ISSN: 2413-5267

Effect of The Particle Solid Loading on The Performance of The Cyclone Separators

Abdallal S. Algoud*

Marine Mechanical Engineering, Faculty of Marine Resources, Alasmarya Islamic University, Zliten City, Libya

*Corresponding author: abdallagoud@gmail.com

تأثير معدل تحميل الجسيمات الصلبة على أداء الفرازات الاعصارية

عبدالله سالم القعود

قسم هندسة الميكانيكا البحرية، كلية الموارد البحرية، الجامعة الأسمرية الإسلامية، زليتن، ليبيا

Abstract

Extensive experimental tests were conducted to study the effect of solid loading on the collection efficiency and pressure drop across gas – solid cyclone separators. The experiments were conducted at four different cyclone sizes 0f 7.5,10,14 and 16 *cm*, various particle sizes ranged from 70 to 510 μm and various dust loading varied from 50 to 350 g_{solids}/kg_{air}. The results indicated that the collection efficiency decreased with increasing the solid loading. The pressure drop across the cyclone decreases with increasing the solid loading for a 10 *cm* size cyclone and no considerable variation is noted for cyclone sizes larger than 10cm. Also, the study reported visual observation of cyclone flow patterns during separation.

Keywords: *Cyclone separator; Solid loading; Collection efficiency.*

الملخص

العيب الدراسة المعملية تبيّن تأثير معدل تحميل العوائق الصلبة على كفاءة التجميع وهبوط الضغط خلال الفرازات الاعصارية والخاصة بتجميع العوائق الصلبة من تيار الغاز. اجريت التجارب على أربع أحجام مختلفة للفرازة وهي 7.5, 10, 14 ,16 *cm*مع أحجام مختلفة للذرات تتراوح ما بين 70 μm الى 510 μm ، ونسب مختلفة للعوائق الصلبة تتراوح مابين 50 الى 350 g_{solid} /kg_{air}. الدراسة المعملية تبيّن تأثير معدل تحميل العوائق الصلبة على كفاءة التجميع وهبوط الضغط خلال الفرازات الاعصارية والخاصة بتجميع العوائق الصلبة من تيار الغاز. اجريت التجارب على أربع أحجام مختلفة للفرازة وهي 7.5, 10, 14, 16 *cm* مع أحجام مختلفة للذرات تتراوح ما بين 70 μm الى 510 μm ، ونسب مختلفة للعوائق الصلبة تتراوح مابين 50 الى 350 g_{solid} /kg_{air}.بيّنت النتائج أن كفاءة التجميع تقل بزيادة نسبة العوائق الصلبة ،هبوط الضغط خلال الفرازة يقل بزيادة نسبة العوائق الصلبة لحجم الفرازة 10 *cm* ولا يظهر تأثير لحجم الفرازة الأكبر من ذلك. كما تظهر الدراسة صورة مرئية لنمط السريان خلال انفصاله.

الكلمات الدالة: الفرازات الاعصارية، تحميل صلب، كفاءة التجميع.

1. Introduction

Cyclones are preferred to other gas–solid separators for a number of industrial applications, such as in the petro-chemical and process industries to separate dust from gas streams and for product recovery. But it can also be used as a preheated in cement industry, as reactor or a dryer, and also for the hot gas cleaning plays a key role in the development of new power generation. In special for pressurized fluidized bed power plants, the removal of solid particles from the combustion flue gasses is essential to strengthen the technology. Cyclone separator systems offer nowadays the only solution commercially available for removing particles from high temperature, high pressure installations. An important application in petroleum industry, is the recovery of catalytic in fluid catalytic cracking process, it is cheap and simple equipment that can easily remove particles bigger than 5 μm from a gaseous phase. Cyclones operate under very high solid loadings. The application is recommended for being capable to ensure steady state operation, recycling the catalyst back to the process and preventing its emission to the atmosphere. From an engineering point of view, the most important parameters in cyclone operation are pressure drop and collection efficiency, these two parameters are the direct outcome of the flow developed inside the device. Both these performance parameters are affected by the solid loading. A number of studies have been reported in literature, predicting the effect of solid loading on the collection efficiency and pressure drop through the cyclone. Fassani and Goldstein (2000) studied the effect of high inlet solid loadings on the cyclone pressure drop and collection efficiency. The particles used were FCC catalyst. An extended range of concentrations, up to 20 *kg* of solids/*kg* of gas was used. The average entrance velocities were 7, 18 and 27 *m/sec*. The experiments showed that, in the range of concentration tested, the cyclone pressure drop for the solids laden air flow was about 47% of that for clean air. A trend of increasing collection efficiency with concentration was observed, up to 12 *kg* of solids/*kg* of gas, above which, the efficiency decreased. At test conditions, the collection efficiency was higher for the entrance velocity of 18 *m/sec* than for 27 *m/sec*. Gil *et al.* (2002) presented a detailed flow analysis inside cyclone dip legs equipped with bottom gas extraction. The results indicated that, increasing solid loading, an upward movement of the vortex end is detected from wall pressure measurements. The solid loading causes an important decrease of the vortex energy and consequently a weakening of the dip leg tangential velocity.

