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IMPACT OF THE DESIGN OF DISCHARGE ELECTRODE ON THE CURRENT/VOLTAGE CHARACTERISTICS AND THE RATE OF MIGRATION IN ELECTROSTATIC PRECIPITATION (ESP)

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Efficient removal of submicronic particles is a major challenge in off-gas purification. Due to the diverse nature of chemicals produced and the chemical nature of several air born particulates (aerosols), removal by filtration and/or dry electrostatic precipitation may cause efficiency and liability problems. Problems may arise in off-gas purification of high temperature processes like off-gases from steel mills, manufacturing of multi component composite materials, thermo-mechanical treatment of materials and incineration processes. Rapid changes of thermodynamic states may also cause a high rate of particle formation with limited or negligible growth in size. Wet electrostatic precipitation has found specific application in this field of off-gas purification. In principle three different types of wet electrostatic precipitators are offered on the market. The tube-type electrostatic precipitator is either operated with intermittent or continuous flushing of the collecting electrodes or it is operated with rinsing by condensation. The effect of discharge electrode design on the current/voltage characteristics with specific consideration of the effect on the corona onset field intensity is being investigated in this research project.

Keywords: Discharge electrode, Rate of migration, Collection efficiency, Electrostatic precipitation, Off gas purification

1. Introduction

Industrial and population growth on the globe is increasing day by day. Therefore demand of energy is also increasing. Major portion of energy is coming and will come from fossil fuels (especially solid and liquid fuels) which are the source of major pollutants such as particulate matter, organic and inorganic constituents as the source of acid rain, photochemical smog, deforestation, global warming, and ultimate effects on the human health, terrestric and aquatic life.

Electrostatic precipitation has been invented about a hundred years ago [1]. Due to the high operation cost and the limited applicability of dry electrostatic precipitation [2, 3] alternative technologies such as bag filtration covers the needs of the market. To achieve the Kyoto protocol emission targets and to face the strict environmental legislation for hazardous pollutants along with fine particles, we have need for efficient processes to mitigate also pollutants from off-gas which can not be precipitated by state of the art processes such as filtration. In dry electrostatic precipitators there are several efficiency problems to consider highly conductive particles [4, 5] tend to redispersion from collecting electrode [6] to [9]due to loss of charge particles with insulating properties may cause a break down of the electrical field. Wet tube type electrostatic precipitators have potential to separate low density particulate matter, aerosols and sticky constituents from off-gas [10] without limitation by the specific conductivity of the particulate constituent.

In electrostatic precipitation aerosols are ionized in the Passive zone [11] and then collected at the collecting electrode. Mechanism of ionization in wet tube type electrostatic precipitator is more efficient due to homogenous corona field intensity. The rate of migration and the collection efficiency are the performance indicators of ESPs. They mainly depend on the design, the geometry and the position of the discharge electrode [12, 13].

2. Material and Method

2.1. Material

For plate type wet ESPs

Plate distance 60 mm

Discharge Electrodes; Tungsten wire of 0.2mm

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diameter is used in three planes.

Distance in planes was 120mm.

Plate material; SS.316

Scrubbing liquid: water

Scrubbing liquid flow rate: 1.2 m^3/hr and per meter length of precipitation plates.

Same material of construction is used for wet tube type ESP.

2.2. Method

Raw gas containing ultrafine particle (uniformly distributed) entered from the bottom of ESP and the velocity of gas was less then 2m/sec and purified gas was obtained from the top. Scrubbing water is used to remove the particles continuously from the surface of the collecting electrodes.

3. Design Basics and Effect of Different Parameters

Corona discharge of an electrostatic field is initiated by exceeding the critical corona field intensity E_o. For given radius r of the discharge electrode and the relative density δ of the gas the corona starting field intensity E_0 can be estimated empirically, as shown by equation 1.

$$E_o = 3000 \cdot \delta + 90 \cdot \sqrt{\frac{\delta}{r}} [KV/m] \quad (1)$$

With

$$\delta = \frac{T_o \cdot P}{T \cdot P_o}$$

T_o 293 [K]

P_o 1013 [h Pa]

T Temperature of gas (K)

P Pressure of gas (h Pa)

r radius of the discharge electrode [m]

Based on electrostatic SI-units we may apply the following conversion factors:

$$1KV = 1 \cdot 05 \cdot 10^{-2} \left[\frac{\sqrt{kg \cdot m}}{s} \right]$$

$$1A = 9 \cdot 49 \cdot 10^{4} \left[\frac{kg^{0 \cdot 5} \cdot m^{1 \cdot 5}}{s^2} \right]$$

