EXPERIMENTAL INVESTIGATION OF COLLECTION EFFICIENCY IN GAS - SOLIDS CYCLONE SEPARATORS

Abdallah S. Alkaud, Sobeih M. A. Selim* and Taib El Bakoush

Mech. Eng Dept Faculty of Engineering Al-Margib University, Al-Khoms Libya
*Mech. Power Eng Dept Faculty of Engineering Menoufiya University Shibin El-Kom, Egypt

الملخص

من خلال العديد من الدراسات على الفرازات الاعصارية والخاصة بفصل العوالق الصلبة من الغازات والمجودة في الدوريات تبين أنه زيادة كفاءة الفرازات الاعصارية يعتمد على التجارب المعملية أكثر من النماذج الرياضية. تعتبر كفاءة التجميع احد خصائص الاداء الهامة للفرازات الاعصارية. هذه الدراسة المعملية تدرس تأثير المتغيرات ذات التأثير المباشر على أداء الفرازة وبخاصة على كفاءة التجميع. هذه المتغيرات هي حجم الفرازة، خواص العوالق الصلبة وسرعة دخول الهواء. تبيّن الدراسة أن كفاءة التجميع تزيد بزيادة حجم الجزيئات وسرعة دخول الهواء وأقصي كفاءة كانت تحدث عند قطر 10 سم.

ABSTRACT

From a number of studies in gas-solids cyclone separators which have been reported in literature, it is shown that, developing more efficient cyclone separators have been essentially based on experiments rather than mathematical models. One of the main performance characteristics of the gas-solids cyclone separators is the collection efficiency. The principle object of this work is to study experimentally the effect of some of the major controlling parameters that have direct effect on the cyclone performance, essentially on the gas-solids cyclone separators collection efficiency. These parameters are the cyclone size, properties of solid phase and air inlet velocity. The results obtained showed that collection efficiency increases with increasing the particle size, inlet velocity and the maximum efficiency was occur at 10 cm cyclone diameter.

KEYWORDS: Cyclone separator; Collection efficiency; Gas-solid flow; Particle size; Inlet velocity.

INTRODUCTION

Cyclones are being used extensively in industrial to separate solids from gasses due to their advantages. The cyclone performance plays a key role in the reliability of the separation of the solids from gasses. The advantages of the cyclones are based on the low manufacturing and maintenance costs, effective controllability, and ability to operate at high temperatures and pressures. Therefore, many researches have directed to study the cyclone performance. Researches have attempted to reach the optimum design conditions and to determine the operation conditions for cyclones, which increase its efficiency. A number of studies have been reported in literature, predicting cyclone efficiency. For example, De, et al. [1] investigated experimentally the collection efficiency of simple plate type impact separators. Effects of air velocity, solid loading and included angle of impact blades on the collection efficiency were discussed. Their experimental results demonstrated that this gas–solid separator had impact structure, satisfactory collection efficiency especially at low air velocity. Moreover, Avci and Karagoz [2] developed a mathematical model for calculation of fractional efficiencies in cyclone separator based on the assumption that the mixture of fluid and particles is homogeneous. The collection efficiency curves predicted by the model showed a good agreement with experiments over a wide range of inlet velocities for different types of cyclone. Furthermore, Shin, et al. [3] conducted numerical and experimental studies for the development of high efficiency cyclone dust separator applicable to extreme environments of high pressure of 6 bars and temperature up to 400^{o} C. The experiments showed that the increase of pressure and temperature generally affect significantly the collection efficiency of fine particle less than 10μm. However, the effects of pressure and temperature appeared to be opposite to each other, i.e., the increase of pressure causes an increase in the collection efficiency, while the increase of the temperature results in the decrease of the efficiency over a certain range of flow rate. More recently, El-Batsh, et al. [4] investigated the flow filed and particle separation process in cyclones using numerical calculations as well as experimental measurements. The collection efficiencies, determined numerically for the tested cyclones, showed a reasonable agreement with those published in the literature.

An attempt here is made to study experimentally the effects of cyclone size, inlet velocity and particle size on the collection efficiency in gas-solids cyclone separators.

