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Impact of operating conditions on the performance of the external loop in a CFB reactor

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ABSTRACT

The effects of operating parameters such as fluidizing gas velocity U_g and total solid inventory M_t on the performance of the external loop composed by the loop seal and standpipe in a circulating fluidized bed (CFB) system were often ignored in the existing studies and the limited data are still in controversy. In this paper, the characteristics of gas–solid flow in the external loop was studied in a CFB cold test rig with a square riser of 0.1 m × 0.1 m in cross-section and 3.2 m in height. The results show that solid circulating rate G_s in the external loop is a function of the operating parameters such as M_t, U_g and aeration rate. An empirical equation was proposed for the G_s in the external loop with the operating parameters in the riser. The pressure drop across the loop seal is directly proportional to G_s while is inversely proportional to the aeration rate. The pressure drop gradient, voidage and solid height in the standpipe are also influenced by the operating conditions. The controversy among the published literature was discussed and clarified. The results of present study indicated that the external loop cannot be isolated from the entire CFB system for quantitative performance evaluation.

1. Introduction

A circulating fluidized bed (CFB) system normally consists of a riser, a gas–solid cyclone, a standpipe and a solid recycle valve. These components form a circulating loop, and the standpipe and the valve are combined as the external loop. In the external loop, the bottom leg of the cyclone is of lower pressure, while the bottom of the riser is of higher pressure. The standpipe functions as a seal against the gas bypassing from the riser to the cyclone. At the lower end of the standpipe installed a mechanical or a non-mechanical valve that is used to control the solid flow rate of the system. Mechanical valves such as screw feeder, rotary feeder, and slide valve usually are not feasible at high temperature and pressure conditions due to their complex structure and moving parts. On the contrary, non-mechanical valves such as loop seal, L-, J- and V-valves are with simple structure and free of moving parts. Therefore, they are commonly used to control G_s by aeration, especially for the process applications under elevated temperature and pressure.

Due to the importance, extensive studies have been conducted on non-mechanical valves such as the L-valve [1–5], J-valve [6] and V-valve [7]. Geldart and Jones [1] experimentally studied flow dynamics of the L-valves up to 100 mm in diameter, using three different types of sand particles in Group B. Some correlations were proposed for the solid flow rate in terms of both the aeration rate and the pressure drop across the L-valve. Daous and Al-Zahrani [2] experimentally studied three L-valves with different diameters of 25, 36, and 50 mm, and found that G_s is correlated to the pressure drop across the L-valve, L-valve diameter, and gas aeration rate. Smolders and Baeyens [4] experimentally studied fluid dynamics in the L-valves with a diameter between 20 and 40 mm for Group B and D powders. It was found that the diameter of L-valve had little influence on the solid flow rate. Knowlton and Hirsan [6] investigated the effects of several parameters such as the dimensions of the valve, particle size, and the location of the aeration tap on the performance of a J-valve. The authors found that the length of the down-comer affected the maximum G_s. Leung et al. [7] developed a model for design and analysis of the V-valve.

The standpipe is a rather dependent part in the entire CFB system. Normally, the pressure at the top of the standpipe is lower than that at the bottom due to the particle holding and movement of the gas–solid flow. Depending on the system design and the properties of the particles used, the dense bed in the standpipe may be fluidized or non-fluidized [8]. Provided the voidage would not change along the standpipe height, the pressure drop over per unit length can be calculated by the Ergun equation as a function of gas–solid slip velocity [8,9]. If the pressure drop changes over any other part in the loop, the pressure drop across the standpipe will adjust itself to maintain the system loop pressure balance.

However, some of above studies on the valve and standpipe were carried out in an open system (or in a free discharge). In such system,

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the pressure at the outlet of the valve is fixed, the only operating parameter influenced the pressure drop across the valve is the aeration air rate because the G_s is also determined by the aeration air rate, and consequently the influence of operating parameters such as fluidizing gas velocity, U_g and total solid inventory, M_t could not be assessed. On the contrary, the pressure at the outlet of the valve in a CFB system is various and depends on the pressure and mass balance in the entire system. The pressure drop across the standpipe changes to balance the pressure drop around the loop. The changes of the pressure gradient and solid height in standpipe, as results of the mass and pressure balance, cause the fraction of aeration air go through the valve changing, and then change the solid circulating rate. Therefore, the valve in the latter case is no longer an independent part but a dependent one. In the studies with entire system, the impact of operating conditions on the external loop was seldom studied and the data available are scarce and in controversy.

Kim et al. [10] studied the effects of particle properties on the gas–solid flow in a loop seal. They also found the pressure drop across the loop seal to increase linearly with M_t at the same U_g. Later, Kim and his co-workers [11] further found that the pressure drop across the loop seal was influenced by G_s, particle properties and aeration rate, and insensitive to U_g in the riser. The recent experimental study by Monazam et al. [12] confirmed that the gas–solid flow of a loop seal is affected not only by G_s and aeration rate. Contrast to what found Kim et al., they declaimed the gas–solid flow of a loop seal is greatly influenced by U_g and M_t in the riser. With a developed pressure balance model, Basu and Cheng [13] discussed the effects of operating conditions on the performance of the external loop, including loop seal aeration, M_t and U_g in the riser. The model analysis provided deep insights in the interaction between the operating conditions in riser and the gas–solid flow in external loop. However, there was limited experimental data to support the simplifications used in the model. For example, they found the solid height in the standpipe to decrease with increasing U_g when aeration rate and M_t were fixed, which was not consistent with the observation of Monazam et al. [12].