Yuu *et al*. (1978) noted that the presence of particles in gas stream reduced the cyclone pressure drop by as much as 30%, even with extremely low solid loadings, such as 0.1633×10^{-3} *kg* of solids/*kg* of gas. In the range from 1.224×10^{-3} to 41×10^{-3} *kg* of solids/*kg* of gas, the pressure drop was found to be nearly independent of the solid loading, then decreasing thereafter. With loadings from 4.0×10^{-3} to 106×10^{-3} *kg* of solids/*kg* of gas. Also, Hoffmannc *et al.* (1992) noted an increase of the collection efficiency. De *et al.* (1999) investigated experimentally the pressure drop and collection efficiency of simple plate type impact separators. Effects of air velocity, solid loading and inclined angle of impact blades on these two performance parameters were discussed. Their experimental results demonstrated that this gas–solid separator had impact structure, low pressure drop and satisfactory collection efficiency especially at low air velocity. Avci and Karagoz (2001) performed theoretical analysis of pressure losses in cyclone separators under the consideration of geometrical and flow parameters including inlet geometry, surface roughness, velocity and particles concentration. The results obtained are compared with experimental values for different type cyclones. It was found that the proposed equation could be used to predict the pressure losses easily and it is worthy especially industrial applications. Gil *et al.* (1999) introduced results about the effects of solid loading on the performance of a cyclone with bottom ash extraction of solids. Experiments conducted at inlet gas velocities ranged from 9 to 14 *m/sec*, inlet solid loadings range from 30 to 230 g_{solid}/kg_{gas}, and bottom gas extraction percentages from 0.3–1.5 %. The results showed that, for the vortex penetration in dip leg effect not accounted for in published correlations, causes lower pressure drop values and higher collection efficiencies than predicted. For the cyclone design, a new correlation of pressure drop, including the influence of the solid loading is proposed. Also based on the evolution of the pressure drop resistance coefficient, a new method for detecting cyclone fouling, not previously addressed has been presented. In relation with collection efficiency, enhanced separation efficiency has found, especially important for particle sizes below 10 μm, which reveals agglomeration effects. Cortes and Gil (2007) undertake a review of the most relevant semi-empirical models proposed for the time averaged flow in cyclones, as found in the literature. Predicted flow field, cyclone nature length, effect of solid loading on collection efficiency and pressure drop and compared with experimental data. From literature, there is a difficulty of theoretical treatment of dust collection phenomena in cyclone; this is due to lack of experimental results to verification of theoretical treatment of cyclone collector performance. Therefore, experimental in the performance of gas–solids cyclone separators for industrial applications operating conditions is required to establish these effects. To achieve these requirements, the presented work, include, effect of dust loading on the collection efficiency and pressure drop in gas–solids cyclone separators.

