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NOx Removal Using Non-thermal Surface Plasma Discharge Powered by a Modulated High Voltage Waveform

変調高電圧を用いた非熱平衡沿面放電プラズマによるNOx除去

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This paper focus on the NOx removal with the help of a non-thermal surface plasma discharge powered by a modulated high voltage waveform. The underlying idea is the use of an unsteady actuation in order to reduce the power consumption of the cleaning device. To achieve this, the effect of amplitude and burst modulation on NOx remediation is analyzed. These experiments show an important decrease of the electric power in both cases. In addition, NOx removal is enhanced with the BM mode for a duty cycle of 50%. While the AM mode has no effect on the gas exhaust treatment.

1. Introduction

Non-thermal plasma as a possible solution to clean the gas exhaust of next vehicle have generated significant interest. In labs experiments already demonstrated that non-thermal plasma by wet way can overcame some practical problems such as NOx removal [1,2]. A large variety of plasma reactors used for remediation of NOx is based on a volume discharge. Another way to treat the gas exhaust consists of using a surface discharge [3,4].

This paper presents an experimental study on NOx removal using a non-thermal surface plasma discharge powered by a modulated high voltage waveform. The aim is to use an unsteady actuation in order to reduce the power consumption of the cleaning device. To achieve this, the effect of amplitude modulation (AM) and burst modulation (BM) of the high voltage waveform on the treatment process is analyzed.

2. Experimental setup

Figure 1 displays a schematic side-view of the non-thermal surface plasma reactor used in this study. It is composed of two parts. The first part consists of a test chamber with two openings that allow the inlet and the exhaust of gas flow. This test chamber made of PP plate has a rectangular cross-section of 100 mm × 30 mm for 150 mm-long. The second part of the plasma reactor corresponds to the surface discharge placed on the top side of the test chamber. The whole forms the non-thermal surface plasma reactors.

The wet condition is obtained by adding a sodium sulfite solution inside the reactor (see Fig. 1). This solution is used as NOx gas absorbent.

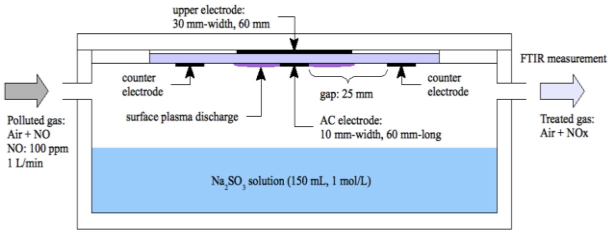

Fig.1. Schematic side-view of the plasma reactor.

The discharge is composed by a surface DBD with a three-electrode configuration [5]. To initiate the plasma discharge, the AC HV must exceed the onset voltage (with $V_{on} \approx 5$ kV peak). Here, a sinusoidal waveform with a peak voltage ranging between 6 to 13 kV and a frequency f_{AC} of 1 kHz is used.

The sinusoidal waveform is modulated by a modulating sinusoidal wave, corresponding to the amplitude modulation (AM). This modulation results in an AC sine waveform driving by the modulation frequency f_{AM} (set at 100 Hz) with 80% modulation depth (see Fig. 2). When the sinusoidal waveform is modulated by a Rectangular function with a duty cycle of 50%, the AC sine waveform is alternatively switched on and off: the discharge is assured by the carrier signal while the modulation frequency f_{BM} (fixed at 100 Hz) drives its ignition.

All experiments are characterized by measuring the power injected into the gas, and the evolution of removal rate of NO and NOx gases via FTIR measurements. In addition, they are conducted at low and stationary flow-rate (1 L/min), with 100 ppm of initial content of NO.

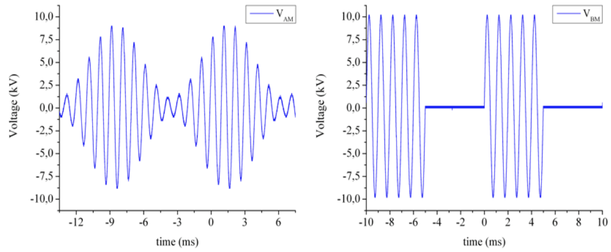

Fig.2. High voltage applied to the discharge with AM (left) and BM (right) modes.

