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VISUALIZATION OF THE MOVEMENT OF FLY ASH PARTICLES IN THE PLATE–BARBED PLATE ELECTROSTATIC PRECIPITATOR

The paper presents the visualization studies of the movement of fly ash particles in the model of an electrostatic precipitator with a barbed plate. The experimental stand and the photographic method for measuring the velocity of particles in the laser light beam are described. The images obtained permitted the knowledge of main directions of particle movement in the inter-electrode space and the determination of the migration velocity of particles.

1. INTRODUCTION

Electrostatic precipitators have had the most widespread application to the cleaning of waste gases that are produced during the fuel combustion processes. It is characteristic that the system of corona and collection plates is rather similar to that in the very first constructions of a wire-in-tube precipitator worked out by Cottrell and of a wire-plate precipitator designed by Möller in 1912. There are some significant differences in geometry of the electrodes themselves. The processes that occur in the inter-electrode space are the objective of thorough research.

First research comes from the very beginning of the twentieth century and had been done by Lodge and then by Cottrell. The following investigations were carried out by White and were fundamental in the field of charging and collection of particles in a precipitator.

The tremendous growth of interest in increasing the precipitator efficiency took place in the sixties. In 1966, ROSE and WOOD [1] found that there was a number of

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phenomena that were inexplicable from the point of view of theory and occurred in electrostatic precipitators. They cited the example of two identically designed and constructed precipitators that had different collection efficiencies for the same dust; it was a proof that there was the difference between theory and practice. At that time the study of an electrostatic collection process was concentrated mainly on the assessment of the effect of individual geometrical and physical parameters on collection efficiency. Only some studies were concerned with the knowledge of phenomena that occur in the inter-electrode space. Those works referred chiefly to determination of the forces that keep particles in place at the collection plate [2], to the charging rate of particles in the field of corona discharge [3], and to the research on the solid particle trajectories in an electric field [4]–[6]. In the seventies, some efforts were directed to a theoretical analysis of phenomena in electrostatic precipitators. The very first mathematical models of dust deposition in precipitators were formulated; amongst other things there were the models that were based on the trajectory of one particle [7], [8] and on the analysis of the turbulence phenomenon [9]. The effect of an electric field on a two-phase flow in an electrostatic precipitator was analysed as well [10]. The problems of resistivity of precipitated dusts and of the initial charging of dust particles were also recognized. The consecutive years were rather stagnant as far as the technology of electrostatic precipitation is concerned; this resulted from the fact that the precipitator efficiencies and performances had the level desired.

At the present time the necessity of a further increase in the precipitator efficiency has arisen again. It is forced by the rigorous standards of air pollution and the negative influence of many newly employed technologies of the cleaning of flue gases for removing gaseous impurities. Against this background the prime importance has the research work aimed at such constructions of electrostatic precipitators that would guarantee that the collection efficiency will grow along with the minimization of capital and running costs.

The essential importance is here, amongst other things, the electrode geometry that has become the focus of interest of some researchers and precipitator manufacturers. In the electrostatic precipitator of the wire-plate type (figure 1), the distributions of discharges and current density are not uniform both in the longitudinal and axial directions.

Experimental work on the electrohydrodynamic (EHD) flows in the laboratory-scale models of wire-plate electrostatic precipitators [11]–[15] shows that the negative corona discharges similar to a tuft and characteristic of industrial precipitators generate the increase in turbulence of a flow and increase the diffusivity at the gas velocities lower than 2.0 m/s [16].

On the basis of the theory of electrohydrodynamics [12] one can admit that the non-uniformity of current density is responsible for all electrically induced changes in the flow of a medium in the inter-electrode space. It is desirable to find such a construction of a corona electrode which reduces the scale of discharge non-uniformity and, at the same time, the harmful effects. Considering various geometries of the inter-electrode space we can see that only symmetric, positive corona discharges at a clean, smooth surface in the system of concentric spheres, coaxial cylinders or parallel plates do not cause essential flow disturbances.