2. Experimental Work

2.1. 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 Fig.1.The air supplied by two blowers providing a volume flow in the range of 14.5 –114.5 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 to the tested cyclone (3). The pressure drop across the cyclone and the orifice is measured using a multi-tube manometer connected to pressure taps of 1 *mm* inner diameter which are drilled normal to the wall. 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 the solids supply reservoir and controlling valve. The solids supply has cylindrical shape with a conical end. The feeding control valve was calibrated with a dial scale to give a desired mass flow rate of feeding solids. Four sizes of cyclones as used, three of them were fabricated from metal sheet with different cyclone diameters 10, 14, 16 *cm* and the remaining one was fabricated from

Perspex with 7.5 *cm* diameter to permit visual observation of the flow inside the cyclone. Figure (2) shows the dimension ratios for Stairmand cyclone design used in this study.

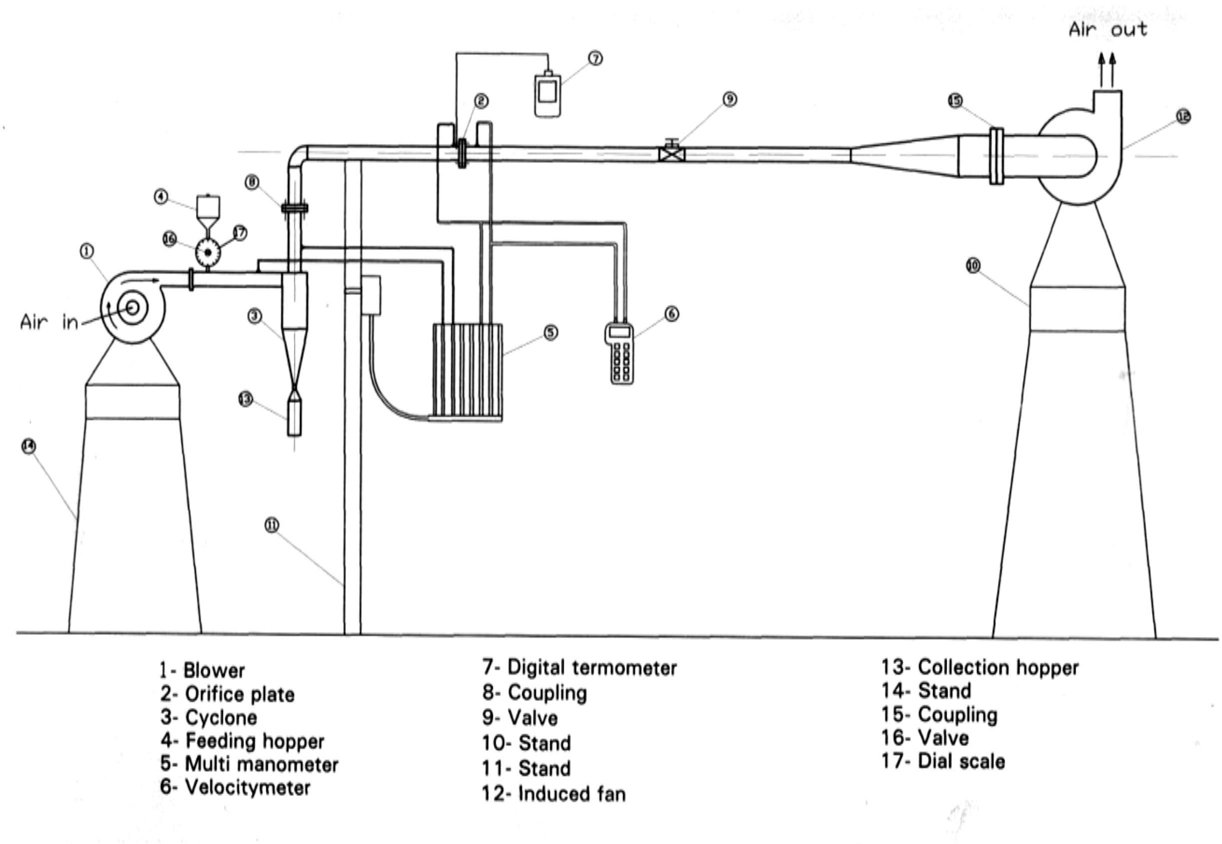
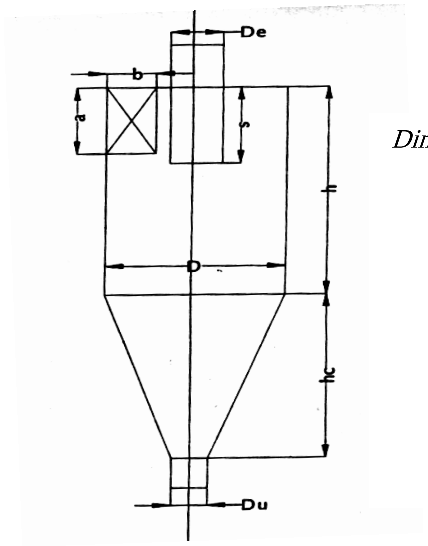


Figure 1. Experimental test rig layout.



Dimension ratio

De = 0.5

a = 0.5

b = 0.25

s = 0.625

h = 2.0

Figure 2. Shape and principal dimensions of the Cyclone.

ISSN: 2413-5267

2.2. Cyclone Performance Parameters

Collection efficiency "overall collection efficiency",

$$\eta_o = M_c/M_i = (M_i - M_e)/M_i = 1 - M_e/M_i \quad \text{(1)}$$

Uncertainty range 0.028 minimum and 0.085 maximum.

Pressure drop,

$$\Delta P = P_{si} - P_{so} \quad \text{(2)}$$

Uncertainty range 0.91 minimum and 3.36 maximum.

Inlet velocity (*m/sec*),

$$V_i = Q/A \quad \text{(3)}$$

Uncertainty range 1.26 minimum and 4.7 maximum.

Solid loading (g_{solids}/kg_{air}),

$$C_{si} = M_i/M_a \quad \text{(4)}$$

Uncertainty range 0.026 minimum and 1.3 maximum.

3. Results and Discussion

3.1. Effect of Dust loading on the Collection Efficiency

A study of the effect of dust loading on the collection efficiency was conducted at various cyclone sizes and different operating conditions. The tests were conducted over a wide range of dust loading of 50–350 g_{dust}/kg_{air}. Typical results are shown in Figures (3-6).

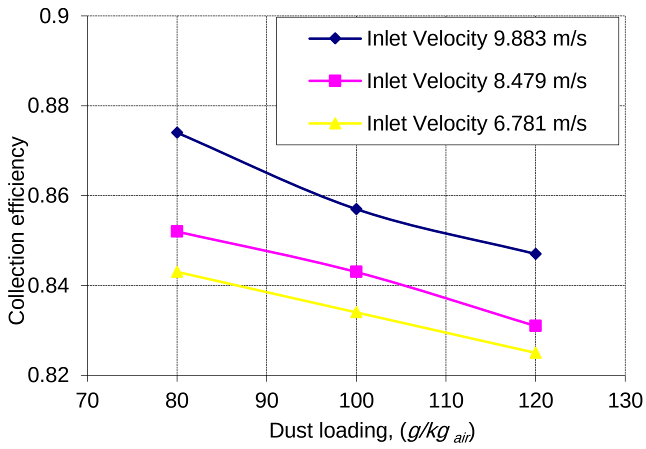


Figure 3. Variation of collection efficiency with dust loading for particle size (70 *μm*) and cyclone diameter (7.5 *cm*) with different inlet velocities

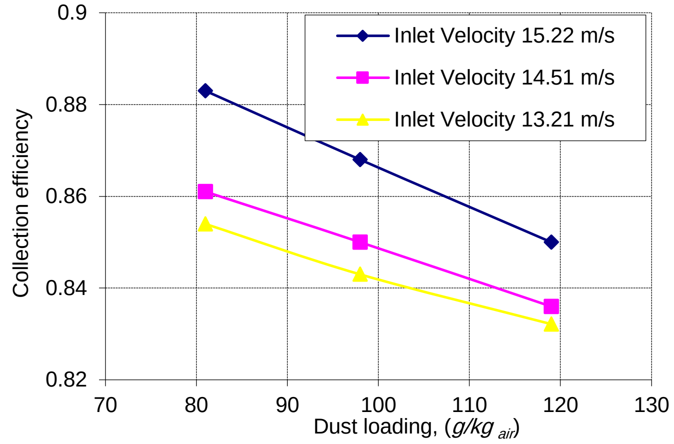


Figure 4. Variation of collection efficiency with dust loading for particle size (70 μm) and cyclone diameter (10 *cm*) with different inlet velocities

