Charging and Discharging of Insulating Particles on the Surface of a Grounded Electrode

Alin Urs, Adrian Samuila, Adrian Mihalcioiu, and Lucian Dascalescu, *Senior Member, IEEE*

***Abstract*—The aim of the present paper is to analyze the corona charging of millimeter-size insulating disks, as well as their discharging when they are no longer exposed to the action of an external electric field. The experiments were carried out on a roll-type electrostatic laboratory separator, equipped with a wire-type corona electrode, simulating the actual charging/discharging conditions in an industrial unit. Disks of various sizes were charged on the surface of the roll electrode, then the high voltage supplied to the corona electrode was turned off and the particles were collected in a Faraday pail, connected to an electrometer. The charge measurements were performed at various time intervals from high-voltage turn-off. In this way, the charge decay could be recorded and the discharge process fully characterized. The measured data show that the discharge process depends on the nature, size, and shape of the particles, as well as on the contact conditions between the particles and the grounded roll electrode. These data could guide the design of the electrostatic separation experiments that precede any new industrial application of this technology.**

***Index Terms*—Charge decay, charge measurements, corona charging, electrostatic applications.**

I. Introduction

The physical phenomena related to the ionic charging of insulating particles [1]–[6] have been extensively studied in connection with the industrial application of several important electrostatic technologies: precipitation of dusts, deposition of powders, and separation of granular materials [7]–[12]. The most widely used mathematical model of unipolar charging of particles was established by Pauthenier and Moreau-Hanot [1], who considered single spherical particles moving freely in a uniform external electric field E_o, where uniform monopolar space charge with density q exists. This is a model that can be accurate enough for the electrostatic precipitators, as in most industry applications the dust particles are larger than 2 μm in diameter (thermal diffusion could be neglected) and their volume concentration is low.

At high electric field strengths, the measured charge may be smaller than the value given by Pauthenier's formula, due to the self-discharge effect [14], [15]. Similar observations were made in the case of fixed or high-inertia particles [16], [17].

Paper MSDAD-A 03–20, presented at the 2002 Industry Applications Society Annual Meeting, Pittsburgh, PA, October 13–18, and approved for publication in the IEEE Transactions on Industry Applications by the Electrostatic Processes Committee of the IEEE Industry Applications Society. Manuscript submitted for review October 15, 2002 and released for publication November 10, 2003.

A. Urs, A. Samuila, and A. Mihalcioiu are with Equipe Electronique et Electrostatique, LAII-ESIP, UPRES-EA 1219, University Institute of Technology, 16021 Angoulême Cedex, France, and also with the Electrical Engineering Department, Technical University of Cluj-Napoca, 3400 Cluj-Napoca, Romania (e-mail: Alin_Urs@yahoo.com; asamuila@iutang.univ-poitiers.fr; madrian@iutang.univ-poitiers.fr).

L. Dascalescu is with Equipe Electronique et Electrostatique, LAII-ESIP, UPRES-EA 1219, University Institute of Technology, 16021 Angoulême Cedex, France (e-mail: ldascalescu@iutang.univ-poitiers.fr).

Digital Object Identifier 10.1109/TIA.2004.824500

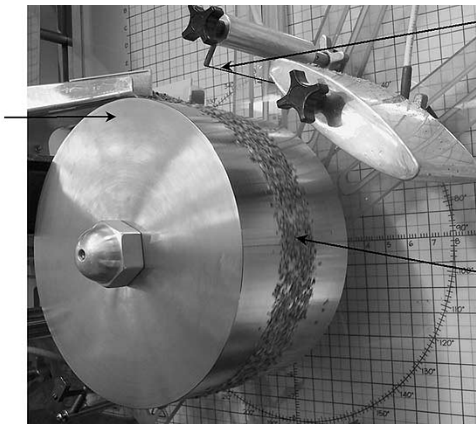

Fig. 1. Charged insulating particles "pinned" on the surface of the grounded electrode of a roll-type corona electrostatic separator. 1: grounded rotating roll electrode; 2: corona electrode; 3: charged particles.