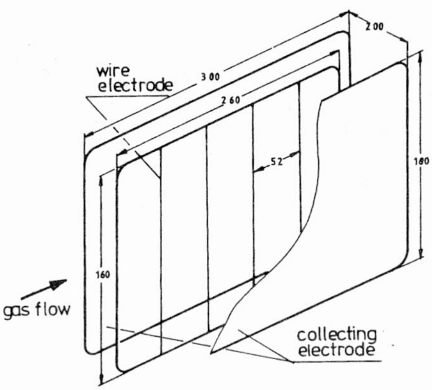

Fig. 1. Schematic of the wire-plate electrode geometry

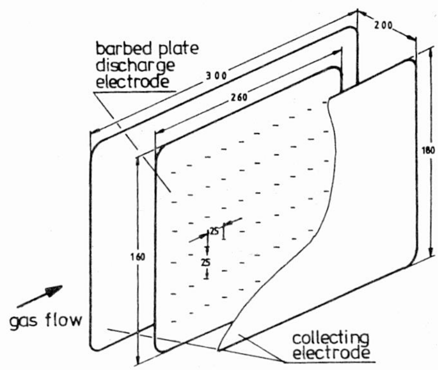

Fig. 2. Schematic of the plate–barbed plate electrode geometry

In this connection numerous constructions of corona electrodes in the form of the so-called barbed plates were designed [17], [18]. The results of investigations along with the visualization of the EHD flow structure (without solid particles) supported the argument that there was the minimization of corona discharge spacings, and thus the decrease in the non-uniformity of an electric field for negative corona was also observed in the geometry of a plate–barbed plate [19], [20]. At the same time it was found that there was the higher turbulence of a gas flow than in the traditional wire-plate electrode geometry. By taking the former results into account the authors of this paper undertook the visualization studies of the behaviour of dust particles in the inter-electrode space between parallel plates one of which has barbs on the surface for initiating the corona discharge.

It is known from the theory and practice that the prime importance for the separation of dust particles in electrostatic precipitators has the migration velocity that is the velocity of a particle in the immediate vicinity of a collection electrode [21]. The research carried out by the authors of this paper is the contribution to this problem.

2. EXPERIMENTAL STAND FOR THE VISUALIZATION STUDIES

The laboratory test installation for carrying out the research has been designed and built. It permitted visualization of the trajectories of solid particles and measurement of their velocity in the inter-electrode space. The experimental stand (figures 3 and 4) was intended to make it possible to study two electrode geometries

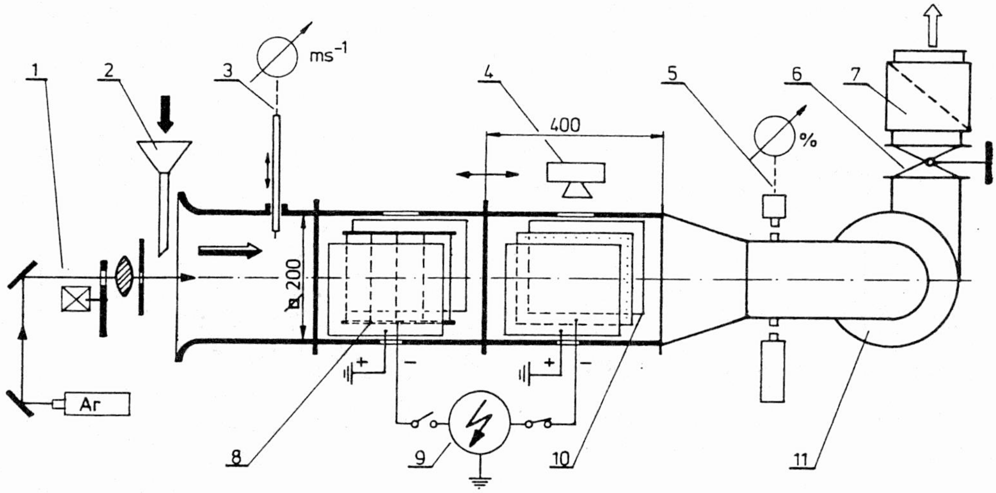

Fig. 3. Experimental stand:
1 – laser optical system, *2* – dust feeder, *3* – hot-wire anemometer, *4* – camera, *5* – laser dustmeter, *6* – flow regulator, *7* – filter, *8* – wire-plate electrode system, *9* – high voltage power supply, *10* – plate–barbed plate electrode system, *11* – fan

