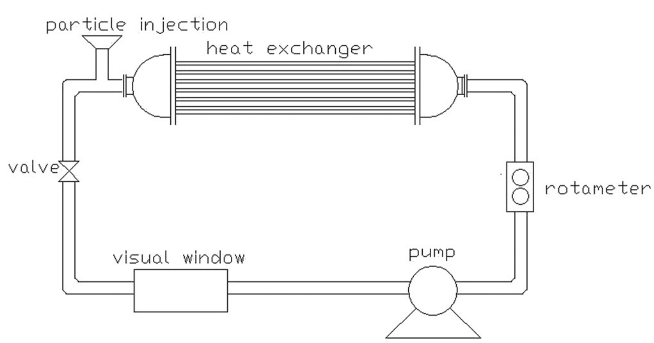

Fig. 1. Schematic diagram of experimental setup.

Table 1
Type and property of particles used in the experiment.

Number	Type of particle	Diameter of particle/mm	Density of the particle/kg/m^3
1	resin (cylinder)	Φ2	1200
2	Polyoxymethylene 1	Φ5.5	1390

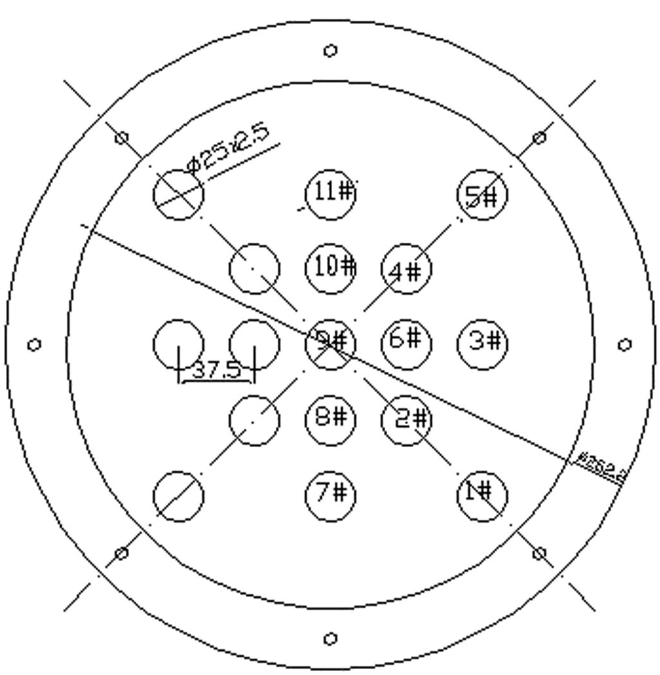

Fig. 2. Dimension and distribution of numbered tube bundle.

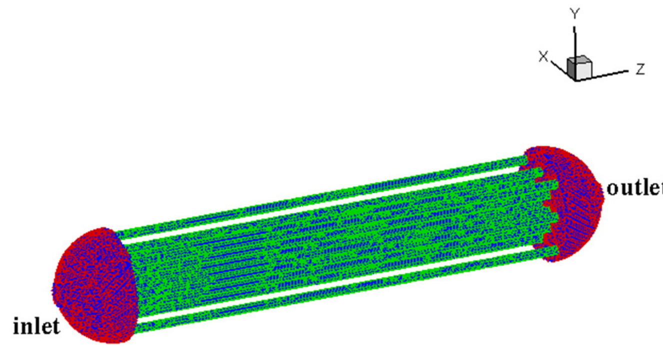

Fig. 3. Physical model of the horizontal tube heat exchanger.

The enhancement of heat transfer was attributed to the disturbance of layer by particle. It was reported that the heat and mass transfer coefficients were enhanced up to eight times higher than for the case without particles [9,10].

P. Pronk [11] investigated the crystallization fouling prevention in the process of eutectic freeze crystallization by employing the technology of solid–liquid fluidized bed heat exchangers. He reported that fluidized beds are able to prevent salt fouling during cooling crystallization from KNO_3 or $MgSO_4$ solutions. The experimental study by M.R. Jalalirad et al. [3] examined the influence of the deposit layer structure on the cleaning action of projectiles. Fouling experiment was performed using $CaSO_4$ as foulant. Wen et al. [12] studied the performance of the three phases of circulating fluidized bed evaporator, and the parameters such as the heat transfer, pressure drop, fouling prevention and removal were discussed. A mathematical model for predicting the flow boiling heat transfer coefficients was proposed.

Numerical studies of mass and heat transfer of multiphase flow in fluidized bed heat exchanger for the prevention of fouling have been reported by many researchers [13,14]. It was reported by Van Beek et al. [15] that the growth of the layers by the deposition of fly ash particles

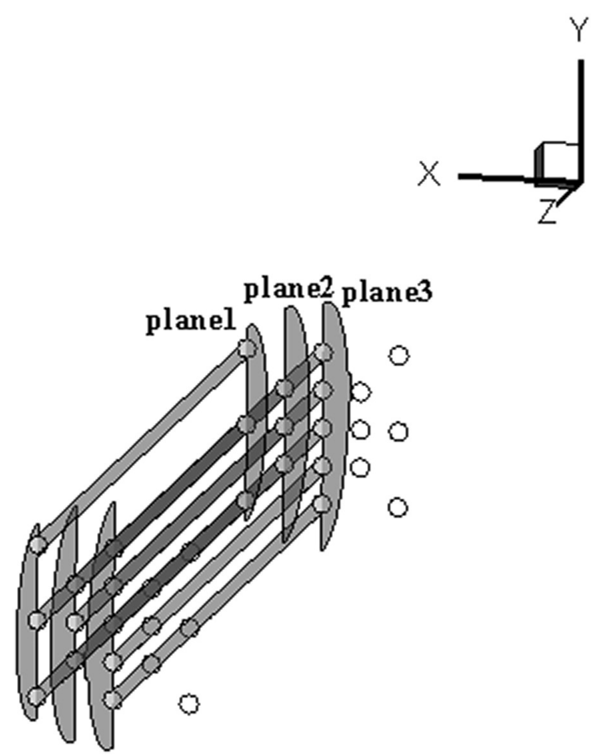

Fig. 4. Schematic diagram of three planes at X = 0 mm, X = 37.5 mm and X = 75 mm respectively.