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Numerical simulation and experimental study on pressure drop of radial jet cyclone

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ABSTRACT

The grade efficiency of fine particles is relatively inefficient for conventional cyclones, but the grade efficiency of the Radial Jet Cyclone (RJC) exceeds 90% for particles larger than 4 μm. The pressure drop of this cyclone is discussed based on the continuity equation, and a theoretical model is used to predict the pressure drop over the cyclone. Experimental results is in good agreement with the calculation. The inner flow field of cyclone is simulated by Reynolds Stress Model (RSM), and it indicates that there is a larger tangential velocity compared with the Stairmand Cyclone (SC) under the same inlet velocity. It reveals that the local loss in cushion chamber is in a significant proportion to pressure drop.

1. Introduction

Cyclone is widely applied to remove the dispersed particles from the carrying gas. Compared with the electrostatic precipitator and bag filter, the obvious advantage is low consumption and small occupation. However, the disadvantage is inefficient for particles smaller than 5 μm [1,2]. Many works have been done to improve the collection efficiency of fine particles. Tsai [3] designed an axial flow cyclone to remove fine particles, but the capacity of cyclone was small. Yoshida [4,5] used both the secondary flow injection and inlet guide plate methods to improve the separation efficiency of fine particles, and it is a useful way to remove the particle less than 5 μm. His experimental results also indicated that fine particles were affected by stronger centrifugal effect in the cylindrical section, and then moved to dust hopper due to the downward velocity in axial direction. Pirker et al. [6] predicted that the short circuit flow carried fine particles directly dispersed into the swirl flow in the vortex finder, which caused the low collection efficiency of fine particles. Fukui et al. [7] injected a clean air through the porous cone to control the cut size. It was found out that the size distribution also effected the collection efficiency of fine particles, even the cut diameter of cyclone was the same [8].

Pressure drop is one of the two important performance parameters playing a significant role in cyclone design and control. For a tangential inlet, reverse flow cyclone, some useful semi-empirical or empirical equations were established to predict the pressure drop [9–13]. These predicted models were assumed that the pressure drop over a cyclone included a frictional loss and a local loss, and then the overall pressure drop was obtained by summing each loss. However, the overall pressure is not the same with the static pressure drop between inlet and outlet, because there was a strong swirl flow in vortex finder. Among different models, different methods were used to deal with the dissipation of swirl flow. Shepherd and Lapple [9] took the downstream pressure as the ambient pressure. Stairmand [10] presumably measured the static pressure at outlet wall immediately downstream of a cyclone as he ignored the influence of the swirl flow. Barth and Leineweber [11] considered the swirl flow in the cyclone, and gave a semi-empirical formula to evaluate the dissipation. Muschelknautz [12] also considered the swirl flow in the cyclone, but added the effect of inlet concentration loading. Casal and Martinez-Benet [13] directly established a empirical formula of overall pressure, which was dependent on the inlet dimensions, diameter of vortex finder and inlet velocity. To more accurately evaluate the pressure drop, computational fluid dynamics (CFD) was used to simulate the distribution of inner velocity field, and some valid models were constructed to simulate the turbulence of strong swirl flow [14–17].

RJC is a new geometric structure cyclone which has a high efficiency for fine particles. Experimental results was shown that the overall collection efficiency was 93.6% for 4 μm, and the cutoff size was 0.3 μm [18]. The present paper analyses the composition of

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Nomenclature

A_R	friction area (m^2)
D	diameter of cyclone cylinder (m)
D_0	diameter of inlet pipe (m)
D_2	diameter of cushion chamber (m)
$D_{f1,2}$	diameter of vortex finder (m)
D_h	diameter of dust hopper (m)
Eu_x	Euler number (dimensionless)
f	friction coefficient (dimensionless)
h_2	thickness of blade (m)
h_3	length of cylinder (m)
H	total length (m)
H_f	length of vortex finder (m)
Δp	overall pressure drop (Pa)
Δp_1	pressure drop from inlet to out of cushion chamber (Pa)
Δp_2	pressure drop from out of cushion chamber to out of blades (Pa)
Δp_3	pressure drop from out of blades to outlet (Pa)
Δp_{body}	pressure drop in cylinder and cone (Pa)
Δp_x	pressure drop in vortex finder (Pa)
Q	volume flow (m^3/h)
R	radius of cylinder (m)
R_h	radius of dust hopper (m)
$R_{x1,2}$	radius of vortex finder (m)
v_{in}	inlet velocity (m/s)
v_2	velocity in cushion chamber (m/s)
v_3	velocity in screw blades (m/s)
v_t	tangential velocity (m/s)
v_x	velocity of vortex finder (m/s)
$v_{\theta cs}$	tangential velocity of CS (m/s)
v_z	axial velocity (m/s)
Z	blades number (dimensionless)