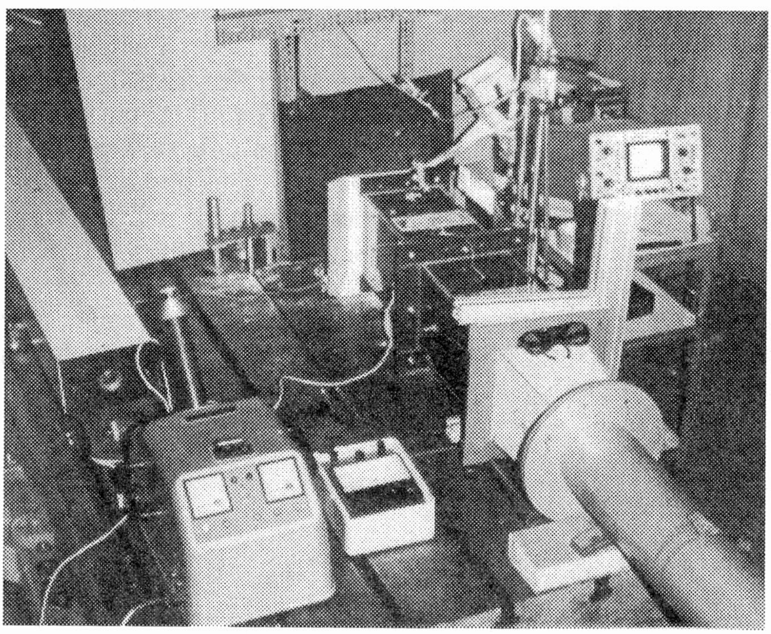

Fig. 4. View of the experimental stand

that are energized independently. The observation zone of the particle trajectories is shown in figure 5. The model of an electrostatic precipitator chamber is made of Plexiglass and the visualization openings are of quartz glass. The inner walls of the model are blacked in order to prevent the light from reflecting.

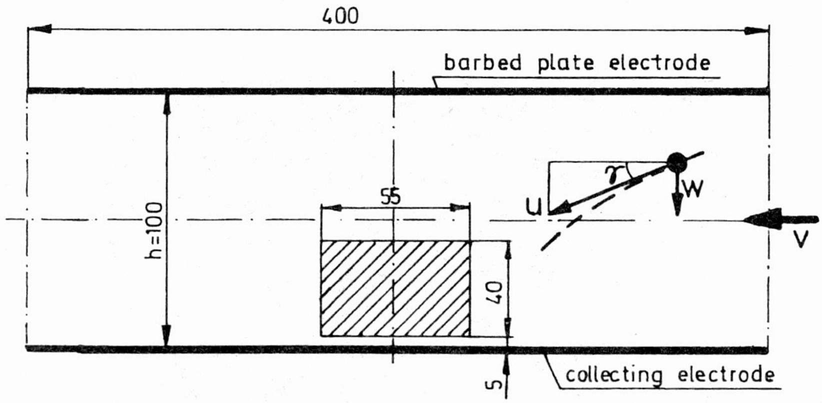

Fig. 5. Observation zone in the electrostatic precipitator model (top view):
v – air velocity, u – tangential particle velocity, w – particle migration velocity, γ – angle of particle trajectory inclination

The traditional geometry of electrodes (figure 1) has its application in the experiments in which two grounded collection electrodes in the form of smooth steel plates spaced by a distance of 200 mm are used. Between the electrodes there are 4 tungsten wires of 0.09 mm in diameter on a frame, being a corona electrode.

The second electrode system is made up of three parallel plate electrodes: two grounded, smooth collection plates and one aluminium corona plate placed between them and having steel barbs on its surface (figure 2).

3. DESCRIPTION OF THE VISUALIZATION STUDIES

The objective of the experiments was to study the movement of solid particles in the plate–barbed plate geometry. The particle trajectories were visualized by means of the light beam from an argon laser of the 3 W power output. Dust particles were introduced into the visualization zone using a feeding system which enabled the variation of dust concentration with time.

