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An optical technique to determine the total collection efficiency of a cylone

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Abstract

An experimental method is proposed to determine the total collection efficiency of a cyclone. An optical technique is utilized to measure and calculate the total collection efficiency by integrating the area below the size distribution curve upstream and downstream of the cyclone by a particle counter–sizer–velocimeter.

The results show that the size distribution upstream and downstream of the cyclone is almost a smooth curve. It could be used to calculate the total collection efficiency. The measured total efficiency by the particle counter–sizer–velocimeter is 2–3% higher than that measured by the weighing method. This close agreement between the two methods suggests that the total collection efficiency may be determined by the optical technique. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Cyclone; Optical technique; Total collection efficiency; Particle counter–sizer–velocimeter

1. Introduction

Cyclones provide a simple and inexpensive means for removing particles from gas streams. Since cyclones are usually used as pre-cleaning devices to decrease the dust loading prior to treatment by a subsequent high-efficiency collector, such as a baghouse or electrostatic precipitator, one needs to know what total efficiency must be achieved, rather than just the grade efficiency.

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There have been many theoretical and experimental studies on measuring and predicting the total efficiency of cyclones. In order to determine the influence of dust concentration on the total collection efficiency, Mothes and Löffler [1] measured the total collection efficiency at various particle concentrations by weighing the dust particles in the hopper. Hoffmann et al. [2] also obtained the overall separation efficiency by weighing the collection hopper. Zhao and Pfeffer [3] showed that the total efficiencies of cyclones could be obtained using the expression for the grade efficiency of a cyclone by simply replacing the particle diameter by the mass median diameter of the particles of a given size distribution. They offered a simpler method than previously used to calculate the total efficiency. Overcamp and Mantha [4] proposed a mathematical model to estimate the overall efficiency of a cyclone. Based on the assumption of a log normal size distribution and the generalized Lapple fractional efficiency curve, the results showed that the overall efficiency was a strong function of the ratio of the aerodynamic geometric mass mean diameter of the particle size distribution to the aerodynamic cut diameter.

The total efficiency can be theoretically calculated knowing the grade efficiency and the particle size distribution function. However, Iozia and Leith [5] showed that the theories have not consistently shown the ability to predict the cyclone collection efficiency well. The grade efficiency predicted by Lapple (1950), Barth (1956), Leith and Licht (1972), Dietz (1981), Dirgo and Leith (1985a), Iozia and Leith (1989) did not appear consistent. For example, Zhao and Pfeffer used the Leith and Licht (1972) model as the grade efficiency of a cyclone to calculate the total efficiency. The results, however, would be different if they have used any other model. Overcamp and Mantha assumed the size distribution of particles was a log normal distribution that could be considered simplistic. Mothes and Löffler measured the total collection efficiency at various particle concentrations by weighing the dust particles in the hopper. This might be considered too rough a method. Thus, The total efficiency of a cyclone is very difficult to predict theoretically and to measure precisely.

The objective of this research is to measure the total efficiency of a cyclone more precisely by using an experimental optical technique.

2. Experimental

The experimental arrangement is shown in Fig. 1. An axial Stairmand high-efficiency cyclone 22 cm in diameter was utilized for the tests. The system consisted of a dust feeder, a cyclone, and two particle counter–sizer–velocimeters. Air was drawn through the system by a fan located near the outlet. Throughout the experiment, particles of a polydisperse size distribution produced by a dust feeder were used to feed fly ash continuously into the gas. The source of the particles came from the fly ash of a coal-fired power plant. The particle counter–sizer–velocimeter simultaneously monitored the incoming and outgoing dust streams to permit real-time computation of the size distribution and particle concentration.

The procedure for measuring the total efficiency of cyclone was designed to first generate the particles, then to pass the particle-laden air through the cyclone at a desired flow rate, and then to measure particle concentration and size distribution upstream and

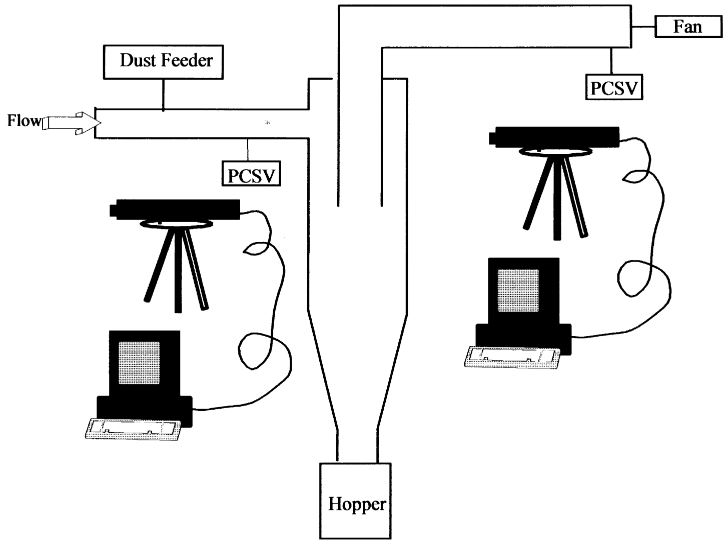

Fig. 1. Schematic diagram of cyclone.

