PERFORMANCE OF PLATE-ELECTROSTATIC PRECIPITATOR FOR REMOVAL OF R.M.O.C. DUST

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ABSTRACT

The removal of raw material of cement (R.M.O.C) dust from the air was studied by using plate-electrostatic precipitator. The electrostatic precipitator contained three discharge electrodes (diameter 2mm and length 30cm) which was equally divided along the field (a square plate 30×30 cm was used as collection plate while the distance between the plates was (4) cm).

The aim of this study was to find the optimum operating conditions (velocity, voltage, and concentration) which were required to operate the electrostatic precipitator at high efficiency.

When the pilot plant operated in various voltages and constant dust concentration, and air velocity, the optimum value of the voltage was (-13.5) kv, then the system operated in various dust concentrations and constant voltage, and air velocity to obtain the optimum dust concentration which was found to be equal to (0.4) g/m³. If the system operated in various air velocities and constant voltage, and dust concentration, the optimum air velocity would be found to be (0.32) m/s. When the factors were changed below or over the optimum values, the collection efficiency was reduced. The theoretical collection efficiencies were calculated according to log – normal distribution of the particle size, and found to be in good agreement with experimental results.

INTRODUCTION

Separation of suspended particles from gases is one of the basic scientific and technical problems of industrial era, and it has been an increasingly important problem since the latter part of 19th century Control of emissions from industrial source has served the three – fold purpose of :- recovery of material for economic reason, removal of abrasive dust to reduce wear of fan components, and removal of objectionable matter from gases being discharged into the atmosphere. (Oglesby, 1978)

The separation process may be classified broadly as mechanical and electrical . Mechanical processes include all those which depend fundamentally on inertial or mechanical forces namely , gravity settling, centrifugal , or cyclonic separation, gas washing or scrubbing , filtration through screens , fabric bags and packed bed .(whit, 1963), (Calvert, 1984)

The electrical precipitation is the industrial process by which solid particulate waste is removed from stream of exhaust gas. The process uses very high voltages and electrical field to charge the particulate waste , so that the electric force upon the particles cause them to separate from gas .(Andrew,1999), (Norman, 1996), (Crawford, 1976)

Therefore the process is based on three major fundamental steps of electric charging of the suspended particles , collection of the charged particles and removal of the precipitated material. The applied voltage is depended on the capacity of H.V transformer and bridge rectifier set. The applied voltage is either half-wave or full-wave depending on the type of bridge rectifier. (White, 1963), (Lioyd, 1988)

The electric field strength at which corona begins has been studied extensively . In theory , the field required to initiated corona is that which will produce electron energies sufficient to cause ionizing collisions in the gas species present . Obviously , the field required for the initialization of corona discharge will depend on the ionization potential of the gas and the mean free path between collisions. (Oglesby, 1978)

Peek, 1929 established semi – emperical equation for the required electric field to initiate corona discharge in air.

$$E_O = 3*10^6 f\left(\delta + 0.03\sqrt{\frac{\delta}{a}}\right) \qquad (1)$$

So the applied voltage of corona initiation will be:

$$V_o = aE_o \ln\frac{4b}{\pi a} \qquad (2)$$

Equation (2) uses for $b/c \le 0.6$.(Davidson , 2000).

The equations that are used to determine particle charge and electric migration velocity require knowledge of the electric field and number of ions in the inter-electrode space. The electrical field and current distribution in the interelectrode space can be determined by Maxwell's equations. (Davidson, 2000) , (Egli,etal, 1996)

$$\varepsilon\nabla\overline{E} = \rho_C \qquad (3)$$

$$\overline{E} = -\nabla V \qquad (4)$$

$$\nabla\bar{I} = 0 \qquad (5)$$

$$\bar{I} = \rho_C.Z.E$$

Simplify these equation, yield the coupled equations.

$$\nabla^2 V = -\frac{\rho_C}{\varepsilon} \qquad (6)$$

$$\nabla(\rho_C.Z.E) = 0 \qquad (7)$$

The analytical solutions for these equations are impossible in plate electrostatic precipitator because of non-linearly of the differential equations, but the numerical solution may be obtained by finite difference method. (Oglesby, 1978) , (Davidson, 2000).