In the case of the electrostatic separation of granular solids, where the particles to be charged form a more or less compact layer on the surface of an electrode (Fig. 1), Pauthenier's model is no longer valid. This justified the studies carried out by the authors on the unipolar charging of insulating particles, either spherical or cylindrical in shape, in contact with the rotating roll electrode of a corona-electrostatic separator [18], [19]. A numerical method was proposed by Dascalescu *et al.* [20] for the evaluation of unipolar charge acquired by single insulating particles near or in contact with an electrode, and the results were in good agreement with the experimental findings in a roll-type corona-electrostatic separator [20]. The reported computational and experimental data clearly show that the charge imparted by "ion bombardment" is higher in those cases.

Very few studies were performed on particle discharging in contact with an electrode. Nevertheless, this phenomenon plays an important role in the electrostatic separation process of granular materials. The electric image force that "pins" the granular matter on the surface of the rotating roll electrode is proportional to the residual charge carried by each of the particles. Therefore, it is important to be able to estimate the rate at which this charge vanishes in contact with the grounded electrode.

In an attempt to address this problem, the aim of this paper is double: analyze the corona charging of mm-size insulating disks at the surface of a rotating roll electrode, as well as their discharging when they are no longer exposed to the action of an external electric field. The experiments were carried out on a roll-type electrostatic laboratory separator, provided with a wire-type corona electrode, simulating the actual charging/discharging conditions in an industrial unit.

