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Study on mass flow characteristics of fluidized bed with a circulative accelerating tube

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ABSTRACT

The heat transfer between annular fluidized-bed and the furnace can be enhanced by adding circulative accelerating tubes in the reactor. Cold state experiments were conducted to test the effect of operation conditions on particles flow in fluidized bed with a circulative accelerating tube. Results showed that the spouting velocity, fluidizing velocity and static bed height all had a beneficial effect on particles circulating efficiency. Shorter and moderate outlet needle nozzles were suitable for circulative accelerating tube to maximize circulating rate. What's more, smaller size particles which had better fluidity should be chosen for the bed material to improve circulating efficiency.

Introduction

Many companies look for new constructions of fluidizing apparatuses due to the increasing demands regarding output and quality of products and new regulations for environment protection [1]. In addition, in many applications of fluidized beds, extract thermal energy is required, leading to demands of specified design of reactor [2]. Therefore, finding new reactor more energy-efficient is an important factor in the proper design of industrial fluidized beds [1–3]. Developed by School of Technology, Beijing Forestry University [4], the annular fluidized-bed reactor combines a cylinder furnace into a fluidized-bed, which is also encircled by a cylinder vessel, as shown in Fig. 1. This design avoids the direct contact between the furnace and atmosphere, thus improves the heat utilization of the reactor. But the limitation of this reactor is the poor heat transfer between the furnace and the annular fluidized-bed, because particles can only absorb the heat through the vessel wall. In order to enhance the heat transfer, a novel circulative accelerating tube is developed and applied simultaneously [5]. Circulative accelerating tubes are mounted vertically in the furnace, as shown in Fig. 1. Particles are picked up by circulative accelerating tube at the dense phase of the bed. After passing through the whole tube along with the spouting gas upwards, particles are discharged into the freeboard of the bed. As a result, more heat will be brought back to the annular fluidized-bed from particles. In addition, this can also improve the mixing of particles in the reactor. The number of circulative accelerating tubes should be determined by the scale of the furnace. In this paper, the operating conditions required to maximize the solids flow through circulative accelerating tubes are determined, for the previous studies have found that solid flow has positive effect on the heat transfer [6,7].

There are a few published studies of this kind of tube. One of them is the vertical lift tube developed by Jacobson et al. [6,7]. The lift tube was also used in the annular fluidized-bed, which was similar to that used in this study. It had been found that a smaller nozzle under lift tube yielded more efficient solids flow. The downstream pressure had a negative effect on flow rate, while flow rate increased with fluidizing velocity. Also, increasing the motive gas flow rate initially increased the flow of solids in the lift tube. In addition, the analysis of the pressure signals in lift tube and optical experiments had also been carried out, which indicated that the maximum heat transfer corresponded to the transition point from dense phase. And all these results would make a contribution to the optimization of the solid circulation through the lift tube.

Chen et al. [9] established a cold experimental model of an internally circulating fluidized bed with draft tube which had a similar function with circulative accelerating tube to test the effects of several factors on solid circulating rate. They found that the solid circulation rate increased with increasing gas velocities to

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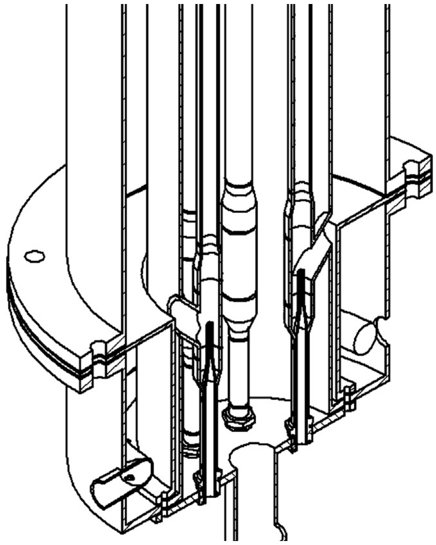

Fig. 1. The annular fluidized-bed reactor.

the draft tube or annulus section, but when the gas velocity to the draft tube or annulus section increased to a certain level, the circulation rate of solid increased slowly. Also, the solid circulation rate grew with increasing static bed height while declined with increasing particle size under constant gas velocities in the two beds.

In addition, many researchers focused on the study of spout-fluid bed with a draft tube. Su et al. [10] analyzed the effects of operating conditions and geometrical parameters on the flow behavior, and found that the minimum spout-fluidizing velocity increases with increasing the length of entrainment zone and the draft tube diameter, but it decreases with the increasing of fluidizing gas flow rate and static bed height. However, Kmiec et al. [1] showed that the minimum circulation velocity is dependent on the static bed height and on the level of the upper edge of the draft tube based on their apparatus. Wang et al. [11] on the other hand, studied the flow behavior of particles in a two-dimensional spouted bed with a draft tube using a continuous kinetic-friction stresses model. Numerical results show that the gas flow rate through the annulus increases with the increase of the entrainment zone while the solids circulation rate decreases with the decrease of inlet gas velocity and the height of the entrainment zone.