At a very low current analytical expression for the current – voltage relationship was obtained by –Cooperman, 1960

$$I = \frac{4\pi\varepsilon_0.z}{2L.b^2 \ln d/a} V(V - V_o) \qquad (8)$$

At a high current , the electric field due to space charge is much larger than the electrostatic field. The electrostatic field can be considered uniform and discharge wire are equivalent to a uniformly current – emitting plate .

In this case , the voltage – current relation is described by equation (9) . (Cooperman , 1981).

$$I = \frac{36\pi.\varepsilon_o.c.z}{2L.8.b^3}(V - V_o)^2 \qquad (9)$$

Another approximation for the duct corona case may be found by replacing the corona wire by a uniform – current sheet electrode . This reduce the field – calculation problem to one dimension which may be solved by Poisson's equation. (White, 1963).

$$\nabla^2 V = -\frac{\rho}{\varepsilon_o} \qquad (10)$$

$$\frac{\partial^2 V}{\partial x^2} = \frac{-\partial E}{\partial x} \qquad (11)$$

But, substitution of equation (11) into equation (10) to get:

$$\frac{-\partial E}{\partial x} = \frac{-\rho}{\varepsilon_o} \qquad (12)$$

$$\rho_i = \frac{I}{Z.E} \qquad (13)$$

substitution of equation (13) into equation (12) ,then equation (14) can be obtained.

$$-\frac{dE}{dx} = -\frac{I}{\varepsilon_0.Z.E} \qquad (14)$$

The integration may be effected by elementary means and gives

$$E^2 = \frac{2I}{\varepsilon_o.Z}x + C \qquad (15)$$

Equation (15) will be reasonably valid in the neighborhood of the collecting – plate surfaces. Now let E1 be the field at the plate represents the pure electrostatic field at the plate , and let x = b, for the case of zero corona current . Then C1= E14 and equation (15) becomes: (Davidson,2000) , (Oglesby, 1978)

$$E^2_{plate} = E_1^2 + \frac{2.b.I}{\varepsilon_o.Z} \qquad (16)$$

Where:

$$E_1 = \frac{\pi.V_0}{2.b \ln d/a} \qquad (17)$$

The partial collection efficiency can be determined by Deutch's equation. (Deutch, 1929)

$$\zeta = 1 - \frac{C_L}{C_o} = 1 - \exp\left(\frac{-w.A'}{Q}\right) \qquad (18)$$

Total collection efficiency is depended on the log – normal distribution of the particle size, and can be obtained from the following equation. (Hammodi, 1994), (white, 1963)

$$\zeta_t = 1 - \left(\frac{1}{\sqrt{2.\pi}} \int_{-\infty}^{\infty} e^{-\left(\frac{t^2}{2}\right)} . e^{-kx_g . e^{t \log \sigma_g}} . dt\right) \qquad (19)$$

EXPERIMENTAL WORK

The air is supplied to the system by means of a centrifugal fan. The air flow rate was regulated by means of flat – plate gate in the discharge side of the fan , and measured by means of a pitot tube device. The powder which is consisted of raw materials of cement (R.M.O.C.) was introduced to the mixing chamber by means of screw conveyor from small conical hopper. The powder was suspended by eddies of the air and the high speed agitators in the mixing chamber.

The redispersed dust was directed to the electrostatic precipitator unit to be collected on the collection plates of electrostatic precipitator , and the remaining dust was captured by means of the bag filter which was placed in the exit of the fan.

A sampled dust was taken from the system by means of vacuum pump through sampling train . The samples were examined to determine the particle size distribution by using optical microscope.

The main dust and air properties used in this work was presented in table (1) three steel wires with four edges for each one were used as discharge electrodes with diameter was equal to 2mmas shown in figure 1. E.S.P of a single cell is used with space between the collection plate was equal to 4cm, and wire to wire spacing was equal to 10cm, and aspect ratio was equal to one as shown in figure 2.