In the experiments, fly ash obtained as a result of the hard coal combustion in a pulverized-fuel boiler WP-120 was used (figure 6). The size classification of the fly ash particles was done with the use of a series of screens of the mesh of 40, 63, 100 and 160 μm. The ash resistivity and density were 10^7–10^8 ohm·cm and 2200 kg/m^3, respectively, under the laboratory conditions. During the visualization process the air velocity, which was measured using a hot-wire anemometer, amounted to 0.6 and 1.0 m/s. The barbed electrode was energized with the DC voltage of negative polarity and regulated within the range of 0–45 kV. During the experiments the plate spacing was not changed. For taking pictures of the particle trajectories a photographic camera and the black-and-white Kodak T/Max 3200 film of a speed of 400 ASA were used.

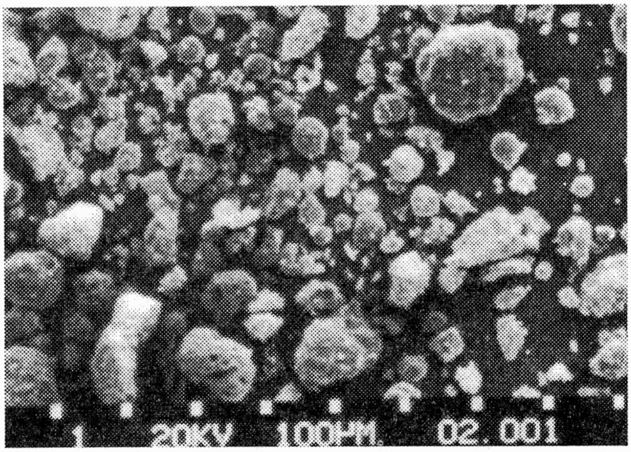

Fig. 6. Microscope photograph (×100) of the fly ash particles under investigations

The observation zone in the electrostatic precipitator model comprises the close proximity of the collection electrode. The flat laser beam is formed by a special optical system and has the thickness of 2–3 mm and the shape of a ribbon (sheet) whose cross-section is rectangular. The beam is perpendicular to the camera's lens axis and parallel to the particle trajectory. The particle tracks as recorded on the film come from the light reflected from their surface.

In order to examine the particle movement two kinds of experiments were performed. In the first of them, the visualization of a gas jet of the high dust particle concentration was made in order to determine the direction of a particle flux and its dispersion. The second experiment relied upon the visualization of trajectories of the small number of particles from the selected ranges of their diameters and upon the determination of their velocity. To this end a stroboscopic disk was used the strobe time of which is 1 ms. The particle velocity was determined from

$$u = \frac{\Delta s}{\lambda t}$$

where: Δs is the length of a trajectory track in a photograph, λ denotes the enlargement scale, and t is the strobe time.

4. RESULTS OF STUDIES

4.1. CURRENT-VOLTAGE CHARACTERISTICS

The current-voltage characteristics are presented in figure 7. In the wire-plate geometry the initial corona voltage amounted to 14 kV, while the influence of corona polarity was unnoticeable. For the system with the barbed plate, the voltage of initial corona was some 15 kV for negative polarity and 17 kV for positive polarity. The system of electrodes was energized with the voltage of the maximum value of 40 kV and the sparkovers were not observed.

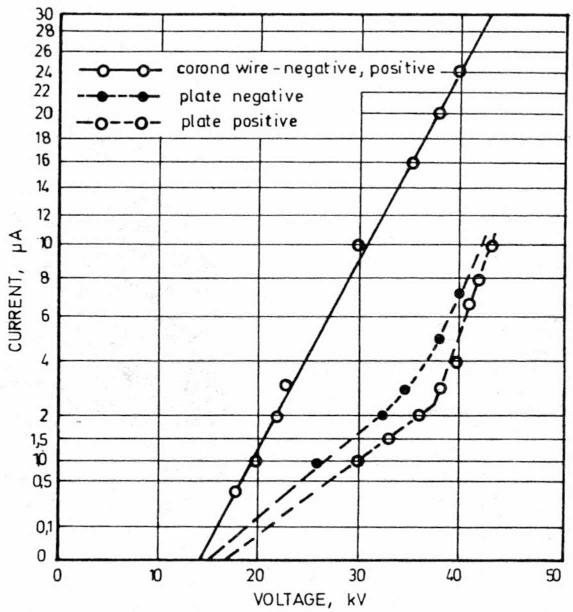

Fig. 7. Current-voltage characteristics of the two electrode geometries

4.2. DUST MOVEMENT VISUALIZATION

The image of a large number of dust particles moving with the air jet in the inter-electrode space without an electric field is shown in figure 8. The movement has a very systematic character.

