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EXPERIMENTAL INVESTIGATION OF COLLECTION EFFICIENCY IN GAS – SOLIDS CYCLONE SEPARATORS

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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 cyclone size, particle size and inlet velocity.

من خلال العديد من الدراسات على الفزازات الاعصارية والخاصة بفصل العوالق الصلبة من الغازات والمجـوده فى الدوريات تبين انه لزيادة كفاءة الفزازات الاعصارية يعتمد ذلك على التجارب المعمليه اكثـر مـن الدراسـة النظرية. تعتبر كفاءة التجميع احد خصائص الاداء الهامه للفزازات الاعصارية . هذه الراسـة المعمليـة تـدرس تاثيرالبارمترات ذات التأثير المباشر عل اداء الفزازة وبخاصةعلى كفاءة التجميع . هذة البـارمترات هـى حجـم الفزازة، خواص العوالق الصلبه و سرعة دخول الهواء. تبين الدراسة ان كفاءة التجميع تزيد بزيادة حجم الفزازه ، حجم الجزيئات و زيادة سرعة دخول الهواء.

Keywords: Cyclone separators – Gas- solids – Particle size.

1. 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 advantageous of the cyclones are based, among others, on the low manufacturing and maintenance costs simple, effective controllability, and ability to operate at high temperatures and pressures. Therefore, a lot of 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. Biffin, et al. [1] proposed a new type of cyclone separator (Cardiff cyclone) combines two stages in one compact unit to enhance collection efficiency. Their experimental results indicated that the Cardiff cyclone has a higher fractional efficiency than that for similar high efficiency Stairmand separator at particle size lower than 16μm. They concluded that the Cardiff cyclone separator offers many advantages over conventional cyclones – higher collection efficiencies and less tendency to chocking. De, et al. [2] 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 was discussed .Their experimental results demonstrated that this gas – solid separator had impact structure, satisfactory collection efficiency especially at low air velocity. Gil, et al. [3] 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 14m/s, inlet solid loadings range from 30 to 230 g_{solids}/kg_{gas}, and bottom gas extraction percentages from 0.3 – 1.5 %. In relation with collection efficiency, enhanced separation efficiency has found, especially important for particle sizes below 10μm, which reveals agglomeration effects. Fassani and Goldstein [4] studied the effect of high inlet solid loadings on cyclone separation efficiency. The particles used were FCC catalyst. Their experiments were conducted at entrance velocities of 7, 18 and 27 m/s .The experiments results showed that, a trend of increasing separation efficiency with concentration was observed, up to 12 kg_{solids}/kg_{gas}, above which, the efficiency decreased. At test conditions, the collection efficiency for the entrance velocity of 18 m/s was higher than for 27m/s. Avci and Karagoz [5] devolved a mathematical model for calculation of fractional efficiencies in cyclone separators, by taking into account the effects of flow, particle, geometrical parameters, and acceleration assuming that the mixture of fluid and particles is homogenous, and acceleration diminishes depending on the friction and geometry. Collection efficiency curves predicted by the proposed model showed a good agreement with experiments over a wide range of inlet velocities for different types cyclone types. Comparison of the obtained results with semi empirical models available in literature are also indicated that the present model may be used successfully for determination of the performance of a tangential inlet cyclone. Correa, et al. [6] investigated experimentally and theoretically the particle residence time in a cyclone. Their theoretical and experimental results showed that the dimensions of the conical part of the cyclone had a very important influence on flow and consequently on particle residence time. Shin, et al. [7] conducted numerical and experimental studies for the development of high ·efficiency cyclone dust separator applicable to the extreme environments of high pressure of 6 bars and temperature up to 400^0 C. The experiments showed that the increase of pressure and temperature generally affect significantly the collection efficiency of fine particle less than 10μm, but the effect of pressure and temperature appears contrary each other .That is, the increase of pressure increase the collection efficiency, while the increase of the temperature results in the decrease of the efficiency over a certain range of flow rate. Derksen, et al. [8] performed three – dimensional, time – dependent Eulerian Lagrangian simulations of the turbulent gas – solid flow in a cyclone separator. They studied the effect of particle – to –gas coupling on the gas flow and particle behavior. The presence of solid particles causes the cyclone to lose some swirl intensity. Furthermore, the turbulence of the gas flow gets strongly damped. These two effects have significant consequences for the way of the particles with different sizes get dispersed in the gas flow. It is anticipated that the collection efficiency gets affected in opposite senses, negatively by the loss – of – swirl and positively by the reduced turbulence. El- Batsh, et al. [9] investigated the flow filed and particle separation process in cyclones using numerical calculations as well as experimental measurements .In addition, the effects of cyclone size and inlet velocity on cyclone performance were investigated. The collection efficiencies are determined numerically for the tested cyclones and compared to those obtained from published analytical models, and their experimental measurements. The comparison shows reasonable agreements. Chen, et al. [10] studied the influence of the bottom – contracted and edge – sloped vent – pipe on the separation efficiency of a cyclone separator under different vent – pipe insert depth and different orientation of the sloped edge. The correlative results were also compared with the traditional linear – pipe – shaped cyclone separator. Their results indicated that the cyclone inlet stream velocity has a strong influence on the separation efficiency, and the results are similar to that of conventional cyclone. Namely, the separation efficiency increases with increasing cyclone inlet velocity. Also, the separation efficiency changes with the orientation of the sloped edge and has the same rule of change, the maximum occurs at 90^0 and the minimum occurs at 270^0. Due to the configuration of the bottom – contracted and edge – sloped vent – pipe on bottom – contracted and edge – sloped vent – pipe is suitable with flow field inside cyclone separator, the separation efficiencies of the modified cyclone separator are usually higher than those of traditional cyclone separators. From literature, there is a difficulty of theoretical treatment of dust collection phenomenon in cyclone; this is due to lack of experimental results to verification of theoretical treatment of cyclone collector performance. Therefore, experimental investigation of gas – solids cyclone separators performance for industrial applications operating conditions is required to establish these effects. To achieve these requirements the present research include, the effect of cyclone size, inlet velocity, and particle size on the collection efficiency 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 of flow in the range of 14.56 – 114.46 m^3/hr. Air flow rate measured using a calibrated orifice meter (2).This stream 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 orifice is measured using a u – 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 are 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. Fig. 2 shows the dimension ratios for Stairmand cyclone design used in this study.