Table (1) properties of dust and air

Dust			Air		
$C_o \frac{g}{m^3}$	$\rho_p \frac{g}{cm^3}$	$\overline{\varepsilon}$	Ta C°	$U \frac{m}{s}$	$Z \frac{m^2}{v.s}$
0.2-2	2.75	4	30	0.1-2.5	1.4×10^{-4}

Fig. (1), Geometry of Corona discharge wire

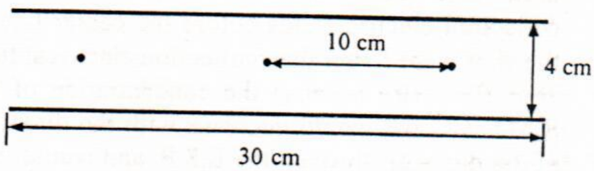

Fig. (2), Schematic diagram of geometrical dimensions of E.S.P unit

RESULTS AND DISCUSSION

Effect Applied Voltage

Corona current

When the applied voltage was increased ,the corona current and electric field were increased , therefore, the collection efficiency was increased . The corona current was changed experimentally in two cases as follows :

a- When the influent stream contained clean air ;

b- When the influent stream contained dusting air.

If the influent stream contained clean air, the current would increase more than the current in the second case as shown in figure (3), because of the mobility of the charge carrier in the first case depended on the air ions, While in the second case depended on the air ions, and dust particles. The optimum value of the corona current density was obtained to be equal to (2718) $\frac{\mu_A}{m^2}$ under effect of the dusty air.

Electric field

The experimental results of electric field gave two different behaviors as follows:-

a- Distribution of electric fields toward the collection plate.

b- Distribution of electric field with air flow direction.

In the first behavior electric field would decrease toward the collection plate, then increased in the region adjacent to the collection plate. That was because of the space charge density which was generated by accumulation of ions and charged particles in this region as shown in the figures (4).

In the second behavior the electric field would decrease , when it moved far away from the center line of corona electrode along the collection plate until half point wire to wire spacing. The collection electric fields before the center line of the wire were larger than collection electrical field after the wire because the concentration of the R.M.O.C. dust would decrease with the direction of the dusty air through the E.S.P. and would lead to decrease the space charge density of the particle along this line as shown in figure (5).

Collection efficiency

According to the change in the voltage, corona current and electric field the collection efficiency was changed. The experimental collection efficiency was increased with increasing the applied voltage , until it reached the optimum range . The optimum value of the applied voltage was equal to (-13.5) kv, where the efficiency was maximized . The efficiency would be reduced when the voltage increased above the optimum value because of the spark over voltage was reaching as shown (6).

Effect of R.M.O.C. Dust Concentrations

Variation of R.M.O.C dust concentration would affect the charges which attached to the surface of the particle . Where the space charge associated with each particles was equal to(N_o/N_p) , where N_p is the average number of particle per unit volume, and N_o is the ion density . This ratio vary from 1 to 10 , or to 100 .(Smith, 1975)

The optimum number of particles obtained when the R.M.O.C. dust concentration through the E.S.P. was equal to (0.4) g/m^3. When the concentration was increased , the number of particles per unit volume were also increased in the same range of the particle size and applied voltage. If the ratio (N_o/N_p) was decreased , the collection efficiency would be reduced, as shown in figure (7).

Effect of air Velocity

The velocity was an important factor affecting the performance of the E.S.P.. Effect of the velocity might be taken in three different manners as follows :

a- The retention time of the particle inside the electrostatic precipitator could be controlled by changing the velocity of the air.

b- Re-entrainment of the collected dust on the collection plate was directly affected by the velocity.

c- Gravitational settling was increased with decreasing the velocity .

The optimum velocity was found to be equal to (0.32) m/s as show in figure (8).

CONCLUSIONS

1. The concentration of the R.M.O.C. dust would affect the performance of E.s.p.
2. The spark over phenomena would lead to reduce the collection efficiency of E.S.P. Therefore the applied voltage was always lower than the spark over voltage.
3. Increasing of the gas velocity would reduce the collection efficiency because OF increasing the reentrainment of collected dust and reducing of the retention time through E.S.P.
4. Reducing of the gas velocity below the optimum velocity would lead to increase the gravitational setting of dust through the space of E.S.P. and connection dusts.
5. The resistivity of R.M.O.C. dust at 30C$^\circ$ was in a good range (4.3*10^{10} ohm. cm) to achieve the optimum performance of E.S.P.
6. The collected dust on the collection plate was not uniform because of the corona discharge was not continuously distributed but occurred in localized brushs along the discharge electrode.