EXPERIMENTAL WORK

Experimental Apparatus and Instrumentation

In the present study, the experimental data were obtained by conducting experiments using a specially designed and fabricated experimental facility. The schematic view of the test rig is shown in Figure (1). The air supplied by two blowers, providing a volume of flow in the range of 14.56 – 114.46 m^3/hr, is drawn and measured using a calibrated orifice meter (2). This volume of air is mixed with the injected particles in the rectangular cross section inlet of the cyclone, and discharged tangentially from the cyclone under study (3). The deposited particles from the cyclone are collected in the hopper part (13). The air-particles mixture is adjusted with different controlling valves (9) and (16). The solid feeding system (4) consists of solids supply reservoir and controlling valve. The solids supply reservoir has cylindrical shape with a conical end. The feeding control valve was calibrated with a dial scale to give the desired mass flow rate of feeding solids. Four different sizes of cyclones were used and three of them fabricated from metal sheet, i.e., the cyclone diameters 10, 14, and 16 cm. The remaining one was fabricated from Perspex with 7.5 cm diameter. Figure (2) shows the dimension ratios for Stairmand cyclone design used in this study.

Test Conditions

The experiments were carried out at almost equal room temperature and atmospheric pressure in order to obtain accurate results. The detailed operating conditions are summarized in Table (1).

Table (1) Test conditions employed in this study

Variables	Specifications
Dust loading (g_{solids}/kg_{gas})	50 , 80 ,100 ,125 , 200 , 275 , 350
Particle size (μm)	70 , 125 , 360 , 510
Inlet velocity (m/s)	from 5.3 to 16.8

Cyclone Performance Parameters
Collection efficiency" overall collection efficiency",

$\eta_o = M_c/M_i = (M_i - M_e)/M_i = 1 - M_e/M_i$,
Where:
Mc = mass of solids collected by cyclone (g)
Mi = input solids mass to cyclone (g)
Me = solids loss mass due to entrainment (g)
Uncertainty range 0.028 minimum and 0.085 maximum.

EXPERIMENTAL RESULTS AND DISCUSSION

Effect of Cyclone Size on the Collection Efficiency

A study of the effect of cyclone size on the fractional collection efficiency is very important from economical point of view. In order to investigate the effect of the cyclone size on the collection efficiency experimental tests were conducted to measure the variation of the collection efficiency with cyclone diameter. The same procedure was repeated for various particle sizes, inlet velocities, and dust loading conditions. Typical results for a particle size of 70 µm are shown in Figures (3) to (5). From the figures one can clearly see the dependence of the efficiency on the cyclone size. The general trend of the curves is that the fractional collection efficiency increases with increasing cyclone size and reaches a maximum at a diameter of about 10 cm. It then decreases with increasing cyclone size. Moreover, an interesting observation may be worthwhile mentioning. The peak in fractional collection efficiency always occurs at 10 cm diameter of the cyclone, irrespective of the operating conditions, i.e., dust loading, particle size and inlet velocity. This indicates that the collection efficiency is independent of the operation conditions. The observation also reported by [4]. The reduction of collection efficiency with decreasing the size from 10 cm to 7.5 cm may be attributed to that the effect of the distance between the dust inlet and air outlets. When this distance is small as in small cyclones, the duct inlet and air outlets are situated near to each other. This implies that there is a better chance for dust to move with an inner vortex and leaves with discharged air. On the other hand, in a larger cyclone the dust inlet and air outlets are slightly farther apart. This allows the restrained dust to move back into the outer vortex and be collected again before leaving the cyclone.
The present results suggest that better efficiency can be obtained when cyclones with smaller diameter are used. However, it must be noted that this type of cyclone cloud present operational problems.

