3D Simulation of Fine Particle Collection Efficiency in Cylindrical Wire-Plate and Spiked-Plate ESPs

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1 Abstract:

A 3D hybrid Finite Element - Flux Corrected Transport technique is proposed to predict the electrical and aerodrodynamic characteristics of one-stage electrostatic precipitator consisting of a corona discharge electrode mounted in the middle of the channel between two parallel collecting plates. FLUENT commercial software is used for calculating the turbulent flow distribution assuming *k-ε* flow model. Two discharge electrode configurations are considered: smooth cylindrical wire and flat tape spiked electrode, where the electrohydrodynamic flow patterns and various particle concentration effect on corona discharge current, airflow velocity and the precipitatipon performance in removal of fine particles are compared.

2 Introduction

Improving the collection efficiency of fine particles in electrostatic precipitators (ESPs) has been subject of interest of many authors during past years. Particles smaller than 1 μm penetrate lung tissues more rapidly with greater toxicity than larger particles and have a detrimental effect on human health.

Due to more strict regulations on pollutant emission standards, improvements of the ESP design are necessary. Using flocking plate electrodes rather than smooth-plate [1] longitudinal wire-plane electrode arrangement [2], different discharge electrode geometries, such as barbed plates or spiked electrodes [3], [4] and particle agglomeration using dielectric-barrier discharge before ESP [5] are among some techniques suggested to increase removal of fine particles.

Optimal ESP design requires accurate evaluation of particle transport and fluid mechanics parameters. Few authors used numerical simulation to evaluate electrical characteristics and to predict electrohydrodynamic (EHD) flow patterns, particle charging, motion and deposition in electrostatic precipitators [6]-[11].

The collection efficiency of an ESP is influenced by many factors including dust particle properties, discharge electrode geometry, electric field, ionic charge density distribution and EHD flow patterns.

In this paper the ESP performance in removal of fine particles is compared for two discharge electrode geometries under different applied voltages. The effect of the EHD flow patterns on particle collection is also investigated.

3 Model Description

Fig. 1 shows the schematic diagram of a single-stage ESP model. The precipitation channel is 600 mm in length, 200 mm in width and 100 mm in height; the horizontal walls are kept at ground potential. The corona electrode is mounted in the middle of the channel and energized with a high dc voltage.

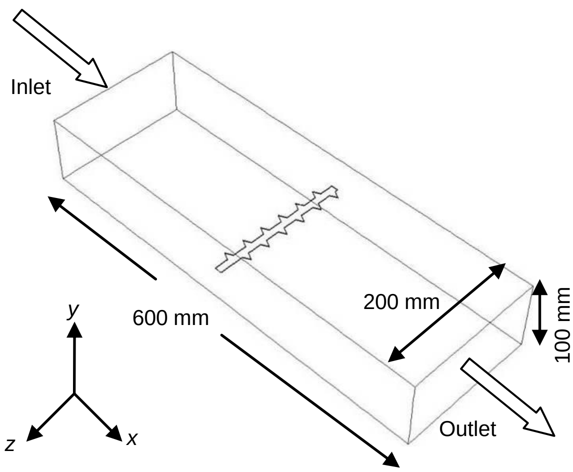

Fig. 1. 3D configuration of a single spike wire-plate model of ESP.

Two corona electrode geometries are considered: smooth corona wire with uniform charge density along the electrode and a spiked tape electrode (Fig. 2), where the spikes are located alternatively along the electrode or on one side of the electrode, directed either in upstream or downstream direction of the channel. The ions are injected from the tip of the spikes only.

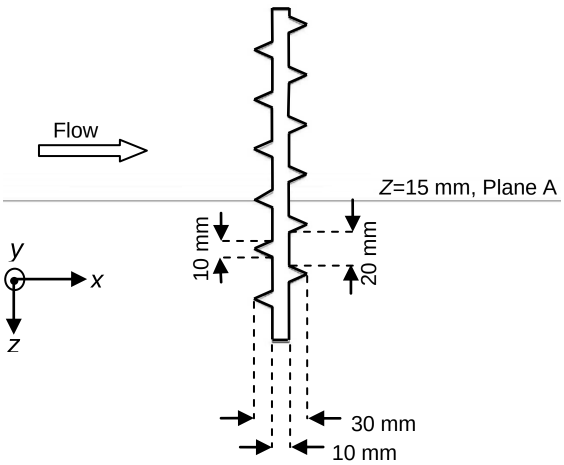

Fig. 2. Schematic drawing of the discharge electrode with spikes on two sides (top view).

Finite Element and Flux Corrected Transport numerical techniques are proposed for solving the governing equations to obtain the electric potential and ionic space charge distribution in the channel [10]. FLUENT commercial software is used for calculating the turbulent flow distribution assuming *k-ε* flow model. Neutral particles of different size and concentration are released with the air through the ESP channel. Particle charging, motion and deposition is modelled using Discrete Phase Model in FLUENT with the aid of User Defined Functions. Particles are considered to be charged by both field and diffusion charging techniques [12].

