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# Electrode geometry optimization in wire-plate electrostatic precipitator and its impact on collection efficiency

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## ABSTRACT

Wide Electrostatic Precipitator (having plate-to-plate spacing 400 mm or more) is one of a promising ways to improve existing ESPs, yet its large-scale application has been limited because of potential collection efficiency reduction. This article focus on study the electrohydrodynamic flow inside the ESP and the particle collection efficiency by using Particle Image Velocimetry and Electrical Low Pressure Impactor respectively when several different electrode geometries were applied, in order to increase wide ESP efficiency. Results showed that geometry with juxtaposed high voltage wires provided best performance of the wide ESP (both in collection efficiency and running cost) among our tests.

## 1. Introduction

Recently there are increasing concerns on particulate matter (PM) pollution in many developing countries. In fact, the increased levels of PM in the air can lead to anthropogenic particulate air pollution, which is consistently and independently related to the most serious effects, including lung cancer and other cardiopulmonary diseases. Some PM occurs naturally, but in large cities of China it is mainly the result of Human activities related to the vehicles, power plants and various industrial processes. Due to the highly toxic health effects of PM, most governments have created regulations for the particulates emission and concentration in the ambient air. Thus, PMs removal is important for the sake of environmental concerns.

Electrostatic precipitator (ESP) is a filtration device that removes PM from the treated gas. ESPs are widely used due to their advantages such as high total mass collection efficiency, low operational costs, high capacity and durability [1]. As European Union HVAC association suggests, a normal emission of ESP should be within range of 10–20 mg/Nm$^3$. With proper maintenance and geometry 5 mg/Nm$^3$ should be also achievable. Emission as low as 1 mg/Nm$^3$ in Wet ESP should be guaranteed. Thus, most probably ESPs will stay in main stream of particle removal equipment, even with a stricter emission standards [2]. However, ESPs should be improved in many ways, especially the collection efficiency of submicron dust particles should be increased.

Our previous work [3] showed that the gas flow inside a wire-plate ESP is quite complex. Under actual operation conditions, ionic wind is generated by corona discharge. The direction of ionic wind in the corona discharge region (in the space between a high voltage (HV) and grounded electrodes) is from discharge electrode to collecting electrode [4], and it is usually directed perpendicularly to the original primary gas flow direction. Ionic wind can disrupt primary flow pattern, causing strong turbulences [5–7]. Normally, the level of turbulence increases along with the voltage increase.

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*Abbreviations:* ESP, electrostatic precipitator; ELPI, electrical low pressure impactor; PIV, particle image velocimetry; TKE, turbulence kinetic energy; PM, particulate matter; HV, high voltage; EHD, electrohydrodynamic.

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Results indicate that resultant electrohydrodynamic (EHD) secondary flow pattern can alter significantly the primary flow [8] and impacts the particle collection efficiency (especially when particle diameter is at the range of 0.1–1 μm). There can be two reasons. Firstly, the gas flow velocity inside a turbulent area is typically higher than in a non-turbulent area, making particles inside this area harder to be collected. Secondly, normal ESP usually has symmetric wire geometry, making the generated flow pattern also symmetric [9,10]. The phenomena of the whole flow pattern can be analog to a flow pattern inside a Venturi tube. It creates a high speed area in the center, through which massive gas pass along with uncollected particles. Certainly, this could reduce efficiency significantly, mainly by reducing the general residence time and inhomogeneous distribution of Coulomb force. The significant decrease of efficiency can be anticipated if the big amount of particles passes through a central high speed area. It can be the case especially for wide wire-plate ESPs, which indeed reduce the investment costs effectively, but typically has lower collection efficiency.

An understanding about how electricity and electrodes geometry influences the collection efficiency is critical during design and operation procedure of wide wire-plate ESPs. In order to optimize related parameters, modern techniques such as Particle Image Velocimetry (PIV) [11] and Electrical Low Pressure Impactor (ELPI) [12] are used to further understand the particle collecting process. Above methods have several key advantages, e.g.: non-contact measurement which can provide instantaneous or time-averaged results, measurement of the flow velocity field inside ESP (in HV discharge region) is possible.

This study was conducted to improve the ESP with a wide wire-plate geometry. One of approach of widening existing ESP geometry by removing every second collecting electrode was proposed and tested during this work. The loss of the ESP collection efficiency seems to be inevitable after such modification. Thus, in order to complement the efficiency loss caused by a fewer collecting plates, the geometries with additional grounded or HV wire electrodes were investigated. Several different electrode geometries were tested and their dust particle collection efficiency and EHD flow velocity fields were measured using ELPI and PIV respectively. The best electrodes geometries, both in collection and energy efficiency, were searched.