0093-9994/04$20.00 © 2004 IEEE

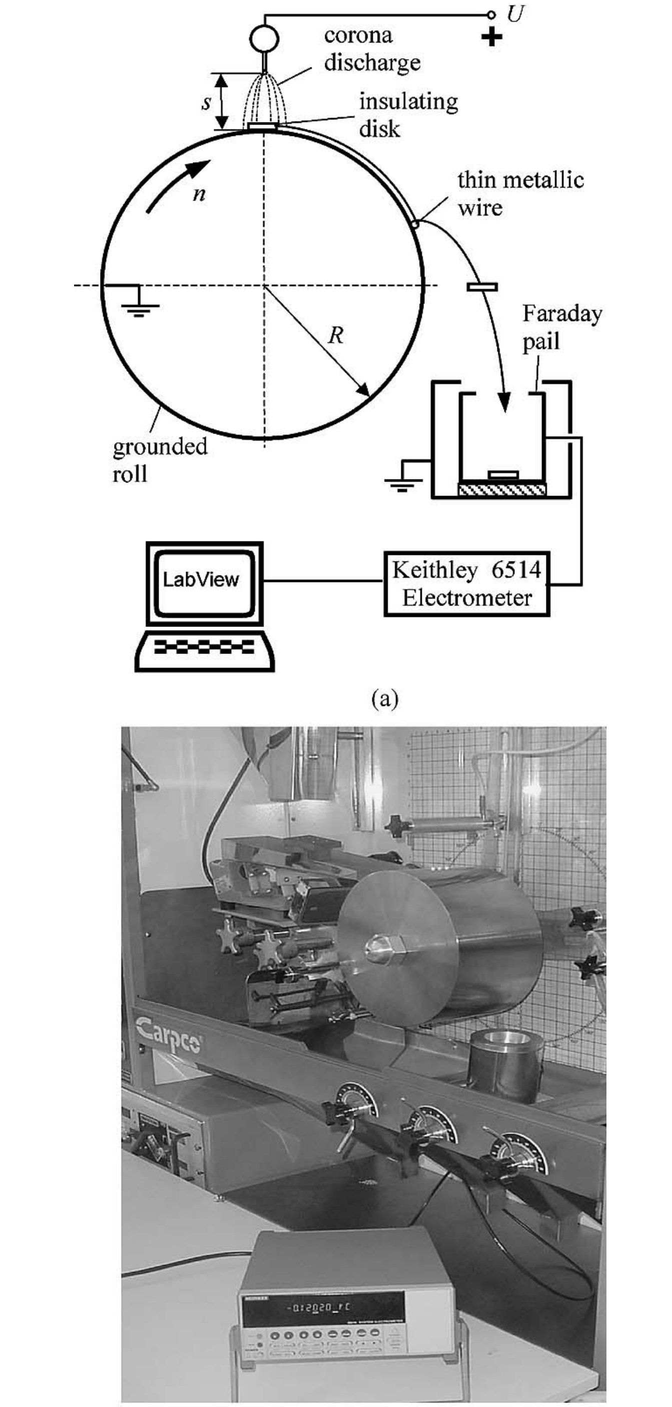

Fig. 2. Experimental setup; schematic representation (a) and physical embodiment (b).

II. Experimental Setup

A laboratory roll-type corona-electrostatic separator (CARPCO, Jacksonville, FL) was employed for the experimental study of particle charging and discharging. The unipolar space charge was generated by a wire-type corona electrode, located at a distance $s = 50$ mm from the surface of the grounded roll electrode and brought to a positive potential $U = 20$ or 25 kV (Fig. 2). An electrometer (Keithley Instruments, Model 6514) was used to measure the charge of four types of insulating particles:

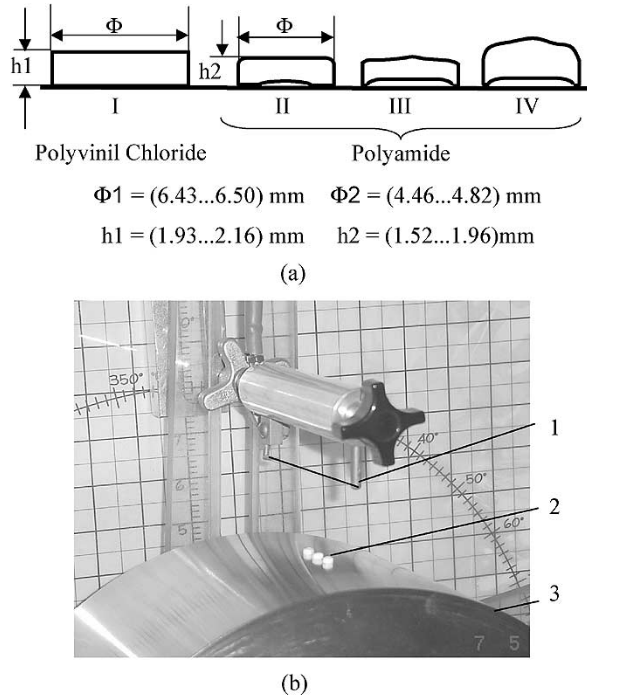

Fig. 3. (a) Schematic representation of the four types of particles employed in this experiment and (b) view of the corona charging experimental setup. 1: corona electrode; 2: charged particles; 3: grounded roll electrode.

- type I, polyvinyl chloride disks of diameter $\Phi 1 = (6.43 \ldots 6.50)$ mm and height $h1 = (1.93 \ldots 2.16)$ mm;
- type II, polyamide "disks" of diameter $\Phi 2 = (4.46 \ldots 4.82)$ mm and height $h2 = (1.52 \ldots 1.96)$ mm;
- type III, polyamide "disks" of diameter $\Phi 3 = (4.42 \ldots 4.64)$ mm and height $h3 < 1.5$ mm, average mass: 2.3 g;
- type IV, polyamide "disks" of diameter $\Phi 4 = (4.58 \ldots 4.84)$ mm and height $h4 > 2.5$ mm, average mass: 6.5 g.

The catalog data of the bars in polyvinyl chloride from which the type I disks were cut indicate a volume resistivity $> 10^{11}$ Ωcm and a dielectric constant ≈4. The polyamide disks were characterized by a volume resistivity $> 10^{13}$ Ωcm and a dielectric constant ≈2.2.

