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Measurements of the velocity field of the flue gas flow in an electrostatic precipitator model using PIV method

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Abstract

In this paper, results of use of the PIV method to measure the flow field in a wire-plate type ESP model are presented. The results show that the PIV method is well suited to investigate the flow field in ESP models, in particular the characteristics of secondary and reversal flows, which increase the flow turbulence. The PIV investigation of the near-collecting electrode region shows the importance of the secondary flows, the velocity of which is several tens of cm/s. This means that the secondary flows can have a great impact on the motion and precipitation of small particles, mainly those in the submicron range. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

In recent years the control of emission of micron and submicron particles is a special environmental concern, as the conventional electrostatic precipitators (ESPs) are not effective in the removal of this particle fraction. Many of fine particles

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in the size range of 1 μm and less contain toxic trace elements such as lead, mercury, arsenic, zinc, etc. Hence, there has long been a high interest in improving ESPs capability of collecting fine particles.

The motion and precipitation of particles in the duct of an electrostatic precipitator depend mainly on the electric field, the space charge and the gas flow field, which interact with each other. As a result, considerable flow structures with turbulence in the volume between the stressed electrodes and the collecting electrode may occur. However, it is still not clear whether these turbulent flow structures advance or deteriorate fine particle precipitation process.

The flow field and the resulting motion and precipitation of particles in the ESP-like ducts have been studied using various visualization (e.g., [1]) and laser techniques, such as laser Doppler anemometry (e.g., [2–5]) and double-pulse holography [6]. Recently the particle image velocimetry (PIV) based on the scattering of laser light on the particles following the flow has been introduced to instantaneous measuring of the flow field velocity, including the turbulence, in large cross-sections of the flow (e.g., [7]).

In this paper, results of introducing the PIV method to measurements of the flow field in a wire-plate type ESP model are presented.

2. Experiment

The experimental apparatus used in the present work is shown in Fig. 1. The laboratory-scale precipitator model is a single high voltage electrode wire-plate system. In this model, several stainless steel wire stressed electrodes (diameter of 0.1 cm, length of 20 cm), 5 cm apart, may be stretched in the middle between the opposite placed stainless steel plate collecting electrodes (60 cm long and 20 cm wide). In the experiment reported only one wire electrode was used. The distance between the collecting electrodes was 10 cm. Applied voltage was varied from corona onset voltage up to 30 kV, which corresponds to a mean electric field strength of 6.0 kV/cm. Mostly the negative voltage polarization was used, but for comparison also the positive voltage was applied. A simulator of flue gas ($N_2:O_2:CO_2:H_2O =$ 79% : 5% : 14% : 2%) was blown along the precipitator with an average velocity from 0.2 to 1.5 m/s. Seed particulate (cigarette smoke) was added to the flue gas simulator before a flow homogenizer which was placed in front of the precipitator inlet to ensure homogeneous spatial distributions of flow and seeded particles inside the precipitator duct.

It is obvious that the precipitator model dimensions are small compared to industrial installations, but as it was shown in [8] the results of experiments in smaller ESP-like devices can be transferred to the industrial units, provided the geometrical and electrical similarities are preserved. In addition to the preservation of both similarities in the model used in this experiment, Reynolds numbers of the flows in the present precipitator model and an industrial ESP also prove similar (the flow viscosity and the distance between collecting electrodes in the ESP are about twice as large as those in the present model).

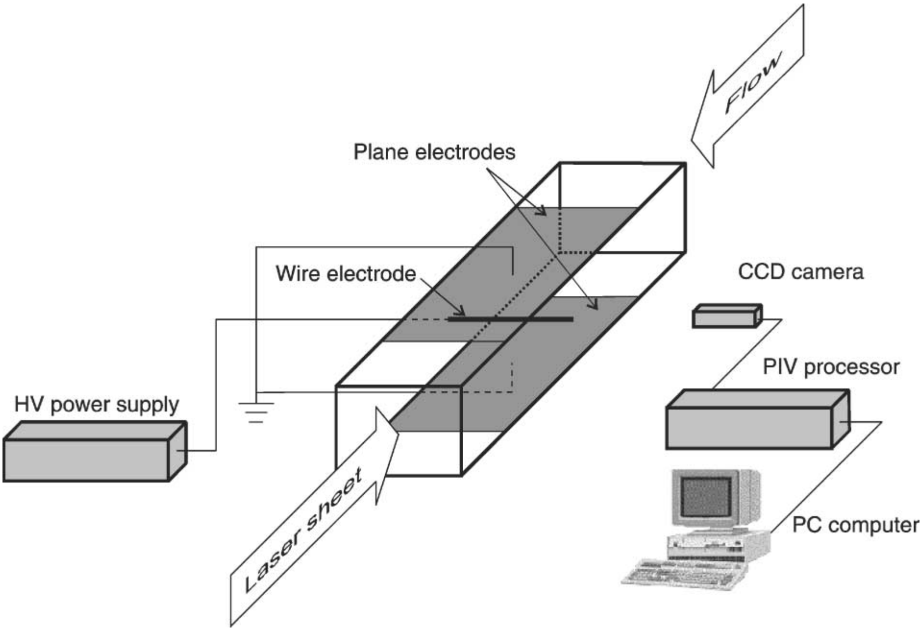

Fig. 1. Schematic of experimental set-up.