3. Results

3.1 *Amplitude modulation (AM)*

Figure 3 presents the removal efficiencies of NO and NOx as a function of the energy density with the conventional (steady) and modulated (unsteady) actuation. It appears clearly that the AM actuation reduces the injected energy and also does not improve the NOx treatment.

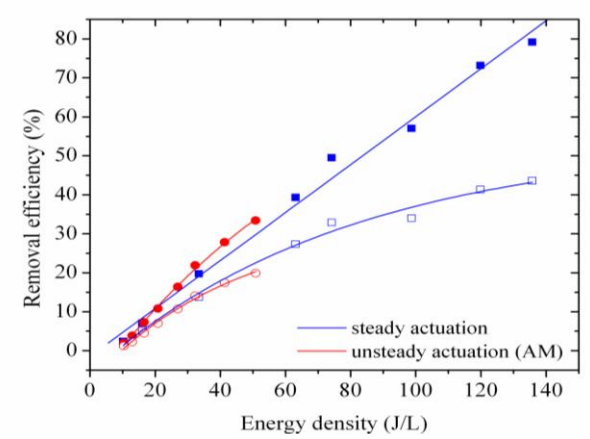

Fig. 3 . Removal efficiency versus energy density. (■: NO, □: NOx with sine and ●: NO, ○: NOx with BM).

3.2 *Burst modulation (BM)*

The evolution of the NO and NOx removal efficiencies as a function of the energy density is shown in Fig. 4. When the discharge operates with the burst modulation mode, the injected energy into the polluted gas is lower than the steady actuation, resulting a decrease of the gas exhaust cleaning.

However, we can remark that at a given energy density, stressing the discharge with the modulated voltage (V_{BM}) seems given higher values of removal efficiency as compared with the sinusoidal AC voltage. The gain reaches 10% on the NO treatment while only 5% on NOx removal. It suggests that the non-thermal surface plasma discharge generates more radical species and / or allows a high contact efficiency between the plasma discharge and the gas to be treated.

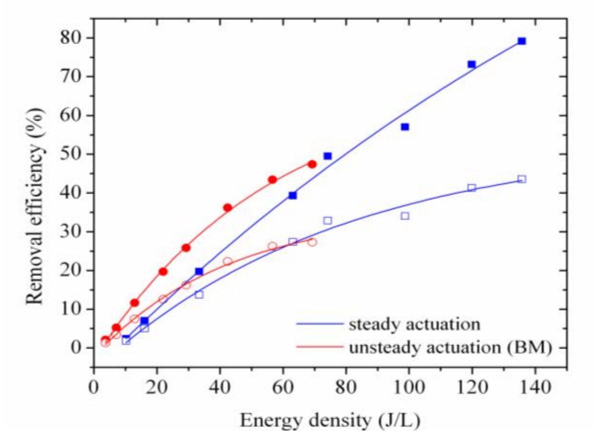

Fig.4. Removal efficiency versus energy density. (■: NO, □: NOx with sine and ●: NO, ○: NOx with BM).

4. Conclusion

In this paper, we have investigated the NOx removal by using a modulated waveform, especially the amplitude and burst modulations of the high voltage waveform.

The main results are as follows:

(1) The fact of using a modulated voltage has a significant effect on the power consumed, *i.e.* a decrease of it. In addition the evolution of the electrical power consumption versus the applied voltage always follows the behavioral law of Pons et al. [6].

(2) The AM mode has no effect on the NOx remediation.

(3) On the contrary, the burst modulation allows to enhance the NO conversion with a duty cycle of 50%. The maximum gain reaches up to 10%.

However, effects of the modulated high voltage on the interaction (increase of radical species due to the use of a pseudo-pulsed discharge, etc.) between the plasma and the polluted gas aren't yet totally distinguished.

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