The samples II–IV were obtained by classification from a genuine polyamide granular material provided by a plastic manufacturer. Types III and IV are cylinders terminated by curved surfaces, as suggested by the schematical representations in Fig. 3. In order to obtain type II particles closer in shape to a "standard" disk, glass paper was used to convert the curved bases of genuine granules similar to those of types III and IV into rather smooth planes.

In each experiment, one or several particles were placed on the surface of the roll electrode, with their centers located in the vertical plane defined by the corona wire and the axis of the roll electrode, as shown in Fig. 2. They were subjected to a corona field for 10 s. Then, the roll drive was turned on, at a speed n high enough to ensure a centrifugal force capable to throw off the particles, to be collected in a Faraday pail connected to the electrometer. The separator was also provided with a thin metallic wire, the role of which was to remove the particles too

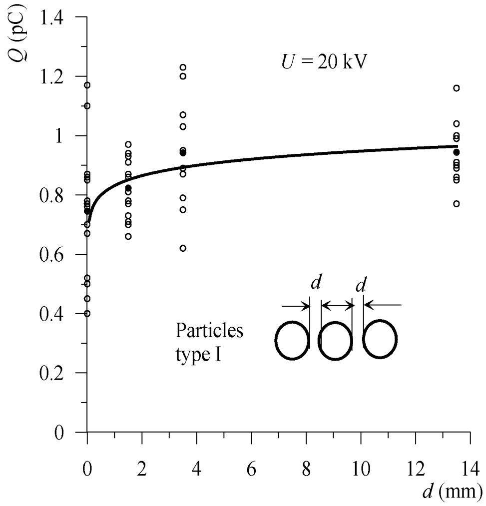

Fig. 4. Charge Q of type—I particles as function of spacing d, for an applied voltage $V = 20$ kV, and a distance $s = 50$ mm between the electrodes.

tightly "pinned" on the surface of the roll electrode. In some experiments, after turning off the high voltage, the particles were maintained in the same position for intervals of time varying from $t_{\rm disch} = 2$ s to 2 min. The ambient conditions were rather constant throughout the experiments: the temperature varied between 19.1 °C–21.3 °C, and the relative humidity ranged from 38.6% to 41.8%.

III. Results

In the first set of experiments, groups of three type I particles were charged in the corona field generated by supplying the wire electrode at $U = 20$ kV. The study was carried out for various distances d between adjacent particles. The results are given in Fig. 4, where each point was obtained by dividing the measured charge by the number of new particles collected in the Faraday pail at each experiment. In this figure, as well as in Figs. 5–8, all measured results were marked with circles. The dots appearing on them are the result of the superimpression of the circles corresponding to several measured values that were very close to each other.

The second set of experiments was designed for the study of the discharging process of individual particles. The charge of the particles was found to decrease with the discharging time $t_{\rm disch}$ as shown in Fig. 5.

Type II particles were employed in the third set of experiments, the results of which can be examined in Fig. 6. The data measured during the other two sets of experiments, involving respectively the particles of types III and IV, are represented in Figs. 7 and 8.

IV. Discussion

Particle charging and discharging phenomena are of paramount importance to electrostatic separation processes. Previous studies demonstrated that the proximity of other bodies modifies the distribution of the electric field and hence the conditions of corona charging of insulating particles, as compared with the case when they are single in a uniform electric field.

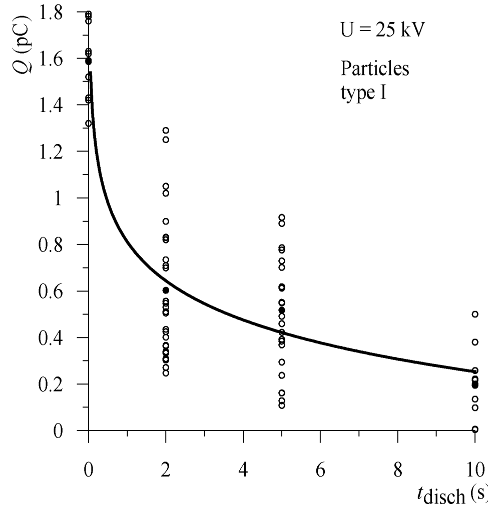

Fig. 5. Charge Q of type-I particles as function of discharging time $t_{\rm disch}$ (the particles were individually charged at an applied voltage $V = 25$ kV, and a distance $s = 50$ mm between the electrodes).