Other researchers such as Zhong and Zhang [12,13] focused on the investigation of the particle dispersion in a spout-fluid bed and the mixing/segregation behavior of a binary mixture. They found that the increase of gas velocity improves the axial dispersion in the flow regime of internal jet. While in the case with bubbling, increasing fluidizing gas velocity promotes the radial dispersion at the lower part of bed and the axial dispersion at the upper part of bed. Also, the particle circulation is combined with the local segregation where smaller particles move to the interface between the jet and stagnant region.

Experimental setup and procedure

Cold state experiments were conducted to test the effect of operation conditions on particles flow in a single circulative accelerating tube, using a fluidized-bed reactor with an ID of 0.1 m and a height of 1 m, as shown in Fig. 2. A gas distributor was 100 mm above the bottom of the column. The bed material was two group of glass beads with particle diameter of 150–212 and 212–300 μm, respectively, and the column was filled to a height of at least 75 mm above the gas distributor. The circulative accelerating tube was 500 mm long with an ID of 24 mm placed at one side of the reactor vertically, as shown in Fig. 2.

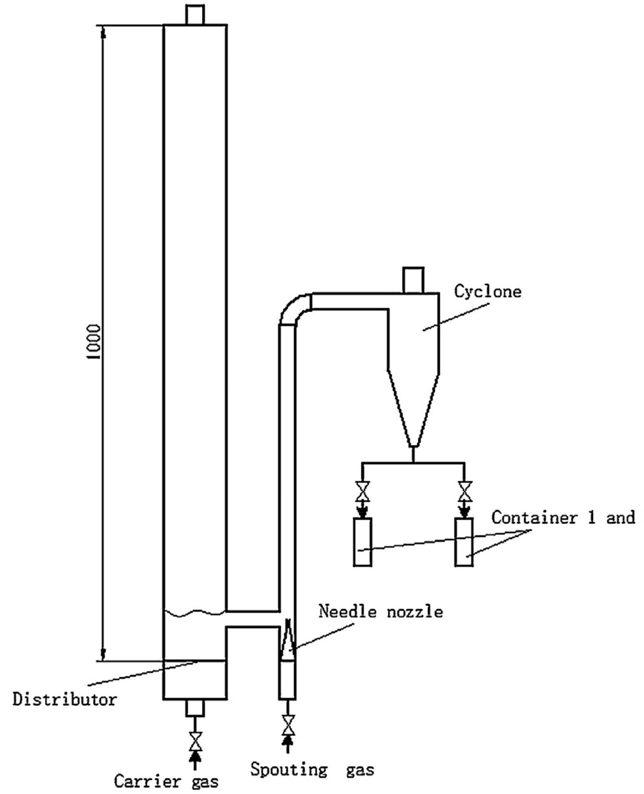

Fig. 2. Schematic diagram of cold state experimental.

A circulative accelerating tube typically consists of a 90° elbow, a straight pipe, a three-way pipe and a needle nozzle. The circulative accelerating tube was connected to the bed with the three-way pipe which is 65 mm above the gas distributor, and it is where particles would enter the circulative accelerating tube constantly from the bed. The Venturi-like needle nozzle plays a crucial role in bed particles circulation, which reduces the pressure inside the circulative accelerating tube while increase the velocity of the spouting gas at the tip of the needle nozzle and as a result particles around the needle nozzle would receive enough momentum from the spouting gas passing through the circulative accelerating tube and return to the bed in the end. In order to determine the effect of the length of needle nozzle on the particles circulation, three types of needle nozzles with different length of outlet were tested. The first needle nozzle, type A had the shortest outlet which was 12 mm below the axis of the branch of the three-way pipe, as shown in Fig. 3. The second needle nozzle, type B had an outlet which was located at the same height of the axis of the branch of the three-way pipe. And type C had the

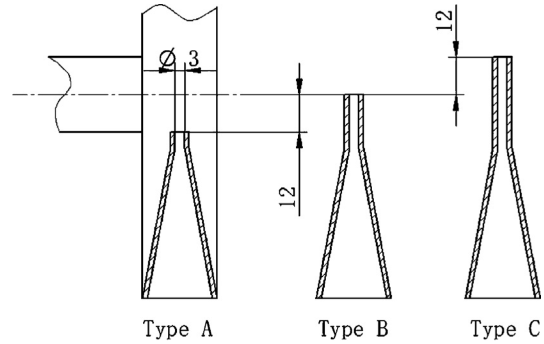

Fig. 3. Three types of needle nozzle.