Powder Technology 145 (2004) 47–50

Short communication

Development of a symmetrical spiral inlet to improve cyclone separator performance

Bingtao Zhao*, Henggen Shen, Yanming Kang

Department of Environmental Engineering, Donghua University, No. 1882, Yanan Rd., Shanghai, Shanghai 200051, China

Received 28 October 2003; received in revised form 24 February 2004; accepted 3 June 2004
Available online 17 July 2004

Abstract

Three cyclone separators with different inlet geometry were designed, which include a conventional tangential single inlet (CTSI), a direct symmetrical spiral inlet (DSSI), and a converging symmetrical spiral inlet (CSSI). 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 the symmetrical spiral inlet (SSI), especially CSSI inlet geometry, has effect on significantly increasing collection efficiency with insignificantly increasing pressure drop. In addition, the results of collection efficiency and pressure drop comparison between the experimental data and the theoretical model were also involved.

Keywords: Cyclone; Symmetrical spiral inlet; Collection efficiency; Pressure drop

1. Introduction

Cyclone separators are widely used in the field of air pollution control and gas–solid separation for aerosol sampling and industrial applications [1]. Due to relative simplicity to fabricate, low cost to operate, and well adaptability to extremely harsh conditions, cyclone separators have became one of most important particle removal device that preferably is utilized in both engineering and process operation. However, the increasing emphasis on environment protection and gas–solid separation is indicating that finer and finer particles must be removed. To meet this challenge, the improvement of cyclone geometry and performance is required rather than having to resort to alternative units. Many researchers have contributed to large volume of work on improving the cyclone performance, by introducing new inlet design and operation variables. These include studies of testing a cyclonic fractionator for sampling that used multiple inlet vanes by Wedding et al. [2], developing a mathematic model to predict the collection efficiency of small cylindrical multiport cyclone by DeOtte [3], testing a multiple inlet cyclones based on Lapple' type geometry by Moore and Mcfarland [4], designing and testing a respirable multiinlet cyclone sampler that minimize the orientation bias by Gautam and Streenath [5], and comparing the performance of a double inlet cyclone with clean air by Lim et al. [6]. In this paper, the new inlet type, which is different type of inlet from that used by former researchers, was developed, and the experimental study on addressing the effect of inlet type on cyclone performances was presented.

2. Experimental

Three kinds of cyclone separators with various inlet geometries, including conventional tangential single inlet (CTSI), direct symmetrical spiral inlet (DSSI), and converging symmetrical spiral inlet (CSSI), were manufactured and studied. The geometries and dimensions these cyclones are presented in Fig. 1 and Table 1. To examine the effects of inlet type, all other dimensions were designed to remain the same but only the inlet geometry.

* Corresponding author. Tel.: +86-21-62373718; fax: +86-21-62373482.
E-mail address: zhaobingtao@mail.dhu.edu.cn (B. Zhao).

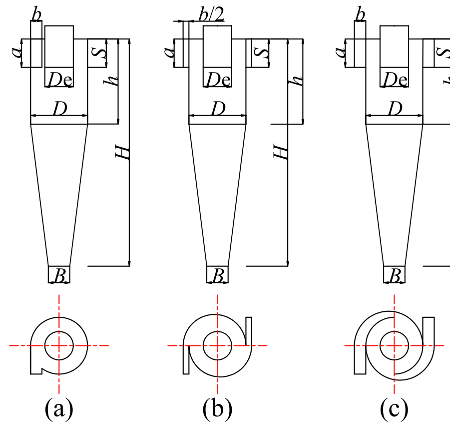

Fig. 1. Schematic diagram of cyclones geometries: (a) conventional tangential single inlet, Model A; (b) direct symmetrical spiral inlet, Model B; (c) converging symmetrical spiral inlet, Model C.

The experimental system setup is shown in Fig. 2.

The pressure drops were measured between two pressure taps on the cyclone inlet and outlet tube by use of a digital micromanometer (SINAP, DP1000-IIIC). The collection efficiency was calculated by the particle size distribution, by use of microparticle size analyzer (SPSI, LKY-2). Due to having the same symmetrical inlet in Model B or C, the flow rate of each inlet of multiple cyclone was equal to another and controlled by valve; two nozzle-type screw feeders were used in same operating conditions to disperse the particles with a concentration of 5.0 g/m^3 in inlet tube. The solid particles used were talcum powder obeyed by log-normal size distribution with skeletal density of 2700 kg/m^3, mass–mean diameter of 5.97 μm, and geometric deviation of 2.08. The mean atmospheric pressure, ambient temperature, and relative humidity during the tests were 99.93 kPa, 293 K, and less than 75%, respectively.

