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Influence of particle concentration and residence time on the efficiency of nanoparticulate collection by electrostatic precipitation

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ABSTRACT

The influence of gas velocity on the efficiency of electrostatic precipitators has previously been discussed exclusively in terms of the gas residence time, even when there are changes in aerosol concentration. Therefore, the aim of this work was to separately evaluate the influences of residence time and concentration by performing sets of experimental tests with KCl nanoparticles in a wire-plate electrostatic precipitator. A proportional increase in the nanoparticles flow rate with increase of the gas stream mitigated dilution effects, allowing exclusive evaluation of the effect of residence time on efficiency.

1. Introduction

Electrostatic precipitation is a very important separation process used for the control of particulate emissions and the recovery of high added value products. Electrostatic precipitators (ESPs) are widely employed for the control of fly ash emissions in coal-fired and biomass-fired power plants, as well as in urban waste incinerators. They have also been used in processes for the synthesis and recovery of silver and gold, both on an industrial scale and in recent studies with nanoparticles [1–9].

The gas velocity is one of the most critical operational variables in this process. Several studies have evaluated the influence of gas velocity on collection efficiency in various types of ESPs, including wire-tube and plate-tube designs with single or multiple stages, operated under dry or wet conditions, using different voltages and a range of particle size distributions (PSDs) and compositions. However, although several techniques have been used to analyze phenomena involving the gas velocity, these methods have neglected the effect of gas flow rate on the particulate concentration when the solids feed flow rate is maintained constant.

Zhuang et al. [10] evaluated the performance of a wire-tube ESP with atomization of a solution of NaCl and a suspension of Al_2O_3 using an aerosol generator (model 3076, TSI), resulting in a particulate concentration on the order of 10^{10} particles m^{-3} and mean particle geometric diameter of 0.25 μm. The gas velocities used were 0.35 and 0.70 $m\,s^{-1}$, and decreased efficiency at higher gas velocity was attributed exclusively to the residence time. Similarly, Huang and Chen [11] studied the performance of wire-plate ESPs with one and two stages, varying the gas flow rate between 50 and 150 $L\,min^{-1}$, with atomization of a sucrose solution using an aerosol generator (model 3076, TSI) and a constant compressed air flow of 100 NL h^{-1}. This resulted in particles with median diameter of 42 nm, geometric standard deviation (GSD) of 1.8 nm, and number concentration of 1.2×10^5 particles cm^{-3}. The authors used the concept of gas residence time to explain the reduction in efficiency as the gas velocity increased.

Morawska et al. [12] used a two-stage wire-plate ESP to evaluate the effect of gas velocity on the collection of NaCl and ETS (environmental tobacco smoke) particulates. Aqueous solutions of 10 and 20% NaCl were atomized using a Collison nebulizer and the efficiency of collection of the aerosol generated with 10% NaCl solution was evaluated using gas flow rates between 472 and 1050 $L\,s^{-1}$. The aerosol concentration varied according to the gas flow rate and a decrease in efficiency with increase of the gas velocity was attributed to the change in the residence time. The behaviours exhibited by the grade efficiency curves were attributed to the combined effects of residence time and particle electrical mobility.

Kim et al. [13] developed a system containing a pre-charger composed of carbon ionizers and an ESP composed of multiple parallel plates. The collection performance was evaluated using KCl particles with diameters between 0.01 and 0.5 μm, which were produced from a 0.1% (w/w) KCl feed solution by an aerosol generator (model 3076, TSI) with a constant output flow rate. Among the different tests performed, the gas velocity was varied between 1 and 2 $m\,s^{-1}$, under different voltages, and a decrease of efficiency was observed as the gas velocity increased. The effect of the particle loading deposited in the collectors on the efficiency was also studied, but no evaluation was

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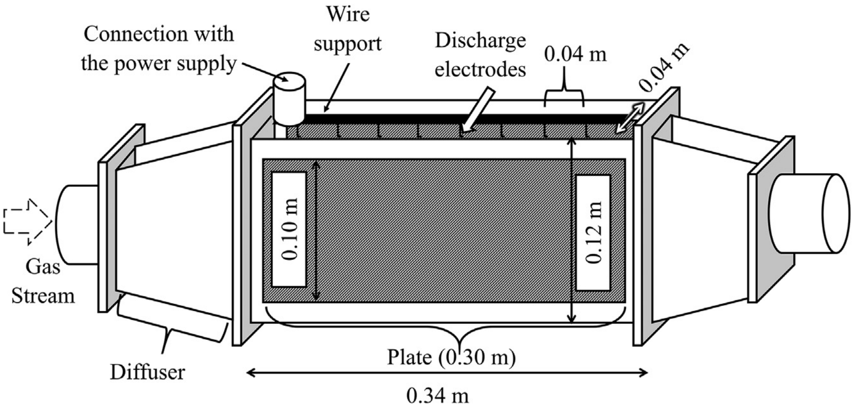

Fig. 1. Schematic view of the ESP.

made of the influence of the aerosol concentration on the performance of the system.

