Experimental study on effects of inlet geometry on cyclone separator performance*

ZHAO Bingtao, SHEN Henggen, KANG Yanming, ZHANG Jiguang, *GAN Changde*

Department of Environmental Engineering, Donghua University, Shanghai 200051, P.R. China

Abstract: The different inlet geometry cyclones including conventional single inlet and symmetrical spiral inlet (SSI) cyclone were designed. The effects of inlet type on cyclone performance characteristics including the collection efficiency and pressure drop were investigated and compared as a function of particle size and flow rate in this paper. Experimental result indicated that inlet geometry has effect on significantly increasing collection efficiency with insignificantly increasing pressure drop. This presents the possibility of obtaining a better performance cyclone by means of improving its inlet geometry design. And the same time, the efficiency comparison between experimental data and theoretical model were also involved.

Keywords: cyclone; inlet geometry; collection efficiency; pressure drop

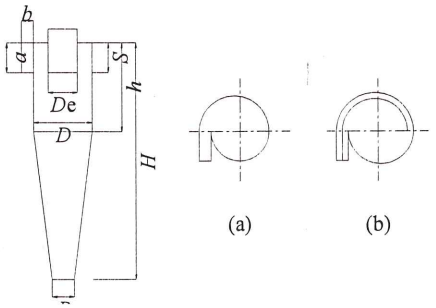
1. Introduction

Cyclone separators are widely used in the field of air pollution control and gas solid separation with especially small cyclones for aerosol sampling and large ones for industrial applications [1]. Due to simple construction, no moving parts, low manufacturing and maintenance costs, and well flexibility and adaptability to a widespread range of extremely harsh operating conditions including high temperature, high pressure, and corrosive environment. Cyclone separators have became one of most important particle removal device that preferably utilized in various technical and industrial operations. Therefore, high performance play important role on improving environment and saving energy.

Although cyclones have been adequate for many applications, the increasing emphasis on environment protection and gas-solid separation is indicating finer and finer particles must be removed. To meet this challenge, improvement of cyclone geometry and performance is required. Many researchers have contributed to large volume of work on improving the cyclone performance with increasing of collection efficiency and decreasing of pressure drop, by introducing new design and operation variables. These include studies by Wedding et al. [2], DeOtte [3], Moore and Mcfarland [4], Gautam and Streenath [5], Lim et al. [6]. Until now, in sharp contrast to work on the cyclone, relatively little work has been reported on the effect of inlet geometry on cyclone performance for large scale industrial applications. In this paper, the new inlet type which different type of inlet from that used former researchers was described, and the experimental study on addressing the effect of inlet type on cyclone performances was presented.

2. Experiment

Two various kinds of 300mm diameter cyclone separators with conventional single inlet and symmetrical spiral inlet (SSI) were manufactured and studied. The geometries and dimensions these cyclones are presented in Fig. 1 and Table 1. As shown in the Figure and table, In order to examine the effects of inlet type, all other dimensions were designed to remain the same but only the inlet geometry.



(a) Single inlet Model A; (b) Symmetrical spiral inlet Model B

Fig. 1. Schematic diagram of cyclones geometries

Table 1 Dimensions of cyclones studied (unit: mm)

D	D_e	h	H	B	S	a	b
300	150	450	1200	1125	150	150	60

The experimental system setup is shown in Fig. 2. It consist of a power feeding system, a tested cyclone with various inlet type, a big filter and a fun, with required pressure, temperature, and pressure drop and

ZHAO Bingtao(赵秉涛): Male; born in 1976; Doctoral candidate, Research field: Air pollution control engineering.

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collection efficiency instruments.