downstream of the cyclone. The polydisperse sizes of the particles produced were controlled by the operating conditions of the dust feeder. A screw feeder was used to introduce the fly ash at a feed rate in the range 7.2–21.2 g/min. The airflow rates were varied between 15.8 and 44.3 m^3/min. The inlet air velocities were varied between 14.7 and 41.8 m/s. The inlet dust concentrations were on the order of 0.5 g/m^3. The measured particle size distribution and concentration upstream and downstream of the cyclone were used for the calculation of the fractional efficiency and total collection efficiency.

Because the resolution of PCSV is very high, the size distribution could be expected to be a smooth curve. An integrating meter was used to determine the area below the curve of size distribution upstream and downstream of the cyclone. From these measurements, the total efficiency of the cyclone could be obtained. The total collection efficiency was also measured by weighing the dust particles in the hopper for comparison with the results derived from the PCSV.

2.1. Particle counter–sizer–velocimeter

The concentration and size distribution of the fly ash were determined using a particle counter–sizer–velocimeter, INSITEC PCSV-P TYPE. PCSV instruments are part of a large group of electro-optical instruments whose principle of operation is based on light scattering. Light scattering techniques include both single-particle counting and ensemble-particle counting instruments.

The PCSV is capable of measuring the particle sizes in the range from 0.2 to 200 μm and loading up to 10^7 #/cm^3 for the submicron range. The PCSV is a laser-based instrument for in-line, in situ particle measurements. The principle of operation is based on measuring the light scattered by single particles moving through the sample volume

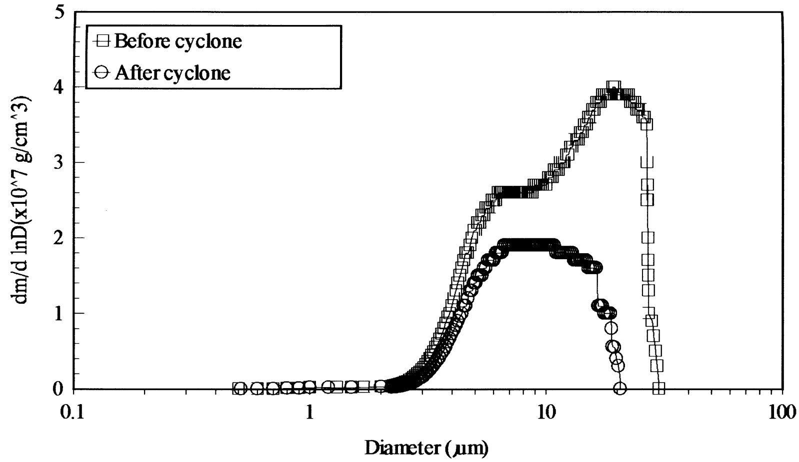

Fig. 2. Size distribution of fly ash (flow rate = 15.75 m^3/min).

of a focused laser beam. For each scattered light pulse, the signal processor measures the peak signal intensity, which is then related to particle size. Once a large number of scattered light signals are collected, the software available uses an intensity deconvolution algorithm to determine the particle concentration and particle size distribution.

3. Results and discussion

The particle concentrations and size distributions measured by the particle counter–sizer–velocimeter at flow rates of 15.8, 28.8, and 44.3 m^3/min are shown in Figs. 2–4.

