Journal of Electrostatics 83 (2016) 7–15

Contents lists available at ScienceDirect

Journal of Electrostatics

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

Study of a new electrostatic precipitator with asymmetrical wire-to-cylinder configuration for cement particles collection

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ARTICLE INFO

Article history:
Received 19 April 2016
Received in revised form
9 June 2016
Accepted 2 July 2016

Keywords:
Electrostatic precipitator
Corona discharge
High resistivity particles
Asymmetrical geometry
Collection efficiency

ABSTRACT

In this paper, a new electrostatic precipitator (ESP) with asymmetrical wire-to-cylinder configuration is investigated experimentally and numerically. The main objective is to evaluate the collection efficiency of high resistivity particles.

The electrical measurements show that the corona discharge behavior is similar to that obtained in symmetrical wire-to-cylinder configuration. Results show that the collection efficiency can reach 95% in the case of negative corona discharge.

In order to understand the particle trajectories inside the ESP, the experimental results are compared with numerical simulation by using a coupled model. Numerical results indicate that particles can be collected on the collecting electrode backside.

1. Introduction

Suspended particles in the air, so-called particulate matter (PM), are liquid or solid aerosols generated from various natural and anthropogenic sources. Their diameter varies from 0.005 μm to 100 μm, but the suspended portion is generally less than 40 μm in diameter [1]. The finest particles PM_{10} (<10 μm) and $PM_{2.5}$ (<2.5 μm) are harmful to human health because they can penetrate deeper into the lungs. The smallest fraction is capable to reach the bloodstream. They are responsible of a several diseases like chronic respiratory illness and various types of cancers [2,3].

Cement manufacturing processes eject an important concentration of particulate matter with various sizes and chemical compositions, which causes several health problems especially to people who are subjected to continuous exposure [2].

Many cleaning devices are used to remove the particulate dust from the polluted gas. They have the same operation principle: the application of external forces (electric, centrifugal, gravity) to the gas flow in order to separate the particles from the primary gas stream. These devices include cyclones, scrubbers, fabric filters and electrostatic precipitators (ESPs). Cyclones are based on centrifugal forces created by the passage of the gas stream into spiral motion. Scrubbers or wet collection systems promote the collision between the particles and water droplets to separate them from the gas stream. In fabric filters, the particles are subjected to several forces allowing their collection: impaction, direct interception and diffusion. Finally, the ESPs use the electric force to separate the particles from the gas. The particles diameter is the principal parameter to choose the appropriate device from those mentioned above, because of the dependence between collection efficiency and particle diameter for each device [4].

The electrostatic precipitators are widely used to reduce the particulate emissions from large industrial process plant. Fundamentally, an ESP eliminates the dust particle from the polluted gas by charging the particles with ions generated from a corona discharge. The charged particles migrate towards the collecting electrodes under the effect of the electric field created by the potential difference between the high voltage and the grounded electrodes [5,6]. Compared to other treatment devices, an ESP offers high collection efficiency even for ultrafine particles, low-pressure drop and low operating costs.

The ESPs can be classified according to the collecting electrode

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http://dx.doi.org/10.1016/j.elstat.2016.07.001

geometry (cylindrical or planar type), the direction of gas flow (vertical or horizontal flow), and particles recuperation system (dry ESPs using rappers or wet ESPs using water) [6,7].

Recently, an innovative electrostatic precipitator have been developed based on moving electrode (MEEP) and rotary brush to remove the collected dust [8,9]. This device meets the need of some factories that eject high resistive dust particles in order to resolve the problem of re-entrainment due to back corona discharge.

One of the simplest and interesting new geometry that allows the movement of the collection electrode is the use of an asymmetrical wire-to-cylinder ESP. The particles are charged due to the corona discharge generated near the wire connected to the high voltage. Then, they are collected on the whole surface of the cylindrical collection electrode. Thus, the rotation of the cylinder enables the homogenization of the dust layer and the cleaning of the surface using a static brush.

In this paper, the asymmetrical wire-to-cylinder ESP is studied experimentally and numerically in order to evaluate the collection efficiency in a static situation (the cylinder is immobile) and to understand the particle trajectories in such configuration.

First, the current-voltage characteristics are measured with and without the presence of particles for both positive and negative polarities. Then, the collection efficiency of cement particle under various electrical conditions is investigated by means of an aerosol spectrometer that measures the particle size distribution at the ESP outlet.

The numerical simulation of particle trajectories in the asymmetrical wire-to-cylinder ESP is elaborated with a coupled model using commercial software (COMSOL Multiphysics). This multiphysics software is based on the finite element method. It contains all the important phenomena affecting the electrostatic precipitation process: electric field, space charge density, particle charging, and particle flow.