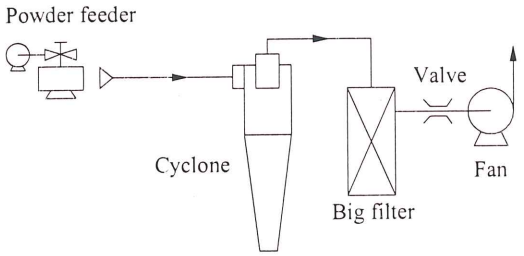

Fig. 2. Schematic diagram of experimental system setup

The pressure drops were measured between two pressure taps on the cyclone inlet and outlet tube, the collection efficiency were calculated by the mass difference of particulate matter on the cyclone inlet and collection hopper.

The solid particles used were talcum powder, whose physical properties are shown in Table 2. It was typical material used in testing industrial cyclone performance. The size distribution of the particle feed is shown in fig. 3. It was obtained by sieving greater particle size in a standard sieve set, and analyzing smaller particles size in a Bacho centrifugal analyzer. Results of instruments were disposed to provide a single distribution curve.

Table 2. Physical properties of the feed particles

Specification	Value
Bulk density ρ_p(kg/m^3)	700
Skeletal density ρ_s (kg/m^3)	2700
Mass-mean diameter d_p (μm)	5.97
Stand deviation σ_p	2.08

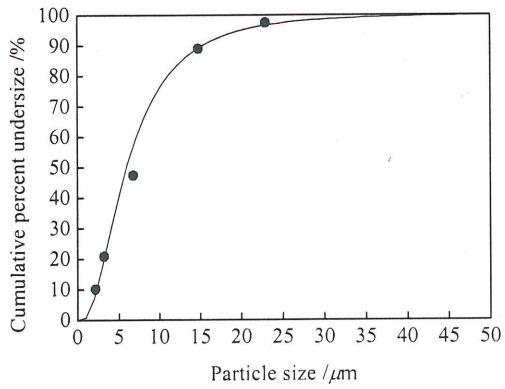

Fig. 3. Feed particle size distribution

The mean atmospheric pressure, ambient temperature and relative humidity during the tests were 99.93 kPa, 293K and less than 75%, respectively.

3. Results and discussion

3.1 Collection efficiency

Fig. 4 compares the grade collection efficiency of the SSI cyclone separator (Model B) with those of the conventional single inlet cyclone separator (Models A) at different flow rates. Fig. 4(a) shows the grade collection efficiencies at the flow rate of 388.34m^3/h for both Models, with an inlet velocity of 11.99m/s. In spite of that Model B have a difference with Model A in inlet geometries, but the total areas of their inlets are equal. Fig. 4(b), (c) and (d) show the grade collection efficiencies of cyclones at the flow rate of 519.80, 653.67 and 772.62 m^3/h, with the inlet velocities of 16.04, 20.18, 23.85m/s, respectively.

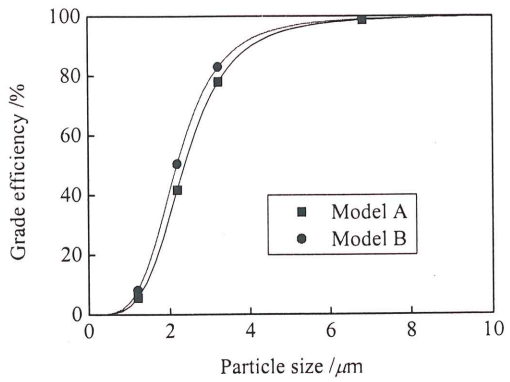

Fig. 4(a) Inlet velocity: 11.99 m/s

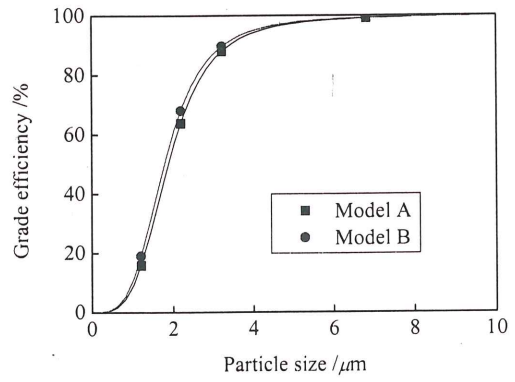

Fig. 4(b) Inlet velocity: 16.04 m/s

As expected, the frictional efficiencies of all the cyclones are seen to increase with increase in particle size and the flow rate. The shapes of the collection efficiency curves of Models A and B have a so-called "S" shape, with little scatter. The friction efficiency of the SSI cyclone, Model B, is greater by 5-10% than that for Model A. This indicates that the inlet type or geometry to the cyclone plays an important role in the collection efficiency. It was expected that particles introduced to the cyclone with SSI would easily collect

