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A peculiarity of silver-based corona wire heating on ozone generation

Rafael Sh. Islamov [a,*], Yuriy A. Krishtafovich [b]

[a] *Institute on Laser and Information Technologies RAS, Svyatoozerskaya 1, Shatura 140700, Moscow Region, Russian Federation*
[b] *Aeolis, Korolev 140700, Moscow Region, Russian Federation*

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A B S T R A C T

The effect of corona wire temperature on the ozone generation in the positive dc corona electrostatic precipitator is studied experimentally. The external heating of the corona wire can suppress the ozone generation. In this study, nichrome and two kinds of silver-based wires 0.1 mm diameter were tested as discharges electrodes. The nichrome corona wire heating shows a well-known monotonic decreasing the rate of ozone production. In the case of the tested silver-based wires the rate of ozone production decreases nonlinearly and passes through a local minimum in the range from 35 to 55 °C with increasing the wire temperature. At the wire temperature about 46 °C ozone generation by positive dc corona discharge is decreased by 53% with Ag:Mn = 0.85:0.15 wire and by 25% with Ag:Ni = 0.7:0.3 wire as compared to the same wire at 26 °C. Under these conditions the corona wire heating increases slightly the corona current and speed of airflow.

1. Introduction

Corona discharge is currently used in numerous industrial and consumer applications, including air filtration, air movement, photocopiers, and many others. In many cases, the production of ozone is not allowed to exceed acceptable limit, since ozone is a toxic gas and may cause a deterioration of many materials.

Electrohydrodynamic flow caused by corona-generated ions emission provides silent airflow and air cleaning. High voltage is required to generate sufficient ionic wind for a practical air cleaner, yet the higher the corona current, the larger amount of ozone is generated.

Positive corona discharge is therefore preferred for such appliances since it produces essentially less ozone than negative corona (Brandvold et al. [1], Boelter and Davidson [2], Nashimoto [3]). For a several cm discharge gap between the corona and accelerating electrodes, with a wire electrode having a diameter of the order of 0.1 mm, a pure glow mode of positive corona exists in air at comparatively low voltage and discharge current density, expressed per unit active discharge length of wire, is less than 0.5 mA/m. This discharge was called by Dzhuvarly, Gorin, and Mekhtizade [4] a positive ultracorona.

Any change in experimental conditions such as applied voltage increase, air humidity, discharging electrodes contamination could lead to the corona streamer or the sparkover. Streamer corona produces audible noise, generates radio interference, intensive ozone generation, and causes wire vibration.

Using of small diameter wire and low current results in the lowest ozone production rate as shown by Castle et al. [5], Boelter and Davidson [2], and Nashimoto [3]. Nashimoto [3] has found a strong impact of the corona electrode material on the O_3 generation. Among the tested wire materials silver wire produced the lowest amount of ozone as shown by Nashimoto [3], Boelter and Davidson [2], and Yehia and Mizuno [6], however it has low strength properties and relatively short life time.

Corona wire heating can significantly decrease (Awad and Castle [7], Ohkubo et al. [8], Liu et al. [9]) ozone generated by corona discharges. Commonly used discharge wires are made of nickel chromium alloys, tungsten or stainless steel. In those cases the ozone production decreases monotonically as the wire temperature increases ([7–9]).

In the present paper our attention is focused on positive dc corona discharge, with the goal of the comparison the corona wire temperature effect on the generation of ozone for the two kinds of silver-based and nichrome wires. Silver alloys have been chosen for longevity reasons.

2. Experimental setup

All experiments were carried out at atmospheric pressure and ambient temperature, using the electrodes system with the cross-section shown schematically in the Fig. 1. The experimental

* Corresponding author. Tel.: +7 495 343 0548.
E-mail addresses: islamov@laser.ru (R.Sh. Islamov), krishtaf@yahoo.com (Y.A. Krishtafovich).

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electrostatic precipitator (ESP) (Krichtafovitch [10]) includes a plurality of the corona wire electrodes and a plurality of accelerating electrodes and falls to the regular-type discharge unbounded crosswise. The electrodes system consists of 9 parallel wires 0.1 mm diameter and 10 parallel plate-like aluminium electrodes 37 mm wide each. The portion of the «plate-like» electrodes nearest corona electrodes is in the form of a cylindrical solid 5 mm diameter (see Fig. 1). Electrodes are spaced apart at the distance $s = 12.7$ mm and the discharge gap $h = 19$ mm. Both the wires and the plate-like electrodes have identical length, equal to 20.6 cm (with active discharge length about 19.3 cm). The wires were subjected to the fixed positive dc voltage equal to 17.7 kV while the plate-like electrodes were kept at the ground potential. The charging section is set in a rectangular plastic duct with an inner cross-section of 19.3×12.3 cm^2, 90 cm long. That long outlet to the electrodes system was selected in order to provide uniform ozone distribution and airflow over cross-section.

Ozone concentration is measured by an ozone monitor (OPTEC Model 3.02 ΠP with sensitivity 1 mkg/m^3) based on the ultraviolet adsorption using Teflon tubing placed in the centre of the rectangular duct 50 cm downstream of the corona wires. The velocity of the airflow is measured by an anemometer KIMO LV110 at the end of duct at 90 cm downstream of the corona wires. A Lighthouse 3016 handheld particle counter was used to measure the temperature and relative humidity. An electrostatic kilovoltmeter C196 with accuracy of 1% was used for measuring the discharge voltage. A floating potential 12-volt storage battery, controlled with a potentiometer, was used for the corona wire heating.