Figure 9 presents the image of a movement of the fly ash particles at the voltage of 30 kV, and in figure 10 the characteristic directions of particle displacement in the space examined are separated. The image indicates that there is a significant

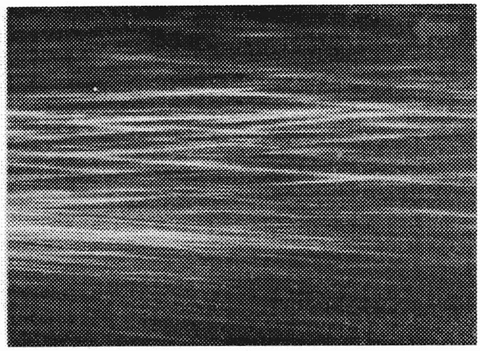

Fig. 8. Particle trajectories in a gas jet without an electric field
particle diameters: 40–63 μm, air velocity: 1 m/s

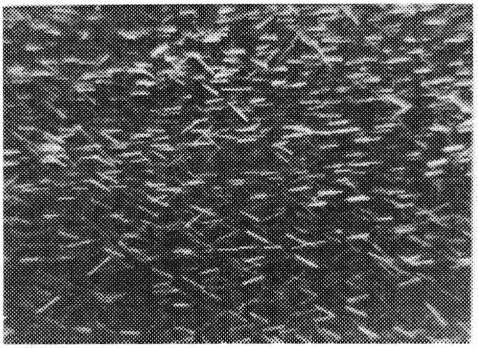

Fig. 9. Particle trajectories in a gas jet with an electric field
particle diameters: 40–63 μm, air velocity: 1 m/s, supply voltage: 30 kV

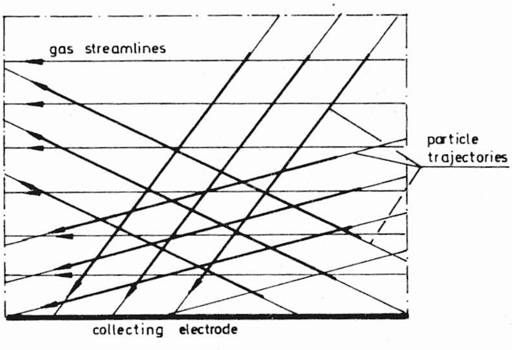

Fig. 10. Sketch of the characteristic and likely directions of particle movement under the electric field in the plate–barbed plate geometry

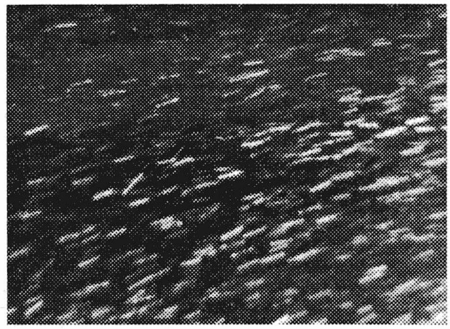

Fig. 11. Particle trajectories in a gas jet with an electric field in the wire-plate geometry
particle diameters: 40–63 μm, air velocity: 1 m/s, supply voltage: 25 kV

difference of particle movement in the space examined in comparison with the wire-plate geometry as shown in figure 11.

The trajectories for different particle sizes and voltages in the plate–barbed plate geometry are illustrated in figures 12a, b and c. Apart from the trajectories of particles, which are consistent with the expectations resulting from the theory of dust collection in an electrostatic precipitator, the trajectories of particles travelling with the high velocity from the corona electrode to a collection one, and from the collection electrode to a corona one can be separated in the photographs. The similar phenomena were already reported in the literature of the subject [6]. Considering the turbulent mixing of a flow that occurs in an electrostatic precipitator with a barbed plate [20], one should perform the additional studies of the flow of gas and particles in the inter-electrode space in order to interpret the phenomenon observed.