on the cyclone wall because they only have to move a short distance, at the same time, the SSI, as a part of new type cyclone, makes the particle pre-separated from the gas before enter the main body of cyclone.

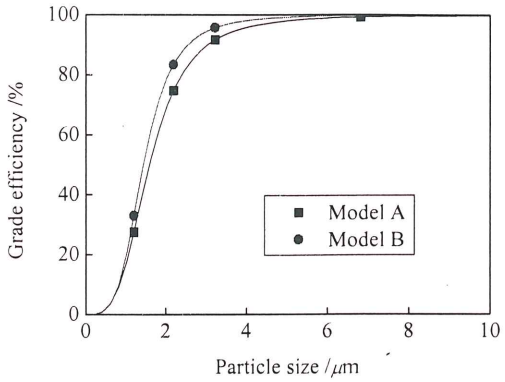

Fig. 4(c) Inlet velocity: 20.18 m/s

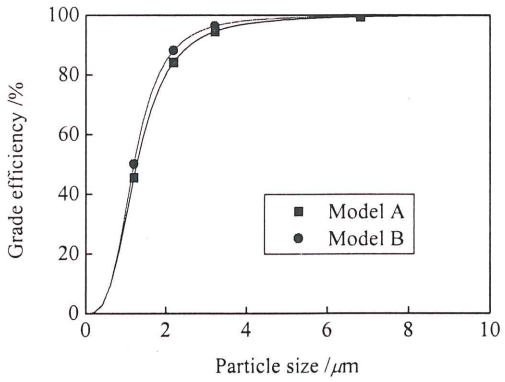

Fig. 4(d) Inlet velocity: 23.85 m/s

Fig. 4. Grade efficiency of the cyclones at different inlet velocities

The experimental data obtained in this study were compared with existing classical theories in order to put the data into better use. Fig. 5 compares the experimental efficiency curves at a flow rate of 653.67 m^3/h (inlet velocity of 20.18m/s) with those generated from the Leith and Licht's [7] theory, Dietz's [8] theory, Mothes and Loffler' [9] theory, Iozia and Leith' [10] theory, and Clift's [11] theory, respectively. Apparently, the efficiency curves based on Mothes and Loffler' model and Iozia and Leith's logistic method match the experimental curves much closer than other theories. The revised Leith and Licht theory by Clift still yields flatter curves. This result corresponds with the study carried out by Dirgo [12] and Xiang [13]. The comparison show that some model can predict a theoretical result that closed the experimental data, but none of these theories take in account the effect of inlet geometry on cyclone performance adequately.

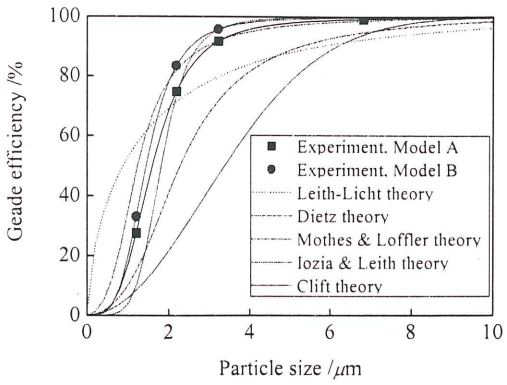

Fig. 5. Comparison of experimental data with theories

To examine the effects of the SSI on cyclone performance more clearly, Fig. 6 were prepared depicting the 50% cut size for both Model A and Model B with varying the flow rate or inlet velocity.