The measurements of the velocity field in the precipitator model were carried out with a standard PIV equipment (Dantec PIV 1100) consisting of a twin second harmonic Nd–YAG laser system ($\lambda = 0.53\,\mu m$, pulse energy 50 mJ) and an image processor (Dantec PIV 1100)—Fig. 1. The laser "sheet" of a thickness of 1 mm was formed from the Nd–YAG laser beam by a telescope and set along the flow direction, perpendicular to the plate electrodes. The area of the measured velocity field was $25\,cm \times 10\,cm$. The images of the particles following the flow in the laser "sheet" were recorded by a Kodak Mega Plus ES 1.0 CCD camera that enabled capturing two images with minimum time separation of $2\,\mu s$. The captured images were transmitted by the image processor to a PC computer. Then, a map of the so-called raw velocity vectors was calculated from the acquired images. The vector map was used for further evaluations that eventually produced the streamlines and the vorticity field.

3. Results

The typical image and velocity field of the flow in the precipitator model for a flow mean velocity of 0.2 m/s when no voltage was applied to the wire electrode is shown in Fig. 2(a) and (d), respectively. The flow was almost laminar, without turbulence.

The character of the flow changed dramatically after applying the voltage. The flow became turbulent, showing many different turbulent structures. Examples of the

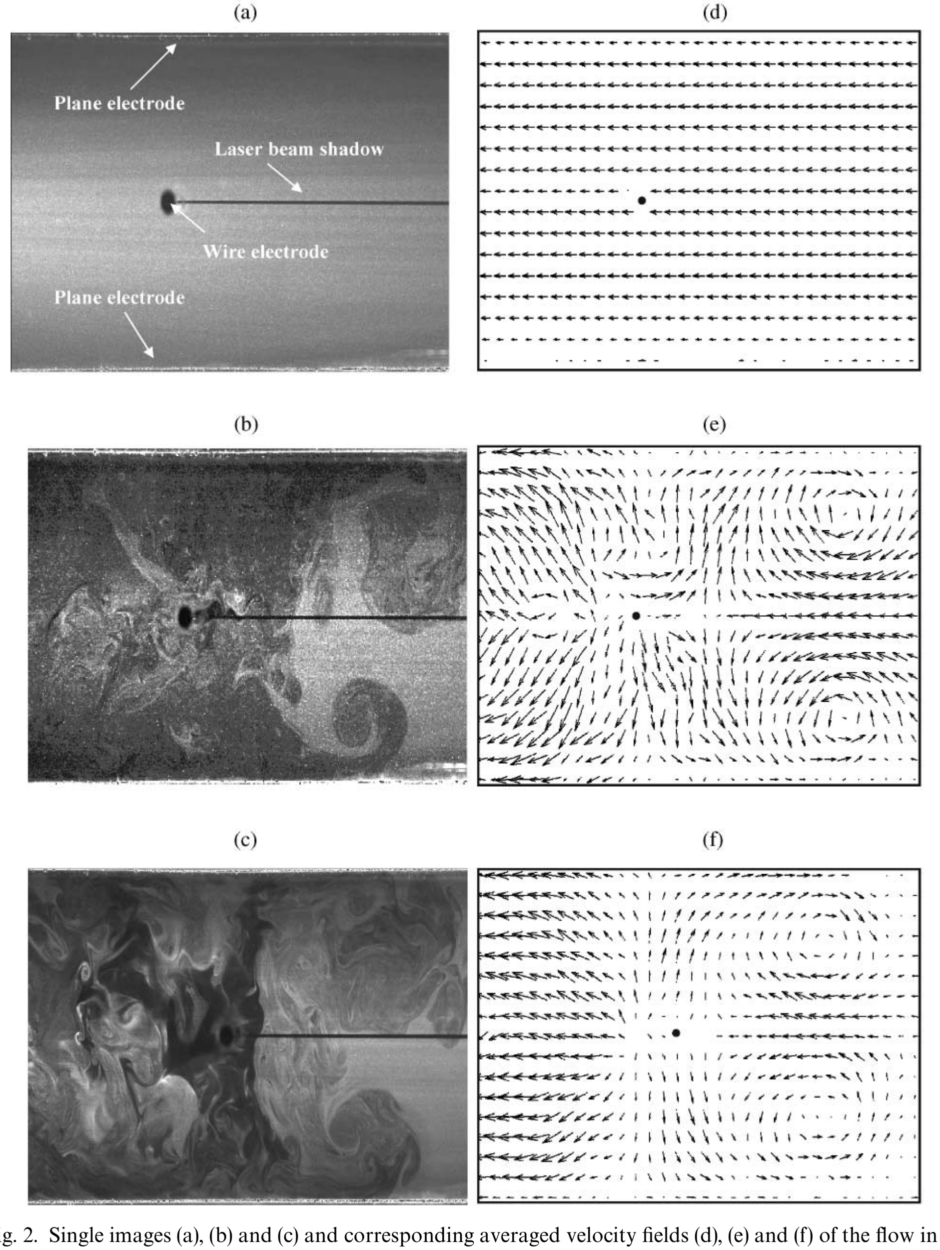

Fig. 2. Single images (a), (b) and (c) and corresponding averaged velocity fields (d), (e) and (f) of the flow in the precipitator model for a flow mean velocity of 0.2 m/s. The dot in (d), (e) and (f) marks the position of the wire electrode. The length of vector is proportional to the velocity. (a), (d): No voltage applied; (b), (e): Negative voltage of 24 kV; (c), (f): Positive voltage of 30 kV.

highly turbulent flows generated by the electric field and charge in the present precipitator model are shown in Fig. 2(b), (c), (e) and (f).

Fig. 2(b) and (e) show a single image and the corresponding averaged (over ten images) velocity field, respectively, of the flow in the precipitator model for a flow mean velocity of 0.2 m/s and a negative voltage of 24 kV applied to the wire electrode. These figures show distinctly the gas flow from the stressed electrode towards the collecting electrode (known as electric wind, ionic wind or secondary gas flow), the reversal flow (or backflow) and the large vortices, resulting from them in the upstream direction of the flow. The velocities of the secondary and reversal flow of about 0.15 and 0.1 m/s, respectively, are in good agreement with the results presented in [6].