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NOMENCLATURE

a	radius Corona wire (m).
A'	collection area (m^2).
b	wire to plate spacing (m).
2c	wire to wire spacing (m).
C_C	integration constant.
C_o	initial dust concentration at entrance of E.S.P. (g/m^3).
d	geometrical factor of E.S.P. ($d = \frac{4b}{\pi}$ for $\frac{b}{c}$).
E.S.P.	Electrostatic precipitator.
E_1	pure electrostatic field ($\frac{V}{m}$).
E_p	electric field at collection plate ($\frac{V}{m}$).
$\overline{E}$	electric field vector (v/m).
E_o	electric field for initiating of corona discharge ($\frac{V}{m}$).
f	roughness factor of the wire surface (acceptable value = 0.6).
I	current density ($\frac{\mu A}{m^2}$).
$\overline{I}$	current density vector ($\frac{\mu A}{m^2}$).
K	numerical factor of migration velocity (1/m).
L	wire to wire spacing is equal to 2C in (m).
p	air pressure at (atm).
p_o	reference air pressure (atm).
Q	volumetric flow rate (m^3/s).
R.M.O.C.	Raw Martial of cement.
T_a	air temperature (C).
T_o	reference temperature (k).
T	Actual temperature of the air (k).
t	statistical variable .
u	Air velocity through the E.S.P. (m/s).
V_o	applied voltage of corona initiation (V).
V	applied voltage (V).
X	Direction of electric field toward the collection plate (m).
X_g	Geometrical mean diameter (m).
Z	mobility of charges carriers as average ($m^2/v.s$).
εo	permitivity of free space ($8.85 * 10^{-12} \frac{c}{v.m}$).
$\overline{\varepsilon}$	ddielectric constant .
δ	relative air density ($\delta = \frac{T_o \cdot p}{T \cdot p_o}$).
ρ_c	space charge density (C/m^3).
ρ_p	particulate density (g/m^3).
ω	migration velocity.
σ_g	geometrical standard deviation.
εp	partial collection efficiency.
εt	total collection efficiency.

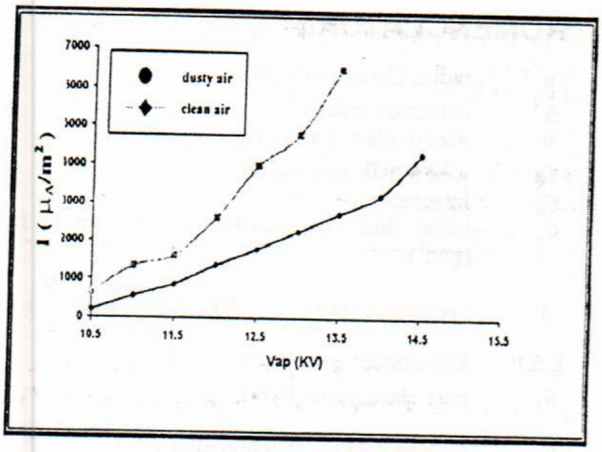

Fig. (3), Current-voltage characteristics for clean and dusty air (experimental results)

