Electrohydrodynamic Flow and its Effect on Ozone Transport in Corona Radical Shower Reactor

Jaroslaw Dekowski, Jerzy Mizeraczyk, Marek Kocik, Mirosław Dors, Janusz Podliński, Seiji Kanazawa, *Member, IEEE*, Toshikazu Ohkubo, *Member, IEEE*, and Jen-Shih Chang, *Senior Member, IEEE*

***Abstract*—New arguments supporting the supposition that the ozone is transported along a corona discharge radical shower (CDRS) reactor by the electrohydrodynamic (EHD) flow are presented. The arguments are based on the analysis of the corona discharge, which is a precursor of the EHD flow in the CDRS reactor, and on the measurements of velocity field of the EHD flow in the CDRS reactor by the particle image velocimetry (PIV). The obtained velocity flow structures and the possible causes of the ozone transport in the CDRS, i.e., diffusion, additional gas flow, EHD flow, and convection by the main flow, were discussed basing on the conservation equations for the EHD flow. The discussion showed that the EHD flow plays a dominant role in the ozone transport. This is also supported by the results of a simple phenomenological model for one-dimensional description of EHD-induced ozone transport in the CDRS reactor. The results of the computer simulation based on this model explained the main features of the measured ozone distribution in the CDRS reactor, establishing the EHD flow as the main cause of the ozone transport from the discharge region upstream, i.e., against the main flow.**

***Index Terms*—Corona discharge radical shower (CDRS), electrohydrodynamic flow, particle image velocimetry.**

I. Introduction

NONTHERMAL plasma techniques [1]–[3] have become an important tool for controlling the emission of various gaseous pollutants, such as acid gases (SO_x, NO_x, HCl, etc.), greenhouse gases (CO_x, N_xO_y, para-fluorocarbons, etc.), ozone depletion gases (freons, halons, etc.), volatile organic compounds (VOCs, e.g., toluene, xylene, etc.), and toxic gases (Hg, dioxins, etc.). The main advantages of the nonthermal plasma techniques are small space volume, low cost, high pollutant removal, and energy efficiencies.

Recently, Ohkubo *et al.* [4], [5] and Kanazawa *et al.* [6] measured the two-dimensional distribution of ground-state NO density by the laser induced fluorescence (LIF) in needle-to-plate and corona discharge radical shower (CDRS) nonthermal plasma reactors, respectively, showing that the concentration of NO molecules decreased not only in the streamer corona discharge and downstream regions of the reactor but also upstream of the discharge region. The reason for the NO removal in the upstream region of the discharge was not clear. However, the results of numerical and experimental investigations [7]–[10] on the electrohydrodynamic (EHD) secondary flow (ionic wind) in electrostatic precipitators allow us to make a supposition [11] that the EHD flow may be capable of transporting the long-live active species (e.g., ozone) from the discharge region to the upstream region of nonthermal plasma reactors. If so, the long-live active ozone (or other species) produced in the discharge region could be transported by the EHD flow into the upstream region to oxidize or reduce NO molecules and efficiently decrease their concentration there, as was experimentally observed in [4]–[6]. Mizeraczyk *et al.* [12] conducted an experiment to elucidate the effect of the EHD flow on ozone transport in the CDRS reactors. By measuring the ozone distribution along the CDRS reactor and visualizing the EHD flow in the CDRS reactor, they confirmed the existence of a strong EHD flow in the CDRS reactor which may easily distribute the ozone inside the reactor, even far into the upstream direction of the reactor.

CDRS reactors have been recently proved to be one of the most efficient nonthermal plasma reactor systems used for NO_x removal [13]–[15]. In a CDRS reactor, an electrode with one or several nozzles is used for additional gas (NH_3, CH_4, etc.) injection across the corona discharge zone into the main flue gas flow. Due to the additional gas injection, the corona discharge produces active species such as NH, NH_2, CH, CH_2, etc., which enhance the removal of NO_x. The performance of the CDRS reactors can be also improved by the transport of the long-life species, caused by the EHD secondary flow, as was suggested in [12]. However, the suggested importance of EHD flow regarding the long-life species transport has not been supported sufficiently by evidence.

In this paper, new arguments for the ozone molecule transport by the EHD flow along a CDRS nonthermal plasma reactor are presented. The arguments were obtained from the analysis of the properties of the corona discharge, which is a precursor of the EHD flow in the CDRS reactor, and of the velocity field of the EHD flow in the CDRS reactor, measured by the particle image velocimetry (PIV). The analysis was supported by a simple phenomenological model of the ozone transport in the CDRS reactor.

Manuscript received August 31, 2003; revised January 20, 2004. This work was supported in part by the Foundation for Polish Science (Fundacja na Rzecz Nauki Polskiej, subsidy 8/2001), the State Committee for Scientific Research under Grant KBN PB 1756/T10/01/21, and the Canadian-Japanese-Polish Scientific Cooperation on Nonthermal Plasma Applications.

J. Dekowski, J. Mizeraczyk, M. Kocik, M. Dors, and J. Podliński are with the Centre for Plasma and Laser Engineering, Institute of Fluid Flow Machinery, Polish Academy of Sciences, 80-231 Gdańsk, Poland (e-mail: kwisatz@imp.gda.pl; jmiz@imp.gda.pl; kocik@imp.gda.pl; mdors@imp.gda.pl; janusz@karol.imp.gda.pl).

S. Kanazawa and T. Ohkubo are with the Department of Electrical and Electronic Engineering, Oita University, Oita 870-1192, Japan (e-mail: skana@cc.oita-u.ac.jp; tohkubo@cc.oita-u.ac.jp).

J. S. Chang is with the Department of Engineering Physics, McMaster University, Hamilton, L8S 4M1 ON, Canada (e-mail: changj@mcmaster.ca).

Digital Object Identifier 10.1109/TPS.2004.828458