Analysis of the Inner Surface Erosion Wear at Cone Parts of Electro—cyclone Separators

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Abstract

The normal cone type Electro—cyclone Separators erosion wear mechanism is analyzed, known that the whole erosion wear process is closely related with Stokes forces, centrifugal forces and electrostatic forces. By analyzing the movement of dust particle group in the cone part, expression of the erosion wear rate has been derived in theory, evaluate the degree of erosion wear, analysis and calculate the most serious wear part. Comparison the wear characteristics of Electro—cyclone and cyclone in the same condition, The results showed that the wear characteristics is similar in the cone part, the erosion wear of electric cyclone was more serious. Analysis of the influence of different voltage on the erosion wear, concluded that the higher the voltage, the more relatively serious of the erosion wear. In the cone part besides the velocity, dust concentration and particle size is a major cause of serious erosion wear. The calculation coincides with the actual situation degree is high, has practical application value.

Keywords: wear analysis; motion analysis; electro—cyclone separators; wear rate

1. Introduction

Erosion of Electro—cyclone inner wall seriously affect the normal operation of the whole system, directly related to the service life and reliability of the system. Reduce wear and prevent wear has been the important direction in the field of electric cyclone research, especially the wear at the cone part. Quantitative analysis of the erosion problem has practical application value to Electro—cyclone Separators design. The wear of Electro—cyclone Separators is inevitable erosion wear phenomenon, there are a lot of complex influencing factors, Including the entrance wind speed, dust concentration, electric field strength, structure, humidity, temperature, wall materials, etc. Any one factor changes, the wear process may change, and the wear mechanism is also changed. The wear mechanism of the Electro—cyclone is mainly based on the cyclone separator. For the wear mechanism of cyclone separator are mainly concentrated in the researches on the wear rate, wear position, air velocity, dust concentration, the nature of the dust particles (such as incident Angle, the spherical degree, hardness, particle size, etc.), etc. But the wear mechanism of the system has not been established.

2. Analysis of the Cause of Erosion Wear

There are two main types of particle fluidization erosion[1]]: surface wear and bulk fracture. Surface wear refers to a large amount of powder falls off from the particle surface, but the size of the particles did not change significantly. Particle surface convex part subject to shear stress and [1]produces a lot of powder, which makes particles more and more circular; Bulk fracture is similar to crushed, referring to when the particles are large enough stress, and broken into several smaller size particles. The former is related to impact elasticity and structure defect of substrate, the latter with crystal materials related to the hardness and wear resistance of the matrix. These two forms will cause serious wear and tear on the machine.

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Author introduction : Longfei Kan(1991 -), male, graduate, engaged in mechanical design, dust removal research; Wei-jun Liu (1963 -), male, professor, master tutor, engaged in clean energy and pollution control.

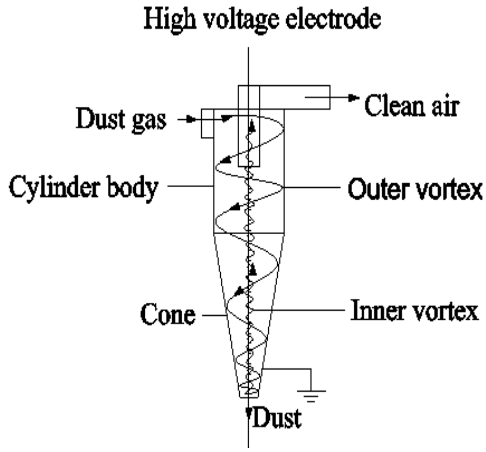

Fig.1 Structure and inner gas flow of Electro—cyclone Separators

Figure 1 is an electric cyclone structure and internal air flow diagram. Particle group under the effect of rotating centrifugal force, with the increasing of rotation speed amplifier area in particle concentration also gradually increased and along the wall spiral downward movement causing erosion wear. Especially in the cone part, with the effect of conical necking that rotating speed and dust concentration increased, make the probability of collision and energy also increases. The impact energy increases with the increase of speed, wear became more serious, Particles in the cone at high concentration along the wall spiral downward, and charged particles by the electric field force increase the stress of the particles on the lining erosion, wear on the main form can be seen as erosion wear. Xin-xue Zhao[2,3] on cyclone and wear mechanism of the research shows that: in the conical section, the wear quantity along the axial down significantly increased, dust concentration has direct relationship with wall wear and tear. Xiu-yan Liu[4]on cyclone wear the CFD numerical simulation and experiment comparison, it is concluded that the biggest wear rate occurs at the bottom of the cone. Based on the former research, the form of the pyramidal wear expression of Electro—cyclone Separators is derived by comparing with the cyclone dust collector.

