Journal of Electrostatics 71 (2013) 808–814

Contents lists available at SciVerse ScienceDirect

Journal of Electrostatics

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

Electrohydrodynamic flow patterns and collection efficiency in narrow wire-cylinder type electrostatic precipitator

A. Niewulis [a,*], A. Berendt [a], J. Podliński [a], J. Mizeraczyk [a,b]

[a] Centre for Plasma and Laser Engineering, The Szewalski Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-952 Gdańsk, Poland
[b] Department of Marine Electronics, Gdynia Maritime University, Morska 81-87, 81-225 Gdynia, Poland

ARTICLE INFO

Article history:
Received 22 November 2012
Received in revised form
6 February 2013
Accepted 8 February 2013
Available online 24 February 2013

Keywords:
Wire-cylinder type electrostatic precipitator
EHD flow
2D PIV
Collection efficiency

ABSTRACT

Recently, narrow electrostatic precipitators (ESPs) have become a subject of interest because of their possible application for the cleaning of the exhaust gases emitted by diesel engines. Diesel engines emit fine particles, which are harmful to human and animal health. There are several methods for decrease particulate emission from a diesel engines, but up to now, these methods are not enough effective or very expensive. Therefore, an electrostatic precipitation was proposed as an alternative method for control of a diesel particulate emission.

In this work, results of electrohydrodynamic (EHD) secondary flow and particle collection efficiency measurements in a narrow wire-cylinder type ESP are presented. The ESP was a glass cylinder (300 mm × 29 mm) equipped with a wire discharge electrode and two collecting cylinder-electrodes. A 0.23 mm in diameter and 100 mm long stainless-steel discharge wire electrode was mounted in the center of the cylinder, parallel to the main flow direction. The collecting electrodes were made of stainless steel cylinders, each with a length of 100 mm and inner diameter of 25.5 mm. An air flow seeded with a cigarette smoke was blown along the ESP duct with an average velocity of 0.9 m/s.

The EHD secondary flow was measured using 2-dimensional particle image velocimetry (PIV) method. The PIV measurements were carried out in the wire electrode mid-plane, perpendicularly to the wire and the collecting electrodes. The results show similarities and differences of the particle flow in the wire-cylinder type ESP for a negative and a positive DC voltage polarity.

The collection efficiency was calculated from the fractional particle concentration. The fractional particle concentration was measured using the optical aerosol spectrometer. The results of the fractional collection efficiency confirmed the common view that the collection efficiency of fine particles in the ESP increases with increasing voltage and it is higher for negative voltage polarity and decreases when decreasing particle diameter.

1. Introduction

Recently narrow ESPs have become a subject of interest because of their possible application in diesel engines for the exhausted particulate matter collection [1–9]. Diesel engines emit fine particles, in size range of 7.5×10^{-3}–1.0 μm [2], that are harmful for human and animal health. Unfortunately, these submicron particles are not efficiently collected by nowadays ESPs.

The precipitation of particles in the duct of an ESP depends on the dust-particle properties, electric field, space charge, particle physical parameters, electrode geometry and electrohydrodynamic EHD secondary flow. The interaction between the electric field and charge and the flow results in considerable turbulences of the flow which, according to Refs. [10,11], seem to lower the fine particle collection efficiency. They suggested that the flow turbulence should be reduced in order to improve the fine particle collection efficiency. Improving other factors, such as ESP electrode geometry or ESP operating conditions, which influence the flow patterns in ESPs, may also increase the fine particle collection efficiency.

In this paper we present investigations of the influence of the EHD secondary flow, generated in narrow wire-cylinder type ESP on the submicron dust particle collection efficiency.

2. Experimental apparatus

The experimental apparatus for the measurement of velocity fields used in the present work consisted of an ESP, high voltage supply and standard 2D PIV equipment [12,13].

* Corresponding author.
E-mail address: aniewulis@imp.gda.pl (A. Niewulis).

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http://dx.doi.org/10.1016/j.elstat.2013.02.002

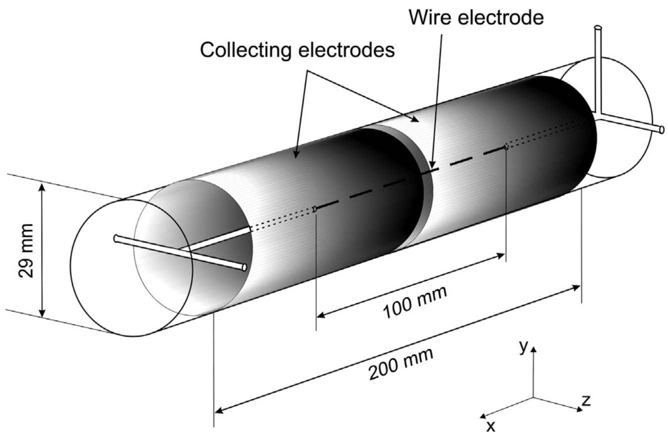

Fig. 1. Narrow circular ESP with longitudinal discharge wire-electrode.