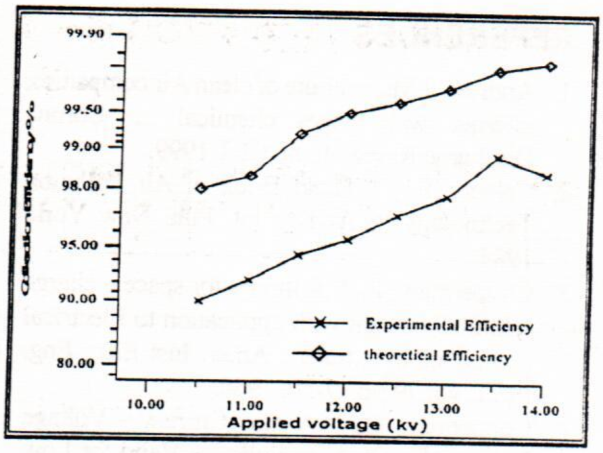

Fig. (6) Variation of the collection efficiency with applied voltage

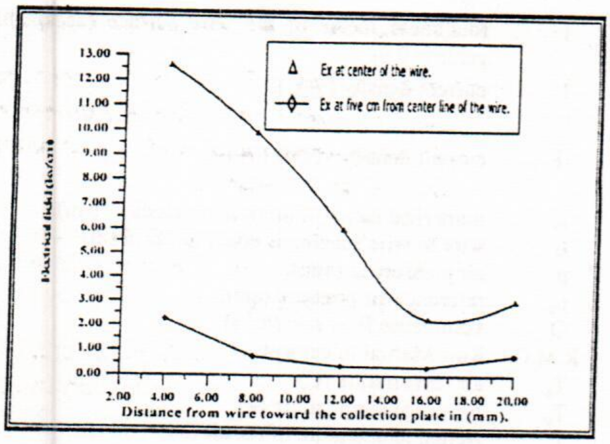

Fig. (4), Electrical field from the center line of the wire toward the collection plate

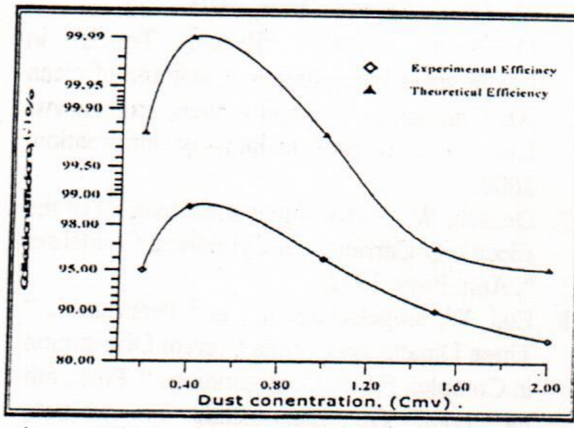

Fig. (7), Variation of the collection efficiency with R.M.O.C. dust concentration

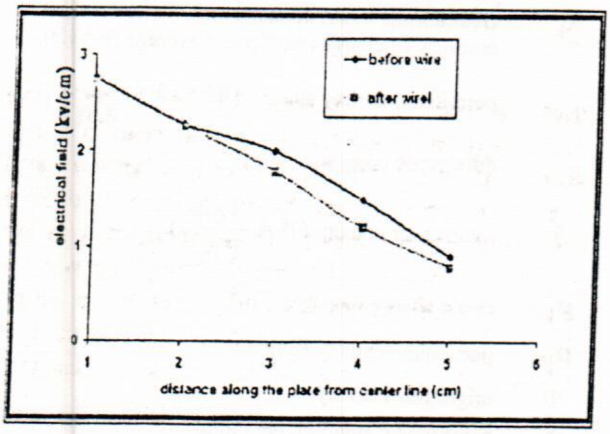

Fig. (5), Electrical fields before and after the center line of a wire along the collection plate

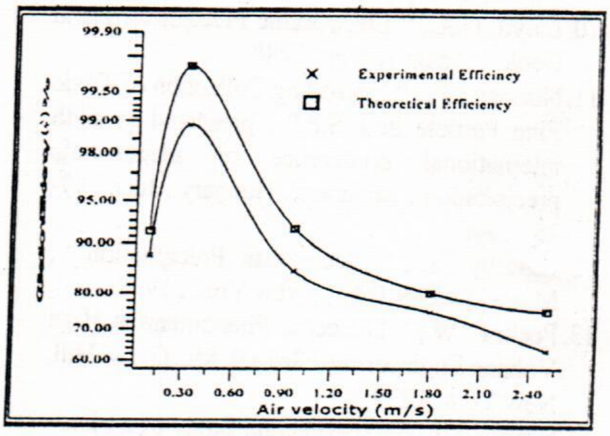

Fig. (6) Variation of the collection efficiency with air velocity