3. Analysis of Wear Mechanism

The erosion process of Electro—cyclone that by dust-containing air flow is very complex. Most of the research is analysis the movement of individual particles of the form. Actually, wear of the walls by particles is based on particle group, especially the cone part. So should the form of particle group movement as research object.

3.1 Erosion Rate

Erosion wear of the cone parts, In the case of the smaller half cone angle α , the following analysis can be carried out. Main evaluation index of wear is wear rate, while the main factor affecting the wear rate is dust flux, impact velocity, incident angle, etc. Zhu[5,6]has been tested for 7 kinds of plastic materials in the range of dust hardness Hp= 40kg/mm^2 ~ 590kg/mm^2. The empirical formula for erosion rate, E ,can be obtained by

$$E = kMd_p^{1.5}V_P^{2.3}(1.04-\psi_P)(0.448^2\cos\theta+1) \quad (1)$$

Where: E is erosion rate, $\mu\mathrm{m}/h$, k is Steel coefficient Take A3 steel as an example,*k*=1.5;*M* is dust flux near the wall, $kg/(m^2\cdot s)$; d_p is particle size; ψ_P is spherical degree of particles, Range is 0.5-0.7;And then *M* can be obtained by

$$M = V_pC\sin\theta \quad (2)$$

Where: C is dust concentration near the wall, kg / m^3; V_p is dust incident speed near the wall, m/s; θ is the angle of incidence, $\theta < 90^\circ$.

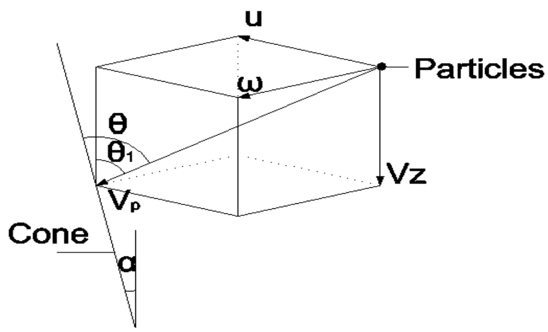

Fig.2 Particulate Velocity Analysis

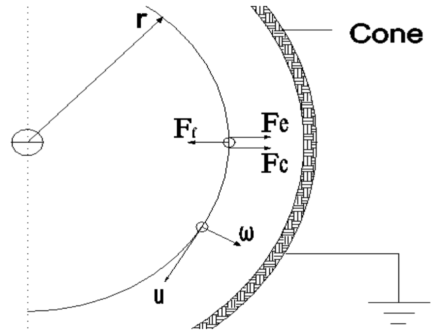

Fig.3 Particulate Force Diagram

3.2 Analyze the incident speed of the particles

In order to simplify the analysis of the incident speed of the particles, assuming:①ignore gravity; ②resistanc movement of the particles obey Stokes law; ③cyclone dust collector in the rotating airflow that cut offered to th, same velocity of airflow velocity and dust;④ignore the inter particle collision. As shown in Figure 2, The incident velocity V_p and the angle of incidence θ can be synthesized by tangential velocity, u , radial velocity, ω ,and fall velocity V_z . Formula for calculation of V_p and θ can be obtained by

$$V_p = \sqrt{u^2 + \omega^2 + V_z^2} \quad (3)$$

$$\theta = \arctan(\sqrt{(\omega^2 + u^2)} / V_z) + \alpha \quad (4)$$

3.2.1 Radial Velocity Analysis and Expression of Particles

As shown in Figure 3, the radial velocity of particles, ω ,is determined by centrifugal force, F_c ,electric field force , F_e ,and airflow resistance, F_f . The particles have a formula for equilibrium state[7]

$$F_c + F_e - F_f = 0 \quad (5)$$

And then the air flow resistance [8] F_f of the movement dust particles can be expressed as

