Proceedings of the International Seminar on Mineral Processing Technology - 2006, Chennai, India. pp. 352 - 357.

Studies on the Performance of Air Cyclone Separator for Removal of Particulate Matter

Ch. Hari Krishna, P. Srinivasa Rao[1] and P.V. Gopal singh[1]

NML-Madras Centre, C.S.I.R.Madras Complex, Taramani, Chennai.
[1] M.V.G.R. College of Engineering, Vizianagaram, Andhra Pradesh.

Abstract

Emissions from industries and air pollution from these emissions adversely affects the environment and public health. For instance, India depends largely on coal for its power generation. The problem with Indian coal is that it carries a lot of dust with it. Hence, dust carried along with the flue gases has to be separated before sending the gases for further treatment. Cyclone separator, bag filter and electrostatic precipitator have found applications in technological use. ESP demands high voltage (power requirements) whereas general bag filters cannot work beyond 120°C. However, cyclone separators have less temperature and pressure limitations and requires low pressure drop. Hence, cyclone separators are usually selected to separate dust from fluid streams.

In this work the collection efficiency of air cyclone is observed with change in parameters like particle size(ranging from22.5μm to 63.5μm), density(ranging from 689Kg/m^3 to 3030Kg/m^3), inlet gas velocity(ranging from 4.151m/s to 7.43m/s) and pressure drop across cyclone (ranging from 0.014m.H_2O to 0.045m.H_2O) for different samples like fly ash coal dust and limestone. The theoretical estimation of efficiencies for given parameters are studied and correlation developed efficiency as a function of diameter of the particle, density of the particle and velocity of gas.

Keywords: *cyclone, particulate matter, Pollution.*

INTRODUCTION

Cyclone separators utilize centrifugal force generated by the spinning gas stream to separate the particular matter from the carrier gas. The centrifugal force on the particles in the spinning gas stream much greater than the gravity: therefore, cyclones are effective in the removal of much smaller particles than gravitational settling chambers and requires much less space to handle the same gas volumes. Cyclone separators are not superior in the case of particles smaller than 10μm to ESP and bag filters. However, they may act as pre cleaners to reduce inlet loading of particulate matter to this devices.

LITERATURE REVIEW

Cyclone separators unlike filter bags belong to the class of equipment called non-contacting equipment. The governing principle is based on centrifugal force. Air and hydro cyclones use a vertical cylinder and the gas stream travels from the entry located at the top to the exit points. Hydro cyclones use water as a fluid medium whereas air cyclones use air as a fluid medium.

Hydro Cyclone Separators

Cyclones are also used for separating solids from liquids, sometimes as a thickener but much more commonly as classifiers. In these services they are called as hydro cyclones. Feed enters tangentially near the top. The liquid flows in the spiral path near the vessel wall, forming a strong downward vortex. Larger are heavy solid particles separate to the wall and are pushed downward and out of cyclone as a slurry or paste. A variable discharge orifice controls the consistency of the under flow. Most of the liquid goes back upward in an inner vortex and leaves the central discharge pipe which is known as vortex finder. In a hydro cyclone it is not possible to have good solid removal and high underflow concentration, in the thickening operation with nearly all the concentrated, up to maximum of about 50% by volume for slurries of lime stone and coal.

Hydro cyclones find applications in degritting operations in alumina productions, removing carbon in upgrading gypsum for phosphoric acid manufacture, classifying pigments and crystal magmas in crystallization operations and similar process steps one such application is a starch washing system with multiple stages, where the mixture of starch, proteins and water were pumped into a system of separators that separates the starch and protein slurry from excess water and grit. They have replaced mechanical classifiers in closed circuit grinding.

Air Cyclone Separator

Cyclone separators separate particles from gas streams. A cyclone usually consists of a cylindrical upper section and conical lower section. Pumping fluid tangentially into a stationary cylindrical under pressure usually produce a necessary vortex. The word cyclone implies an air pressure drop. Meteorologically, hurricanes, tornadoes and devil dusters are cyclones. As such, swirling or rapidly revolving air currents accompanies defined regions of a concentrated low air pressure. A cyclone separator works on a similar principle where by mechanically forced air is introduced into the top of a cylinder with a cone shaped base. Entrance duct is perpendicular to the vertical axis and tangent to the centre, and with in the center region of the upper cylinder is a sleeve or exit duct. The swirling motion of the air creates a negative pressure drop across the top of the cylinder. This provides pressure gradient. The higher pressure of air in the lower levels of the cone are pulled upward through a exit duct, moving from a region of relatively higher pressure to a lower pressure. At the same time, particulate matter in the moving air stream will fall out in accordance with specific gravity is the density of standard reference material.