A similar behaviour of the flow field, resulting from the interaction between the electric field, gas ionic current emanating from the stressed electrode and the flow of the neutral gas molecules was observed when the stressed electrode was positively polarized (Fig. 2(c) and (f)). The secondary flow, the reversal flow and the resulting vortices were even more pronounced than those at the negative polarization (Fig. 2(b) and (e)). The velocities of the secondary and reversal flows were equal to about 0.3 and 0.2 m/s, respectively.

4. Conclusions

The results presented show that the PIV method is well suited for investigation of the flow field in ESP models, in particular the characteristics of secondary and reversal flows, which result in the flow turbulence. The level of this electrically generated turbulence is significant due to a strong interaction between the electric field, the electric charge and the gas flow. The investigation of the near-collecting electrode region shows the importance of the secondary flows, the velocity of which is several tens of cm/s. This means that the secondary flows can have a great impact on the motion and precipitation of small particles, mainly those in the submicron range. Further investigations of the flow field in ESP models using the PIV method can make it clear whether these turbulent flow structures advance or deteriorate fine particle precipitation process.

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References

[1] M. Jędrusik, A. Świerczok, P. Modzel, Migration velocity and visualization of the trajectory of fly ash particles inside an electrostatic precipitator, J. Electrostat. 44 (1998) 77–84.

[2] S. Masuda, K. Akutsu, T. Nakane, Study on velocity distribution in ES-type electrostatic after collecting device using a lased Doppler anemometer, in: Proceedings of the Annual Conference of the Institute of Electrostatics, Japan, 1978.
[3] P.A. Lawless, E.J. Shaughnessy, Laser Doppler anemometer measurements of particle velocity in a laboratory precipitator, in: Proceedings of the IEEE-IAS, 1981, p. 1124.
[4] C. Riehle, F. Löffler, Particle dynamics in an electrohydrodynamic flow field investigated with a two-component laser-Doppler velocimeter, Part. Syst. Charact. 10 (1993) 41–47.
[5] C. Halldin, R. Hakansson, L.E. Johansson, K. Porle, Particle flow field in a commercial design ESP during intermittent energization, in: Proceedings of the 6th International Conference on Electrostatic Precipitation, Technical University of Budapest, Budapest, Hungary, 1996, pp. 406–416.
[6] H.J. Schmid, H. Umhauer, Investigations on particle dynamics in a plate-type electrostatic precipitator using double-pulse holography, in: Proceedings of the 6th International Conference on Electrostatic Precipitation, Technical University of Budapest, Budapest, Hungary, 1996, pp. 375–381.
[7] J. Westerweel, Fundamentals of digital particle image velocimetry, Meas. Sci. Technol. 8 (1997) 1379–1392.
[8] J. Miller, A.J. Schwab, Electrical similarity concerning particle transport in electrostatic precipitator, J. Electrostat. 29 (1992) 147–165.