Greek letters

α	angle of screw blades (dimensionless)
θ	angle of flow channel between two blades (dimensionless)
$\lambda_{1,2,3,4}$	local friction coefficient (dimensionless)
μ	viscosity of gas (pa · s)
ρ	density of particles (kg/m^3)

overall pressure drop over the RJC, and then establishes a universal model for this structure based on continuity equation. Experimental results is in good agreement with the calculation, which is shown that the model is suitable to predict the pressure drop over the cyclone. The distribution of inner velocity fields is simulated based on the RSM, and the results is compared with the SC under the same inlet velocity. It indicates that the pressure drop of cushion chamber is in a significant proportion to the overall pressure drop.

2. Structure and advantages

2.1. The geometric structure

The structure of the cyclone is shown in Fig. 1. The streams through the inlet (2) go to the cushion chamber (3) and then turn downward in a channel (or coaxial pipe) which between the cushion camber and the outer wall of vortex finder (1). The streams move into the radial blades (4) and then turn around the corner along the wall of blades, where the direction is turned to axial. The streams swirl into the cylinder (6) by screw of the axial blades (5). Gas and solids separate in the cylinder by centrifugal force, which is caused by the tangential velocity. At the bottom of cone, the streams turn reversal as an upward flow. Collected particles move downward along the wall of cone (7) to dust hopper (8), and the uncollected particles escape from the vortex finder with gas.

2.2. Advantages

Compared with the tangential inlet, reverse flow cyclone, the characteristic structure of RJC has some advantages on the collection efficiency of fine particles. Firstly, this structure eliminates the phenomenon that fine particles directly escaping in short circuit under the vortex finder. Secondly, the function of radial blades divide the streams into 12 equal segments, which is useful for fine particles rapidly reaching the wall of cyclone, where they are easy to be collected. Thirdly, the gas -solid streams are pre-separated at the arc segment between the radial blades and the axial blades, which is helpful for particles acceleration in the cylinder. Finally,

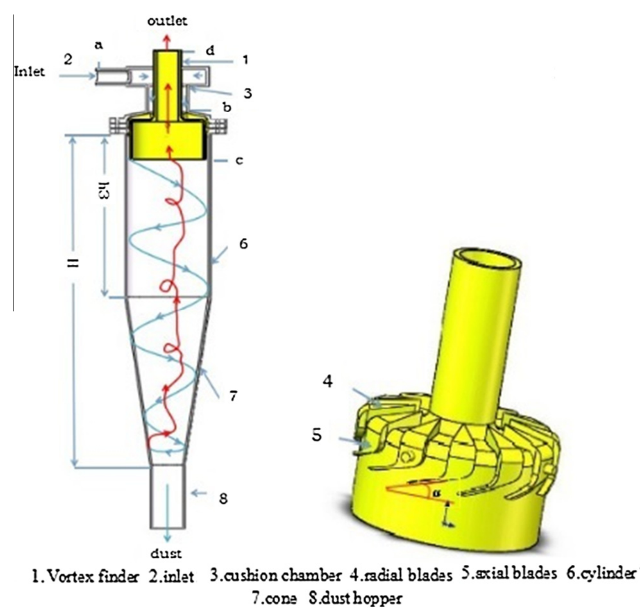

Fig. 1. Structure of cyclone.

the wall of blades is useful to reduce the dissipation of upward swirl flows before entering into the vortex finder. All these factors will greatly improve the separation performance of this cyclone in comparison with the conventional cyclone.

3. Theoretical model of pressure drop

The overall pressure over a cyclone includes a local loss and a friction loss. For the new cyclone, the overall pressure drop (ΔP) consists of three independent parts, as shown in Fig. 1. It includes that the loss (ΔP1) of the inlet (a) to the outlet of cushion chamber (b), the loss (ΔP2) of the outlet of cushion chamber (b) to the outlet of blades (c) and the loss (ΔP3) of the outlet of blades (c) to the outlet of vortex finder (d), so the overall pressure drop can be obtained by: