



Effects of geometric parameters and electric indexes on performance of a vertical wet electrostatic precipitator



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ABSTRACT

A single-stage, single-wire vertical wet electrostatic precipitator was designed and operated in air–water droplets flow to investigate its performance. The efficiency was compared with a glass micro fiber filter and proposed semi-empirical efficiency model, which was in good accuracy while considering the vapor content. Effects of geometric parameters on efficiency under different charge conditions were discussed. Due to evaporation mechanism, the corona current decreases for high flow rates at the same applied voltage. Findings indicated while developing flow is created inside the ESP, there exists an optimum wire-to-flow inlet spacing that provides maximum droplet collection efficiency.

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1. Introduction

Electrostatic precipitators (ESPs) are one of the most commonly employed particulate control devices to collect fly ash emissions and particulate matters from exhaust gases originating from various production installations such as boilers, incinerators, coal-fired power plants, mining installations, metallurgical and chemical industries and many other industrial processes. They can operate in a wide range of gas temperatures, pressures and flow rates as well as very fine suspended particles, achieving high particle collection efficiency compared with mechanical devices such as cyclones, scrubbers and bag filters [1]. Although the process of electrostatic precipitation involves several complicated and inter-related physical mechanisms between the fluid and particle flow such as turbulent and Brownian diffusion, particles collisions etc., it is definite the geometric parameters and electric field characteristics have significant effects on the efficiency of ESPs [2–4].

Several experimental studies on the collection efficiency of ESPs at different operation indexes have been carried out. In this regard, Navarrete et al. [5] investigated influence of plate spacing and ash resistivity on the efficiency of electrostatic precipitators through

real tests carried out on different types of coal with real flue gases in a pilot precipitator installed at a pulverized-coal power plant. Miller et al. [6] presented results of an experimental investigation conducted with a laboratory scale electrostatic precipitator for optimizing the geometric parameters. They showed the optimum ratio of discharge electrode distance to gap width depends on the duct width. Chang and Bai [7] presented experimental results for the influence of back corona on the performance of a laboratory scale single-discharge-wire ESP system. They indicated as back corona occurs, the output current and the power consumption increase under constant voltage operation. Kim and Lee [8] examined a laboratory-scale single-stage ESP to seek the operating conditions for increasing the particle collection efficiency. They found that as the diameter of the discharging wires and the wire-to-plate spacing are set smaller and further the air velocity increases, the higher collection efficiency can be obtained. Zhuang et al. [9] performed experimental and theoretical studies of ultra-fine particle behavior in cylindrical electrostatic precipitator. They observed the corona current decreases at the higher gas velocities because fewer ions reached the collector surface. Jędrusik et al. [10] presented the results of experimental research on the movement of fly ash particles in the model of an electrostatic precipitator with different corona electrodes. They employed photographic method for measuring the particle velocity using laser light and determined the migration velocity of particles with different size. Kim et al. [11] used a pilot

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scale electrostatic precipitator to get a modified Deutsch equation that can be applied to real conditions. They evaluated the effects of operational variables as resistivity and concentration of particles as well as temperature, moisture contents and velocity of gas on the ESP collection efficiency. Falaguasta et al. [12] investigated effects of some geometric, hydrodynamic and electric parameters on the collection efficiency of a laboratory scale plate-wire electrostatic precipitator, operating in the removal of airborne $PM_{2.5}$. Haque et al. [13] evaluated influence of the inlet velocity profiles on the prediction of velocity distribution inside an electrostatic precipitator experimentally and theoretically. Khaled and Eldein [14] presented and experimentally validated a laboratory-scale model for prediction of the voltage–current characteristics of wire-plate electrostatic precipitators under clean air conditions. Jedrusik and Świerczok [15] tested different constructions of discharge electrode in the aspect of discharge current uniform distribution on collecting electrode surfaces to determine the optimal discharge electrode construction ensuring high collection efficiency of fine particles. Nevertheless, there are few experimental studies concerning the effects of geometric parameters on the efficiency of ESPs with such altered electric indexes as the electric field strength, the average current density and the corona power ratio based on nominal and consumed powers, especially covering collection of fine water drops size inside developing flow condition. Since in the core region of developing flow droplets have accelerated motion across the ESP, the wire-to-flow inlet spacing as a geometric parameter can affect the efficiency of ESPs.