Cyclones are used to control PM (particulate matter), and primarily PM grater than 10μm in aerodynamic diameter. However, there are high efficiency cyclones designed to be effective for PM less than or equal to 10μm. Cyclones serve an important purpose as pre cleaners for more expensive final control devices such as Fabric filters or Electrostatic Precipitators. In addition to use in pollution control work, cyclones are used in may process applications, for recovery of food products and process materials such as catalysts. Cyclones are used extensively after spray drying operations in food and chemical industries and after crushing, grinding and calcining operations in the mineral and chemical industries to collect useful minerals.

The advantages of air cyclones separators includes low capital cost, no moving parts, therefore few maintenance requirements and low operating costs, low pressure drops, temperature and pressure limitations are only dependent on the materials of construction, dry collection and disposal and relatively low space requirements. Whereas, disadvantages are relatively low PM collection efficiencies particularly less than 10μm size, unable to handle sticky or tacky materials and high efficiency units may experience high pressure drops.

EXPERIMENTAL SETUP AND PROCEDURE

A cyclone can be considered as a continuously working centrifuge with out moving parts. A conversional cyclone consists of cylindrical body joined to a cone. It consists of a vertical cylinder with conical bottom, a tangential inlet near the top, and an outlet for dust at the bottom of the cone. The inlet is usually rectangular. The outlet pipe is extended into the cylinder to prevent short-circuiting of air from inlet to outlet. The incoming dust laden air travels in a spiral path around and down the cylindrical body of the cyclone. The centrifugal force developed in the vortex tends to move the particles radially towards the wall slide into the cone be collected. The cyclone is basically a settling device in which a strong centrifugal force, acting radially is used in place of a relatively weak gravitational force acting vertically.

Experimental Procedure

Feed stock (samples of Fly ash, Coal dust and Lime stone) of about 100 grams with constant average size is prepared.

Sizes: 22.5μm, 28.5 μm, 35 μm, 41.5 μm, 49.0 μm and 63.5 μm.
Sieves: B.S.S 200,270,325,400,450,500 and 635.

The cyclone is run with air at a fixed velocity u_t by adjusting the blower valve. At the same time the pressure drop across the cyclone inlet and outlet in terms of cms of water is measured i.e $\Delta p_c = 0$. Dust particles of one particular size (25 μm) are fed at constant rate and solid particles are colleted at the outlet of the cyclone. The weight of the collected particles (W_c) and pressure drop across the cyclone are measured. By changing velocity the same procedure is repeated for particular size and feed stock. Experiments are repeated for sizes (22.5μm, 28.5 μm, 35 μm, 41.5 μm, 49.0 μm and 63.5 μm)

Measurement of Velocity of Air

$$Uair = \frac{Co}{\sqrt{1-\beta^4}}\sqrt{\frac{2g_c \Delta P_{air}}{\rho_{water}}}$$

$$Q_{air} = U_{air} * So$$

$$U_{tgas} = Q / (Hc * Bc)$$

$$\Delta P_{air} = g/g_c * R_m (K_{water} - K_{air})$$

ΔP_{air}, $\Delta P_{c=0}$ & ΔP_c = Pressure drop across air inlet, without load and with load respectively
C = Concentration of load (Kg/m^3)
S_o = Area of orifice = 0.00572555 m^2
C_o = Coefficient of discharge of orifice = 0.61
H_c = Height of cyclone duct
B_c = Width of cyclone duct = 32.5 mm and β = 0.5

Cut-Off Size Determination

$$\text{Cut size } D_{pc} = \sqrt{\frac{9\mu_g b}{2\pi N_e U_{tgas}(\rho_p - \rho_g)}}$$

ρ_p, ρ_g = Density of particle and gas respectively
μ_{gas} = Viscosity of gas
Ne = Effective number of turns a gas makes in traversing cyclone range (5-10)
U_{tgas} = Inlet gas velocity
b = width of cyclone duct.

RESULTS AND DISCUSSIONS

The various materials with different densities (Fly ash, Coal dust and Lime stone) are taken at different sizes and are passed through the cyclone separator at different velocities and the data is presented in the form of graphs. For each material, the individual parameters like inlet gas velocity, particle size and pressure drop are varied and their effect on the efficiency of removal are presented in the following discussions.

Fly Ash, Coal Dust and Lime Stone

Fly ash with a density of (689 Kg/m^3), Coal dust with a density of (841 Kg/m^3) and Lime stone with a density of (1914 Kg/m^3) was subjected to removal by air cyclone separator for various particle sizes and various velocities.