## 2. Experiment

### 2.1. Experimental setup

The schematic diagram of the experimental apparatus is shown in Fig. 1. The apparatus consisted of a six major parts, i.e.: an ESP; a fan forcing the primary flow through the ESP; a dust generator; a negative polarity DC high voltage power supplier; an ELPI for collection efficiency measurement and a standard 2D-PIV equipment for EHD flow velocity field measurement.

The ESP was made as a Perspex parallelepiped. The electrical electrode set consisted of a stainless-steel plate collecting electrodes and a stainless-steel wire electrodes (diameter of 0.09 mm). Several different electrodes geometries were investigated during this experiment and they will be described in the next subsection. An ambient air with a dust particles was introduced to the ESP inlet through a diffuser equipped with a mesh board, in order to distribute the primary flow uniformly along the ESP cross-section.

The high voltage and the current on the DC power supplier output were measured with a resolution ±0.1 kV and ±0.1 μA respectively. A 1 MΩ current limiting resistor was inserted between the DC power supplier and the HV wire electrodes. The plate electrodes were grounded.

The dust particles suitable for our experiment should meet those key features: 1 - it won't hinder major gas flow; 2 – amount easily controllable and stable; 3 – good dispersion of laser light. All this features are fulfilled by moxibustion smoke particles. Thus, it has been chosen as a dust source for collection efficiency measurements with ELPI and as a tracer particles for PIV measurements. As it was measured by ELPI, almost 99% of moxibustion smoke particles are fine and submicron particles having diameters from 80 nm to 0.5 μm.

The dust particles concentration was analyzed by ELPI at the ESP outlet. The ELPI was equipped with a 12 particle distributors, which can measure particle concentration for different diameters (0.02, 0.04, 0.08, 0.13, 0.21, 0.32, 0.50, 0.79, 1.26, 1.99, 3.13, 6.35 μm). For each electrodes geometry the dusty air sampling started at 0 kV and stepped every 10 kV, up to 50 kV. The collected data were averaged out by using software provided by the ELPI manufacturer. The ESP collection efficiency was calculated by using the following equation:

$$\eta(r) = \left(1 - \frac{N_o(r)}{N_i(r)}\right) \cdot 100\% \qquad (1)$$

where, η(r) represents collection efficiency for each particle diameter (in %),$N_o$(r) represents outlet concentration of particles of size class r (in mg/$m^3$), $N_i$(r) represents inlet concentration of particles of size class r (in mg/$m^3$).

The PIV measurements were carried out by using the second harmonic Nd:YAG laser as a light source. The light sheet produced from the laser beam was introduced along the ESP duct at the ESP symmetry plane, perpendicularly to the plate and wire electrodes. 200 images having resolution 2048 × 2048 pixels were captured for every single electrodes geometry and voltage, and then 100 instantaneous flow velocity fields were obtained by using a two-images cross-correlation algorithm. Time-averaged flow velocity fields and apparent flow streamlines were calculated and presented afterwards.

### 2.2. Electrodes geometry

The ESP duct was 600 mm long, 400 mm high and 200 mm wide. The original ESP geometry consisted of a three parallel plate collecting electrodes (on the top of the duct, bottom and in the middle between them). Thus, the distance between the plate electrodes was 200 mm. Four HV wire electrodes were mounted in the middle of each two plate electrodes (parallel to them); two wire electrodes in the top half, and other two in the bottom half of the ESP duct. The distance between the wire and plate electrodes was 100 mm, and the distance between the wire electrodes mounted in the same half of the ESP duct was 250 mm. The original ESP geometry hereafter is called to as '**4hv3plates**'.

Widening of the ESP geometry by removing central plate collecting electrode (which corresponds to the removal of every second collecting electrode in a large industrial ESP) is proposed. After such modification the ESP with two plate electrodes (on the top and bottom of the ESP duct; 400 mm distance between them) and four HV wire electrodes in between them was obtained and hereafter is called to as '**4hv**'.

Widening of the ESP just by removing plate collecting electrode inevitably decrease the collection efficiency. Therefore, in order to compliment the efficiency loss the geometries with additional grounded or HV wire electrodes were investigated. In order to dissipate the primary flow in the central area of the duct, an extra ionic wind was generated by lead-in the extra grounded or HV wire electrodes. Four different geometries with additional wire electrodes were tested.