3. Results and discussion

3.1. Collection efficiency

Fig. 3 shows the measured overall efficiencies of the cyclones as a function of flow rates or inlet velocities. It is usually expected that collection efficiency increase with the entrance velocity. However, the overall efficiency of the cyclone with symmetrical spiral inlet both Models B and C was always higher than the efficiency of the cyclone with conventional single inlet Model A at the same velocity; and especially, the cyclone with CSSI, Model C has a highest overall efficiency. These effects of improved inlet geometry contribute to the increase in overall efficiency of the cyclone

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

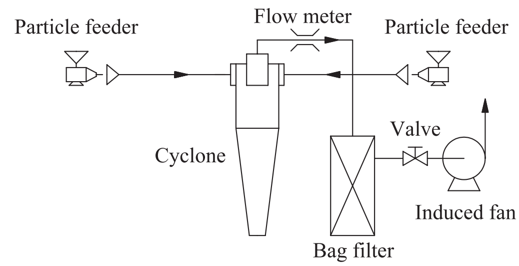

Fig. 2. Schematic diagram of experimental system setup.

by 0.15–1.15% and 0.40–2.40% in the tested velocity range.

Fig. 4(a)–(d) compares the grade collection efficiency of the cyclones with various inlet types at the flow rate of 388.34, 519.80, 653.67, and 772.62 m^3/h, with the inlet velocities of 11.99, 16.04, 20.18, and 23.85 m/s, respectively.

As expected, the frictional efficiencies of all the cyclones are seen to increase with increase in particle size. The shapes of the grade collection efficiency curves of all models have a so-called "S" shape. The friction efficiencies of the DSSI (Model B) and CSSI cyclones (Model C) are greater by 2–10% and 5–20% than that for the CTSI cyclone (Model A), respectively. 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 symmetrical spiral inlet (Models B and C) would easily be collected on the cyclone wall because they only have to move a short distance, and especially, the CSSI (Model C) changes the particle concentration distribution and makes the particle preseparated from the gas before entering the main body of cyclone.

Fig. 5 compares the experimental data at a flow rate of 653.67 m^3/h (inlet velocity of 20.18 m/s) with existing classical theories [7–11]. Apparently, the efficiency curves based on Mothes and Loffler' model and Iozia and Leith's method match the experimental curves much closer than other theories do. This result corresponds with the study carried out by Dirgo and Leith [12] and Xiang et al. [13].

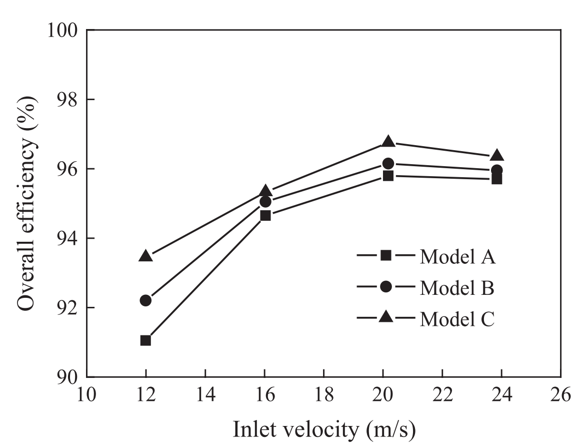

Fig. 3. Overall efficiency of the cyclones at different inlet velocities.