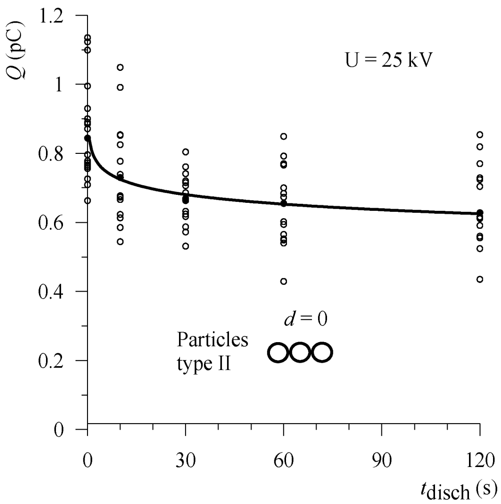

Fig. 6. Charge Q of type-II particles as function of discharging time $t_{\rm disch}$ (the particles were charged by groups of three, for a spacing $d = 0$ mm, at $V = 25$ kV, and $s = 50$ mm).

The data in Fig. 4 indicate that the charge of disk insulating particles of radii R on the surface of an electrode affected by a corona field is smaller when they are spaced at a distance $d < R$. This result is in good agreement with the previously-reported computed and experimental data regarding the corona charging of cylindrical insulating particles [21].

From a practical point of view, this stresses the need to correlate the feed rate with the velocity of the roll electrode, so that to ensure optimum charging conditions for all the particles passing through the high intensity field zone of a corona-electrostatic separator. The development of any new electrostatic separation technology should take into account this aspect, as well as the dynamics of particle discharging in contact with the carrier electrode.

The charge of a type I disk reduced to 1/2 in about 2 s, or less (Fig. 5). The polyamide employed in the experiments was a better insulator than the PVC from which the type I disks were made (its volume resistivity was about two orders of magnitude

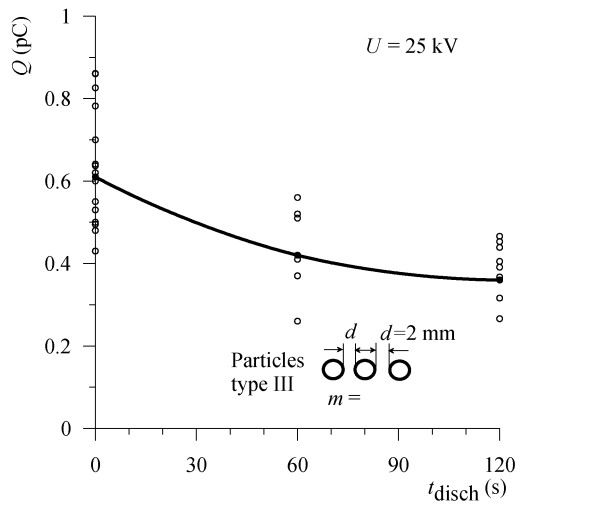

Fig. 7. Charge Q of type-III particles as function of discharging time $t_{\rm disch}$ (the particles were charged by groups of three, for a spacing $d = 2$ mm, at $V = 25$ kV, and $s = 50$ mm; the represented points are average values computed by dividing the measured charge by the number of particles collected in the Faraday pail).