In this paper, a series of experiments are conducted on the effect of operating parameters on the performance of the external loop in a circulating fluidized bed with a loop seal. The operating parameters include the aeration rate, M_t and U_g. The performance of the external loop includes pressure drop gradient, solid height and voidage in the standpipe. In addition, the effect of the pressure balance in the entire circulation loop is also discussed. Based on the experimental results, the controversy among the existing studies is to be clarified.

2. Experimental

Experiments were conducted with a CFB cold installation as shown in Fig. 1. The installation consisted of a distributor, a riser, a cyclone, a screw feeder, a standpipe and a loop seal.

The riser had a cross-section area of 0.1 m × 0.1 m and a height of 3.2 m, with a smooth exit at the top. The standpipe had a height of 1.7 m and a diameter of 0.08 m. The cyclone used in the system had high efficiency, and nearly all particles were collected down into a bunker on the top of the screw feeder. Then the screw feeder fed the collected particles into the standpipe with a controllable solid circulating rate, G_s. A bypass tube was connected at both sides of the screw feeder for the pressure balance. 20 pressure taps were installed at different heights along the riser and standpipe to measure the local pressure drop online.

The fluidizing air was fed into the riser through the perforated plate distributor. Air was injected through the aeration port at the bottom into the loop seal. The bed material was quartz sand, with density 2650 kg/m^3, bulk density 1440 kg/m^3, static voidage 0.46 and average diameter of 157 μm.

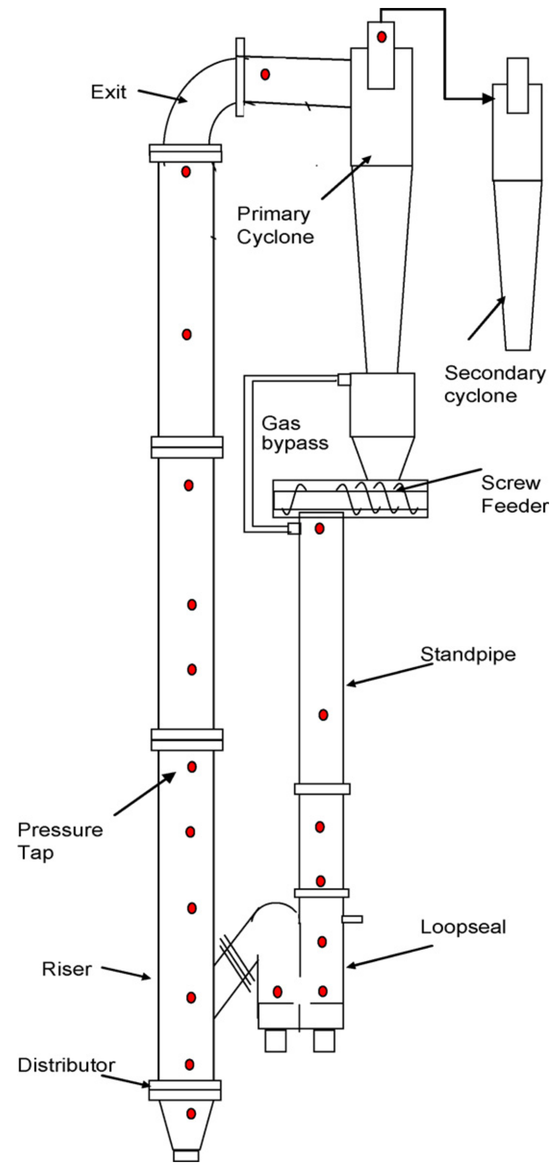

Fig. 1. A schematic diagram of the experimental system.

3. Results and discussion

3.1. Operation of loop seal

A loop seal was used to connect the riser and the standpipe, and its schematic structure is shown in Fig. 2. It consists of two chambers, the supply chamber and the recycle chamber, connected with a rectangular channel. In this non-mechanical valve, the solid

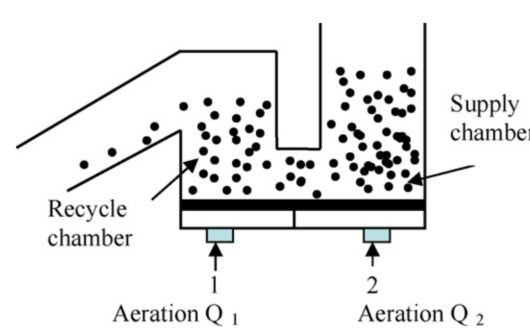

Fig. 2. Schematic of the loop seal.