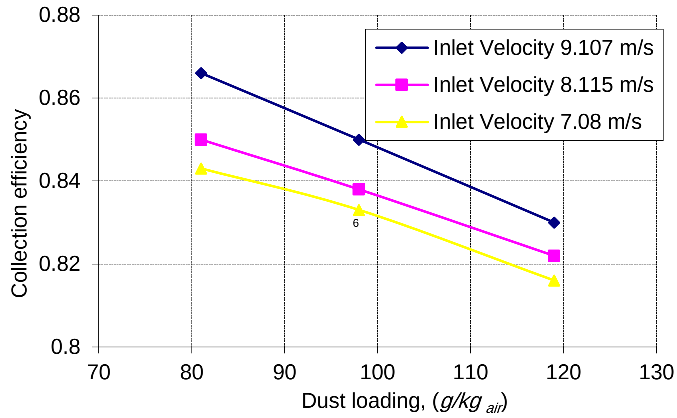


Figure 5. Variation of collection efficiency with dust loading for particle size (70 μm) and cyclone diameter (14 *cm*) with different inlet velocities.

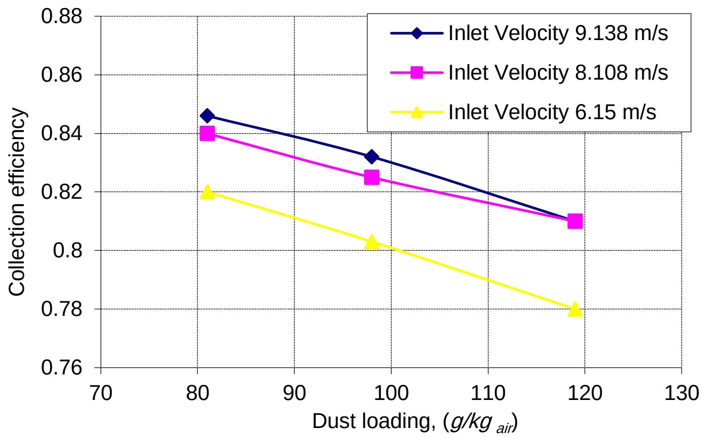


Figure 6. Variation of collection efficiency with dust loading for particle size (70 μm) and cyclone diameter (16 *cm*) with different inlet velocities.

Generally, these Figures show that the fractional collection efficiency depends strongly on the dust loading and decreases with increasing it. The most probably reason is that the particle inertia would tend to equalize the gas momentum of adjacent layers, as they settled out normal to the gas flow direction. Increasing dust loading will cause a reduction in the tangential velocity component and a decrease in the vortex intensity. The separation process involves interplay between centrifugal forces induced by swirl, and dissipation due to turbulence. In this study, both swirl and turbulence are affected by the presence of particles: the turbulent fluctuations strongly reduce, even at the relatively low solids loadings that we have considered so far. The swirl in the cyclone gets less intense, especially in its lower part. Both features have consequences for the way the particles distribute inside the cyclone. Visual observation during tests showed an increase particle concentration levels close to the wall for low mass – loading caused by reduced turbulence. This effect was most pronounced in the lower part of the separation section of the cyclone. At higher mass–loading the effect of reduced swirl may become visible at Perspex cyclone (7.5 *cm*) as shown in photograph Figure (7).