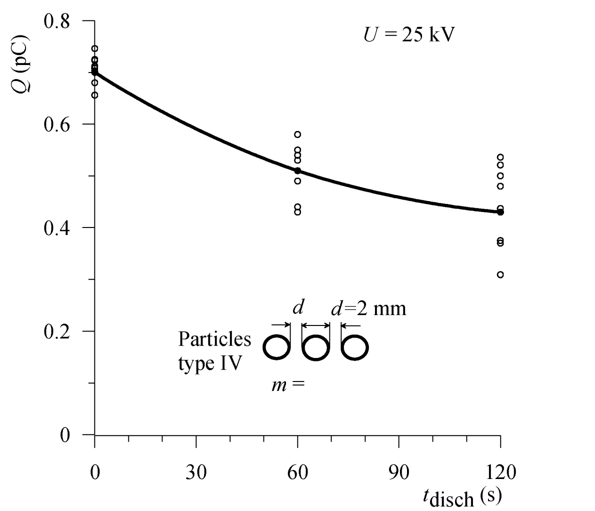

Fig. 8. Charge Q of type-IV particles as function of discharging time $t_{\rm disch}$ (the conditions of the experiment are similar to those in Fig. 7).

higher). As a consequence, the charge decay for polyamide disks (types II–IV) was much slower. Thus, 2 min after high-voltage turn-off, the polyamide disks (sample II) preserved about 3/4 of their initial charge, as shown by the data represented in Fig. 6. This suggests the possibility of using the difference in charge decay rate as a mean for separating the constituents of a granular mixture of insulating materials in contact with a grounded electrode.

At same diameter, the disks in sample IV having a larger lateral surface carry a larger amount of charge than those in sample III, but the dynamics of charge decay seems to be the same: the charge at 2 min after high-voltage turn-off is about 0.6 of the initial value (Fig. 7).

The difference between the behavior of particles in sample II and those in samples III and IV can be explained by the contact conditions between the respective bodies and the grounded roll electrode. This observation emphasizes the need of controlling the state of the surface of the insulating particles, as it may significantly change the discharging conditions, and hence the results of the separation process.

The dispersion of the measured charge values in the reported experiments is due to several factors: the dispersion of particle size, the nonuniformity of the corona generated by the wire electrode, the state of the surface of the grounded electrode, the aspect of particle-electrode contact. These factors should be taken into account when analyzing the feasibility of any new application of electrostatic separation of granular mixtures.

V. Conclusion

The corona charging experiments carried out with millimeter-size PVC and polyamide disks on the surface of a grounded electrode point out several aspects that should be considered in the design of new electrostatic separation technologies.

1) The charge acquired by the insulating particles depends on their shape and size, but also on their density on the surface of the carrier electrode. The feed rate should be chosen such that the material to form a uniform monolayer on the surface of the roll electrode, with particles slightly distanced from one another.
2) The charge decay rate of a particle on the surface of a grounded electrode depends on its volume resistivity. This could be used for separating good and bad insulators from a granular mixture of dielectric materials.
3) Homogeneity of particle size is a prerequisite for uniform discharge conditions. An effective electrostatic separation should be proceeded by the classification of the material to be processed.

Researches are in progress to better characterize the particle-electrode contact conditions and to quantify their effect on the charge decay rate of insulating granules in roll-type corona-electrostatic separators.

References

[1] M. Pauthenier and M. Moreau-Hanot, "La charge de particules sphériques dans un champ ionisé," *J. Phys. Radium*, vol. 3, pp. 590–613, 1932.
[2] J. R. Mc Donald, M. H. Anderson, and R. B. Mosley, "Charge measurement on individual particles existing in laboratory precipitators with positive and negative corona at various temperatures," *J. Appl. Phys.*, vol. 51, pp. 3632–3643, 1980.
[3] B. D. Meyle and J. F. Hughes, "Corona charging of insulating particles," in *Proc. Electrostatics 1983*, Inst. Phys. Conf. Ser. 66, Oxford, U.K., 1983, pp. 155–160.
[4] L. Salasoo, J. K. Nelson, R. J. Schwabe, and W. L. Snaddon, "Estimation of particulate charging and migration for pulsed precipitator applications," *J. Electrostatics*, vol. 19, pp. 1–19, 1987.
[5] A. F. Howe and J. A. Houlgreave, "An experimental investigation of the charging of different sized particles in a precipitator," in *Proc. Int. Conf. Electrostatic Precipitation*, Padova, Italy, 1987, pp. 329–336.
[6] J. S. Chang, "Electrostatic charging of particles," in *Handbook of Electrostatic Processes*, J. S. Chang, A. J. Kelly, and J. M. Crowley, Eds. New York: Marcel Dekker, 1995, pp. 39–49.
[7] M. Robinson, "Electrostatic precipitation," in *Electrostatics and Its Applications*, A. D. Moore, Ed. New York: Wiley, 1973, pp. 180–220.
[8] J. F. Hughes, *Electrostatic Powder Coating*. New York: Research Studies Press, 1985.
[9] J. M. Crowley, *Fundamentals of Applied Electrostatics*. New York: Wiley, 1986.
[10] J. A. Cross, *Electrostatics. Principles, Problems and Applications*. Bristol, U.K.: Adam Hilger, 1987.