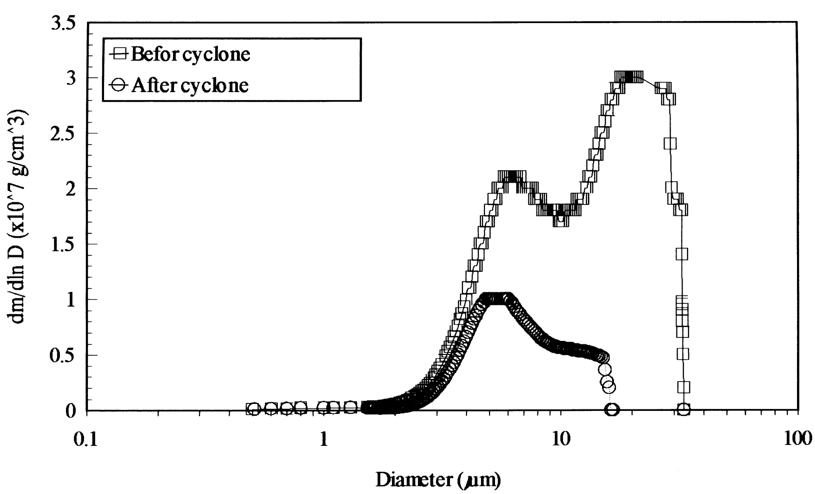

Fig. 3. Size distribution of fly ash (flow rate = 28.8 m^3/min).

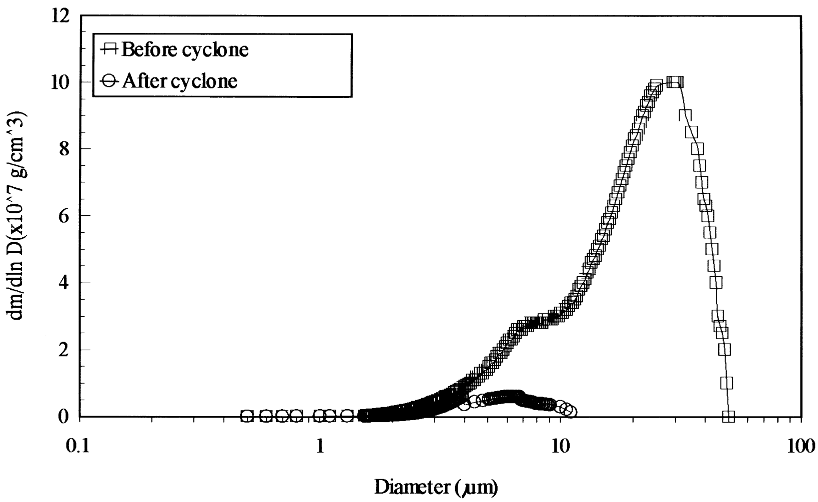

Fig. 4. Size distribution of fly ash (flow rate = 44.26 m^3/min).

The size distribution upstream of the cyclone is denoted by “Before Cyclone”, downstream is denoted by “After Cyclone”. These size distribution curves are seen not to be a log normal distribution, although many researchers assumed such a distribution in view of the interaction among particles of polydisperse sizes being very complex. It is impossible to predict the size distribution of polydisperse particles and this is the reason why this study has to be done experimentally.

At the lower flow rates, as shown in Figs. 2 and 3, the particle size distribution of the fly ash “Before Cyclone” ranged from 0.5 to 30 μm and from 0.5 to 20 μm for “After Cyclone”. The mass distribution “Before Cyclone” reached a maximum at about 20 μm and at 5–10 μm for “After Cyclone”. The size distribution curve for “Before Cyclone” indicated that the concentration exhibited two peaks in Fig. 3. The similar observation was also made by McElroy et al. [6] and Kauppinen and Pakkanen [7].

The total collection efficiency of the cyclone was determined by calculating the area below each of the size distribution curves before and after the cyclone. An integrating meter was used to calculate the area below the size distribution curve. After comparing

Table 1
Comparison of total efficiency for two different measuring methods

Flow rate (m^3/min)	Total efficiency (%) by PCSV	Total efficiency (%) by weighing	Difference (%)
15.8	58.4	57.2	2.1
28.8	68.6	66.7	2.8
44.3	83.5	81.8	2.1

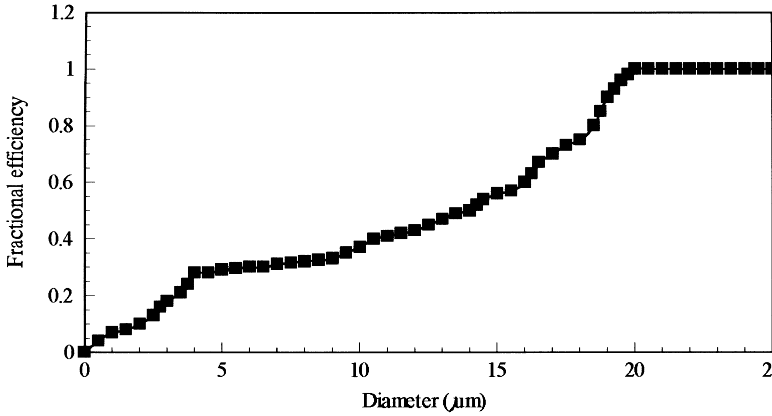

Fig. 5. Fractional efficiency of cyclone (flow rate = 15.75 m^3/min).

