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A transient method to study the pressure drop characteristics of the cyclone in a CFB system

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ABSTRACT

A transient method was developed and applied to study the variation of pressure drop characteristics of the cyclone ΔP_c used in a circulating fluidized bed (CFB) system with the solid concentration at the inlet $C_{s,in}$. Experiments were conducted in a CFB apparatus, with a square riser of 0.1 m×0.1 m in cross-section and 3.2 m in height, and with a smooth riser exit. When the system was in a steady state with a large $C_{s,in}$, the supply of solid material to the riser was suddenly cut-off while the gas velocity was maintained at a constant. $C_{s,in}$ was derived by the pressure drop measured across the smooth riser exit. ΔP_c and $C_{s,in}$ were measured on-line during the transient process. Experimental results showed that ΔP_c and $C_{s,in}$ obtained by the transient method were in good agreement with those obtained by the steady state experiments. Furthermore, ΔP_c decreased at first with increasing $C_{s,in}$ and then reached at a minimum at the critical $C_{s,in}$, thereafter it increased with $C_{s,in}$. The transient method offers an acceptable accurate, cost-effective and productive means to study the ΔP_c over a wide range of $C_{s,in}$.

1. Introduction

Cyclones, featured with simple structure, high separation efficiency and adaptability at high temperature, have been widely used as the gas-solid separators in chemical and petroleum industries, and coal-fired CFB boilers. Efficiency and pressure drop, the key operational parameters of cyclones, have direct influence on system performance. There are numerous studies on pressure drop of cyclones in the literature [e.g., [1–6], most focus on solid-free flow (or pure gas flow). Researches with solid loading are rather limited. It was found that the pressure drop is related to the structure and surface roughness of cyclone, particle properties, and operational conditions. When particles are introduced in the gas flow, the existing results show that the pressure drop of a cyclone decreases. However, the results on the relationship between cyclone pressure drop ΔP_c and solid concentration $C_{s,in}$ are in contradiction. Muschelknautz et al.[7] found that ΔP_c decreased with the increasing $C_{s,in}$ at first and then increased with $C_{s,i}$ when $C_{s,in}>1.0$ kg/m^3. The result was confirmed by Chen et al.[8]. Based on their experimental results the transition of ΔP_c with $C_{s,in}$ happened when $C_{s,in}=0.5$ kg/m^3. On the other hand, Hoffman et al.[9] and Fassani et al.[10] found that ΔP_c remains constant with $C_{s,in}$ in the range of 2–20 kg/kg-gas. Recently, Li et al.[11] found that, when $C_{s,in}>0.3$ kg/m^3, ΔP_c increases lineally with $C_{s,in}$.

Besides the difference of experimental method and apparatus, one of the main causes for above controversy was due to the insufficient experimental data, especially in a wide range of $C_{s,in}$. All the reported experiments were carried out in steady state, i.e. with constant gas velocity and solid concentration at the cyclone inlet. To obtain data at various steady states is costly and of massive work load, let alone limited by experimental apparatus. Thus, the existing experiments of each group of researchers were conducted only in a few cases, within a narrow range of $C_{s,in}$. To resolve this problem, it is desired to breakthrough the measuring method of $C_{s,in}$ that can be only applied in a steady state.

Recently, a transient method was proposed by Monazam et al.[12] to identify operational features and critical transition velocities in CFB riser. During the experiment, when the system was in a steady state, the supply of solid material to the riser was suddenly cut-off while the gas flow was maintained at a constant. In the riser, transient of the flow regime happened, from fast fluidization (or dense transport regime) to dilute transport. At the same time, the solid circulation rate G_s, thereby $C_{s,in}$ at cyclone inlet decreased gradually from a large value to zero[12]. Obviously, such a transient method is of great time saving and cost-effective. Most importantly, it was reported that the method was accurate in engineering view. Based on our recent studies [11], ΔP_c is directly related to $C_{s,in}$ in a steady state. Consequently, it is of significance to assess whether a similar transient method can be applied to study the dependency of ΔP_c with the inlet $C_{s,in}$.

2. Experimental

Experiments were conducted with the CFB cold rig shown in Fig. 1, consisted of a distributor, a riser, a primary cyclone and a secondary cyclone, a screw feeder, a standpipe and a loopseal. The riser had a

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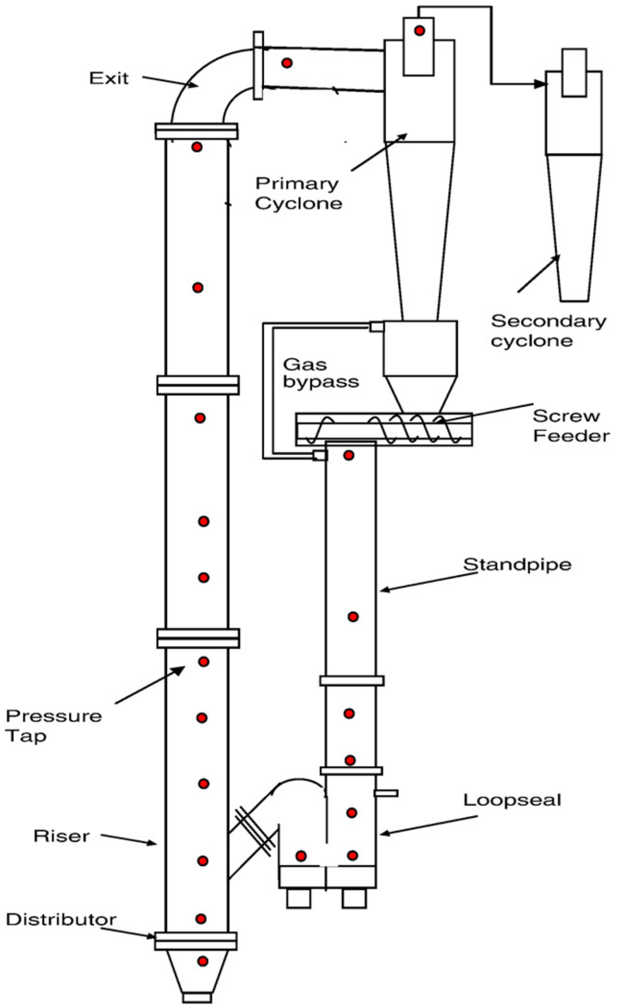

Fig. 1. Experiment system.

