DIESEL EXHAUST CONTROL USING A MAGNETIC PULSE COMPRESSOR

D. Wang, K. Fujiya, T. Namihira[ξ], S. Katsuki and H. Akiyama
Department of Electrical and Computer Engineering, Kumamoto University
2-39-1 Kurokami, Kumamoto 860-8555, JAPAN

Abstract

A magnetic pulse compressor was used to control the exhaust gases from a diesel generator employing a wire-to-plate plasma reactor. The energy efficiency of NO_X removal increased by increasing the number of wires and increasing the wire-to-wire distance of the plasma reactor. This was due to the decreased impedance of the plasma reactor. The lower impedance of the plasma reactor results in higher energy transfer efficiency from the magnetic pulse compressor to the plasma reactor, enhancing the energy efficiency of NO_X removal.

I. INTRODUCTION

Air pollution caused by emission of pollutants produced by a variety of sources must be substantially reduced as mandated by recent national legislation and international agreements. Several techniques have been used to remove pollutants from air in recent years with various degrees of success. Non-thermal plasmas, in which the mean energy of electrons is substantially higher than that of the ions and the neutrals, offer a major advantage in reducing the energy requirements to remove pollutants. The application of short duration pulsed power to a gaseous gap at atmospheric pressure results in the production of a non-thermal plasma. Applications of pulsed streamer discharges for the removal of NO_X (=NO+NO_2) have been reported at various energy efficiencies [1-4].

In the present work, a magnetic pulse compressor (MPC) has been used to remove NO_X from a diesel generator exhaust in a wire-to-plate plasma reactor. The effects of the number of wires, wire-to-wire distance of the plasma reactor, and energy transfer efficiency of the MPC on the NO_X removal ratios are reported.

II. EXPERIMENTAL SET UP AND PROSEADURE

Fig.1 shows the schematic diagram of the wire-to-plate electrode. The diameter of the stainless steel wire was 0.5 mm, and the length and width of the plate were 500 and 300 mm, respectively. Three plates were placed in parallel. The distance between each neighboring plates was 60 mm, and the wires could be arranged on center with each neighboring plate and electrically connected to one another. The distance between the wire and plate was 30 mm. The minimum gap of the neighboring wires was 40 mm. The positive high voltage pulses were applied to the wire, and the plates were grounded. Therefore, the wires and plates acted as the anode and cathode, respectively.

Fig.2 shows the experimental set up. Three wire-to-plate electrodes were employed as a plasma reactor to remove NO_X from the diesel generator exhaust. The diesel generator (SGD 3000S-III, 3.2 kW, SUBARU, Japan) was driven at 2.38 kW. The exhaust gases from this generator containing NO_X were directed through the plasma reactor. The gas temperature was 411 K at inlet of the plasma reactor and 318 K at outlet. The flow rate was 236.7 L/min. A MPC with a maximum output voltage of 60 kV, a maximum pulse repetition rate of 500 pulses per second (pps), and pulse duration of about 130 ns, was used to process the exhaust gases. The applied voltage to the plasma reactor was measured using a resistive voltage divider (ratio, 20×10^3), which was connected between the anode and the cathode. The current into the plasma rector was measured using a Rogowski coil (Pearson current monitor, Model 2878, Pearson Electronics). A Hewlett Packard digital oscilloscope (HP 54542A) with a maximum bandwidth of 500 MHz and a maximum sample rate of 2G samples/s recorded the signals. A pulse repetition rate of 100 to 400 pps was used. The concentrations of NO and NO_2 were measured using a gas analyzer (Testo 350, Hodakatest, Japan) after a steady state condition was reached. In the present work, the peak of the pulsed voltage applied to the plasma reactor was maintained constant for all experiments by adjusting the charging voltage of the MPC.

A. Effects of Number of Wires

In this experiment, the wire-to-wire distance was fixed at 40 mm. The number of wires strung through the plasma reactor was either 24 or 48.

B. Effects of Wire-to-Wire Distance

To understand the plasma physics on wire-to-plate plasma reactor, different wire-to-wire distances were examined. The total number of wires was fixed at 24, and the wire-to-wire distance was adjusted to 40, 80, and 120

[ξ] email: namihira@eecs.kumamoto-u.ac.jp

0-7803-7915-2/03/$17.00 ©2003IEEE.

mm corresponding to one, two, or three electrodes, respectively.