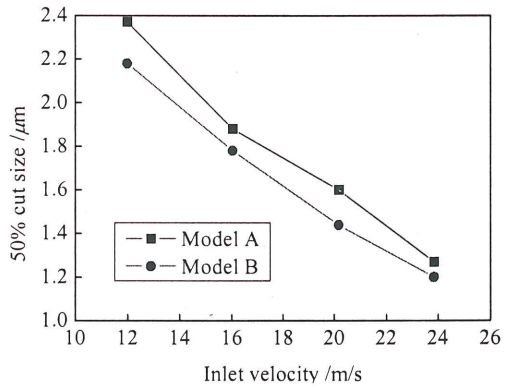

Fig. 6. The 50% cut size of the cyclones

The cut size of Model B is the lower than Model A at the same inlet velocity. As the inlet velocity is decreased, the 50 % cut size is approximately decreased linearly. With inlet velocity 20.18 m/s, the decrease rate of 50 % cut size of Model B is up to 10 %, this indicated the new inlet type can help to enhance the cyclone collection efficiency.

3.1 Pressure drop

Except for the collection efficiency, the pressure drop across the cyclone is another important concern from the point of view of energy consumption. In this work, pressure drops were measured between two pressure taps on the cyclone inlet and outlet tube by means of a digital micro pressure gauge. The pressure drop and pressure drop ratio values for the two cyclones corresponding to different flow rates from 388.34 to 772.62m^3/h are presented in Fig. 7 and Table 3.

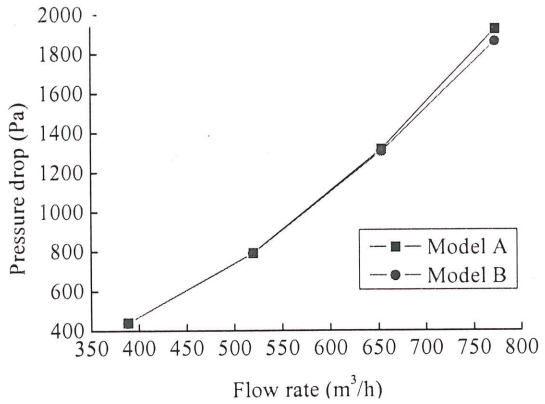

Fig. 7. Pressure drop of the cyclones

Table 3. Pressure drop ratio of the cyclones

	Flow rate /(m³/s)				
Cyclone model	388.34	519.80	653.67	772.62	Average
A	5.16	5.19	5.45	5.70	5.55
B	5.14	5.17	5.39	5.50	5.42

Obviously, higher pressure drop is associated with higher flow rate for a given cyclone. However, specifying a flow rate or inlet velocity, the difference of pressure drop between Model A and B is less significant, and the pressure drop ratio varied between 5.16~5.55 with an average value 5.55 for Model A and 5.14~5.42 with an average value 5.42 for Model B is calculated by linear regression analysis. This is an important point because it is possible to increase the cyclone collection efficiency without increasing the pressure drop significantly. This presents the possibility of obtaining a better performance cyclone by means of improving its inlet geometry design.

4. Conclusions

1) Experimental result show the grade efficiency of the SSI cyclone, Model B, is greater by 5-10% than that for Model A, a traditional single inlet cyclone, and have a lower 50% cut size. These indicate that inlet geometry plays an equally important role in affecting cyclone performance.

2) By comparing the experimental and theoretical result, it was observed that the Mothes and Loffler's and Iozia and Leith's methods match the experimental data much closer than other existing theories.

3) The pressure drop ratio is 5.55 for Model A and 5.42 for Model B, this suggest that cyclone with SSI make it to possible increase the cyclone collection efficiency without increasing the pressure drop significantly.

4) The findings from this work suggest that attention should be also pay to the inlet geometry to improve the design of cyclones and the predictive ability of cyclone models.

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