Lin et al. [14] constructed a wire-plate ESP for use as a nanoparticle generator. Potassium sodium tartrate (PST) particles were produced by an atomizer (model 3076, TSI) operated at a constant output flow rate of 1.5 L min^{-1}. Assessment was made of the effect of temperature on the current-voltage curves, using velocities between 0 and 150 cm s^{-1}, and on the efficiency of the device, using temperatures from 31 to 43 °C and velocities between 10 and 30 cm s^{-1}. Increased efficiency with decrease of the velocity was attributed to the particle retention time. The effect of the dust loading accumulated on the plates on the performance of the equipment was studied, but the influence of aerosol concentration on the efficiency was not investigated.

Yang et al. [15] evaluated the influence of the gas flow rate on the efficiency of SO_3 removal by a wet electrostatic precipitator (WESP), using a fixed SO_3 feed flow rate and correcting the SO_3 concentration according to the gas flow rate. However, increased efficiency with decrease of the flow rate was related exclusively to the residence time.

Based on the examples described above, it can be seen that the effect of gas velocity on ESP efficiency has been evaluated in different ways, but that the particulate feed flow rate has been maintained fixed, while the effect of variation of the aerosol concentration according to the gas flow rate has not been considered. Instead, the results obtained were interpreted exclusively in terms of the residence time. Therefore, the purpose of the present work was to investigate the influence of the aerosol concentration and the gas velocity, with dilution provided by varying the gas flow rate, while maintaining a constant particulate feed flow rate. Determination was made of the impact of dilution on the collection efficiency of a wire-plate ESP operated under dry conditions. Assessment was also made of the effect of the aerosol concentration, maintaining a constant gas flow rate, since it was verified a lack of information in the literature for the particle size range evaluated in the present work. In order to execute these experiments, it was used an aerosol generator that operated by the nebulization technique, similarly to the abovementioned studies. Additionally, a method is proposed for the exclusive evaluation of residence time, minimizing the effect of dilution as the gas velocity increases. Therefore, the novelty of the present work is the development of a method to study the effect of the residence time on the ESP efficiency by varying proportionally the gas flow rate with the particle flow rate. Further investigations will may take account the results obtained in the present work to study the phenomena according to the present method. This work contributes to the development of more sophisticated techniques for the study on the effects of operational conditions in electrostatic precipitation, enhancing the technology in this field.

In addition, tests were performed at main gas velocities under 10 cm s^{-1} in the present work, following previous studies on nanoparticle collection by ESPs. Kim, Kim, and Jun [16] evaluated the effect of carbon coating in electrodes on the performance of an ESP at 6.7 cm s^{-1}. Lin et al. [14] studied the generation of nanoparticles in an ESP using gas velocities between 10 and 30 cm s^{-1}. Kherbouche et al. [17] performed tests with a wire-tube ESP coupled with a wind tunnel, with gas velocity of 10 cm s^{-1}. In fact, gas velocities lower than 10 cm s^{-1} enhance the efficiency of nanoparticle filtration due to the diffusional mechanism, for example [18]. In its turn, in electrostatic precipitation the mechanism of charge transfer by diffusion is prominent for particle diameters less than 200 nm [19], which is the range of size that was evaluated here. The rationale for the present work was that most of the knowledge acquired in this field is based on studies focusing only on a range of gas velocities for which effects have already been described. In addition, studies in laboratory scale on the synthesis of nanoparticles of high added-value materials used ESPs to collect the particles formed at low gas flow rates [5]. Therefore, by presenting the advantages to operate in this range of conditions to collect nanoparticles, there will be incentive to promote further studies on optimization of ESPs for these conditions, even in large scale.

2. Materials and methods

This section is divided in two subsections: the first one will present the experimental apparatus used in the tests and the second one will present the experimental procedure performed in this work.

2.1. Experimental apparatus

The experimental system employed in the tests consisted of a dry single-stage wire-plate type electrostatic precipitator, made of acrylic. A schematic view of the ESP is shown in Fig. 1 and the main ESP dimensions are presented in Table 1. The collection plates were composed of copper and the discharge electrodes (arranged in the longitudinal axis of the ESP) were made of stainless steel. There was a diffuser immediately before the inlet of the ESP in order better distribute the gas flow.

Other items of equipment associated with the ESP were as follows:

Table 1
Geometric characteristics of the ESP.

Cross-sectional area (m^2)	0.004
Plate height (m)	0.10
Plate length (m)	0.30
Number of plates	2
Collection area (m^2)	0.06
Duct width (m)	0.04
Distance between plate and discharge electrodes (m)	0.02
Distance between discharge electrodes (m)	0.04
Diameter of discharge electrode (m)	3×10^{-4}
Number of discharge electrodes	8