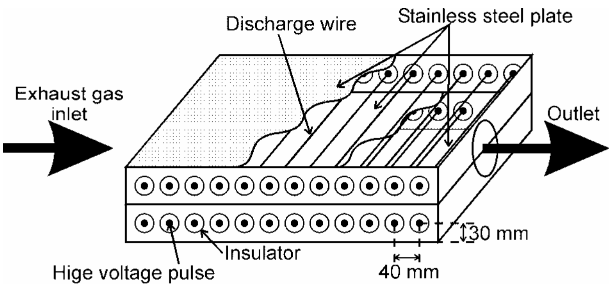


Figure 1. Schematic diagram of the wire-to-plate electrode.

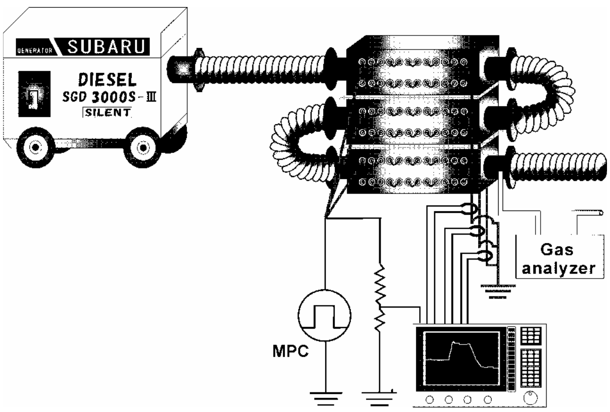


Figure 2. Experimental set up for treatment of diesel generator exhaust using the wire-to-plate plasma reactor.

III. RESULTS AND DISCUSSIONS

A. *Effects of Number of Wires*

Fig.3 (a) and (b) show the typical waveforms of the applied voltage and the discharge current to the plasma reactor for different numbers of wires. The peak value of the applied voltages was 42.4 ± 0.1 kV for both cases. The peak of the current was 278.5 A and 558.9 A for 24 and 48 wires, respectively. The input energy to the plasma reactor per pulse was calculated from the voltage and the current waveforms, and was 0.67 and 1.44 J/pulse for 24 and 48 wires, respectively. The characteristics of these results suggest that the impedance of the plasma reactor decreased with increasing number of wires. This is because a larger number of streamers were produced and a larger current flowed with increasing number of anode wires [5].

Fig. 4 shows the dependence of the NO_X removal ratio on the power consumption of the MPC for different numbers of wires. The power consumption *P* is

$$P = f \times E_{ch} \qquad (1)$$

$$E_{ch} = \frac{1}{2} C_0 V_{ch}^{\ 2} \qquad (2)$$

where f, E_{ch}, C_0, and V_{ch} are the pulse repetition rate [pulse/sec], charging energy of MPC, capacitance of MPC (800 nF), and charging voltage of MPC, respectively. Fig.4 shows that the NO_X removal ratio increased with increasing power consumption and by increasing the number of wires. This means that larger numbers of wires in the plasma reactor are more effective removing NO_X from diesel generator exhaust gases.

Table 1 shows the plasma reactor impedance and the energy transfer efficiency for different numbers of wires. The plasma reactor impedance, Z_{Rn}, is calculated from the voltage and current waveforms in Fig.3; and the energy transfer efficiency, E_{Tn}, is calculated from the charging energy of the MPC, E_{ch}, divided by the input energy to the plasma reactor. Table 1 indicates that the energy transfer efficiency increased with decreasing plasma reactor impedance. Since the impedance of MPC is less that 10 Ω, this result suggests that the lower impedance of the plasma reactor results in a better impedance match with the MPC yielding higher energy transfer efficiency.

Table 1. Plasma reactor impedance, Z_{Rn}, and energy transfer efficiency, E_{Tn}, for different numbers of wires.

Number of Wires	24 wires	48 wires
Z_{Rn}	$\boldsymbol{Z_{24}}$	$\boldsymbol{Z_{48}}$ **$(Z_{48}<Z_{24})$**
E_{Tn}	**30.0 %**	**44.0 %**