Figure.7 Photograph of spiral bands of particles through the Perspex cyclone

However, at low mass–loading case particles tend to be less concentrated near the wall. These changes in the way the particles are distributed will have consequences for the collection efficiency. As both turbulence attenuation and weakening of the swirl occur with increased mass loading of particles, one can readily envision the possibility of complex dependence of collection efficiency on particle mass loading. For example, the collection efficiency would increase monotonically if the beneficial effects of turbulence damping always outweighed the adverse effects of loss of swirl. In contrast, if the loss of swirl was a bigger factor at all times, the efficiency would decrease monotonically with increasing loading. An intermediate possibility where the collection efficiency first increases and then decreases at large loading level is also possible. Linden (1949) observed a small increase of collection efficiency with increasing loading. Stern *et al.* (1955) correlated data from several services and reported an increase in collection efficiency with solid loading in the range of 1.868×10^{-3} to 186.8×10^{-3} *kg* $_{solids}$*/kg*$_{air}$. Similar trend was reported by Mori (2002). Nevertheless, no effect was observed by Seheid and Massarani (1994) for loading varying 0.3163×10^{-3} to 41×10^{-3} *kg* $_{solid}$*/kg*$_{air}$. Also no variation in collecting efficiency with dust loading was reported by Hoffmannc *et al*. (1992). Tuzla and Chen (1997) reported a reduction in collection efficiency with increasing solid loading. These contradictory in results reflect the complexity of flow processes within the cyclone and that the mechanism of particle separation is quite difficult.

3.2. Effect of Dust Loading on the Pressure Drop

The effect of solid loading on the pressure drop at various particle sizes and constant mean inlet velocity of 10.3 *m/sec* for all types of cyclones used is shown in Figures (8-11).

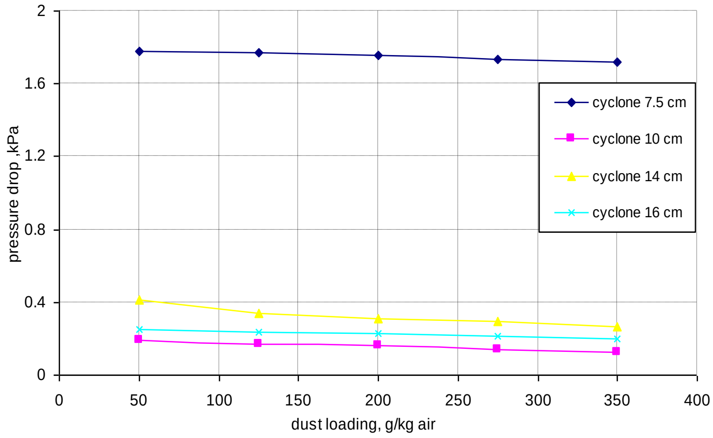


Figure 8. Variation of pressure drop with dust loading for particle size (70 μm) with different cyclone size at constant inlet velocity of 10.3 *m/sec*.

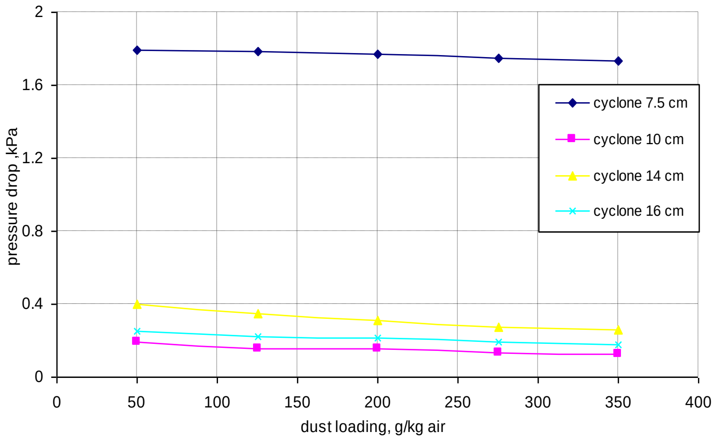


Figure 9. Variation of pressure drop with dust loading for particle size (225 μm) with different cyclone size at constant inlet velocity of 10.3 *m/sec*.