$$F_f = C_f \frac{1}{4} \pi d_p^2 \frac{\rho \omega^2}{2} \quad (6)$$

Where: is density of air; is drag coefficient, in Electro-cyclone Separators ,according to the range of changes, the following equation is established:

$$C_f = 24 / Re_p \qquad (Re_p \le 1.4) \quad (7)$$

$$C_f = 21.4 / Re_p^{0.625} \qquad (1.4 < Re_p \le 500) \quad (8)$$

By formula (5), (6) we can draw:

$$\omega = \sqrt{\frac{8(F_c + F_e)}{C_f \pi d_p^2 \rho}} \quad (9)$$

And then the centrifugal force[9] F_c of the movement dust particles can be expressed as

$$F_c = \frac{1}{6} \pi d_p \mathrm{d_p} \frac{u_i^2}{r_z - \Delta r} \quad (10)$$

Where: d_p is density of particles; u_i is tangential velocity , r_z is radius of tube in electric cyclone ; Δr is boundary layer thickness, $\Delta r << r_z$; Tangential velocity can be approximate as the inlet velocity, u .So (10) can be written as

$$F_c = \frac{1}{6}\pi d_p^3 d_p \frac{u^2}{r_z} \quad (11)$$

In Electro—cyclone Separators, The particle charge is the important stage of the dust removal process. The amount of electricity that the particles can get is related to the particle size, electric field strength and residence time and other factors. Can be expressed as[10]

$$q_{pb} = \frac{3}{2}\pi\varepsilon_0 d_p^2 E_0 \quad (12)$$

Where: ε_0 is vacuum dielectric coefficient, $\varepsilon_0 = 8.85\times10^{-12} F/m$; E_0 is undisturbed electric field intensity, V/m, can be obtained by

$$E_0 = \frac{V_{cr}}{R_1 \ln(r/R_1)} \quad (13)$$

Where: is corona critical voltage,; is corona electrode; radius of out cylinder; Then V_{cr} can be obtained by

$$V_{cr} = 3.04\times10^6\left(\beta + 0.0311\sqrt{\frac{\beta}{R_1}}\right)R_1 \ln\frac{r}{R_1} \quad (14)$$

$$\beta = \frac{p_b \pm p_g}{101300}\frac{293}{273+t_g} \quad (15)$$

Where: β is gas density ratio in test status and standard state[T=(273+20)℃，P=101300Pa]; p_b is atmospheric pressure ,Pa; p_g is manometer pressure in gas channel, Pa; t_g is gas temperature, ℃.

The electric field in the cylinder can be considered as the transient electric field. Therefore, though the coulomb's law, F_e can be obtained by

$$F_e = E_c q_{pb} \quad (16)$$

And then E_c , dust collecting pole electric field intensity on average can be obtained by

$$E_c = \sqrt{2i_0 / 2\pi\varepsilon_0 K} \quad (17)$$

And then, i_0 ,A/m, is corona current can be obtained by

$$i_0 = C_0 V(V - V_{cr}) \quad (18)$$

Where: V is electric field voltage, V; C_0 is constant ; K is ion mobility.

3.2.2 Expression of Velocity Speed

The descent speed is a function of the radius of rotation and the vertical downward direction (the cone on the bottom center of the circle as the origin of coordinates, then vertical down to shaft). The expression [11]can be obtained from empirical formula by

$$V_z = K(1-\frac{r_0}{r_z})(1-\frac{z}{L}) \quad (19)$$

Where: r_0 is boundary radius of the upstream flow and the downstream flow,m; L is natural reentry length,m; K is constant and can be obtained by

$$K = -\frac{Q}{\pi r^2}\left[\left(1-\frac{r}{r_1}\right)\left(1-\frac{2r_0 - r}{r_1}\right)\right]^{-1} \quad (20)$$

Where: Q is dust laden gas flow, m^3/s; r_1 is radius of inner cylinder,m.