Corona discharge current and collection efficiency obtained experimentally will be compared to numerical simulation for validation. Then, particle trajectories in the inter electrode space are carried out numerically to understand the main parameters that affect the performance of an asymmetrical wire-to-cylinder ESP.

In the first part of this paper, the experimental setup is described. Then, results concerning the discharge characteristics and the collection efficiency are discussed. Afterward, the numerical simulation results are presented and compared with the experimental data. Finally, conclusions are summarized.

2. Experimental setup

The schematic representation of the asymmetrical wire-to-cylinder ESP used in this investigation is shown in Fig. 1. The high voltage electrode consists of stainless steel wire (0.2 mm-diameter and 132 mm-length). The collecting electrode made of stainless steel cylinder (50 mm-diameter) is connected to ground and placed at about 30 mm from the high voltage electrode. The origin of the coordinates corresponds to the center of the wire and the airflow is directed from the wire toward the cylinder (OX direction).

The complete experimental bench illustrated in Fig. 2 is divided into 4 parts: the power supply unit, the particle detection instrumentation, the particle supply and the wind tunnel.

2.1. Power supply section

In this study, both positive and negative dc high voltage polarities are used. The dc high voltage is provided by two power supplies for each polarity (Spellman SL 1200, +100 kV, +12 mA for positive voltage and Spellman SL 150, −40 kV, −3.75 mA for negative one) with an accuracy of 0.1 kV. They are protected by a ballast resistor of 10 kΩ. The time-averaged current is measured using a digital multimeter.

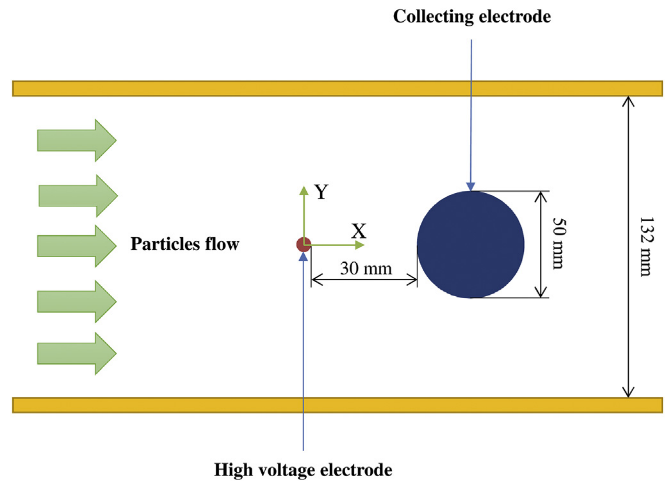

Fig. 1. Schematic representation of the ESP.

2.2. Particle supply section

In order to analyze the ESP performance, cement particles are introduced into the wind tunnel through a dust feeder. They are generated by using an industrial dust generator (Topas SAG, model 410) that allows the dosing and the dispersing of powders with mass output range from 0.05 to 6000 g h^{-1}.

The cement particles used for the experiments underwent a size classification using an automatic sieving device (Endecotts, model Octagon 200). Several classification levels are carried out between 0.1 and 150 μm. For our experiments, only the particles with size less than 32 μm are used to feed the dust generator.

2.3. Particle detection section

Inside the ESP, the particles are electrically charged and collected on the cylindrical electrode. In order to calculate the collection efficiency of the ESP, the particle concentration in the exhaust gas sample is measured using an aerosol spectrometer (Pallas, Model Wellas-1000, sensor range of 0.18–40 μm, concentration up to 10^5 particles cm^{-3}). The counting technique is based on the use of a white light source. A small measurement volume defined optically is illuminated with white light to analyze the scattered light and determine the number and size of particles. The counting system includes four main organs: the optical assemble, the electronic circuitry, the pump unit and the cooling device.

2.4. Wind tunnel section

The experiments are conducted in a wind tunnel made of polymethyl methacrylate (PMMA). The test section of the wind tunnel has a square section (132 mm-width and 132 mm-height). The length of the overall tunnel is about 2 m. A centrifugal fan, controlled by a speed regulated motor, generates a time averaged velocity (U_o) within the test section of about 0.1 m s^{-1}. Flow measurements are undertaken to obtain this velocity by using a hot wire anemometer (Testo, model 405-V1, 10 m s^{-1} full scale, and a resolution of 0.01 m s^{-1}).

All the experiments are conducted in normal atmospheric conditions of temperature and pressure.