NOx Removal by Corona Plasma Generated by Nanosecond Pulse Modulator

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1. Introduction

Nitrogen oxides (NOx) generated by the reaction of nitrogen with oxygen at high temperatures are not only harmful to living organisms but also cause pollution such as photochemical smog and acid rain. For these reasons, regulations on NOx emissions from diesel engines are being tightened. To cope with this, the development of technologies for minimizing NOx emissions is essential. As an effective NOx removal method, it has been proposed to convert NOx into other harmless substances using reduction reactions with chemical radicals [1]. Oxygen radicals are known as one of the proper substances to reduce NOx effectively [2,3]. Thus, various methods such as corona discharge have been extensively studied to generate oxygen radicals cost-effectively [4].

To generate sufficient amounts of ozone with corona discharge, high voltage must be applied to generate high energy electrons. However, applying high voltage in long duration by direct current discharge consumes a large amount of energy due to arc transition. Pulsed power technology, which accumulates electrical energy for a relatively long period of time and releases it in a very short time, is notable for its ability to apply high voltage pulses with high energy efficiency. Using this technique, the total energy consumption can be drastically reduced, while not losing the effect of high-voltage discharge. Especially, if the pulse width could be reduced to less than 100 ns, more effective removal would be possible. This paper presents a method that reduces NOx by utilizing the corona plasma generated by nanosecond pulsed discharge.

2. Experimental Setup

Figure 1 shows the schematic diagram of NOx removal system which consists of a nanosecond pulse modulator and a corona plasma reactor. The plasma reactor is connected to the exhaust system of the diesel vehicle, and the NOx gas from the exhaust vent passes through the corona plasma formed by high-voltage pulsed discharge.

2.1. Nanosecond Pulse Modulator

To generate the corona plasma for NOx removal reactions, a pulsed power system that compresses high electrical energy into a short pulse is required. In this work, we design and fabricate a 3-stage Blumlein pulse modulator as schematically shown in Fig. 2. A PFL (Pulse Formation Line) generally consists of a high-voltage power supply, switches, transmission lines and resistors (or inductors) for impedance matching. Three Blumlein PFL circuits [5] are stacked in series in order to increase the output voltage. A spark-gap switch is used to perform repetitive operation of the PFL.

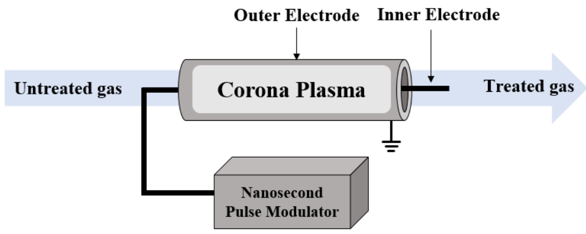


Fig. 1. Overall schematic diagram of NOx removal system.

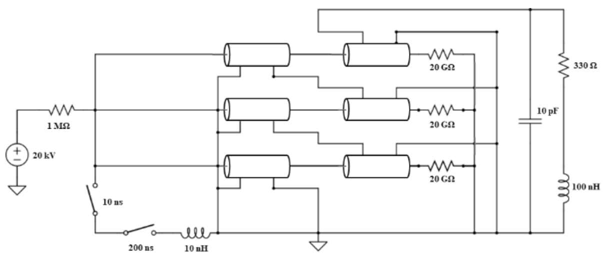
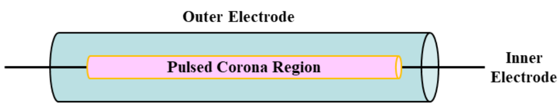


Fig. 2. Equivalent circuit of 3-stage Blumlein pulse modulator.

2.2. Corona Plasma Reactor

Corona plasma reactors designed for NOx removal is shown in Fig. 3. It consists of a straight anode passing through the center of a cylindrical cathode. The axial length of the two electrodes is equal to 1 m, with an anode thickness of 1.5 mm and a cathode internal diameter of 47 mm. Oxygen radicals are produced along the corona plasma zone caused by the ionization of air around the electrode. The NOx gas injected from the vehicle exhaust passes through this section, being converted into harmless substances through the chemical reactions, and then releases out. In the NOx removal experiment of exhaust gases, multiple reactors were stacked to increase operational efficiency, as shown in Fig. 3(c).