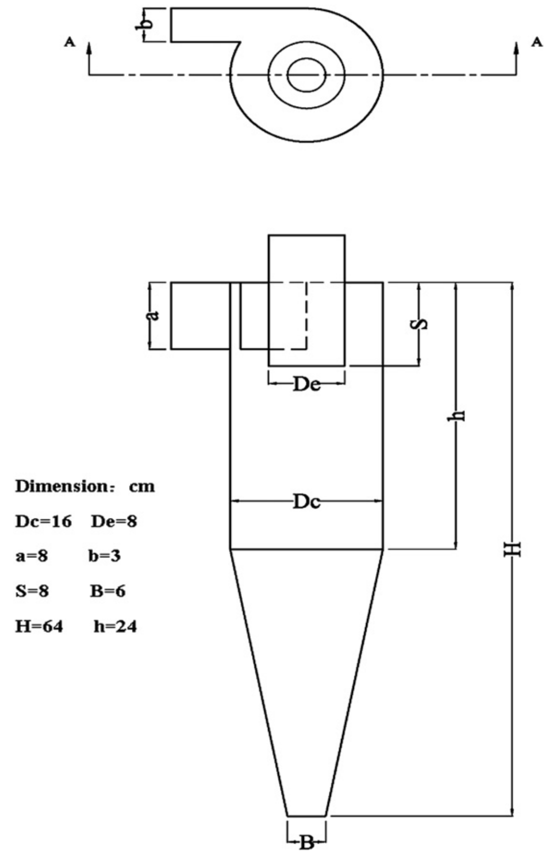

Fig. 2. Cyclone geometry.

cross-section area of 0.1×0.1 m^2 and a height of 3.2 m. The top of the riser had a smooth exit. Shown in Fig. 2, the primary cyclone is a standard Stairmand cyclone with a high efficiency. The particles separated from the cyclone were collected in a bunker on the top of the screw feeder and then fed into the standpipe. G_s was measured by the rotation speed of the screw feeder, and the relation between G_s and the rotation speed was pre-calibrated by weighing. A gas bypassing tube was connected at both side of the screw feeder to delete the pressure drop across it, which can maintain the solids fraction in the screw feeder nearly same during different operations. At the same time, the bed level in the bin above the screw feeder is maintained near the bottom layer of the cylinder. The standpipe had a height of 1.7 m and a diameter of 0.08 m. 20 pressure taps were installed at different height along the riser and standpipe. Two taps were installed on the side wall at the inlet and outlet of the cyclone respectively. Pressure transducers were connected to the pressure taps to measure the local pressure drop. The variable parameters in the experiment were fluidizing gas velocity in the riser U_g, G_s, bed inventory and aeration rate in the loopseal. The bed material was quartz sand ranges mainly from 91 to 152 μm, which physical properties were given in Table 1.

The on-line measurement of G_s is crucial for the transient method. Burnell et al. [13] summarized existing measuring methods on G_s in a CFB reactor as Impact Flowmeter method, Spiral Revolution method, Calorimetric method and Pressure Drop method. Among them, the pressure drop method proposed by Patience [14] was simplest and most convenient, and thus was employed in present study. Particularly, the pressure drop across riser elbow-type exit $^{\triangle}P_{ex}$, instead of the pressure drop across a section of riser was used. The relationship between $^{\triangle}P_{ex}$ and G_s or $C_{s,in}$ was pre-calibrated. The biggest advantage for selecting $^{\triangle}P_{ex}$ was that the flow regime cross the smooth exit remains as pneumatic transport, and thus no internal solid recirculation in the riser is needed to be considered [14].

At a specific U_g, after a steady state with a large G_s was maintained for a few minutes, the fluidizing air for loop seal was suddenly cut off. The bed inventory was then elutriated out of the riser and accumulated in the stand pipe while the flow regimes in the riser changed from fast fluidization to dilute transport regime and eventually free of particles. The cyclone pressure drops, $^{\triangle}P_c$, and $^{\triangle}P_{ex}$, were measured continuously on-line. With the pre-calibrated correlation between $^{\triangle}P_{ex}$ and $C_{s,in}$, the $C_{s,in}$ at the transient state was obtained. The variation of $^{\triangle}P_c$ with the wide range of $C_{s,in}$ at a given fluidizing velocity was obtained in one transient process.

3. Results and discussion

3.1. The pressure drop ΔP_{ex} cross the riser exit at steady states

The exit pressure drop ΔP_{ex}, namely the pressure drop between the riser exit and the inlet of the cyclone was investigated to estimate

Table 1
Physical properties of the quartz sand used in the experiments

ρ_s (kg/m^3)	ρ_b (kg/m^3)	d_{10} (μm)	d_m (μm)	d_{90} (μm)	ε_b	U_{mf} (cm/s)	U_{tr} (m/s)	ε_{mf}
2650	1440	91	127	152	0.46	1.52	3.0	0.54