Wet ESPs were developed to control a wider variety of particulate pollutants and exhaust gas conditions compared to dry ESPs, especially for particles that are sticky, corrosive, or have high resistivity [16,17]. For example, wet ESP is good option for effective control of sulfuric acid aerosol emissions [18]. In addition, the periodic or continuous scrubbing water flow, used to wash the collection electrode surfaces, was found to prevent particle re-entrainment caused by rapping, which occurs in dry ESPs [19]. However, various problems caused by materials and non-uniform distribution of water film have limited high performance of wet ESPs. Recently researchers on wet ESP technology have tried to find some appropriate methods to solve these imperfections and increase wet ESP performance. In this regard, Bologna et al. [20] designed a wet electrostatic precipitator for effective control of fine aerosol from humid gases which operates on the principle of unipolar particle charging in the corona discharge and particle precipitation under the field of their own space charge and gives mass collection efficiency of 90–97% for one-field and up to 99% for two-field electrostatic precipitator. Lin et al. [21] designed and tested an efficient parallel-plate single-stage wet electrostatic precipitator to control fine and nanosized particles. They compared the corona current between the dry and wet ESPs, at various supplied voltages and indicated at the same voltage, the corona current was decreased after supplying the scrubbing water on the collection plate surfaces, due to the resistivity of the water film. However, they did not consider the effect of different vapor content in the flow of wet ESPs on corona current variations. Several researchers focused on the collection electrode to solve the shortcomings of wet ESPs (see e.g. Refs. [22–25]). Chang et al. [26] employed single terylene or polypropylene collection electrodes for excellent removal of sulfuric acid aerosol in a wet electrostatic precipitator. Nevertheless, experimental research on effect of some geometric parameters and electric indexes such as wire-to-flow inlet spacing and corona power ratio to enhance the performance of vertical wet ESP is scarce. Most of the researchers focused their research on the material of collection electrode to increase the efficiency of wet ESPs, while this method is crucially expensive.

Added to the experimental studies, some researchers investigated effects of geometric parameters theoretically and presented helpful conclusions. In this regard, Hall [2] summarized several beneficial effects when employing wider duct ESPs. He reported that wider duct ESPs result in reduced gas flow shear stress, more uniform current and electric field distributions as well as more stable electrical operation due to the increased range between corona start and sparkover. Abdel-Sattar [3] and further Pontius and Sparks [27] investigated the effect of the corona wire diameter on the efficiency of ESPs, but presented different conclusions. Pontius and Sparks [27] pointed out that improved efficiency can be obtained with large corona wire by evaluating the efficiency of a pilot-scale ESP, whereas Abdel-Sattar [3] indicated that the precipitation efficiency increases by decreasing corona wire diameter. In addition, Abdel-Sattar [3] found that the most crucial geometric parameter, which affects the performance of ESPs, is the wire-to-plate spacing. Chang and Bai [4] theoretically indicated that influences of wire-to-wire spacing and plate (wire)-to-plate spacing on the ESP performance do not have regular trends if the electric field strength is used as the comparison basis. The mentioned studies suggested that optimal design values exist but these values vary with changes in the electric field strength. However, there is no doubt that changing wire-to-plate spacing would alter the spatial arrangement of the wire and plate and consequently influences the collection efficiency. Yang et al. [28] mentioned that additional work is required to examine the effect of changing the spatial configuration of ESPs on their efficiency.

The purpose of this study is to investigate experimentally the effects of geometric parameters on the efficiency of vertical wet electrostatic precipitator in a laboratory-scale size at different electric indexes to collect fine water droplets. The weighing technique is employed to measure the ESP efficiency. Vertical flow precipitators are mainly used for self-draining liquid and mist type particulates, where efficiencies in excess of 99 percent can be readily achieved from a single field. A high negative voltage is applied to the corona discharge wire. The upward air–water droplets flow is strongly under developing condition in the entire collection duct of ESP. This kind of flow can be created in small length, wide duct ESPs that serve in high flow rates such as some types of fly ash precipitators and those related to small power generators and boiler plants. In these experiments, an ultrasonic atomizer produces fine water droplets in a size range of 1–10 μm measured using laser light scattering technique. The efficiency was compared with a glass micro fiber filter and proposed semi-empirical efficiency model.

2. Experimental apparatus and procedure

2.1. Test setup for measuring multiphase flow properties

Fig. 1 shows the experimental setup of mechanism of generating droplets, conveying into the ESP and measuring instruments. Ultrasonic atomizer generates droplets with constant rate in a size range of 1–10 μm . A commercial type, Malvern Mastersizer 2000, laser particle sizer based on laser scattering technique is used to measure the droplets size. Fig. 2 shows the droplet size distribution produced by the ultrasonic method. In the experiment, air mixes with the produced droplets and enters into a primary separator. The primary separator used for gravitational sedimentation of large drops and consequently generates an outcome of more uniform size droplet especially at high flow rates. Then flow is conducted to the ESP. A piston type compressor is used which has the same power over the testing time and produces the suction. In order to control flow rate of the path, a bypass valve is positioned between the flow meter and the compressor units. It should be mentioned

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