(a)

(b) (c)

Fig. 3. (a) Schematic diagram of the plasma reactor. (b) Single-cylinder type and (c) multi-cylinder type plasma reactors. Violet glow is one of the typical features of corona discharge.

3. Results and Discussion

Typical voltage and current waveforms measured across the plasma reactor are shown in Fig. 4(a). For the charging voltage of 20 kV, the maximum output voltage is measured to be 37 kV with a pulse width of 36 ns. Figure 4(b) shows the power and the energy delivered to the corona reactor, calculated from voltage and current waveforms. The peak power reaches about 5 MW, while the delivered energy is relatively low as 0.15 J.

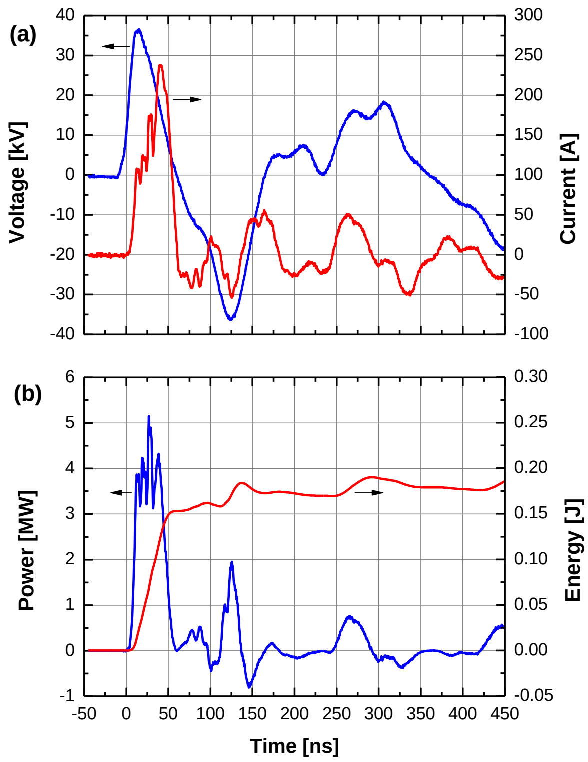


Fig. 4. Transient waveforms of (a) voltage and current from the 3-stage Blumlein pulse modulator, and (b) calculated power and energy.

Figure 5 shows a transient change in the NOx concentration of the exhaust gas by applying nanosecond pulse discharges. The pulse repetition rate is set to 100 Hz, so the average power is as low as 15 W. The discharge is repeated at approximately 3-minute intervals. It is clearly observed that the pulsed discharge treatment reduces NOx concentration by approximately 20%.

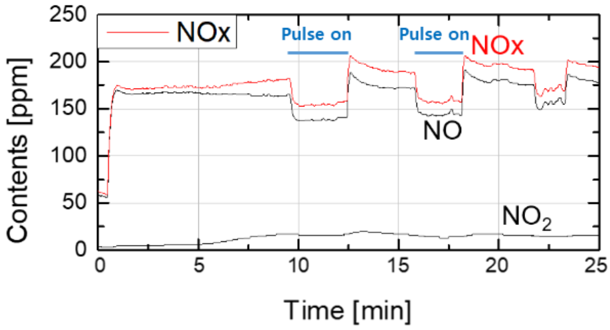


Fig. 5. Transient changes of NOx concentration during the pulsed discharge treatment.

4. Conclusion

The electrical properties of the nanosecond pulse modulator indicate that its peak power is very high, while its overall average power is very low. This high instantaneous power makes the NOx removal process effective, and the low average power is beneficial for the energy efficiency which have to be considered in long-term operations. When this technology is combined with the conventional SCR (selective catalyst reduction) technique, the overall efficiency for NOx reduction is expected to be increased further.

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