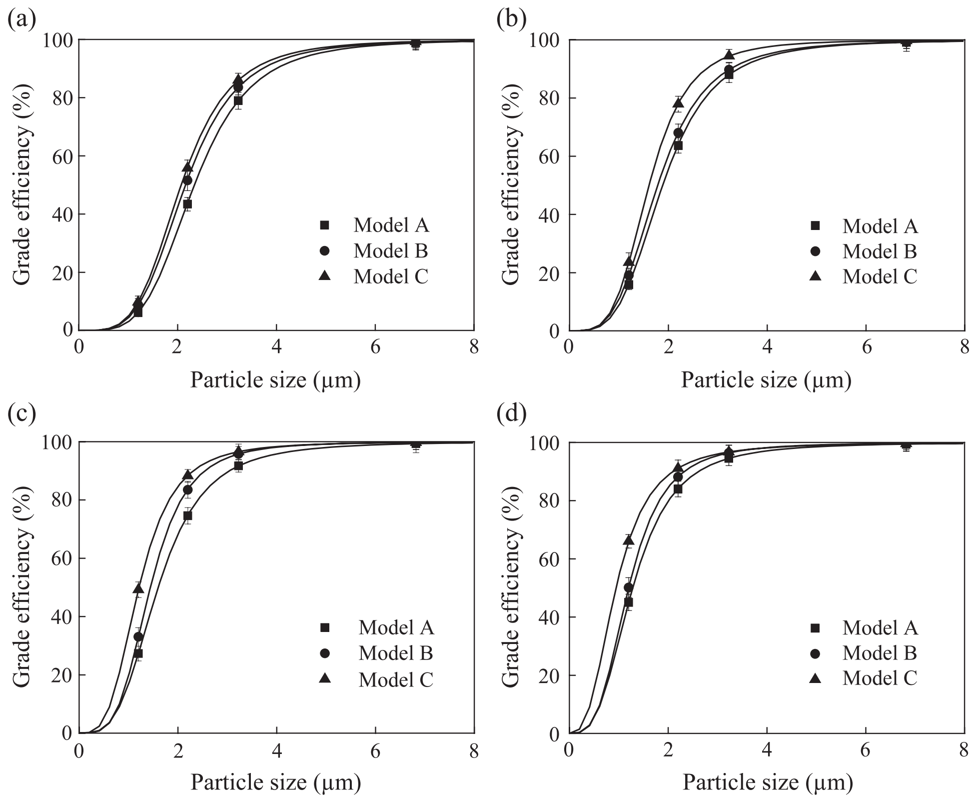

Fig. 4. Grade efficiency of the cyclones at different inlet velocities. (a) Inlet velocity = 11.99 m/s. (b) Inlet velocity = 16.04 m/s. (c) Inlet velocity = 20.18 m/s. (d) Inlet velocity = 23.85 m/s.

The comparison show that some model can predict a theoretical result that closed the experimental data, but the changes of flow pattern and particle concentration distribution induced by symmetrical spiral inlet having effects on cyclone performance were not taken into account adequately in developed theories.

To examine the effects of the symmetrical spiral inlet on cyclone performance more clearly, Fig. 6 was prepared, depicting the 50% cut size for all models with varying the flow rate or inlet velocity. The 50% cut size of Models C and B are lower than that of 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, for example, the decrease rate of 50% cut size is up to 9.88% for Model B and 24.62% for Model C. This indicated that the new inlet type can help to enhance the cyclone collection efficiency.

3.2. Pressure drop

The pressure drop across cyclone is commonly expressed as a number gas inlet velocity heads ΔH named the pressure

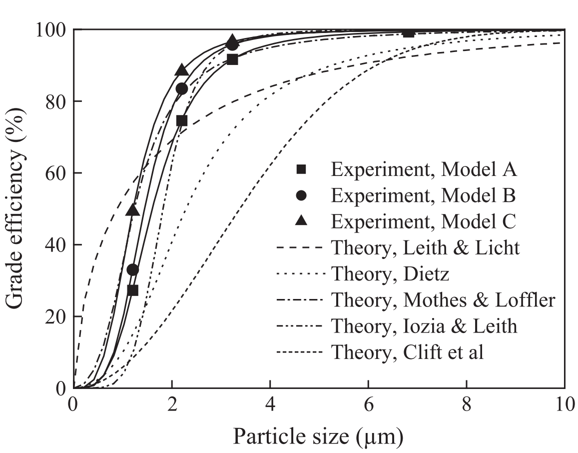

Fig. 5. Comparison of experimental grade efficiency with theories.

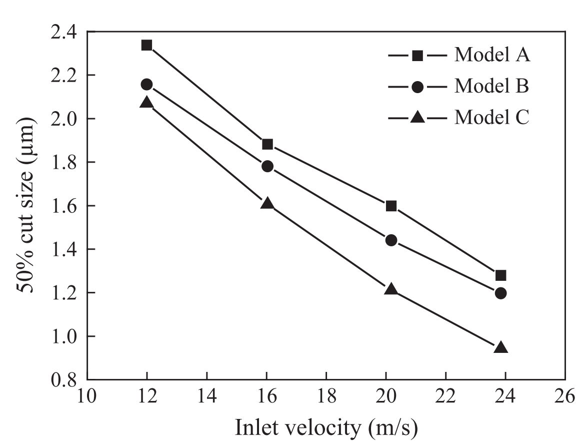

Fig. 6. The 50% cut size of the cyclones.

Table 2
Pressure drop coefficient of the cyclones

Cyclone model	Inlet velocity (m/s)				
	11.99	16.04	20.18	23.85	average
A	5.16	5.18	5.45	5.70	5.55
B	5.21	5.27	5.57	5.76	5.63
C	5.22	5.35	5.67	5.76	5.67

Table 3
Comparison of pressure drop coefficient with theories

Theory	Shepherd	Alexander	First	Stairmand	Barth	Casal	Dirgo	Model A	Model B	Model C
Value	6.40	5.62	6.18	5.01	5.18	7.85	4.85	5.55	5.63	5.67

drop coefficient, which is the division of the pressure drop by inlet kinetic pressure $\rho_g v_i^2/2$. The pressure drop coefficient values for the three cyclones corresponding to different inlet velocity are presented in Table 2.