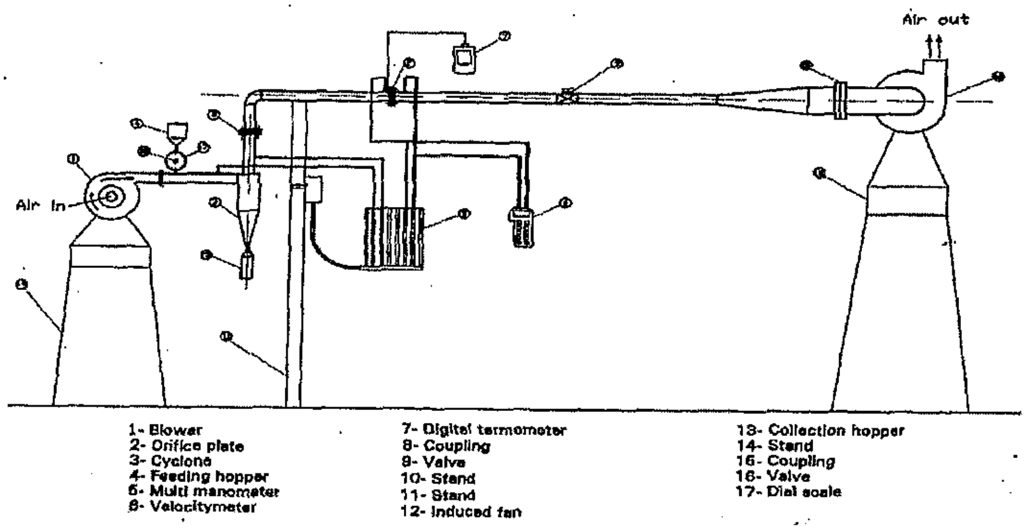

Fig. 1 Experimental test rig layout

2.2 Test Method

In order to study the effect of the particle size on the cyclone collection efficiency, two solids materials were used in conducting experiments, commercial sand and white cement. Sand is used as the solid particles. The particle sizes in terms of median diameter were 70, 225, 360, 510μm and sand overall. The particle size distribution (PSD) is shown in fig. 3 and its density of about 1400 kg/m3. The physical properties of the white cement are 70μm median diameters and density of about 1315 kg/m3.