the area of size distribution before and after the cyclone, the total efficiency was obtained. The total collection efficiency was calculated by the following equation:

$$\eta_{tot} = 1 - A_{out}/A_{in}$$

where η_{tot} is the total collection efficiency of the cyclone, A_{in} is the area below the size distribution curve upstream of the cyclone and A_{out} is the downstream area. The results for the calculation of the total efficiency are listed in Table 1. The total collection efficiencies are increased as the flow rates increase because the centrifugal forces increase. As a method for comparison, the total collection efficiencies were also measured by weighing the fly ash collected in the hopper. This allows the results to be easily compared with an accepted method. The results are also listed in Table 1 and have the same trend and reasons as those of PCSV. Although the PCSV results are 2–3%

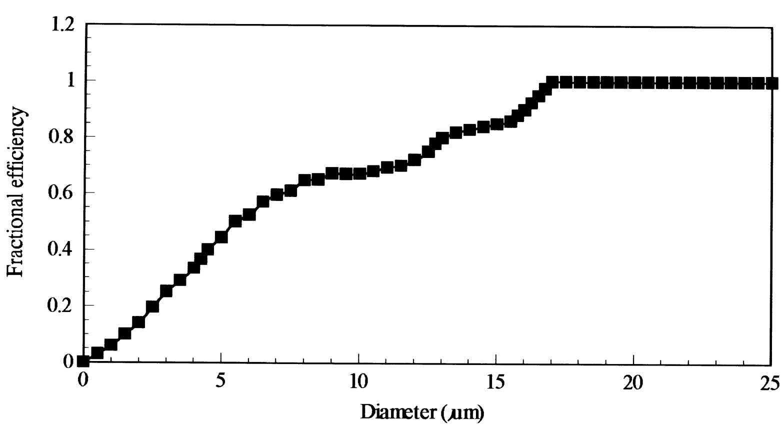

Fig. 6. Fractional efficiency of cyclone (flow rate = 28.75 m^3/min).

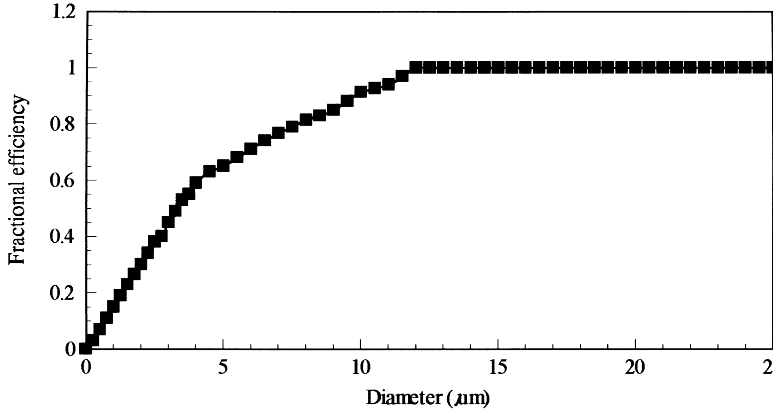

Fig. 7. Fractional efficiency of cyclone (flow rate = 44.26 m^3/min).

higher than weighing results, it appears that the measuring method of the total efficiency agrees well between the optical technique and weighing method.

Additionally, the fractional efficiencies of the cyclone at various particle sizes were calculated according to the size distribution curves obtained from Figs. 2–4. The results are shown in Figs. 5–7. The fractional efficiency curves are not seen to be "S" shape that many researchers assumed to be. The total collection efficiency of the cyclone was also calculated by the fractional efficiency multiplied by the mass fraction of the particles and summed them up. The results are the same as those data listed in Table 1.

The close agreement between the measured total efficiency by particle counter–sizer–velocimeter and the weighing method confirms the total efficiency of the cyclone as determined by the optical technique.

4. Conclusions

This paper presents a new method for measuring the total efficiency of a cyclone by the use of a particle counter–sizer–velocimeter. The results indicate that the total collection efficiency of cyclone could be calculated by integrating the size distribution curves for the gas streams entering and leaving the cyclone and these results are confirmed by the traditional weighing method. Thus, the technique presented here may be useful in reducing the error caused by the traditional measuring instrument.

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