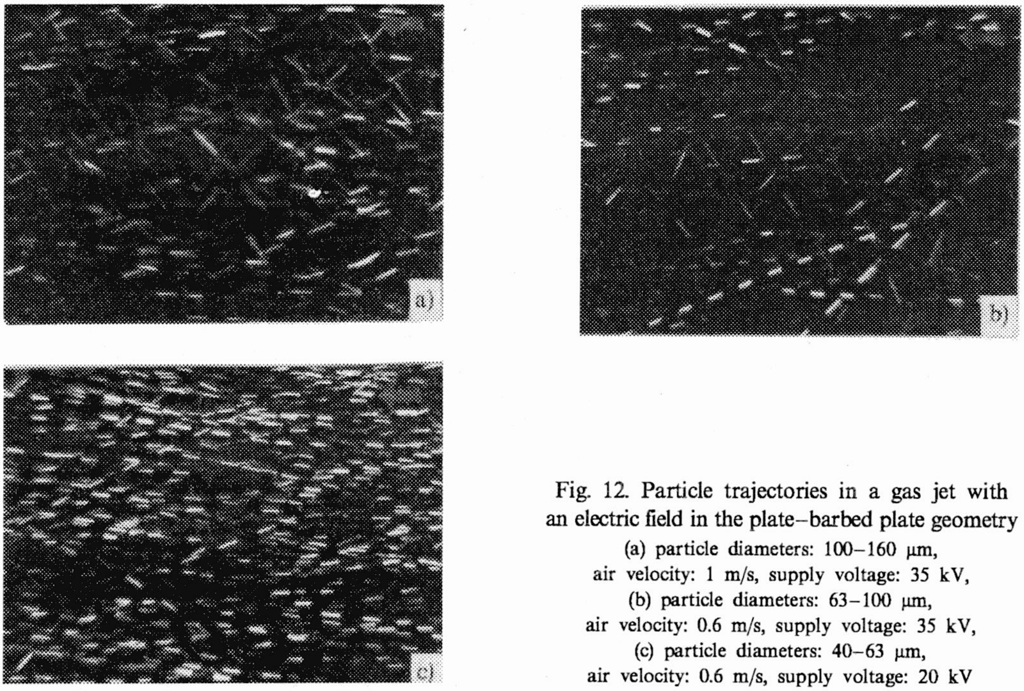

Fig. 12. Particle trajectories in a gas jet with an electric field in the plate–barbed plate geometry
(a) particle diameters: 100–160 μm,
air velocity: 1 m/s, supply voltage: 35 kV,
(b) particle diameters: 63–100 μm,
air velocity: 0.6 m/s, supply voltage: 35 kV,
(c) particle diameters: 40–63 μm,
air velocity: 0.6 m/s, supply voltage: 20 kV

4.3. VELOCITY OF A PARTICLE IN THE ELECTRIC FIELD

The collection of solid particles in an electrostatic precipitator is determined by the migration velocity w which is the component of a particle movement perpendicular to the collection electrode (figure 5). In order to determine the real migration velocities in the model, many series of photographs were made for the three ranges of particle diameters as a function of supply voltage. In figure 13, the changes of the mean migration velocity are presented versus the equivalent diameters of particles for different supply voltages and a constant gas velocity.

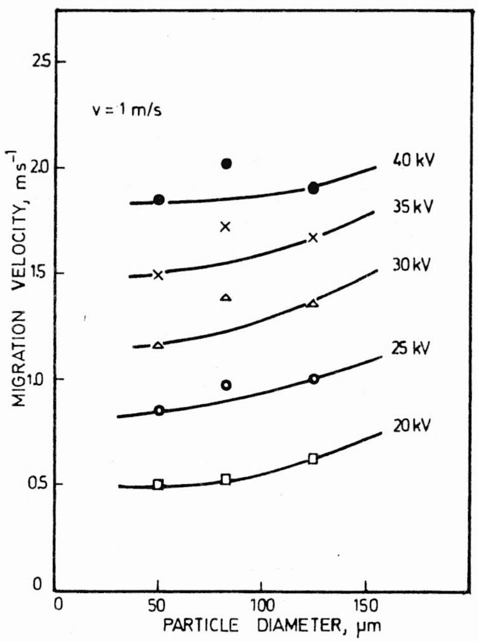

Fig. 13. Migration velocity of particles vs. their diameters

By analyzing the curves one can conclude that the profound significance has the supply voltage in the examined range of diameters and velocities. Comparison of the migration velocity for the wire-plate and plate–barbed plate geometries is shown in figure 14. These curves show that the same migration velocity in the case of the plate–barbed plate geometry may be gained at higher voltages.

