Journal of Electrostatics 80 (2016) 85–94

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Electrical characteristics of electrostatic precipitator with a wet membrane-based collecting electrode

Xiang Wang [a], Jingcai Chang [a, b], Chunyan Xu [a], Peng Wang [a], Lin Cui [a], Chunyuan Ma [a, *]

[a] National Engineering Laboratory for Coal-Fired Pollutants Emission Reduction, Jinan 250061, PR China
[b] Shandong Shenhua Shanda Energy & Environment Co.Ltd., PR China

A R T I C L E I N F O

Article history:
Received 21 September 2015
Received in revised form
12 January 2016
Accepted 11 February 2016
Available online 26 February 2016

Keywords:
Electrostatic precipitator
Membranes collecting electrode
Polypropylene
Discharge current density
Collection efficiency

A B S T R A C T

Electrostatic precipitators (ESPs) with the wet membrane-based collecting electrode play an important role on the flue gas cleaning process. However, the mechanism researches on the excellent collection efficiency of the membrane-based ESPs are insufficient. This paper aims at characterizing the excellent collection efficiency of the ESPs in the aspect of the electrical characteristics. The discharge current density and distribution of the metal and wet membranes collecting electrode were measured using the boundary probe method under different conditions. The differences of the discharge current density and distribution between the wet membranes collecting electrode and the metal one were discussed in detail. In addition, the effects of applied voltage, distance between the electrodes and discharge electrode construction on the difference of the discharge current density between the wet membranes electrode and the metal one were also presented. The results show that the discharge current density is strongly increased by the wet membranes electrode, the increased discharge current density is the main reason for the excellent collection efficiency of the membrane-based WESPs.

1. Introduction

Electrostatic precipitators (ESPs) are widely used to reduce the emissions of smoke, fumes and dust [1] because of the low pressure drop, low energy consumption, high collection efficiency and long service life. However, many current ESPs cannot be adequate to address the challenges of fine particulate collection [2]. The Wet electrostatic precipitators (WESPs) have exhibited good control of fine particulate as well as the sulfuric acid aerosols, heavy metals [3–5] in field applications. Among them, the membrane-based WESPs are widely used in recent years because of more efficient, corrosion resistant, light weight and uniform water distribution [6]. The WESPs operate on the same principles as the dry ESPs and the working processes are consistent [7,8].

The discharge current density and distribution of the collecting electrode are the major parameters of the electrical characteristics of the ESPs because of two reasons. Firstly, the discharge current density is in direct proportion with the corona power [9]. A higher corona power may lead to a more effective particle charging and the charged particle can deposit onto the collecting electrode surface quickly. Secondly, the non-uniform distribution of discharge current density of the collecting electrode may lead to a "back-corona" for the high resistivity ash in the dry ESPs. However, the collected ash on the collecting electrode is intermittently cleaned by the flowing water in the WESPs, preventing "back-corona". Therefore, the discharge current density of the collecting electrode is the main parameter of electrical characteristics of the WESPs.

There have been many experimental studies on the electrical characteristics of the ESPs performed in the laboratory as well as in industry. The experimental studies of M. Jedrusik [10]determined the optimal discharge electrode construction by testing the discharge current distribution of the collecting electrode. The increased discharge current density as well as the uniform distribution contributes to high collection efficiency. H. Nouri [11] analyzed the effect of relative humidity (RH) on the voltage–current (*V*–*I*) characteristics of an ESP and further research is in progress on the RH effects on the collection efficiency. M. Jedrusik [12] and D. Blanchard [13] found that the pattern of the collected ash is strongly correlated with the discharge current distribution of the collecting electrode. All of the researches indicate that it is practical to estimate the collection efficiency by testing discharge current density and distribution of the collecting electrode.

---

* Corresponding author.
E-mail addresses: rickwangx@139.com (X. Wang), sdetechym@163.com (C. Ma).

http://dx.doi.org/10.1016/j.elstat.2016.02.003

The particulate collection efficiency of the ESPs equipped with the wet membranes collecting electrode was measured to exceed that of the metal one under the same conditions [6,14,15]. However, the reasons for the excellent collection efficiency of the ESPs is mainly concentrate on the effective control of the re-entrainment. The effect of the wet membranes collecting electrode on the electrical characteristics of the ESPs is not clear. In this paper, a comparison of the electrical characteristics between the ESPs with the wet membranes collecting electrode and the metal one is analyzed and discussed. Then we characterized the excellent collection efficiency of the wet membrane-based WESPs in the aspect of the electrical characteristics.