Effect of Particle Size on the Collection Efficiency

To evaluate the effect of the particle size on the collection efficiency several experiments were carried out. For a given diameter of the cyclone the collection efficiency was measured as a function particle size for various inlet velocities, as specified in figures 6 to 9 which show plots of the results obtained, i.e., graphs of the collection efficiency versus particle size. From these it can be seen that the collection efficiency increases as the particle size increases and approach almost 100% for particle sizes greater than 225 µm. The increase of the efficiency with the particle size is due to the fact that as the particles get larger the gravitational force becomes more and more dominant in comparison with other forces (i.e. the drag and centrifugal forces). The results agree with those of [3] and [4]. These findings may be explained by the following mechanisms. It is well known that for smaller particles sizes, the turbulence intensity within the cyclone affects the separation efficiency. An increase in turbulence intensity decreases the residence time, which in turn causes the separation efficiency to decrease. However, for larger particle sizes the intensity of turbulence has almost no effect on the residence time because the particles have relatively bigger inertias. In addition, the thickness of boundary layer has an influence on the collection efficiency and as published in the literature, the efficiency increases as the boundary layer thickness decreases [10]. Moreover, small size particles get dispersed in the cyclone as consequence of the imposed inlet conditions. Because of the dispersion they are likely to be caught by the flow in the cone of the cyclone and exit through the vortex finder. In the inlet area the smaller size particles are dispersed as a result of the imposed inlet conditions. This implies that they do not attach immediately to the wall once they enter the body of the cyclone as the bigger particles do. Therefore, they will have less chance to enter the weak shortcut flow, which directly guides the air from the annulus in between vortex finder and the cyclone wall into the exit pipe and hence get exhausted.

Effect of Inlet Velocity on the Collection Efficiency

The effect of the inlet velocity on the collection efficiency was also considered in the study, Figures (10) to (13). Generally, these figures show that the collection efficiency increases with increasing the inlet velocity. The results agree with those reported in the literatures [1], [4] and [5]. The collection efficiency, of course, depends on the flow regime. This is affected by the flow parameters such as inlet velocity, temperature, viscosity and surface roughness. With high velocities, the flow is generally fully turbulent and the effects of flow parameters decrease with Reynolds number. On the other hand, at low velocities, the flow is laminar and the effects of flow parameters increase up to a certain point and then start to decrease beyond that. The interesting results have been obtained for small cyclones, Figures (10) and (11) in which the collection efficiency was found to be higher than that in the case of big cyclones. This is expected since transitional flow regime is most likely to be the dominant one at low velocities [2].

CONCLUSION

Based on the results obtained from the experimental investigation, the following conclusions can be drawn:

- The collection efficiency of the cyclone increased with increasing cyclone size, reached a maximum and then decreased with increasing cyclone size. The peak of the collection efficiency occurred at 10 cm cyclone size and its position was found to be independent of other parameters (i.e. particle size, inlet velocity and solid loading).
- The collection efficiency increases with increasing particle size and approached 100 % for particle sizes bigger than 225μm.
- The collection efficiency increases with increasing the inlet velocity.

Finally, as a general conclusion the results obtained are very encouraging when compared with those reported (both theoretical and experimental) in the literature. In fact this has given us the motivation to extend the study to consider the effects of same parameters on the pressure drop and solid loading.