All solid samples were dried in an oven at 600 C before use. The experiments were carried out at almost equal room temperature and atmospheric pressure. The experimental readings were taken with more care, tabulated and plotted graphically. The experiments were carried out at dust loading values of 50, 80,100,125,200,275 and 350 gsolids/kgair and inlet velocity varied from 5.3 to16.77 m/s.

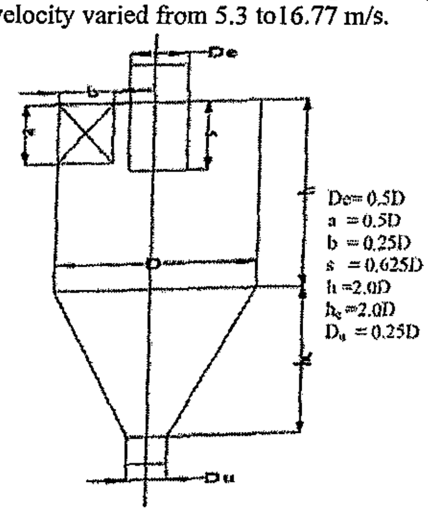

Fig.2. Shape and principal dimensions of the Cyclone.

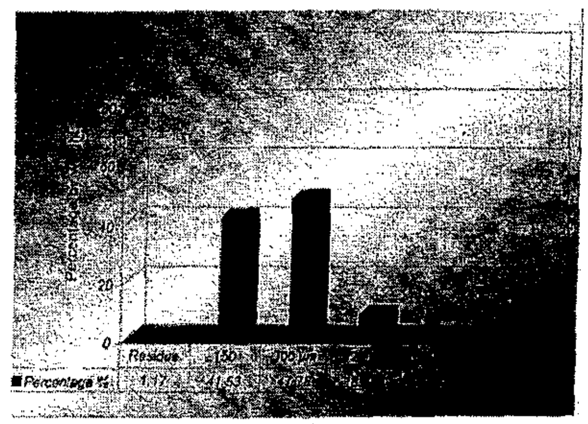

Fig.3. Particle size distribution of sand

The forced and induced blowers were run for sufficient time till stable conditions of the flow have been established before the test was started. The delivery valve was adjusted at a certain opening to give the required flow rate. Solid particles of (sand) sample of a given particle diameter is weighed by the scale to determine its mass and is introduced into the solid supply reservoir .The calibrated solid control valve is adjusted at a certain opening to give the required solid flow rate. The solid loading valve opened and the measurement of the pressure drop in the orifice meter, the time of solid loading and the air temperature in the inlet of the orifice meter corresponding to the condition were recorded. Solid particles were collected by the cyclone over a specified period of time and weighted by the scale to determine its mass flow rate. These observations of clean air and dusty air conditions were repeated for many other possible flow rates and the corresponding readings were determined.

2.3. Cyclone Performance Parameters

Collection efficiency" overall collection efficiency", $\eta_o = M_c/M_i = (M_i - M_e)/M_i = 1 - M_e/M_i$, uncertainty range, is 0.028 minimum and 0.085 maximum.

3. EXPERIMENTAL RESULTS AND DISCUSION

3.1. Effect of Cyclone Size on the Collection Efficiency

A study of the effect of cyclone size on the collection efficiency is very important from economical point of view. In order to evaluate this effect, extensive testes were conducted at various particle sizes, different cyclone sizes, various inlet velocities, and various dust loading. Typical results are shown in figs 4 to 6, from tests conducted at particle size 70μm. In all tests it appears that the efficiency depends on the cyclone size. Similar trend was reported by EL – Batsh, et al. [9].