The narrow wire-cylinder type ESP (i.e. circular ESP) consisted of two collecting circular cylinder-electrodes with a longitudinal wire discharge electrode, enveloped by a glass tube (Figs. 1 and 2). The collecting and discharge electrodes were made of stainless steel. Each cylinder-electrode has a length of 100 mm and inner diameter of 25.5 mm. The discharge wire-electrode was 0.23 mm in diameter and 100 mm in length. It was placed in the center (concentric configuration, Fig. 2a) and slightly off-center (nonconcentric configuration, Fig. 2b) of the circular ESP. The nonconcentric configuration was obtained by displacing the electrode by 2% of the tube radius.

The PIV measurements were carried out in the wire electrode mid-plane (i.e. at $x = 0$ mm), perpendicularly to the wire and the collecting electrodes. The velocity fields presented here resulted from the averaging of 100 measurements, which means that each velocity map is time-averaged.

The experimental set-up used for the collection efficiency measurements consisted of the ESP, an aerodynamic channel and an aerosol spectrometer (Fig. 3).

Positive or negative voltage of 10 kV was supplied to the wire-electrodes through a 10 MΩ resistor. Air flow seeded with cigarette smoke was blown along the ESP duct with an average velocity of about 0.9 m/s.

The collection efficiency was calculated from the fractional cigarette smoke particle concentration. The fractional particle concentration was measured using an aerosol spectrometer GRIMM 1.109. Its measuring range was from 0.25 μm to 32 μm with 31 particle size channels. The measuring of particle concentration was performed at the ESP outlet with high applied voltage ($c_{HV}(d_p)$ – the particle concentration after ESP operation) and without applied voltage ($c_0(d_p)$ – the initial particle concentration).

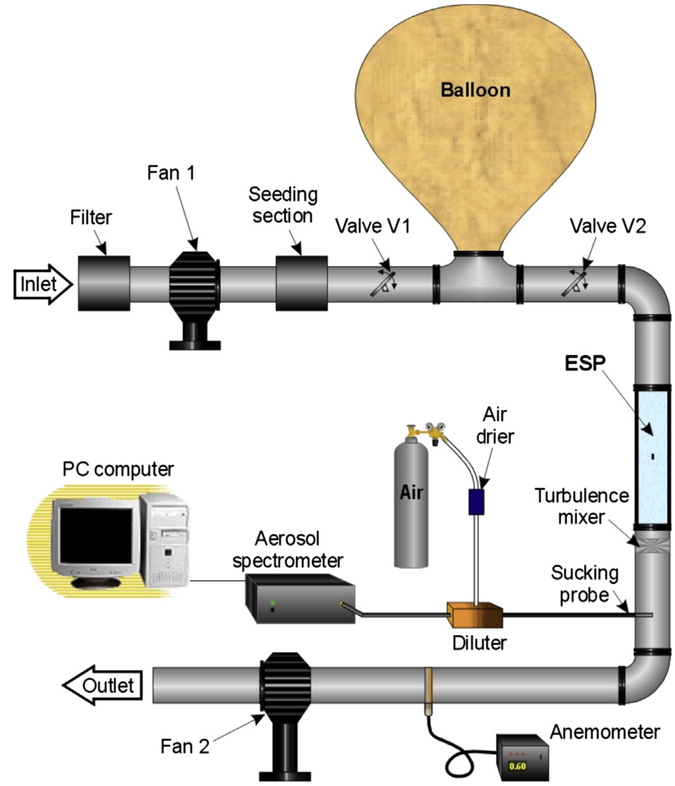

Fig. 3. Experimental set-up.

In order to reduce the statistical fluctuations, the counting of particles was performed every 6 s during 4 min measurement for both $c_{HV}(d_p)$ and $c_0(d_p)$. The experiment was repeated three times.

For a given size class of particles characterized by a diameter d_p (averaged over the given size class), the fractional particle number density collection efficiency $\eta_f(d_p)$ was calculated from the following equation:

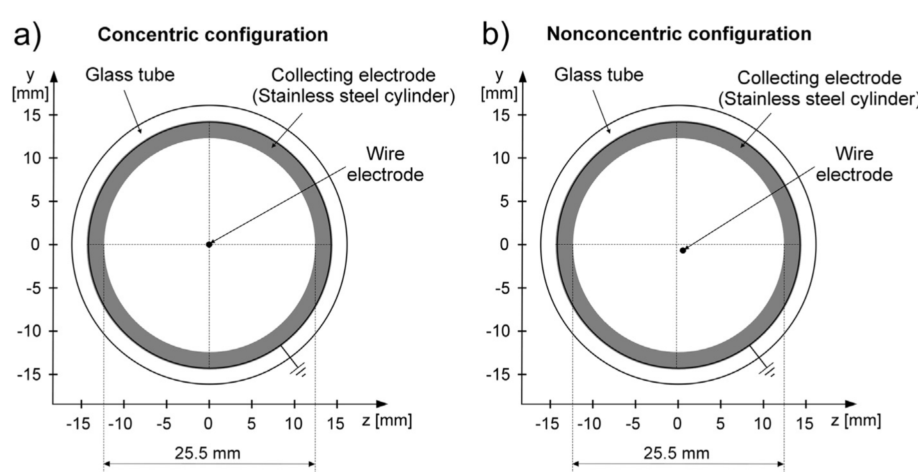

Fig. 2. Front view of the narrow circular ESP with longitudinal discharge wire-electrode, a) concentric configuration, b) nonconcentric configuration.