4 Results

4.1 Cylindrical wire-plate ESP

The precipitation performance for collecting particles in the range of 0.3-10 μm for various particle concentrations at inlet is summarized in Table 1. The collection efficiency is decreased for reduced particle sizes [11]. For 0.3 and 1.4 μm particles the collection efficiency is increased at increasing concentration at the inlet. However, the collection efficiency is very low for these fine particles.

Table 1. Cylindrical wire-plate ESP performance for different particle mass flow rates, c_0=0.01 mg/s, inlet velocity 1 m/s, applied voltage +30 kV.

Total Mass Flow Rates (kg/s)	Collection Efficiency			
	0.3 μm	1.4 μm	5 μm	10 μm
$c=0.5c_0$	8.50%	20.75%	59.50%	98.50%
$c=2c_0$	10.00%	19.50%	58.50%	98.50%
$c=10c_0$	10.75%	22.50%	60.00%	97.75%
$c=20c_0$	12.50%	26.25%	64.75%	96.75%

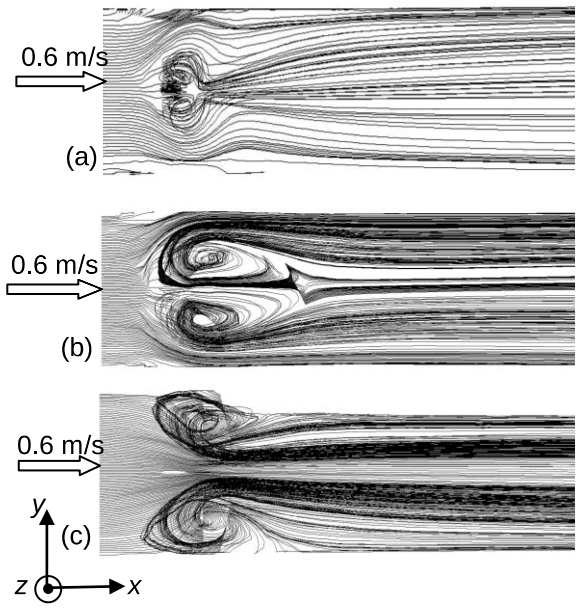

Fig. 3. Velocity streamlines in plane A for ESP with (a) spikes on two sides (b) spikes in upstream direction, (c) spikes in downstream direction (applied voltage -30 kV and inlet velocity 0.6 m/s).

4.2 Spiked-plate ESP

Considering spike electrode geometry, Figs. 3a-3c demonstrate the velocity streamlines in plane A for spikes located on two sides, in upstream and downstream direction of the channel, respectively. Significant differences in the flow patterns are observed. In Fig. 3a, where the spikes are located on both sides of the electrode, two vortices are generated in the vicinity of electrode in the upstream direction of the channel and two very tiny and almost invisible vortices in the downstream direction of the channel, close to the collecting plates, where a detour in velocity streamlines from the collecting area can be noticed.

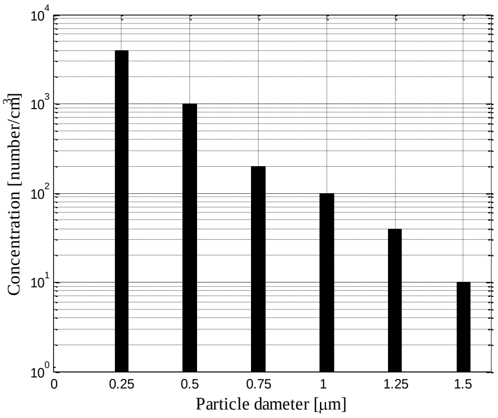

Fig. 4. Distribution of particle concentration versus particle diameter at inlet.

Since fine particles obtain less charge than larger particles, their trajectory is more affected by air drag forces and they mostly follow the velocity streamlines. Two strong vortices in upstream direction of the channel push the particles toward the deposition area and increase the collection efficiency.

For a discharge electrode with spikes in the upstream direction of the channel (Fig 3b), the two vortices generated in upstream direction of the channel are much stronger than for the previous geometry. These vortices push the particles from the centre of the channel towards the collecting plates and increase the collection efficiency. For spikes located in downstream direction of the channel (Fig. 3c), two strong vortices are generated downstream of the channel close two the collecting plates and they push the particles from the deposition area towards the centre of the channel, causing a reduction in collection efficiency of fine particles. These velocity patterns are in good agreement with the experimental results presented by Mizeraczyk et al. in [3] and [4].

Neutral particles with the concentration profile shown in Fig. 4 are injected to the ESP channel with spiked electrodes. The collection efficiency of ESP for the three electrode geometries are evaluated for four particle sizes (0.25, 0.5, 0.75 and 1.5 μm) under four different applied voltages: -19.2, -23.5, -27.5 and -30kV and the results are shown in Figs. 5a - 5d.