The general trends of curves are that the collection efficiency increases with increasing cyclone size, reaches a maximum and then decreases with increasing cyclone size. In addition these Figures show that the peak in collection efficiency occurs at 10 cm cyclone size .Therefore, the value of cyclone size for peak efficiency independents of the other operational conditions, i.e., dust loading, particle size and inlet velocity.

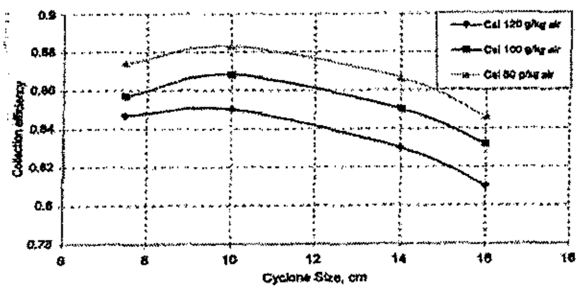

Fig.4. Variation of collection efficiency with cyclone diameter for particle size (70μm) with different solid loading at constants inlet velocity of 9 m/s.

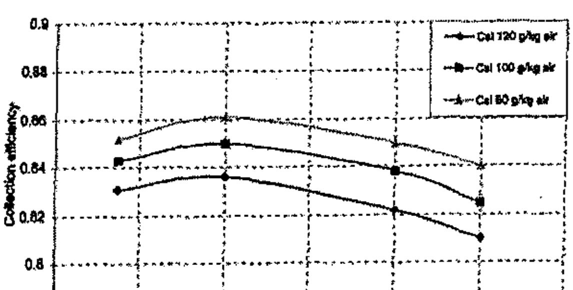

Fig.5 Variation of collection efficiency with cyclone diameter for particle size (70μm) with different solid loading at constants inlet velocity of 8 m/s.

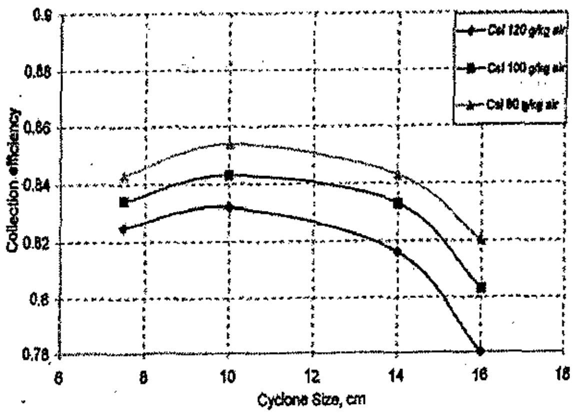

Fig.6 Variation of collection efficiency with cyclone diameter for particle size (70μm) with different solid loading at constants inlet velocity of 7 m/s.

The consequences of increasing the cyclone size at constant gas flow rate is to reduce the inlet velocity which in turn leads decrease in the magnitude of the tangential velocity, to increase the residence time, to increase the natural length of the cyclone, and to decrease the radial velocity. Thus the combination of these factors results in the shape of the efficiency versus size curve. Furthermore, collection of particles inside a cyclone is naturally a result of the forces acting on them (centrifugal, drag, and gravitational forces), who's resultant dins them to cyclone walls. The reduction of collection efficiency with decreasing the size from 10 cm to 7.5 cm may be attributed to that the distance between the dust and gas outlets is very small and this gives a better chance for dust to move with inner vortex and leaves with discharge air. However, in large size cyclone there is a greater distance between the dust and gas outlets which gives restrained dust a better chance to more back into the outer vortex and be collected again before leaving the cyclone. The present results showed that better efficiency results when smaller – diameters cyclones are used. In addition diameters that are too small can also present operational problems. Industrial dusts are poly disperse, containing particles of many sizes. Although a fractional efficiency curves defines the cyclone collection for any particle sizes, it doesn't by itself provide an estimate of overall efficiency. Therefore testes for overall sand were conducted because in practical applications, overall efficiency is of primary concern. Fig. (7) Shows the variation of the overall collection efficiency with cyclone size for overall sand at different solid loading and constant inlet velocity of 10.3 m/s for all type of cyclones. This Figure indicate that the collection efficiency increases with increasing cyclone size reach a maximum and then decreases with increasing cyclone size. In addition this Figure also shows that the peak in collection efficiency depends on the value of C_{si} and occurs at about 11 cm.