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 coefficient between Models B, C, and A is less significant, and varied between 5.21 and 5.76, with an average value 5.63, for Model B, 5.22–5.76, with an average value 5.67, for Model C, and 5.16–5.70, with an average value 5.55, for Model A, calculated by regression analysis. This is an important point because it is possible to increase the cyclone collection efficiency without increasing the pressure drop significantly.

The experimental data of pressure drop were also compared with current theories [14–20], and results are presented in Table 3. The results show that the model of Alexander and Barth provided the better fit to the experimental data, although for some cyclones the models of Shepherd and Lapple and Dirgo predicted equally well.

4. Conclusions

A new kind of cyclone with symmetrical spiral inlet (SSI) including DSSI and CSSI was developed, and the effects of these inlet types on cyclone performance were tested and compared. Experimental results show the overall efficiency the DSSI cyclone and CSSI is greater by 0.15–1.15% and 0.40–2.40% than that for CTSI cyclone, and the grade efficiency is greater by 2–10% and 5–20%. In addition, the pressure drop coefficient is 5.63 for DSSI cyclone, 5.67 for CSSI, and 5.55 for CTSI cyclone. Despite that the multiple inlet increases the complicity and the cost of the cyclone separators, the cyclones with SSI, especially CSSI, can yield a better collection efficiency, obviously with a minor increase in pressure drop. This presents the possibility of obtaining a better performance cyclone by means of improving its inlet geometry design.

References

[1] Y.F. Zhu, K.W. Lee, Experimental study on small cyclones operating at high flowrates, Aerosol Sci. Technol. 30 (10) (1999) 1303–1315.
[2] J.B. Wedding, M.A. Weigand, T.A. Carney, A 10 μm cutpoint inlet for the dichotomous sampler, Environ. Sci. Technol. 16 (1982) 602–606.
[3] R.E. DeOtte, A model for the prediction of the collection efficiency characteristics of a small, cylindrical aerosol sampling cyclone, Aerosol Sci. Technol. 12 (1990) 1055–1066.
[4] M.E. Moore, A.R. Mcfarland, Design methodology for multiple inlet cyclones, Environ. Sci. Technol. 30 (1996) 271–276.
[5] M. Gautam, A. Streenath, Performance of a respirable multi-inlet cyclone sampler, J. Aerosol Sci. 28 (7) (1997) 1265–1281.
[6] K.S. Lim, S.B. Kwon, K.W. Lee, Characteristics of the collection efficiency for a double inlet cyclone with clean air, J. Aerosol Sci. 34 (2003) 1085–1095.
[7] D. Leith, W. Licht, The collection efficiency of cyclone type particle collectors: a new theoretical approach, AIChE Symp. Ser. 68 (126) (1972) 196–206.
[8] P.W. Dietz, Collection efficiency of cyclone separators, AIChE J. 27 (6) (1981) 888–892.
[9] H. Mothes, F. Loffler, Prediction of particle removal in cyclone separators, Int. Chem. Eng. 28 (2) (1988) 231–240.
[10] D.L. Iozia, D. Leith, The logistic function and cyclone fractional efficiency, Aerosol Sci. Technol. 12 (1990) 598–606.
[11] R. Clift, M. Ghadiri, A.C. Hoffman, A critique of two models for cyclone performance, AI ChE J. 37 (1991) 285–289.
[12] J. Dirgo, D. Leith, Cyclone collection efficiency: comparison of experimental results with theoretical predictions, Aerosol Sci. Technol. 4 (1985) 401–415.
[13] R.B. Xiang, S.H. Park, K.W. Lee, Effects of dimension on cyclone performance, J. Aerosol Sci. 32 (2001) 549–561.
[14] C.B. Shepherd, C.E. Lapple, Flow pattern and pressure drop in cyclone dust collectors: cyclone without inlet vane, Ind. Eng. Chem. 32 (1940) 1246–1256.
[15] R.M. Alexander, Fundamentals of cyclone design and operation, Proc. Aust. Inst. Min. Met. (New Series) (1949) 152–153, 202–228.
[16] M.W. First, Cyclone dust collector design, Am. Soc. Mech. Eng. 49 (A) (1949) 127–132.
[17] C.J. Stairmand, Design and performance of cyclone separators, Trans. Inst. Chem. Eng. 29 (1951) 356–383.
[18] W. Barth, Design and layout of the cyclone separator on the basis of new investigations, Brennst. Wärme Kraft 8 (1956) 1–9.
[19] J. Casal, J.M. Martinez-Bennet, A batter way to calculate cyclone pressure drop, Chem. Eng. 90 (3) (1983) 99–100.
[20] J. Dirgo, Relationship between cyclone dimensions and performance, Doctoral Thesis, Harvard University, USA, 1988.