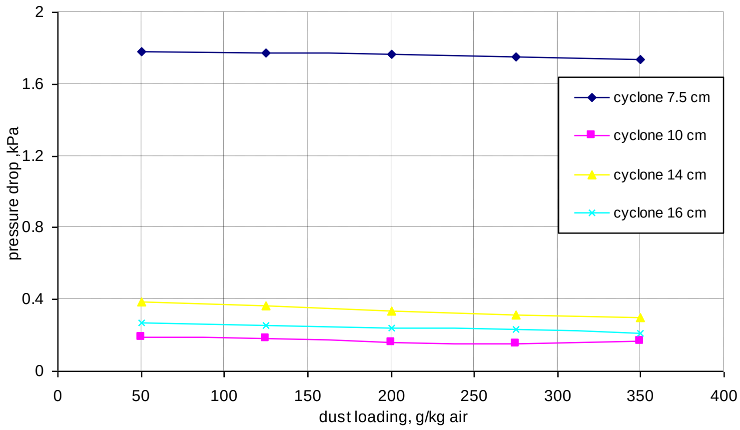


Figure 10. Variation of pressure drop with dust loading for particle size (360 μm) with different cyclone size at constant inlet velocity of 10.3 *m/sec*.

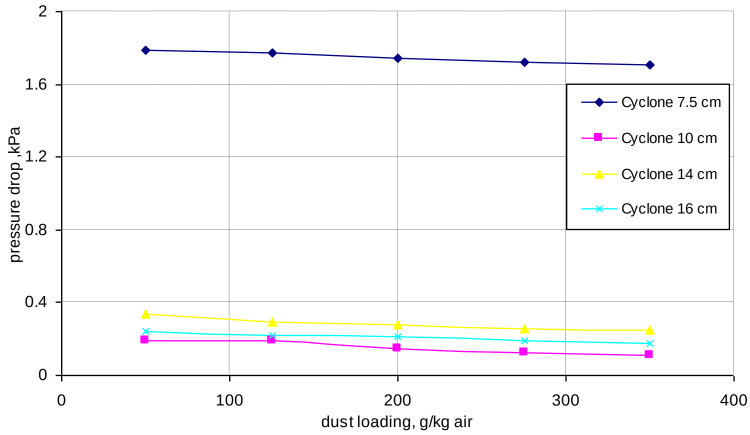


Figure 11. Variation of pressure drop with dust loading for particle size (510 μm) with different cyclone size at constant inlet velocity of 10.3 *m/sec*.

These Figures show that the pressure drop in cyclone decreases with increase the solid loading for 10 cm cyclone for all particle sizes. However, this trend is not apparent for the 7.5, 14 and 16 *cm*. sizes cyclone and there is no considerable variation of pressure drop for these sizes with particle sizes. This may be attributed to, as the dust loading increases, the tangential velocity and the vortex length decreases. The vortex length is the axial distance from the vortex finder at which the outer vortex weakens and changes its direction from downward flow to upward flow. The pressure loss is mainly determined by events occurring above. Moreover, the vortex end can be itself a dynamic and complicated phenomenon. In addition, through an increase of the dust loading will lead to a greater expansion loss at cyclone inlet, the swirling loss decreases due to a weaker swirling flow. Consequently, the combination of these two effects cause considerable pressure drop. The pressure drop trend for 10 *cm* cyclone is agreed with Fassani and Goldstein (2000) and De *et al*. (1999) results. However, Yuu *et al.* (1978) found that the pressure drop was nearly independent of solid loading. Hoffmannc *et al.*

ISSN: 2413-5267

(1992) observed an opposite trend, *i.e.*, an increase in pressure drop with increasing solid loading, possibly because their cyclones were tested as part of a circulating fluidized bed system.

3.3. Visual Observation of the Separation Process

There is not sufficient experimental data to elucidate definitely the separation process involved, but some considerations can be already being made for a preliminary discussion. This relies on a visual observation and video camera recordings of the separation zone, shot through the Perspex cyclone wall. Visual observation of cyclone flow patterns showed that the flow pattern consists of an outer vortex spiraling downward along the cyclone walls. This vortex is created when the gas stream enters the cyclone tangentially. The number of revolutions (spirals) that the gas stream make in the cyclone is about six and the spiral bands of particles attached to the cyclone wall seemed to have the same width for solid loading up to 125 g_{solds}/kg_{air} as shown in Figure (12) and that the number of particles increased in the radial direction. At this loading, the bands suddenly widened and covered the entire cylinder wall.

Figure 12. Photograph of spiral bands of particles through the Perspex cyclone.