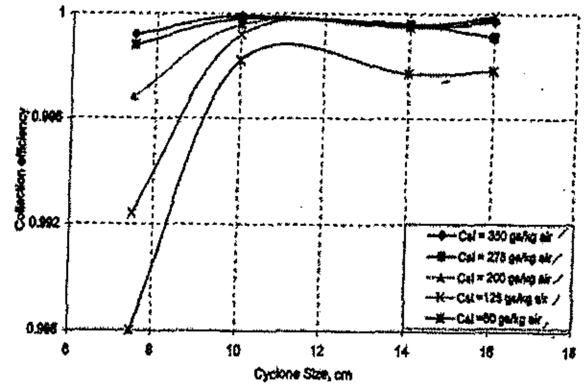

Fig.7 Variation of collection efficiency with cyclone diameter for particle size (sand overall) with different solid loading at constants inlet velocity of 10.3 m/s.

3.2. Effect of Particle Size on the Collection Efficiency

Extensive testes were conducted at various cyclone sizes and different operation conditions to evaluate the effect of particle size on collection efficiency. Typical results are shown in figs 8 to 11.

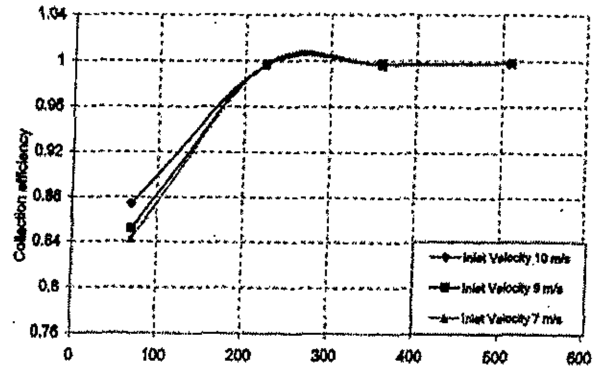

Fig.8 Variation of collection efficiency with particle size for cyclone diameter (7.5 cm) with different inlet velocities

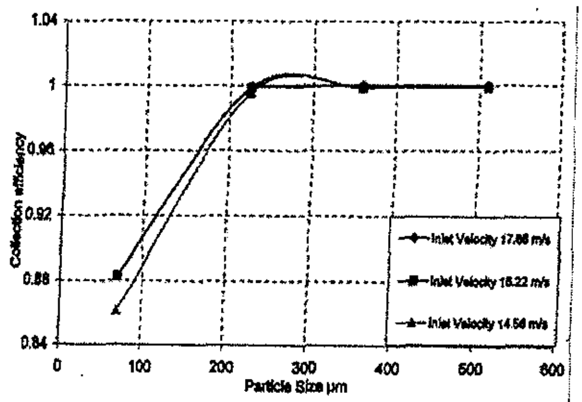

Fig.9 Variation of collection efficiency with particle size for cyclone diameter (10 cm) with different inlet velocities.

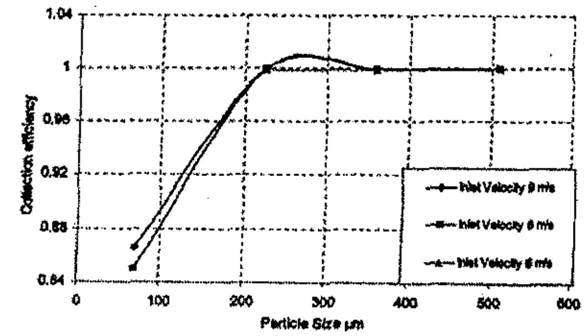

Fig.10 Variation of collection efficiency with particle size for cyclone diameter (14 cm) with different inlet velocities