[11] S. Masuda and S. Hosokawa, "Electrostatic precipitation," in *Handbook of Electrostatic Processes*, J.-S. Chang, A. J. Kelly, and J. M. Crowley, Eds. New York: Marcel Dekker, 1995, pp. 441–480.
[12] A. Iuga, R. Morar, A. Samuila, and L. Dascalescu, "Electrostatic separation of metals and plastics from granular wastes," *Proc. IEE—Sci. Meas. Technol.*, vol. 148, pp. 47–54, Mar. 2001.
[13] A. Mizuno, "Review of particle charging research," in *Proc. Int. Conf. Electrostatic Precipitation*, 1981, pp. 304–325.
[14] F. Isahaya, "Specific surface charge density of nonspherical particle and charge decrease by partial self-discharge in high electric field intensity," in *Proc. Int. Conf. Modern Electrostatics*, Beijing, China, 1988, pp. 101–104.
[15] A. Mizuno and M. Fukuma, "Decrease in charge of sharp edge ellipsoidal particles by self-discharge," *IEEE Trans. Ind. Applicat.*, vol. 21, pp. 52–57, Jan./Feb. 1985.
[16] S. Masuda and M. Washizu, "Ionic charging of a very high resistivity spherical particle," *J. Electrostatics*, vol. 6, pp. 57–67, 1979.
[17] I. I. Inculet, N. H. Malik, and J. A. Young, "Corona charging of immobilized spherical particles," in *Proc. Electrostatics 1983*, Oxford, U.K., 1983, pp. 99–104.
[18] A. Samuila, A. Iuga, R. Morar, R. Tobazéon, and L. Dascalescu, "Factors which affect the corona charging of insulating spheres on plate and roll electrodes," *J. Electrostatics*, vol. 40, pp. 377–382, 1997.
[19] L. Dascalescu, D. Rafiroiu, A. Samuila, and R. Tobazéon, "Charging of insulating spheres on the surface of an electrode affected by monopolar ions," *IEEE Trans. Ind. Applicat.*, vol. 34, pp. 35–42, Jan./Feb. 1998.
[20] L. Dascalescu, R. Morar, A. Iuga, A. Samuila, V. Neamtu, and I. Suarasan, "Charging of particulates in the corona field of roll-type electroseparators," *J. Phys. D, Appl. Phys.*, vol. 27, pp. 1242–1251, 1994.
[21] L. Dascalescu, A. Urs, L. Dumitran, and A. Samuila, "Charging of one or several cylindrical particles in monoionized electric fields," in *Conf. Rec. IEEE-IAS Annu. Meeting*, vol. 1, Chicago, IL, 2001, pp. 412–416.

Alin Urs received the M.S. and Advanced Studies degrees in electronics and telecommunications engineering from the Technical University of Cluj-Napoca, Romania, in 1997 and 1998, respectively, and the Ph.D. degree jointly from the Technical University of Cluj-Napoca and the University of Poitiers, Poitiers, France, in 2003.

He began his professional career as a Teaching and Research Assistant in the High Intensity Electric Fields Research Laboratory at the Technical University of Cluj-Napoca. His main interests are triboelectrostatic effects, corona charging of particulates, and optimization of electrostatic separation processes.