The conversion factors are based on the convention:

$$1ESL = 1\sqrt{dyn} \cdot cm$$

$$1C = 3 \cdot 10^{9} ESL$$

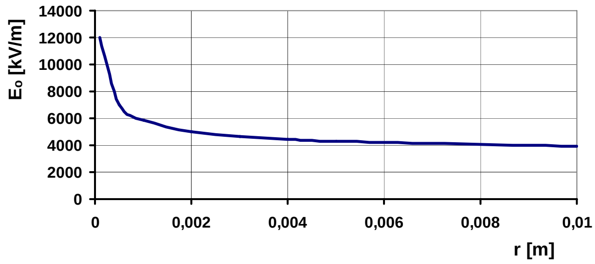

Figure 1. Dependence of Corona field intensity on radius of the discharge electrode.

After having estimated the corona starting field intensity E_o the corona starting voltage U_o can be calculated with equation 2.

$$U_o = E \cdot r \cdot Ln\left(\frac{R}{r}\right) \left[\frac{\sqrt{Kg \cdot m}}{s^{-1}} \right] \quad (2)$$

R radius of the collector tube [m]

and for the plate type ESP

$$U_o = E \cdot r \cdot Ln\left(\frac{2 \cdot b}{\pi \cdot r}\right) \left[\frac{\sqrt{Kg \cdot m}}{s^{-1}} \right] \quad (2\text{-a})$$

From Equations 2 and 2a the comparison between tube and plate type ESP when the radius of discharge electrode, distance between two electrodes and relative gas density is of same size, can be derived. Difference in voltage indicates the impact on the corona current and migration velocity of aerosols.

Due to uniform and therefore high density corona in tube type electrostatic precipitators an efficient ionization is possible.

Table 1 shows the comparison of corona onset voltage in tube and plate type ESP with same wire radius, same distance between electrodes and at constant relative gas density.

Table 1. Comparison of corona onset voltage in tube and plate type ESP with same wire radius and distance between electrodes.

δ	r (m)	Eo (KV/m)	R(m)	U_t (KV)	U_p (KV)	Difference(KV)
1	0.0001	12000	0.06	7.67	7	0.67
1	0.0005	7024	0.06	16.81	15	1.81
1	0.002	5012	0.06	34.09	30	4.09
1	0.003	4643	0.06	41.72	35	6.72
1	0.004	4423	0.06	47.91	40	7.91
1	0.005	4272	0.06	53.02	43	10.02
1	0.006	4161	0.06	57.49	44	13.49
1	0.007	4075	0.06	61.29	49	12.29
1	0.008	4006	0.06	64.57	50	14.57
1	0.01	3900	0.06	69.87	52	17.87

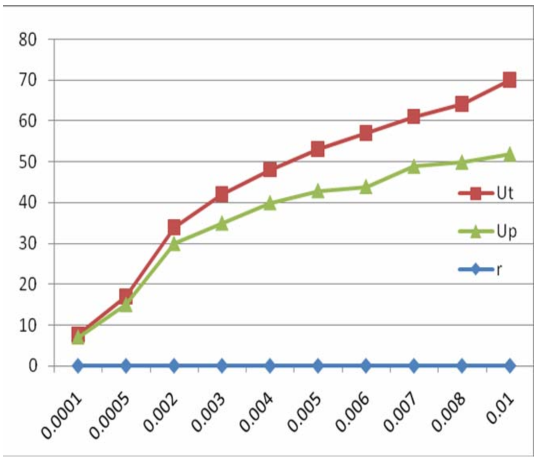

Figure 2. Shows the difference in Voltage (kV) in plate and tube type ESP at same radius (m) of discharge electrode.

At low current density the specific corona current I [m A/m] is evaluated with equation 3.

$$I\left[\frac{\sqrt{kg*m}}{s^2}\right]=\frac{U_{op}*2*K*\left(U_{op}-U_0\right)}{R^2*\ln\left(\frac{R}{r_0}\right)} \qquad (3)$$

With the ion mobility K

K = 17 to 21 [m1.5 kg-0.5]

and given operation voltage U

U = operation voltage [kg0.5 m0.5 s-1]

And for plate type ESP

$$I\left[\frac{\sqrt{kg*m}}{s^2}\right]=\frac{U_{op}*K*\left(U_{op}-U_0\right)}{b^2*\ln\left(\frac{4*b}{r_0\pi}\right)} \qquad (3\text{-a})$$

From equation (3) and (3-a), the corona current is calculated.