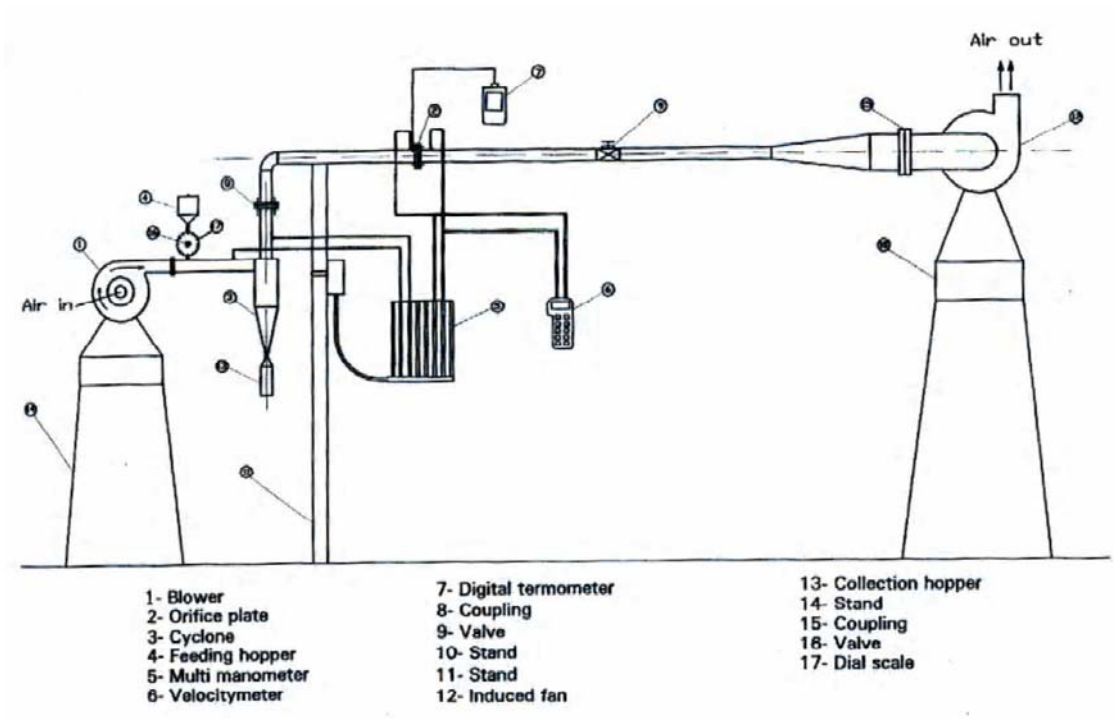

Figure 1: Experimental test rig layout

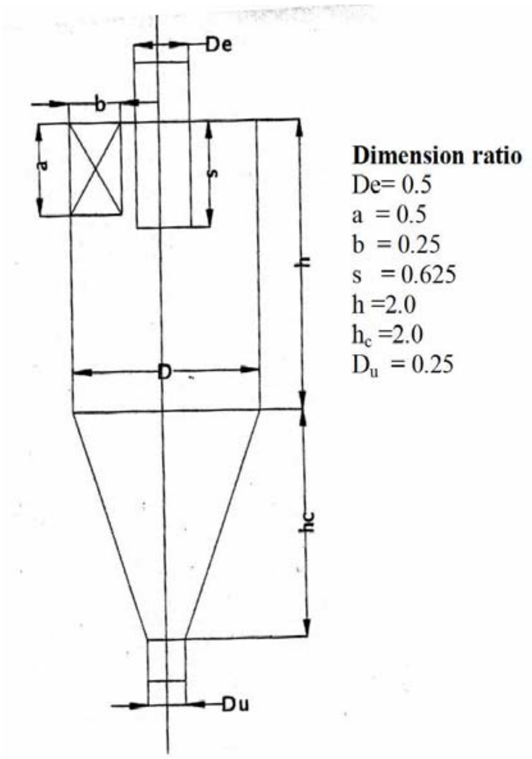

Figure 2: Shape and principal dimensions of the Cyclone

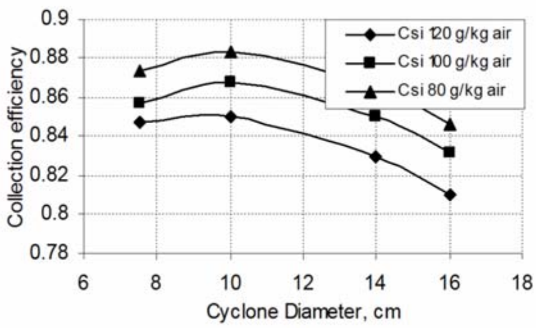

Figure 3: Variation of collection efficiency with cyclone diameter for particle size (70 µm) with different solid loading at constant inlet velocities of 9 m/s

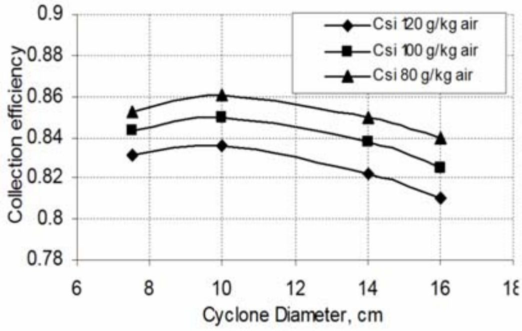

Figure 4: Variation of collection efficiency with cyclone diameter for particle size (70 µm) with different solid loading at constant inlet velocities of 8 m/s

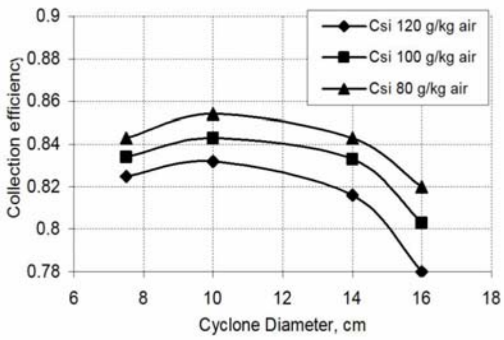

Figure 5: Variation of collection efficiency with cyclone diameter for particle size (70 µm) with different solid loading at constant inlet velocities of 7 m/s