With increase in velocity, the removal efficiency was observed to increase continuously for each particle size and various velocities. However this increase in efficiency was found to be less significant in case of higher particles (>50μm) when compared to those lesser particles (<50μm). But there was a limitation in handling less particle sizes (< 20 μm). These observations for all the three samples are reflected from the graph plotted efficiency Vs velocities (*fig 1*) for different particle sizes.

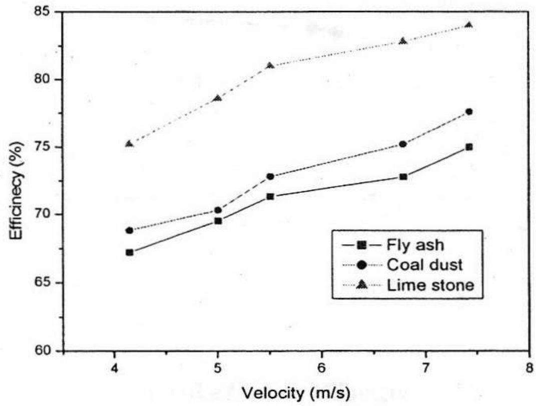


Fig. 1: Efficiency Vs Velocity for Fixed Size (22.5μM)

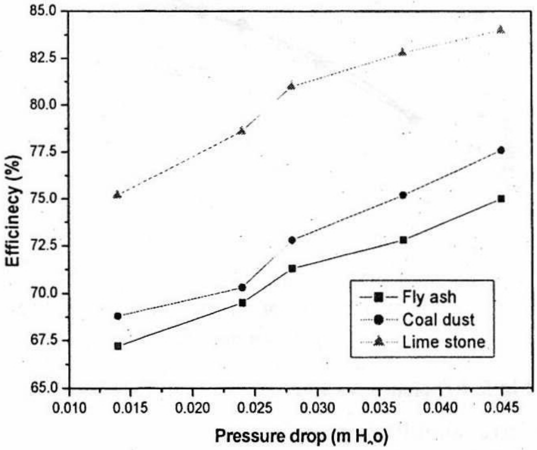


Fig. 2: Efficiency Vs Pressure Drop for Fixed Size (22.5μM)

Plot was also drawn for efficiency Vs Pressure drop for all the three samples (*fig 2*) and it was observed that with an increase in pressure drop across cyclone, efficiency also increased. When observing the plots of Efficiency Vs Particle size for individual samples (*fig 3*), it was observed that efficiency is increased up to 50 μm. There after no significant increase in efficiency was observed with increase in particle size.

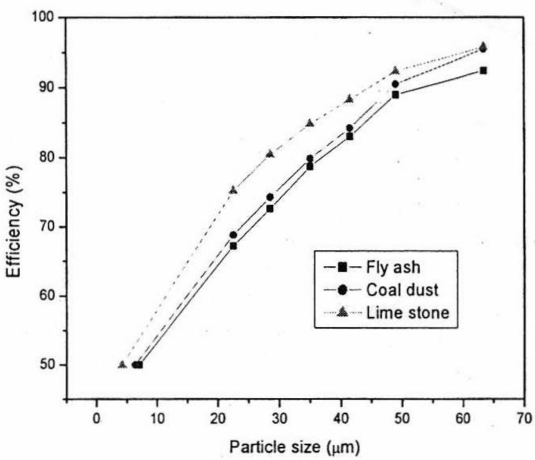


Fig. 3: Efficiency Vs Particle Size for All Samples

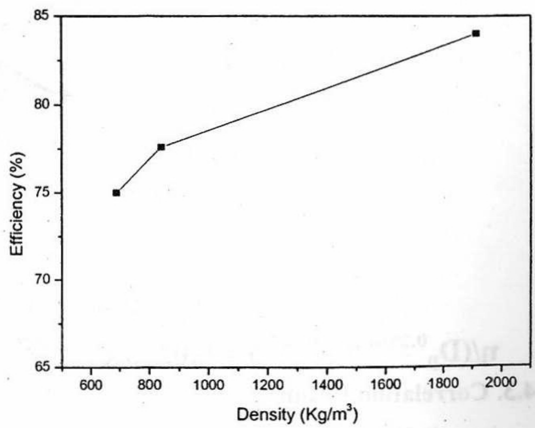
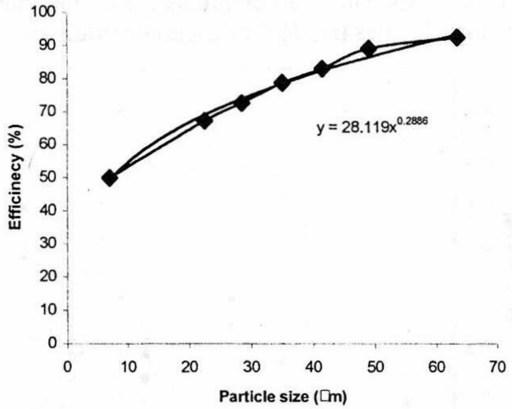