It is shown that by increasing the applied voltage the collection efficiency is increased. The discharge electrode with spikes in downstream direction demonstrates the lowest collection efficiency for all particle sizes. For the smallest particle size (0.25 μm) the discharge electrode with spikes in upstream direction shows a slightly better collection efficiency comparing with the spikes located on both sides. Generally, we can conclude that

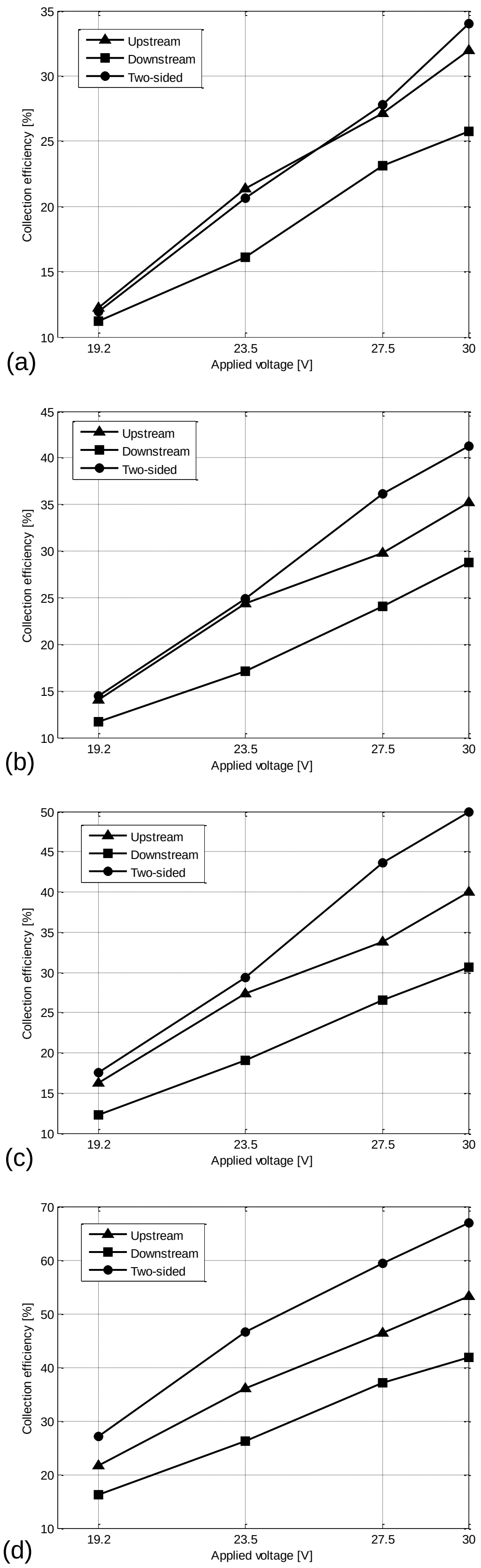

Fig. 5. Collection efficiency of ESP with spikes on two sides and one side directed either upstream or downstream for different negative applied voltages and particle sizes of (a) 0.25 μm, (b) 0.5 μm, (c) 0.75 μm and (d) 1.5 μm (inlet velocity 0.6 m/s).

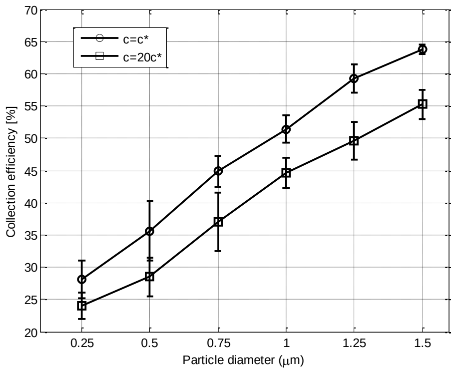

Fig. 6. Particle collection efficiency versus particle diameter for ESP with spikes on two sides for the lowest (*c*=*c**) and highest (*c*=20*c**) particle concentrations at inlet (applied voltage -30 kV and inlet velocity 0.6 m/s).

the discharge electrode with spikes on both sides is still the best design for collecting fine particles and the collection efficiency is increased up to 35% for 0.25 μm and 70% for 1.5 μm particles under -30 kV applied voltage; showing significant improvement comparing with the cylindrical wire geometry.

Fig. 6 shows the effect of increasing particle concentration at inlet on the collection efficiency. It is shown that the collection efficiency of particles decreases with increased concentration, which is due to corona discharge suppression resulting in reduced electrostatic forces on particles and lower collection efficiency.

5 Conclusions

The precipitation performance is simulated using a 3D numerical model. The influence of particle concentration at inlet and discharge electrode geometry on velocity patterns and precipitation performance was investigated. It was proven that the ESP with spikes on two sides has better collection efficiency for very fine particles than other ESP configurations.

6 Literature

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