Rate of migration and collection efficiency is a function of corona current, area of collecting electrode, gas flux and particle size.

$$W(x)=f(A/F_v,I)$$

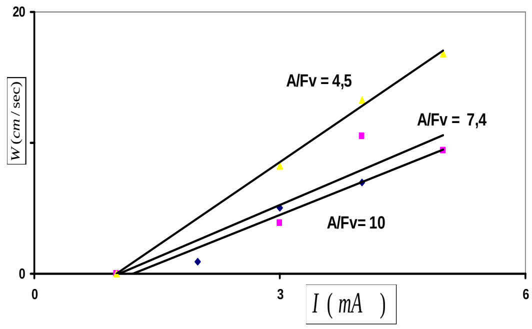

Figure 3. Shows the dependency of rate of migration on current and A/F.

The grade precipitation efficiency T(x) is derived from the Deutsch equation, as represented by equation 4.

$$T(x)=1-\frac{C(x)L}{C(x)E}=1-\exp\left(\frac{-2\cdot w(x)\cdot L}{R\cdot V}\right) \qquad (4)$$

With

T(x) grade precipitation efficiency

C(x)L particle content of the off-gas at the exit of the precipitator

C(x)E grade particle content of the off-gas at the outlet of the precipitator

W (x) particle migration velocity

V gas velocity

L length of the precipitator

x particle size

For given operation voltage according to equations 2 and 2-a.

The migration velocity w(x) is calculated with equation 5.

$$w(x) = \frac{E_a \cdot E_p \cdot d}{4 \cdot \pi \cdot r}\left[\frac{m}{sec}\right] \quad (5)$$

With

E_a discharge field strength [$kg^{0.5}$ $m^{0.5}$ s^{-1}]

E_p precipitation field strength [$kg^{0.5}$ $m^{0.5}$ s^{-1}]

d particle diameter [m]

η Dynamic viscosity of the gas [Pas]

For plain discharge electrodes with small diameter (< 1 mm), the discharge field intensity is proportional to the corona starting field intensity E o 5.

The precipitation field intensity Ep is derived from the empirically evaluated equation 6.

$$E_p = \sqrt{\frac{2 \cdot I}{K}} \quad (6)$$

4. Discussion

Figure 1 shows that the corona onset field intensity is inversely related to the radius of the discharge electrode. With the increase in diameter of discharge wire radius, corona onset field intensity will be less and ultimately have a limiting effect on collection efficiency.

Difference in voltage produced in plate and wet tube type electrostatic precipitator under the same operating conditions and parameters shows that wet tube type electrostatic precipitator has more collection efficiency then the plate type ESP.

Figure 2 shows that the corona onset voltage is directly related to radius of discharge electrode. With the increase in radius of discharge wire electrode, corona onset voltage is increases and has a negative effect on corona current on set voltage for given operation voltage according to equations 2 and 2-a.

Figure 3 shows that the rate of migration is dependent on the corona current, area of collecting electrode and gas flux. At constant velocity we changed the position of discharge electrode which actually increases or decreases the collection area in plate type electrostatic precipitator. At higher A/Fv value we observed a decreased limited rate of migration when comparing the collection efficiency with the Deutsch equation because of loss of charged particles at elongated position.

4. Conclusions

Novel fibres and surface coatings enable a broad field of application for bag filters. Nevertheless wet electrostatic precipitation has still a domain in off-gas purification. Target of this project is the investigation of the effect of the shape of discharge electrodes on operation of tube type electrostatic precipitators. Equation 1, an empirical correlation of the corona onset field intensity with the electrode geometry and the off-gas composition will be subject of improving the design algorithm.

Equation 2 & 3 the empirical correlation of corona onset voltage and current density with the radius of discharge electrode having the direct relation which ultimately influence the migration velocity and collection efficiency of dust particle in the off-gas.

Collection efficiency of wet tube type electrostatic precipitators is better then of plate type ESP because of its more homogeneous corona and effective mechanism of particle ionization in passive zone for comparable geometric boundaries while the radius of discharge electrode is same.

List of Symbols and Abbreviations

b Distance between discharge electrode and collector [m]

δ Relative density of the gas

η Dynamic viscosity of the gas [Pas]

E_o Corona starting field intensity [kV/m]

E_p Precipitation field intensity [kV/m]

E_a Discharge field intensity [kV/m]

I Specific Corona current [A/m]

K Particle mobility [Vs/m2]

r Radius of the discharge electrode [m]

U Voltage of Operation [kV]

U_p Voltage for plate type

U_t Voltage for tube type

U_o Corona starting voltage [kV]

V Gas velocity [m/s]

w Particle migration velocity [m/s]

b Distance between two electrode

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