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Charge distribution of welding fume particles after charging by corona ionizer

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ABSTRACT

An experimental technique, including the differential mobility analyzer and laser aerosol spectrometer, is proposed for determining the aerosol particles charge distribution, charged by the corona discharge. Experimental data processing procedure for determining the polydisperse welding fume particles charge distribution is proposed. Unipolar particle charging process in the environment saturated by ions is studied. Proposed theoretical model of unipolar charging in approximation of the dust–ion plasma demonstrates good correlation with experimental data. The two-dimensional size and charge distributions of welding fume particles are demonstrated.

1. Introduction

The particles' charging control is of great importance for aerosol science and technology. Indoor air cleaners, industrial electrostatic precipitators, and smoke detectors are instances of practical apparatuses and instruments, which ultimately rely upon the capability of airborne particles to acquire a net electric charge (Alonso, Santos, Hontañón, & Ramiro, 2009). Particulates in the exhausts from industrial processes are either uncharged or weakly charged both positively and/or negatively, depending on their previous history. Therefore, aerosol particles need charging by unipolar ions for their effective electrostatic precipitation. Unipolar charging has advantage over bipolar charging (by radioactive sources or UV-radiation) as it enables the attainment of a higher charging efficiency (Kruis & Fissan, 2001). Corona discharge is among the most common technique to produce high number density of unipolar ions and it is used in many industrial applications such as electrostatic coating and precipitation (Sparks, 1988); in determining aerosol size distribution by electrical mobility analysis (Biskos, Reavell, & Collings, 2005b; Tammet, Mirme, & Tamm, 2002).

The arc welding processes are accompanied by formation of toxic welding fumes, representing the danger for human health and environment. As a result, the harmful welding fume must be collected and treated before entering the worker's breathing zone. Welding fume inhaled particles range in the size from 0.002 to 5 μm as a result of different particle formation mechanisms (Vishnyakov, Kiro, Oprya, & Ennan, 2014). Particles fraction below 0.1 μm in mass distribution corresponds to a very small, nearly negligible part of generated mass. The primary particles agglomerates with different spatial structures and sizes over 0.1 μm and coarse fume particles mostly prevail in the welder's breathing zone (Berner & Berner, 1982; Sowards, Lippold, Dickinson, & Ramirez, 2008a).

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Portable electrostatic precipitators are ideally suited for welding fume collection if the air is to be returned into the workspace. They require very little maintenance and do not need expenses for periodic cartridge filter replacement (Ravent, 2006). But the electrostatic precipitator collection efficiency reaches a minimum for particles in the 0.1–0.2 μm size range (Cheng, Yeh, & Kanapilly, 1981) and reflects the size-dependent combined field and diffusion charging behavior (Hinds, 1999) in transition regime ($0.1 < Kn < 1$), to which the welding fume particles belong. For different welding and cutting processes, the median of welding fume particle size distribution is in the range 0.1–0.25 μm; the mass median aerodynamic diameter is in the range 0.2–0.45 μm (Pohlmann, Holzinger, & Spiegel-Ciobanu, 2013). The particle size distribution in the worker's breathing zone (at a distance of 40 cm from the welding arc) does not change during the process.

The particles' morphology influence their charging rate (Oh, Park, & Kim, 2004; Shin et al., 2010). Besides, for a polydisperse aerosol, the charge distribution of various-size particles will depend upon the size distribution peculiarities (Hoppel & Frick, 1986). The ability of welding fume particles to acquire a net charge in the corona discharge, their size and charge distributions determine the electrostatic parameters of their separation and precipitation, for which the high charges of particles are necessary. Therefore, the feasibility of measuring the particle charge distribution in the range of high charges has great practical interest. The particle charges measurement is usually based on a certain theoretical model of the particle charging. The Fuchs limiting-sphere theory (Fuchs, 1963) is the most commonly used for particle charging in the transition regime. However, this theory is inapplicable for systems with high ion number density, which is necessary for obtaining high particle charges. For example, inapplicability of the Fuchs theory for ion number density exceeding 10^7 cm^{-3} is demonstrated in the paper by Biskos, Reavell, and Collings (2005a). Therefore, the study of the welding fume particles charging by the corona discharge has great importance to achieve the portable electrostatic precipitators optimal design.

Especially important is a separation of particles by sizes during their collection, because the welding fume dust fine fractions is a valuable raw material, which is suitable for some industrial applications. For example, these fractions, which contain the transition metal oxides, can be used for the manufacturing of catalysts without any special treatment, in particular, for the ozone decomposition reaction (Rakitskaya, Ennan, Truba, Kiro, & Volkova, 2014).

In the present paper, the experimental equipment in which a long differential mobility analyzer (DMA) is supplemented by the laser aerosol spectrometer LAS-P (LAS-P, 2010) is used for measuring the welding fume particle charges in the size range 0.15–1.5 μm. The mobility-equivalent particle diameter, determined from DMA, in general case is not equal to optical diameter, determined with LAS-P. However, Emets, Kascheev, and Poluektov (1991) used such a tandem system already, and has demonstrated correctness of these diameters comparison in the range of 0.3–10 μm.

A theoretical model of unipolar particle charging in the environment saturated by ions is proposed and two-dimensional welding fume particle size and charge distributions are obtained. These results are intended, basically, for portable electrostatic precipitator designing, which can separate the particles by sizes in the process of their collection.

2. Corona discharge ionizer

The corona discharge ionizer (corona charger) used for particles' charging is shown in Fig. 1. The ionizer consists of coaxial inner multi-needle discharge electrode and grounded housing with an inner radius 53 mm (8). This configuration provides the annular aerosol flow with 300 Lpm flow rate. The discharge electrode has six steel disks (5) with 32 mm radius and 2 mm thickness; and each one contains fifteen stainless steel needles with the tip radius of 25 μm (6) radially mounted and connected to a high-voltage power supply. The needle tips are equally spaced on a 38 mm radius circle. The distances from the needle tips to the grounded housing are 15 mm.

Disks with needles are mounted between the special designed insulated holders (4) so the needles are in the ring channel with a width 8 mm and depth 6 mm into which the sheath air enters through the axial hole (7). The sheath air with a flow rate of 5 Lpm is used to prevent the aerosol particles from entering into the high-intensity corona region.

The distance between the disks with needles is 17 mm. The needles into each subsequent disc were pre-placed with a displacement 4° in respect to the needles of the previous disc, i.e. all aerosol particles pass through the identical ion number density corona regions. Such a design of the multi-needle discharge electrode provides the low threshold voltage (~3.2 kV) and a high power of corona discharge. The measured current of corona discharge is used for estimate the average ion number density.

The aerosol flow with rate $Q_I \cong 301$ Lpm enters into the corona ionizer through the axial channel (1), and into the charging region through the four tangential holes. The cross-section of charging region is $S_I = 38$ cm^2, and length is $L_I = 120$ mm. The particle charging time in the ionizer is $t_I \cong 80$ ms. The sheath air with a flow rate of 50 Lpm also enters into the charging region along the inner surface of housing through the inlet chamber (2) and the narrow annular channel (3), for the particles' loss minimization.

3. Experimental equipment

The experimental equipment schematic diagram used for the charge and size particle distribution measurement is shown in Fig. 2. It consists of four parts: a welding fume source; a corona charger; a differential mobility analyzer (DMA); and a laser aerosol spectrometer (LAS-P).