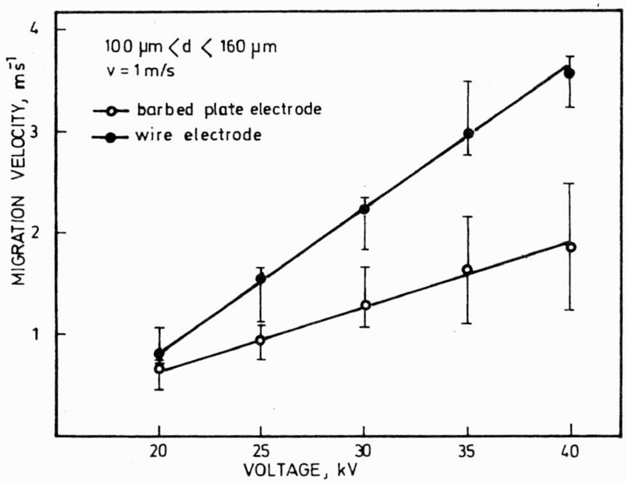

Fig. 14. Particle migration velocity vs supply voltage

5. SUMMARY

The performance efficiency of an electrostatic precipitator is strongly dependent on the geometry of electrodes. While searching new constructions of electrostatic precipitators, one tried to apply a system in which the corona electrode is a plate with barbs. Previous studies of movements in such inter-electrode spaces did not take the solid particle movement into account.

The principal result of the research presented in the paper was the experimental determination of the migration velocity of fly ash particles; this velocity is characterized by the ability of particles to be collected in an electrostatic precipitator. Moreover, the hitherto existing information has been collected about the character of dust movement in the plate–barbed plate geometry with the particular regard to the influence of the particle diameter and supply voltage.

In the experiments, we used such dusts whose particle diameters were in the range from 40 to 160 μm. It was found that in this range the voltage exerted stronger influence on the migration velocity than the particle diameters. At the same time there was observed a phenomenon that could testify to the occurrence of the positive electric charges in the inter-electrode space (the collection of dust particles on the corona electrode) and the large-scale movement of dust particles from the collection electrode to a corona one which creates the secondary flow of dust particles. The particle velocities in the same direction do not depend practically on the particle diameter but on the supply voltage.

It is assumed that such a phenomenon can be an outcome of depolarization of dust particles in the immediate vicinity of the collection electrode which gives, as a result, the return of particles to the gas jet. It can deteriorate the precipitator performance. As a result of the previous research on the electrohydrodynamic flow in electrostatic precipitators, the above phenomenon requires further investigation of other kinds of dusts (including those from the process of desulfurization of flue gases) and the particle diameters below 40 μm.

Considering the complexity and time consumption of the studies carried out it was possible to examine the system: plate–barbed plate only in one version. In this connection and from the practical point of view it is necessary to continue these investigations which would permit one to optimize the electrode geometry and the performance efficiency.

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WIZUALIZACJA PRZEPŁYWU CZĄSTEK POPIOŁU LOTNEGO W ELEKTROFILTRZE O GEOMETRII ELEKTROD PŁYTA–PŁYTA OSTRZOWA

Zaprezentowano badania wizualizacyjne ruchu cząstek popiołu lotnego w modelu elektrofiltru z ulotową płytą ostrzową. Opisano stanowisko badawcze i fotograficzną metodę pomiaru prędkości cząstek stałych w świetle laserowym. Otrzymane obrazy umożliwiły poznanie głównych kierunków ruchu cząstek popiołu lotnego w przestrzeni międzyelektrodowej i określenie ich prędkości wędrowania.

ВИЗУАЛИЗАЦИЯ ПРОТЕКАНИЯ ЧАСТИЦ ЛЕТУЧЕЙ ЗОЛЫ В ЭЛЕКТРОФИЛЬТРЕ ЭЛЕКТРОДОВ ПЛИТКА–ОСТРИЕВАЯ ПЛИТКА

Представлены визуализационные исследования движения частиц летучей золы в модели электрофильтра с коронной остриевой плиткой. Описаны исследовательский стенд и фотографический метод измерения скорости твердых частиц в лазерном свете. Полученные образы дали возможность познания главных направлений движения частиц летучей золы в межэлектродном пространстве и определения их скорости движения.