Visual observation showed that the spiral bands of collected particles on the cyclone wall were wider for the large size particles, which were present outer the entire cyclone wall surface. As the gas spiral reaches the gas outlet duct, the gas spins upward through the inner vortex or central cone rotates in the same direction as the outer vortex, the gas spins upward to the gas outlet. Collection takes place as particles in the outer vortex are thrown to the cyclones walls by centrifugal force. These particles slide down the walls of the cyclone to dust hopper. Particles drawn into the central cone are not collected. It was observed that the effect of adding particles to the stream of clean air entering a cyclone was always the same, namely, for a constant pressure drop across the cyclone the air flow rate increased rapidly at first, then more slowly, and finally leveled off.

ISSN: 2413-5267

4. Conclusion

Based on the results obtained from the present extensive experimental investigation, the following broad conclusion can be obtained:

- The collection efficiency decreased with increasing solid loading.
- The pressure drop decreased with increasing the solid loading for 10 *cm* cyclone. However, for 7.5, 14 and 16 *cm* cyclone sizes there was no considerable variation of pressure drop.
- Visual observation of cyclone flow patterns during separation showed that the spiral bands of collected particles on the cyclone wall were wider for the larger size particles.
- The number of revolutions that the gas stream makes in the cyclone was about six.

Nomenclature

A = flow area (m^2)

C = solid loading (g_{solids}/kg_{air})

M = mass (*g* or *kg*)

P = pressure (*kPa*)

Q = volumetric flow rate of air at inlet (m^3/sec)

V = average velocity of air (*m/sec*)

ΔP_{sd} = pressure drop for dusty air

ΔP_{sc} = pressure for clean air

Subscripts

a = air

i = inlet of the cyclone

o = outlet of the cyclone

s = static

References

Avci A., and Karagoz I. (2001). Theoretical Investigation of Pressure Losses in Cyclone Separators. *Int. Comm. Heat Mass Transfer*, 28(1): 107-117.

Cortes C., and Gil A. (2007). Modeling the gas and particle flow inside cyclone separators. *Progress in energy and combustion Science*, 33(5): 409-452

De S., Lal A. K., and Nag P.K. (1999). An Experimental Investigation on Pressure Drop and Collection Efficiency of Simple Plate–Type Impact Separator. *Powder Technology*, 106: 192-198.

ISSN: 2413-5267

Fassani F.L., and Goldstein L. (2000). A Study of the Effect of High Inlet Solids Loading on a Cyclone Separator Pressure Drop and Collection Efficiency. *Powder Technology*, 107: 60-65.

Gil A., Luis M., and Cortes C. (1999). Effect of the Solid Loading on the Performance of a Cyclone with Bottom Pneumatic Extraction of Solids. *Zaragoza*, 3.50015: 1-24.

Gil A., Cortes C., Romeo L.M., and Velilla J. (2002). Gas Particle Flow Inside Cyclone Dip legs with Pneumatic Extraction. *Powder Technology*, 128: 78-91.

Hoffmannc A.C., Van Santen A., Allen R.W.K., and Clift R. (1992). Effects of geometry and solid loading on the performance of gas cyclones. *Powder Technology*, *70*(1): 83-91.

Linden A.J. (1949). Investigations into Cyclone Dust Collectors. *Proc. Inst. Mech. Eng.*, 160: 233-251.

Mori M. (2002). Effect of Solid Loading a PFBC Cyclone. *Chem. Eng. Tech.*, 25(4): 407-415.

Seheid and Massarani (1994). Effect of Design and Operating Parameters on Cyclone Performance. In: Avidan A.A. Editor *Circulating Fluidized bed Technology*, New York, AICHE, pp.525-31.

Stern A.C., Kaplan K.J., and Bush P.D. (1955). *Cyclone Dust Collectors*, American Petroleum Institute, New York, USA.

Tuzla and Chen (1997). Experimental Research on the Pressure Drops PV-Type Cyclone Concentrations. In Proceedings of the *Symposium on Multiphase Flow*, pp. 332-4.

Yuu S., Jotaki Y., Tomita K., Yoshida K. (1978). The Reduction of Pressure Drop due to Dust Loading in a Conventional Cyclone. *Chem. Eng. Sci.*, 33: 1573-1580.