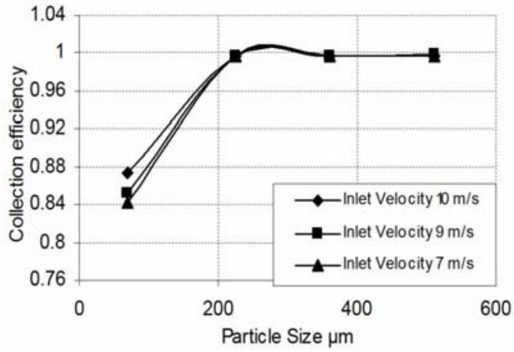

Figure 6: Variation of collection efficiency with particle size for cyclone diameter (7.5 cm) with different inlet velocities

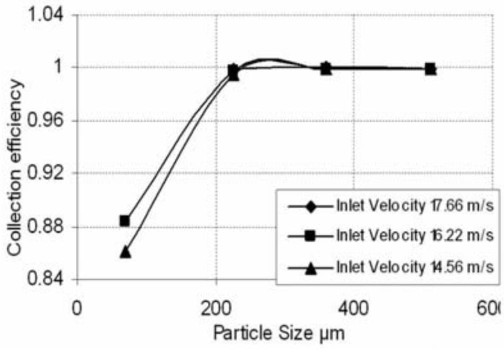

Figure 7: Variation of collection efficiency with particle size for cyclone diameter (10 cm) with different inlet velocities

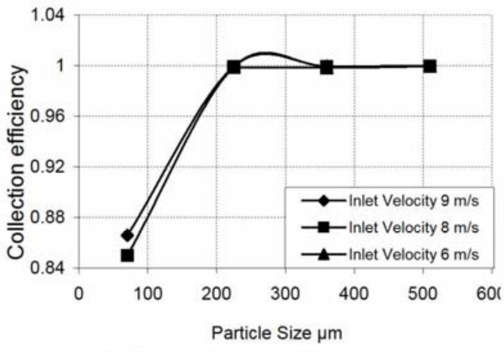

Figure 8: Variation of collection efficiency with particle size for cyclone diameter (14 cm) with different inlet velocities

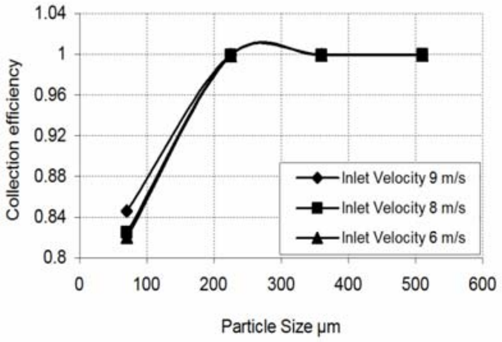

Figure 9: Variation of collection efficiency with particle size for cyclone diameter (16 cm) with different inlet velocities

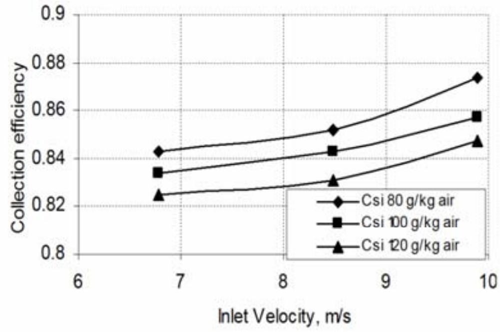

Figure 10: Variation of collection efficiency with inlet velocity for cyclone diameter (7.5 cm) and particle size (70 µm) with different solid loading

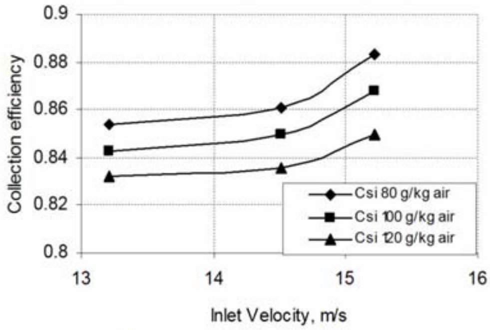

Figure 11: Variation of collection efficiency with inlet velocity for cyclone diameter (10 cm) and particle size (70 µm) with different solid loading