3. Determination of the corona wire temperature as a function of external heating power

Two digital millimetres were used for the measurements of the wire heating voltage v and current j. One of the millimetres worked in ampere meter mode and another one as a voltmeter. The wire resistance R is calculated according to the following proportion:

$$R = \frac{|v|}{|j + i/2|},$$

where the corona current i is measured independently. The discharge electrode temperature was thereafter estimated from the calculations of the wire resistance R in the case of the Ag:Ni = 0.7:0.3 wire. The temperature factor of resistance α for wires was measured in temperature controlled oven. The test shows that the Ag:Ni = 0.7:0.3 wire has temperature coefficient $\alpha = 0.00283$ K^{-1}. The temperature factor of resistance for the Ag:Mn = 0.85:0.15 and nichrome wires is one or more order of magnitude lower than that of the Ag:Ni wire and thus it is practically inapplicable to evaluate the wire temperature in these cases. For this reason it is assumed that the temperature of the nichrome or Ag:Mn wire on Joule heating is identical to that for the Ag:Ni wire with the same diameter for the same velocity of the ionic wind.

Within the limits of methodical error (around 2 °C), to start a corona leaves the temperature of the Ag:Ni wire for negligible Joule heating (heating current $i = 30 \div 100$ mA) unchanged. For the corona wire surface temperature profile measurements by using a real-time IR thermoimage processing system, it is observed (Ohkubo et al. [8]) that the heat generated by corona discharge itself only increases the surface temperature of the corona wire by a mere several Centigrade.

In the case without corona discharge (e. g. no applied voltage: $\Delta U = 0$), the wires are cooled by conduction, convection and radiation. The nonlinear relationship between the corona wire temperature and the external heating power can be seen in the Fig. 2 at a fixed discharge voltage (designated as $V = 1.53 \div 1.59$ m/s), along with no applied potential (designated as $V = 0$). Electrohydrodynamic flow inside an ESP has a profound effect on the corona wire temperature since this induced flow change the key heat-removal mechanism for the corona wire. Fig. 3 shows that the corona wire heating increases the speed of airflow only slightly.

4. Experimental results and discussion

The external heating power, the high voltage applied to the reactor and the discharge current were measured along with the velocity of ionic wind and the concentration of the ozone generated

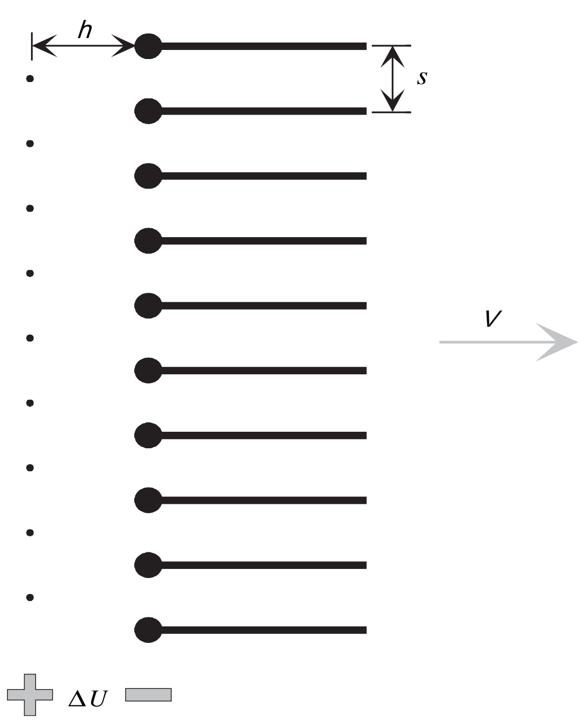

Fig. 1. Schematic diagram of the electrodes system: wires (·), plate-like electrodes with rods (•—) and direction of ionic wind V (→).

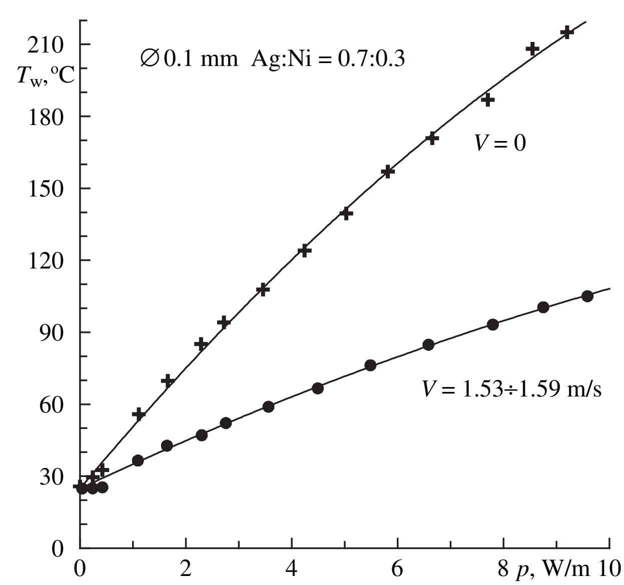

Fig. 2. Corona wire temperature T_w as a function of external heating power p. $\Delta U = 0$ ($V = 0$) or 17.7 kV ($V \neq 0$).