2. Theoretical basics

2.1. The collection efficiency

The collection efficiency of the ESP can be estimated from the Deutch equation (1) as follows:

$$\eta = 1 - e^{-\omega A/Q} \tag{1}$$

Where ω is the migration velocity of the particulate, A is the surface area of collecting electrode and Q is the gas flow rate.

2.2. The theoretical migration velocity

The particulates motion in the ESP is defined by the vector equation and it is balance of forces:

$$F_e - F_c - F_i = 0 \tag{2}$$

Where F_e is the electrostatic force, F_c is the viscous force and F_i is the inertia force.

There is a non-uniform electrical field between the electrodes when a high voltage is applied to the discharge electrode, the non-uniform electrical field can be divided into three regions according to the field intensity. The ionization region closed to discharge electrode and the field intensity is high enough to ionize the gas and there are a lot of electrons and positive ions in this region. While, in the region of charging, the electrons adsorb on the gas molecule and forming the anions, the particulates are charged by collision with the anions in the region of discharging. In the region of collecting, the charged particulates are driven to the collecting electrode by the electrostatic force while the viscous force resists the motion.

Normally, the electrostatic and viscous force can reach equilibrium in a short time compared with the time of the particulates in the ESPs. After reaching equilibrium, the particulates move to the collecting electrode at the uniform speed. In that case, the field intensity of the collecting region is uniform and approximately equal to that of the collecting electrode, then the inertia force $F_i = 0$, Eq. (2) can be simplified as Eq. (3).

$$F_e - F_c = 0 \tag{3}$$

F_e can be deduced from the conclusions of Coulomb's theorem, while F_c is given by Stokes equation:

$$F_e = qE_p \tag{4}$$

$$F_c = \frac{6\mu\pi\omega r}{C} \tag{5}$$

Where q is the charge of the particulates, ω is the migration velocity, E_p is the field intensity of collecting region, μ is the gas dynamic viscosity, r is the particulate radius and C is the Cunningham correction factor.

The Cunningham correction factor becomes significant when particulates become smaller than 15 μm [16]. The correction factor C is calculated as following [17]:

$$C = 1 + \frac{\lambda}{r}\left[1.257 + 0.4e^{\left(-1.1\frac{r}{\lambda}\right)}\right] \tag{6}$$

Substituting Eq. (4) & Eq. (5) into Eq. (3) leads to:

$$\omega = \frac{CqE_p}{6\mu r\pi} \tag{7}$$

The migration velocity ω is a key factor of the collection efficiency, Eq. (7) indicates several possible means of increasing the migration velocity ω, mainly by increasing the charges of the particle q and the field intensity E_p or decreasing the gas dynamic viscosity μ.

Theoretically, assuming the mechanism of field-induced charging dominates in the ESPs. The saturation charge q achieved by a particulate of radius r can be defined as the formula [18]:

$$q = 4E_c\pi\varepsilon_0 r^2\left\{\left(1+\frac{\lambda}{r}\right) + \frac{2}{1+\lambda/r}\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right)\right\} \tag{8}$$

Where ε_0 is the permittivity of vacuum, ε_r is the relative permittivity of the particulate, λ is the particulate free path and E_c is the field intensity of charging region.

In summary, the migration velocity ω of particulate in the electrical field is governed by the field intensity of charging and collecting region.

2.3. The field intensity

A pipe was chosen as the discharge electrode in the electric field and the pipes were arranged with an equal distance from one pipe to the neighboring pipe (Fig. 1). The field intensity of the collecting region in the X direction can be assumed to be a constant because of the arrangement of the discharge electrodes.

Based on the hypothesis, a two-dimensional closed surface S with a width of dz and length of L was chosen on the collecting electrode. The field intensity E was calculated according to Gauss's theorem:

$$\oint \vec{E}\cdot d\vec{s} = \oint Eds\cdot cos\theta = \frac{P''}{\varepsilon_0} \tag{9}$$

Where θ is the angle between the field intensity E and the normal to

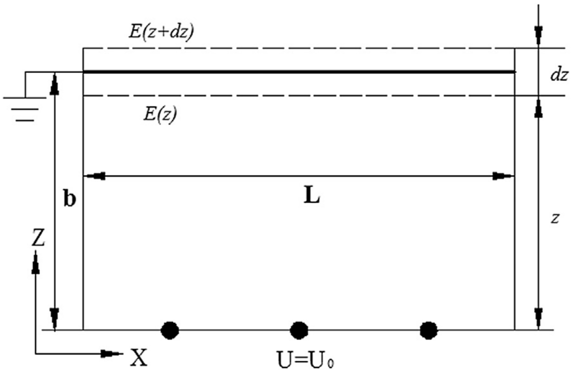

Fig. 1. The electric field between the discharge and collecting electrode.