Natural reentry length[12] is the length of the air flow from the bottom of the exhaust pipe to a minimum position while the air return,and though empirical formula can be obtained by

$$L = 7.3r_1(r^2/ab)^{1/3} \quad (21)$$

Where: a is entrance height,m; b is entrance width,m;

4. Design Case to Verification Analysis

4.1 Structure size and Initial Parameters

In order to verify the reliability and practicality of the above analysis, the verification model of the Electro—cyclone Separators is designed according to the practical application. Its structure size is shown in Table 1 To analyze the erosion rate of different parts of the cone,as shown in Figure 4, the cone is divided into eight detection

Table 1: Electrostatic Cyclonic Structure Size

Number	Name	Symbol	Unit	Numerical
1	radius of out cylinder	r	m	0.70
2	radius of inner cylinder	r1	m	0.38
3	height of out cylinder	h1	m	2.70
4	immersion depth of inner cylinder	s	m	1.50
5	Lower cone radius	r2	m	0.26
6	Entrance height	a	m	0.65
7	Entrance width	b	m	0.33
8	Cone height	h2	m	1.96

positions(CS1、CS2…CS8) from top to bottom, cone cylinder height is1960mm, the interval is 245mm.

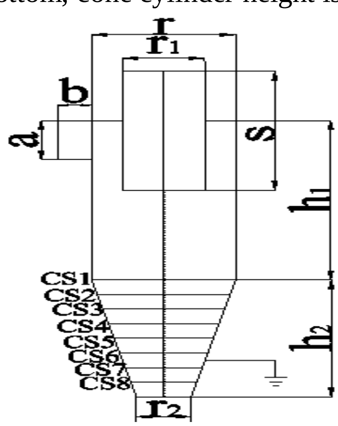

Fig 4: Diagram of Detection

The initial parameters of the model are: The dust laden gas flow $Q=4.17m^3/s$; The inlet velocit $u=20m/s$; Gas dens $\rho=1.21kg/m^3$; Gas dynamic viscosity __ $=1.7894\times10^{-5}kg/(m\cdot s)$; Particle mobility $K=2.11\times10^{-4}\mathrm{m}^2/(\mathrm{V.s})$; Electric field voltage $\mathrm{V}=800000V$; Density of particle $\mathrm{d_p}=2500\mathrm{kg/m}^3$.

4.2 Analysis and Discussion of Calculation Result

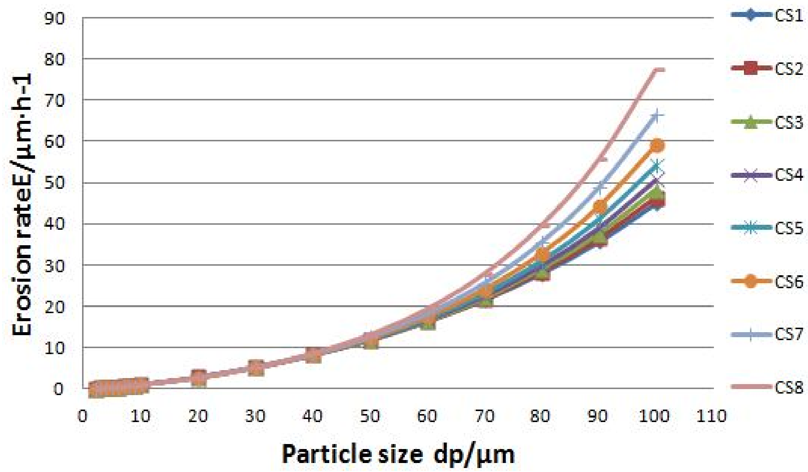

Fig 5: Comparison diagram of Erosion rate in Different Positions

4.2.1Relationship between Particle Size and Wear Rate

Figure 5 is a contrast map that the erosion rate at different positions fellow the particle size changes in the range of 2-100μm, from the figure can be seen that uneven distribution of erosion in the cone inner surface. When the particle size is determined, position under the farther, the greater erosion rate will be, at the lower part of the cone or at the lowest to reach the maximum. The analysis of the above is consistent with the analysis of the cyclone dust collector by literature [2-4], indicates that the cone erosion of the electric cyclone is remarkably similar to that of cyclone dust collector. It can be seen from the diagram that, particle size less than 40μm is smaller than particle larger than 40 μm on the erosion of cone inner surface which caused by particles, larger particles increased erosion damage increased. Therefore, to control dust particle size can effectively reduce the erosion wear.