Fig. 4: Efficiency Vs Density for All Samples

Higher efficiencies were observed with lime stone compared to coal dust and fly ash. This is evident due to the fact that the higher density particles have greater tendency to settle down compared to the lower ones. Which will be reflected in graph (*fig 4*) Hence it can be shown that the cyclone separator, higher density particles can be easily removed compared to the lower density particles.

Correlations

Theoretical estimation of efficiency for given parameters like particle size, density of feed stock and inlet gas velocity



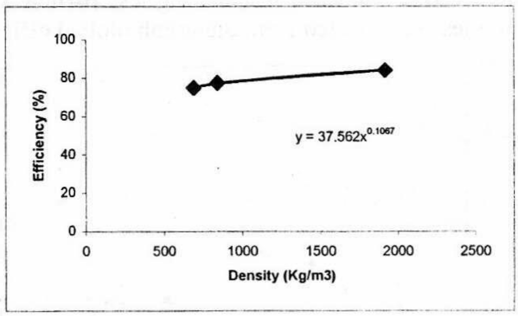


Fig 5. Efficiency Vs Particle Size for Fixed Velocity

Fig 6. Efficiency Vs Density

Correlation from graph

$\eta = 28.119\ D_p^{0.2886}$

Correlation from graph

$\eta = 37.562\ \rho^{0.2886}$

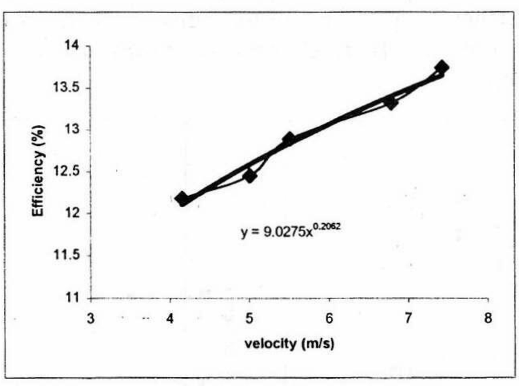


Fig 6. Ratio $H/(D_p^{0.2886} * P^{0.2886})$ Vs Density

$$\eta/(D_p^{0.2886} * \rho^{0.2886}) = 9.0275\ U_{tgas}^{0.2062}$$

4.3. Correlation Results

$\eta = f\,(Dp, \rho, U_{tgas})$

Correlation equation

$\eta = 28.119\, D_p^{0.2886}$

$\eta = 37.562\rho^{0.2886}$

$\eta/(D_p^{0.2886} * \rho^{0.2886}) = 9.0275\, U_{tgas}^{0.2062}$

CONCLUSIONS

Following results have been observed from experimental studies on air cyclone separator.

S.No	Range of particle size (µm) that are collected	Range of collection Efficiency.
1	(3.34-7.01)	<50
2	(20-40)	(65-85)
3	(40-50)	(85-92)
4	(>50)	(>92)

If the size of the sample is more than 50µm, the collection efficiency is almost same for any sample. With an increase in density of the sample, collection efficiency increases linearly. For the same velocity (or for the same power consumption), highly dense particles are removes with higher collection efficiency compare to low dense particles. At high velocities, the efficiency decreased instead of increasing due to carry over solid particles along with the exit gas.

Acknowledgements: The first authors express sincere gratitude Prof. K.L.P Raju, Principal, M.V.G.R College of Engineering, for permission to take up the project work with in the institution.

REFERENCES

[1] A text book of "Unit Operations of Chemical Engineering" by Warrenl. Mc Cabe, Julian C. Smith & Peter Harroit.

[2] Williamson, S.J., 1973." Fundamentals of Air Pollution" Addiron-wesley (Publishing Co., Inc)

[3] Henderson, S.M. and R.L.Perry.1976.APE, 3rd Edition."Agricultural process Engineering" Publishing Co.

[4] Perry 1984" Perry's Chemical Engineers hand Book" edited by Robert Perry and Don Green 6th Edition, Mc Graw Hill Newyork, Ny, 1984.

[5] A text book of "Pollution control in Process Industries" By S.P. MAHAJAN.

[6] A text book of "Environmental Pollution Control Engineering" By C.S.RAO.