Journal of Electrostatics 71 (2013) 801–807

Contents lists available at SciVerse ScienceDirect

Journal of Electrostatics

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

Computational comparison of charge neutralisations of conductors and insulators with corona ionisers

A. Ohsawa*

Electrical Safety Research Group, National Institute of Occupational Safety and Health, Japan (JNIOSH), 1-4-6 Umezono, Kiyose, Tokyo 204-0024, Japan

ARTICLE INFO

Article history:
Received 9 July 2012
Received in revised form
11 October 2012
Accepted 8 February 2013
Available online 4 March 2013

Keywords:
Charge neutralization
Corona ionizer
Electrohydrodynamic simulation
Electrostatic hazards

ABSTRACT

We report a numerical investigation of phenomena of charge neutralisations of insulators and conductors with a balanced DC or AC ioniser using 2-D cylindrical electrohydrodynamic modelling. The early-phase phenomena of the insulator charge neutralisation are complicated and significantly different from the conductor ones, which indicates that the evaluation by the standard test may lead to potential problems in practical applications. In addition, the results of simulations demonstrated that, in the insulator charge neutralisation, ionisers themselves can cause latent hazards during neutralisation. We propose proper use of ionisers and the standard test to avoid such hazards.

1. Introduction

The electric field resulting from static charge on insulating materials yields electrostatic forces and sometimes initiates electrostatic discharges that can lead to problems and accidents in industry. For example, electrostatic forces attract particulate contaminants or cause materials to stick in undesirable ways; in addition, electrostatic discharges, including those from isolated conductive materials by induction, sometimes result in malfunction of electronic equipment, damage to electronic devices, or occasional fires and explosions. Controlling static charge, therefore, is important to prevent such electrostatic hazards in industry. Charge neutralisation is one of the methods to control the static charge, and corona ionisers are very widely used because of their simplicity.

Thus, the standard technique for testing the performance of an ioniser was developed [1,2]. The standard test method relies on the use of a charged conductive plate for convenience in testing, including charging it; with this test, the charge decay time and potential at the steady state (offset voltage) are measured under the use of an ioniser tested. In addition, convenient instruments, charged plate monitors, are commercially provided for the test. However, in practice, charged objects to be neutralised by ionisers are insulating materials; therefore, this difference might lead to problems even when using ionisers evaluated to be appropriate for charged conductive materials by the test. Since surface charges on an insulating material are locally neutralised at places that the corresponding polarity of ions reaches during neutralisation, different phenomena of charge neutralisation of insulating materials from those of conductive ones could be expected. In addition, it is difficult to measure the potential and charge on a local surface of insulating materials during charge neutralisation; in particular, the measurement of the local surface charge is impossible when the materials are thin and their opposite side surface is also charged. In this study, therefore, we numerically investigate the difference of the charge neutralisations of conductors and insulators with ionisers.

Despite the widespread use of ionisers, the understanding of the phenomena of charge neutralisation using ionisers strongly depends on empirical knowledge. Many experimental investigations [3–11] have been carried out by measuring the potential or current of a charged metal plate during neutralisation; however, in such investigations, only resultant phenomena by ion behaviour could be measured. To understand the essential features of charge neutralisation, the investigation of the motion of ions is of great importance. In addition, the manufacture of recent electrostatic-sensitive devices in electronic industries requires more precise neutralisation. Therefore, understanding based on theoretical approaches involving ion behaviour will result in better neutralisation. An electrohydrodynamic model that can solve the self-consistent motion of ions is very useful for this purpose. In our previous studies, a one-dimensional ion fluid model [12,13] was used and demonstrated that the essential conditions for sufficient neutralisation with AC

* Tel.: +81 (0) 42 491 4512; fax: +81 (0) 42 491 7846.
E-mail addresses: ohsawa@s.jniosh.go.jp, atsushi.ohsawa@gmail.com.

0304-3886/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.elstat.2013.02.001

ionisers with air blowing are that, in the region of ion transport, the density distributions of positive and negative ions have less fluctuation and their charges are quasi-neutralised at the steady state, resulting in a small fluctuation in the offset voltage. Furthermore, in the tube transport of ions, we also demonstrated that a quasi-neutralised ion charge distribution (a charge distribution in which the density distributions of the positive and negative ions are the same) created in the tube greatly reduces the radial electric field, resulting in an extremely decreased loss of ions at the tube wall using 2-D fluid simulations with assuming laminar airflow in the tube [14]. In addition, it was found that the formation of such ion charge distributions greatly depends on the relationship between the frequency of the corona discharge and the airflow velocity. Furthermore, results from the investigation of the production and minimisation of the offset voltage using a 2-D electrohydrodynamic model demonstrated that the emission of continuously balanced ions from ionisers can make the offset voltage zero independently of the placement of an object to be neutralised and the air blower velocity used for ionisers [15].

In this paper, the 2-D electrohydrodynamic model is used to compare the phenomena of the charge neutralisations of conductive and insulating materials with a DC or AC ioniser with an emphasis on the investigation of ion behaviour during neutralisation, and the validity of the standard test method using a conductive plate is discussed.