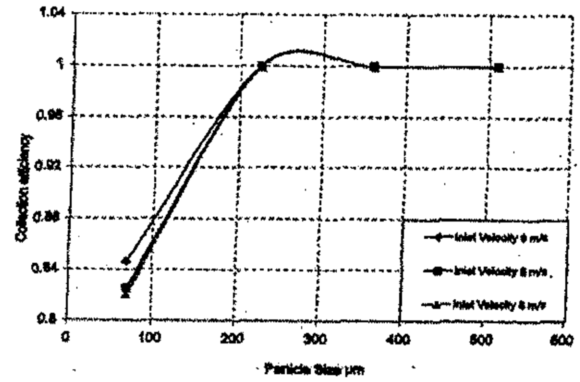

Fig.11 Variation of collection efficiency with particle size for cyclone diameter (16 cm) with different inlet velocities

The general trends of collection efficiency versus particle size are that the efficiency increased as then approach approximately 100% for particles bigger than 225μm. These results agree with results of Shin, et al., [7] and EL – Batsh,[9]. For smaller particles size the turbulence intensity within the cyclone affects the separation efficiency and with increase in turbulence intensity decrease the residence time caused the separation efficiency decreases .However for larger particles size the intensity of turbulent has almost no effect on the residence time because the particles have relatively bigger inertias, and that the residence time of relatively large particles will increase with the turbulent intensity. The effects of the increase on the mean residence time made more complex. In addition, the thickness of boundary layer has an effect on the collection efficiency and that the efficiency increases with a decrease in the boundary layer thickness. Moreover, the smaller size particles get dispersed in the cyclone and 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. They do not attach immediately to the wall once they enter the body of the cyclone as the still bigger particles do , but have small chance to enter the weak shortcut flow directly guides gas from the annulus in between vortex finder and the cyclone wall into the exit pipe and get exhausted.

3.3. Effect of Inlet Velocity on the Collection Efficiency

Figs. 12 to 15 show the effect of the inlet velocity on the collection efficiency.

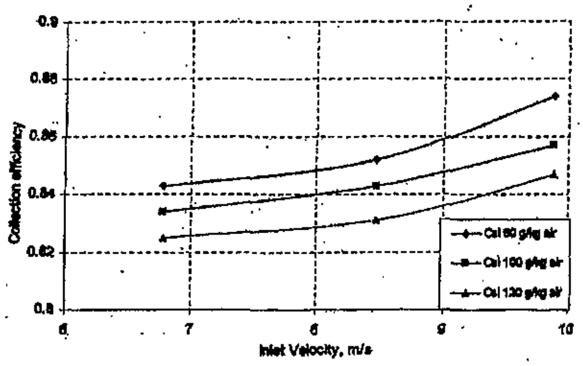

Fig.12 Variation of collection efficiency with inlet velocity for cyclone diameter (7.5 cm) and particle size (70μm) with different solid loading.

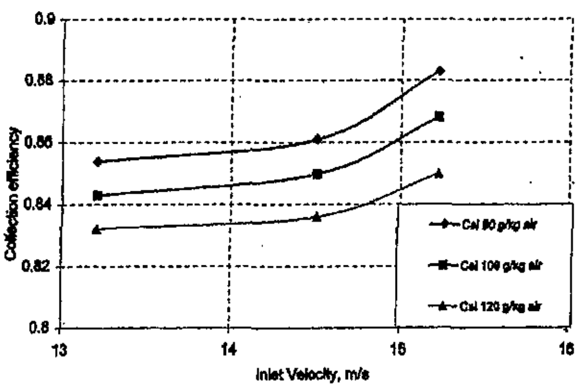

Fig.13 Variation of collection efficiency with inlet velocity for cyclone diameter (10 cm) and particle size (70μm) with different solid loading.