Adrian Samuila received the M.S. degree in electrical engineering and the Dr.Eng. degree in electrical technologies from the Technical University of Cluj-Napoca, Cluj-Napoca, Romania, in 1980 and 1997, respectively, and the Dr.Sci. degree in physics from the University of Grenoble, Grenoble, France, in 1997.

After ten years spent in industry, as a Research and Development Engineer, he moved to the Technical University of Cluj-Napoca, as a Lecturer and, since 1999, an Associate Professor in the Electrical Engineering Department. In 1994, 1996, and 1997, he received research scholarships from the Laboratory of Electrostatics and Dielectric Materials, Grenoble, France, where he studied the action of high-intensity electric fields on granular materials. He has coauthored more than 20 papers in the field of electrostatic separation of granular mixtures, showing a special interest for the study of particle charging phenomena: corona discharge, triboelectrostatic effects, and electrostatic induction. He presently holds a visiting Associate Professor position at the University Institute of Technology, Angoulême, France.

Dr. Samuila was the Secretary of the First Annual Meeting of the Electrostatics Society of Romania, organized in 1995 by the High Intensity Electric Fields Laboratory, Technical University of Cluj-Napoca.

Adrian Mihalcioiu received the M.S. degree in electrical engineering from the Technical University of Cluj-Napoca, Cluj-Napoca, Romania, in 2002. He is currently working toward the Ph.D. degree in a program jointly sponsored by the University of Poitiers, Poitiers, France, and the Technical University of Cluj-Napoca, Romania.

His graduate research work was carried out at the Laboratory of Advanced Electric and Electronic Technologies, University Institute of Technology, Angouleme, France, within the framework of the ERASMUS student mobility program, financed by the European Community. His dissertation research involves the development of measurement techniques and virtual instrumentation for the study and control of electrostatic processes. His interests also cover the optimization of electrostatic separation processes.

Lucian Dascalescu (M'93–SM'95) graduated with first class honors from the Faculty of Electrical Engineering, Technical University of Cluj-Napoca, Cluj-Napoca, Romania, in 1978, received the Dr.Eng. degree in electrotechnical materials from the Polytechnic Institute of Bucharest, Bucharest, Romania, and the Dr.Sci. degree and the "Habilitation à Diriger de Recherches" diploma in physics from the University "Joseph Fourier," Grenoble, France.

His professional career began at CUG (Heavy Equipment Works), Cluj-Napoca, Romania. In 1983, he moved to the Technical University of Cluj-Napoca, as an Assistant Professor, later becoming an Associate Professor of Electrical Engineering. From October 1991 to June 1992, he received a research fellowship at the Laboratory of Electrostatics and Dielectric Materials (LEMD), Grenoble, France, where he returned in January 1994, after one year as an Invited Research Associate and Lecturer at Toyohashi University of Technology, Japan, and three months as a Visiting Scientist at the Laboratory of Physics and Mechanics of Fluids, Poitiers, France. For four years, he taught a course in electromechanical conversion of energy at the University Institute of Technology, Grenoble, France. In September 1997, he was appointed Professor of Electrical Engineering and Automated Systems and Head of the Electronics and Electrostatics Research Unit at the University Institute of Technology, Angoulême, France. Since 1999, he has also been Head of the Department of Management and Engineering of Manufacturing Systems. He is the author of several textbooks in the field of electrical engineering and ionized gases. He is the holder of 14 patents, has authored more than 50 papers, and was invited to lecture on the electrostatics of granular materials at various universities and international conferences in China (1988), Poland (1990), the U.S. (1990, 1997, and 1999), Japan (1992, 1993), France (1991 and 1993), the U.K. (1998), Romania (1999), Canada (2001), and Belgium (2002).

Prof. Dascalescu is a senior member of the IEEE Industry Applications Society and Vice-Chair of its Electrostatics Processes Committee. He is a member of the Electrostatics Society of America, Electrostatics Society of Romania, Société des Electriciens et Electroniciens (SEE), and Club Electrotechnique, Electronique, Automatique (EEA) France.