ELSEVIER
Journal of Electrostatics 51–52 (2001) 218–224
Journal of ELECTROSTATICS
www.elsevier.com/locate/elstat

Elements of pulsed corona induced non-thermal plasmas for pollution control and sustainable development

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Abstract

The paper discusses the relationship between corona discharge modes and pollution emission control. It also discusses the optimization of corona plasma reactor and high-voltage pulse generator. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Non-thermal plasma; Pulsed streamer corona; High-voltage pulse generator; Plasma catalysis; Corona reactor; Pollution control

1. Introduction

Worldwide researches and developments on corona plasma techniques for pollution control and sustainable development are approaching industrial applications. Investigations extend from odor treatment, indoor air cleaning, VOCs abatements, and flue gas cleaning to CO_2 conversion and bio-gas cleaning [1–3]. Much more efficient and reliable high-voltage pulsed power generators become the critical enabling technique for promoting industrial applications. This paper discusses the most critical elements of pulsed streamer corona induced non-thermal plasmas for pollution control.

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PII: S0304-3886(01)00116-4

2. Corona discharge modes and their chemical reactivity

For a centimeter gap point-plate electrode in air, positive DC corona may be transferred from onset streamer to Hermstein glow, pre-breakdown streamer and then to spark breakdown by increasing the voltage level. For multiple point-plate or wire-plate electrodes, both the glow discharge and streamer corona may be generated simultaneously. According to NO to NO_2 conversion in air, the glow discharge induces negligible chemical reactions and a pre-breakdown streamer is less efficient than an onset streamer. Either changing gaseous compositions or using power modulations can control these discharge modes. With regard to pollution control, streamer coronas could be used for inducing chemical reactions and particles charging, while the glow discharge may only be used for particles charging.

Using a pulsed power supply, streamer corona can always be generated provided the applied voltage becomes larger than the streamer corona inception. Streamers propagate from anode to cathode within a few tens of nanoseconds. Streamer coronas in air and in flue gases show the same structure. For each pulse, the volume ratio of streamer channels to the reactor volume is in the order of 10^{-4}. The corona energy is mainly transferred into streamer channels within primary streamer propagation and secondary streamer development. Active electrons are mainly produced during primary streamer propagation [4]. In air-like or flue gases, the produced initial radicals are mainly OH, O and H radicals. N radical generation is negligible when the O_2 concentration is larger than 3.6%. Simplified global chemical kinetic model can be used to evaluate corona plasma reactors and high-voltage pulse generators, which includes a radical production process, a pollutant removal reaction, a radical linear termination reaction, and a radical non-linear termination reaction [3]. If there are no significant radical termination reactions, the pollution removal linearly depends on the corona energy density, and/or the energy yield is a constant. If linear radical termination reactions play a dominant role, the removal rate shows exponential functions in terms of the corona energy density. If the radical concentration is significantly affected by non-linear termination reactions, the removal rate depends on both the square roots of the corona energy density and the residence time. According to our tests on VOCs removal from air, we concluded that when the corona specific energy density is around a few Wh/Nm^3, the global kinetics shows no significant radical terminations as indicated in Fig. 1 for styrene removal. The length, inner and outer diameters of the wire-cylinder reactor are 3000, 3 and 160 mm, respectively. The initial styrene concentration is around 20–30 ppm. The gas flow rate and the average corona power are up to 1000 Nm^3/h and 1.2 kW, respectively. When the corona energy density becomes larger than 2 Wh/Nm^3, the energy yield decreases very rapidly with increasing the corona power. The removed styrene is no more linearly dependent on the corona energy density because of radical terminations. In contrast to traditional control techniques, these unique characteristics of streamer corona plasma treatments give many advantages for low concentration and large flow VOCs and odor emission control. The corona energy density is usually around 0.2–1.0 Wh/Nm^3. Larger corona energy density may lead to O_3 leakage from the reactor due to the O radical termination reaction of $O + O_2 + M \rightarrow O_3 + M$, for