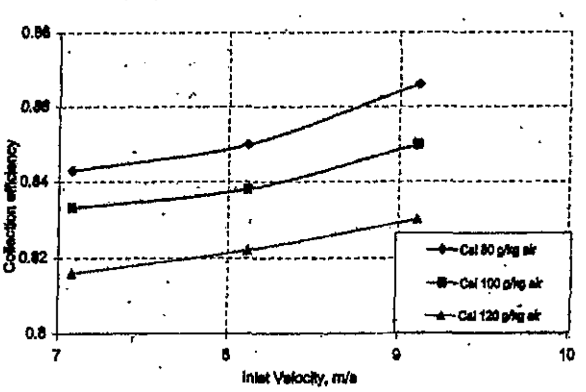

Fig.14 Variation of collection efficiency with inlet velocity for cyclone diameter (14 cm) and particle size (70μm) with different solid loading.

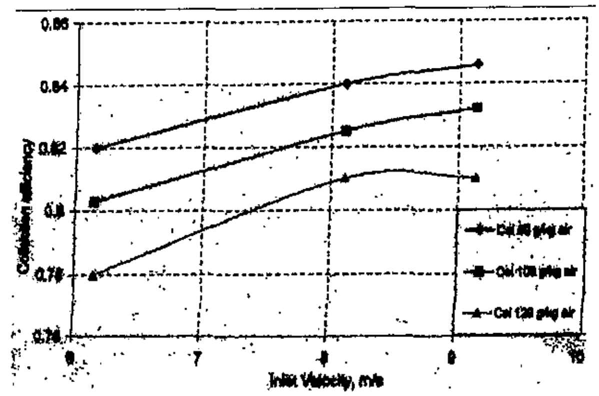

Fig.15 Variation of collection efficiency with inlet velocity for cyclone diameter (16 cm) and particle size (70μm) with different solid loading.

Generally these figures show that the collection efficiency increases with increasing the inlet velocity. These results agree with results of De, et al. [2], EL – Batsh, et al. [9] and Chen, et al. [10]. Collection efficiency depends on the flow regime which is affected by the flow parameters such as inlet velocity, temperature, viscosity and surface roughness. In high velocities, flow is generally fully turbulent and the effects of flow parameters decrease with Reynolds number, whereas, at low velocities, flow is laminar and the effects of flow parameters increase up to a certain point and then start to decrease after that. The most interesting results have been obtained for small cyclones in which transitional flow regime might be dominant. This shows that detail investigation is required to determine transition to turbulence in a cyclone. Decreasing in surface resistance which eventually leads to decrease of velocity is an important way to high efficiency due to increasing in natural vortex length and residence time inside cyclone. The inlet velocity influences strongly the results of collection efficiency intended in Fig. (13). The tangential velocity increases with an increase of the inlet velocity, leading to a greater separation in cyclone. This is due to the decrease in the cut – size with increasing inlet velocity. *Since the cut – off diameter* varies inversely with the square root of velocity.

4. CONCLUSION

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

1. 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. The peak was independent of the other operational conditions for all particle size tested here, but for the sand overall it depends on the flow conditions.

2. The collection efficiency increased with increasing particle size and approached 100 % for particle sizes bigger than 225μm.
3. The collection efficiency increased with increasing the inlet velocity.

5. REFERENCES

[1] Biffin, M., Syred, N., and Sage, P., 1984,"Enhanced Collection Efficiency for Cyclone Dust Separators", Chem. Eng., Vol. 62, PP. 261 – 265.

[2] 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, PP. 192-198.

[3] 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, PP. 1-24.

[4] 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, PP., 60-65.

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

[6] Correa, L. G., Graminho, D. R., Silva , M. A., and Nebra, S. A., 2004, "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.

[7] Shin, M., S., kim, H. S., Jang, D.S., Chung, J.D., and Bohnet, M., 2005,"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.

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

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

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

6. NOMENCLATURE

C_{si} = solid loading (g_{solids} / kg_{air})
D = cyclone diameter,7.5,10,14 and16 cm.
M_c = mass of solids collected by cyclone (g)
M_i = input solids mass to cyclone (g)
M_e = solids loss mass due to entrainment (g)
V = average velocity of air (m/s)