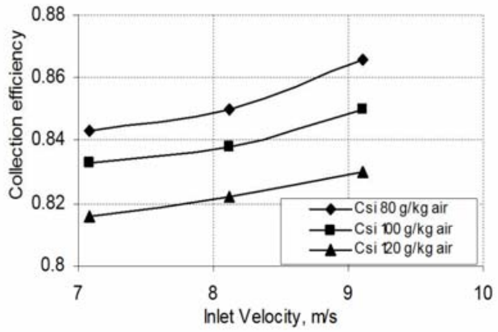

Figure 12: Variation of collection efficiency with inlet velocity for cyclone diameter(14 cm) and particle size (70 µm) with different solid loading

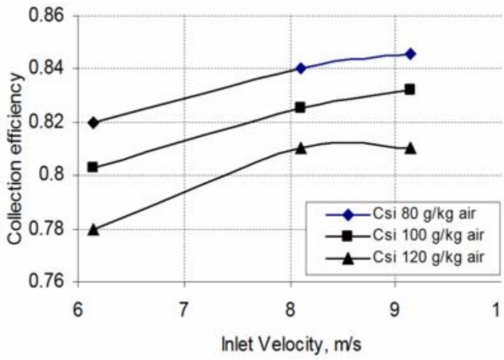

Figure 13: Variation of collection efficiency with inlet velocity for cyclone diameter (16 cm) and particle size (70 µm) with different solid loading

REFERENCES

[1] De. S, Lal. A. K and Nag. P. K., "An Experimental Investigation on Pressure Drop and Collection Efficiency of Simple Plate – Type Impact Separator", Powder Technology 106, PP.192-198, 1999.

[2] Avci. A and Karagoz, I., "Effects of Flow and Geometrical Parameters on Collection Efficiency in Cyclone Separators", Journal of Aerosol Science, 34, PP. 937-955, 2003

[3] Shin. M. S, kim. H. S, Jang. D.S, Chung. J .D and Bohnet, M., "A numerical and Experimental Study on a High Efficiency Cyclone Dust Separator for High Temperature and Pressurized Environments", Applied Thermal Engineering 25, PP. 1821-1835, 2005.

[4] EL – Batsh. H, Abd – Hamied. A, A and Hamed M. H., "Numerical and Experimental Study of the Flow Field and Particle Separation Through Cyclone Separator", Energy: Production, Distribution, and Conservation, Vol. 2, PP. 963-972, 2006.

[5] Che. J, Lu. X, Liu. H and Yang. C., "Effect of the Bottom Contracted and Edge – Sloped Vent-Pipe on the Cyclone Separator Performance", Chemical Engineering Journal, PP.1– 6, 2006.

[6] Gil. A, Luis. M and Cortes. C, "Effect of the Solid Loading on the Performance of a Cyclone with Bottom Pneumatic Extraction of Solids", Zaragoza 3.50015, PP. 1-24, 1999

[7] Fassani. F. L and Goldstein. L, "A Study of the Effect of High Inlet Solids Loading on a Cyclone Separator Pressure Drop and Collection Efficiency", Powder Technology 107, PP., 60- 65, 2000

[8] Correa. L. G, Graminho. D. R, Silva. M. A and Nebra, S. A., "The cyclonic Dryer a Numerical and Experimental Analysis of the Influence of Geometry on Average Particle Residence Time", Brazilian Journal of Chemical Engineering, Vol. 21, No 1, 2004

[9] Derksen. J. J, Sundaresan. S and Akker. H. E. A., "Simulation of Mass – Loading Effects in Gas – Solid Cyclone Separator ", Power Technology163, PP. 59 – 68, 2006

[10] Xiaodong. L, Jianhun. Y, Yuchun. C, Mingjiang. N, Kefa. C., "Numerical simulation of the effects of turbulence intensity and boundary layer on separation efficiency in a cyclone separator ", Chemical Engineering Journal, PP. 235 – 240, 2003