2. Model

A 2-D electrohydrodynamic model used in this paper is the same as one used previously [15] for the charge neutralisation of a conductive object. The model is described in detail in [15], and will thus be only briefly discussed here except for the model for an insulating object. The 2-D electrohydrodynamic model solves self-consistent motion of positive and negative ions, and the governing equations consist of the equations of incompressible fluid for airflow, the continuity equations for positive and negative ions, and Poisson's equation, as follows;

$$\nabla \cdot \mathbf{v}_a = 0, \tag{1}$$

for airflow velocities, which is reduced from the mass conservation equation. The momentum conservation equation of air fluid flow is,

$$\rho_a \frac{\partial \mathbf{v}_a}{\partial t} + \rho_a (\mathbf{v}_a \cdot \nabla) \mathbf{v}_a = -\nabla P + F_E + \nabla \cdot (\mu \nabla \mathbf{v}_a), \tag{2}$$

in which electric force density $\mathbf{F}_E = e(n_p - n_n)\mathbf{E}$ by the space charge of ions is included. Here, $\mathbf{v}_a$, ρ_a, P, and μ are the airflow velocity, mass density of air, pressure, and viscosity coefficient, respectively. The motion of positive and negative ions is expressed by the following continuity equations,

$$\frac{\partial n_p}{\partial t} + \nabla \cdot (n_p \mathbf{v}_p) - D_p \nabla^2 n_p = -\beta n_p n_n, \tag{3}$$

for positive ions and

$$\frac{\partial n_n}{\partial t} + \nabla \cdot (n_n \mathbf{v}_n) - D_n \nabla^2 n_n = -\beta n_p n_n, \tag{4}$$

for negative ions, where n_p and n_n are the positive and negative ion densities, respectively, and $\mathbf{v}_p = \mathbf{w}_p + \mathbf{v}_a$, $\mathbf{v}_n = \mathbf{w}_n + \mathbf{v}_a$, $\mathbf{w}_p$ and $\mathbf{w}_n$ are the corresponding drift velocities, respectively. The symbols D and β denote the diffusion and ion–ion recombination coefficients, respectively. We use the mobilities for the positive and negative ions and the recombination coefficient in air given by Morrow and Lowke [16] and the diffusion coefficients in Ref. [17]. To obtain the electric field, the Poisson's equation,

$$\nabla^2 \phi = -e(n_p - n_n)/\varepsilon_0, \tag{5}$$

and

$$\mathbf{E} = -\nabla \phi, \tag{6}$$

are used. Here, e is the elementary charge (ion charge), ε_0 is the electric constant, $\mathbf{E}$ is the electric field, and ϕ is the potential. For an insulating object to be neutralised, the potential inside the object is obtained from,

$$\nabla^2 \phi = 0, \tag{7}$$

and the boundary condition at the interface of the insulating object,

$$\mathbf{n} \cdot (\mathbf{D}_0 - \mathbf{D}_1) = \sigma_s, \tag{8}$$

is used, where $\mathbf{n}$ is the outwardly directed unit vector normal to the interface and $\mathbf{D}_0$ and $\mathbf{D}_1$ are the displacements of outside and inside at a local surface of the insulating object, respectively. σ_s is the local surface charge density. The relative electric permittivity of the insulating object is 2.0.

The geometry of an ioniser and a charged object (plate) used in the standard test method for overhead ionisers [1,2] is modelled in two-dimensional, axisymmetric cylindrical coordinates (r,z), as shown in Fig. 1. The origin point of (r,z) is point E. To employ the coordinate system, the shapes of the ioniser and the charged plate are assumed to be circular disks with a diameter of 6 cm and thickness of 5 cm for the ioniser and a radius, R_{cp}, of 8.64 cm and thickness of 1 cm for the charged plate. The separation between them is 45 cm, and the charged plate is placed at 15 cm above a grounded plane according to the standard test method.

Poisson's equation, Eq. (5), was solved throughout the entire computational domain, ABCD, and the equations for air fluid flow and ions are solved only in region EGHD, shown in Fig. 1. The potential on the boundary of ABCD is assumed to be zero except on the axis. The body of the ioniser, including the conductive grid generally used for its ion outlet, is grounded. The radial electric field on the axis is zero. In the computational domain for solving Eqs. (1)–(4) for airflow and ions of region EGHD, the following boundary conditions are assumed, where the symbols of u and v denote the velocities of the components of the r and z directions, respectively: at boundary FG, the gradients of the velocities of airflow are assumed to be zero, i.e., $\partial u_a/\partial z = \partial v_a/\partial z = 0$, and the

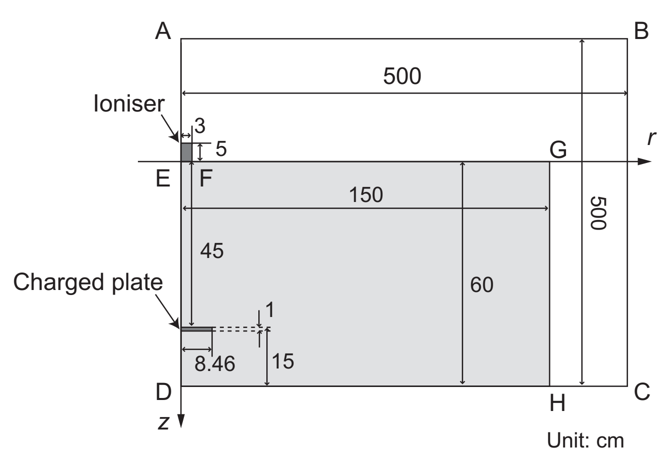

Fig. 1. Computational domains of the model.