4.2.2 Relationship between Voltage and Erosion Rate

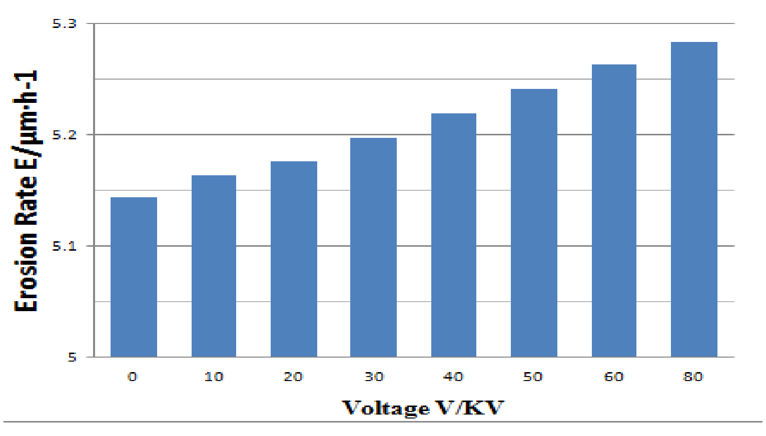

Fig 6: Erosion Rate of the Different Voltages

Compared with the cyclone dust collector, the obvious difference between Electro—cyclone Separators is the electrostatic dust removal。As shown in figure 6, in view of the 30μm particles , select position CS8, calculation the changes of erosion rate when voltage changes from 0 to 80 KV (Other size, other place also has a similar changes).

It can be seen that the erosion rate increased by only 0.14μm/h with the increase of voltage from 0-80KV, so it can be said that the change of voltage has little effect on the erosion rate.

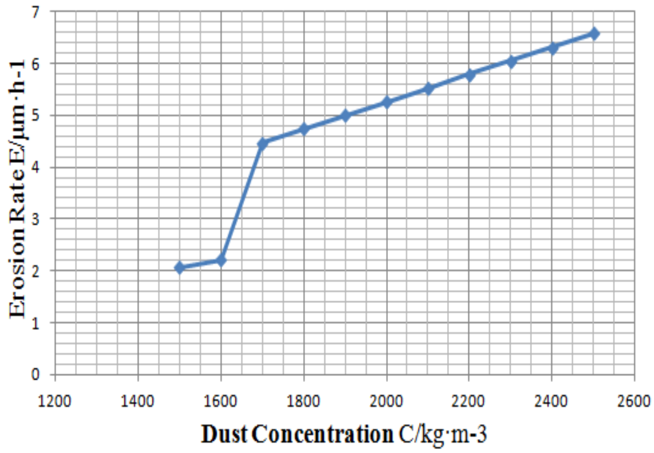

Fig 7: Impact on Erosion Rate of Dust Concentration

4.2.3 Relationship between Dust Concentration and Erosion Rate

By the formula (2), it can be seen that the change of the dust concentration directly affects the erosion rate. Figure 7 is when particle size is 30μm, select position CS8 , calculation the changes of erosion rate when dust concentration changes from 1500-2500 kg/m^3(Other size, other place also has a similar changes).From the diagram, we can see that the wear rate increases slowly when the dust concentration is small; When the concentration increased to 1600kg/m3, the wear rate increased sharply. The erosion rate increased relatively slow after dust concentration reach 1700kg/m^3. In a word, the dust concentration is significantly affected the erosion wear, and is one of the main factors that causing wear.

5. Conclusion

(1)Study found that electrical cyclone cone parts wear features similar to cyclone significantly, but there are differences, mainly is the effect of electric field force increased the amount of erosion wear. Suggested that electric cyclone cone bottom more anti wear measures should be taken, In addition on the premise of meet the dust removal efficiency, should as far as possible to reduce working voltage.

(2) Analysis shows that when the particle size is more than 40μm, the wear rate is accelerated. It is recommended that, the combination of gravity sedimentation and electrostatic cyclone dust collector should be used for larger particles dust airflow，which can effectively extend the service life of the machine.

(3) Through example calculation, comparing the actual operating experience, electricity cyclone reliable formula of wear mechanism and wear rate, and has used reference value

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