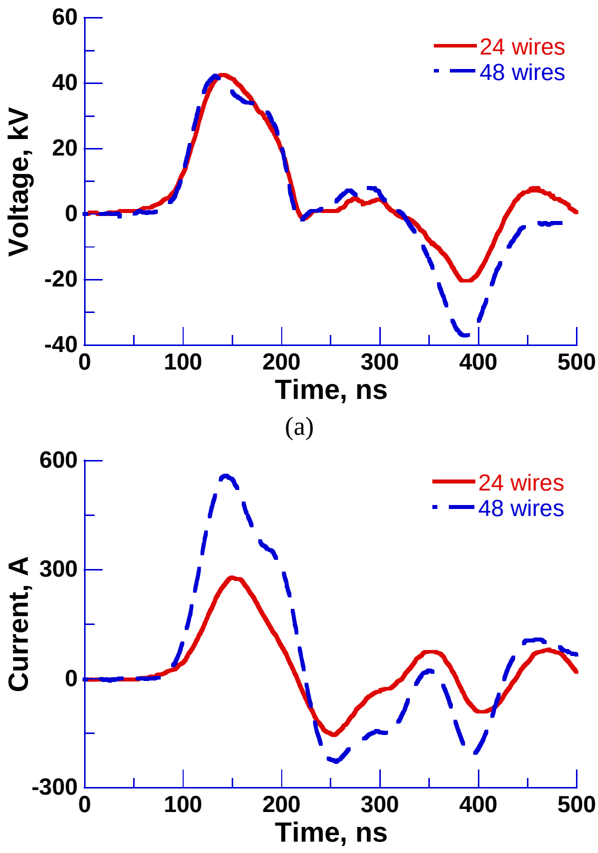


Figure 3. Typical waveforms of the applied voltage (a) and discharge current (b) to the plasma reactor for different numbers of wires.

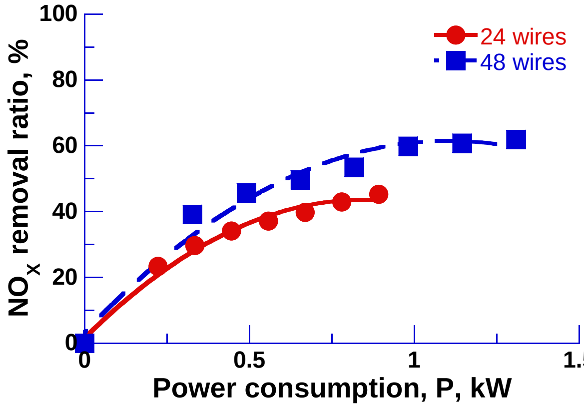


Figure 4. Dependence of the NO_X removal ratio on the power consumption of the MPC for different numbers of wires.

B. Effects of Wire-to-Wire Distance

Fig.5 (a) and (b) show typical waveforms of the applied voltage and current for each wire-to-wire distance. The peak value of applied voltages was 40.1 ± 0.4 kV for all cases. The peak current was 260.3, 374.6, and 399.3 A for 40, 80, and 120 mm of wire-to-wire distance, respectively. The calculated input energy to the plasma reactor was 0.60, 1.01, and 1.17 J for 40, 80, and 120 mm, respectively. The characteristics of these waveforms also indicate that the impedance of the plasma reactor decreased with increasing wire-to-wire distance.

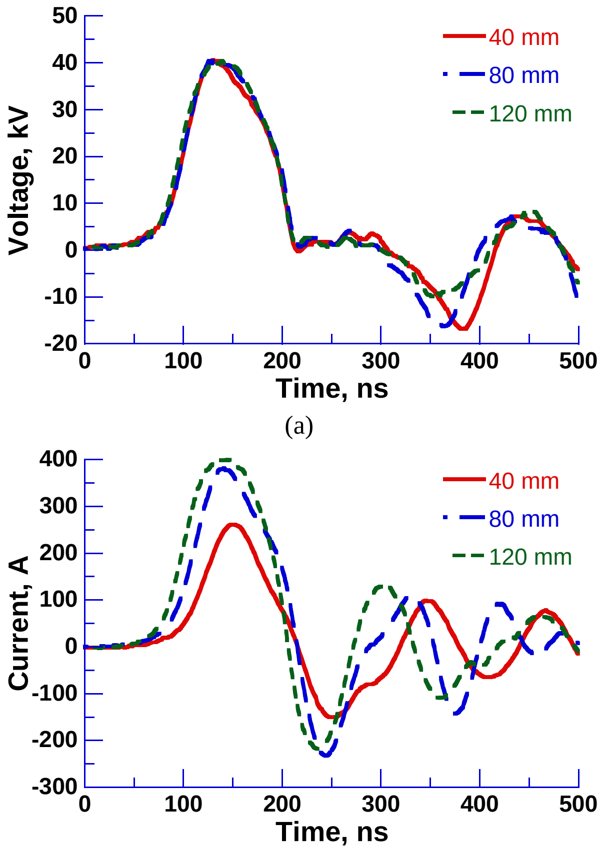
Fig.6 shows the dependence of the NO_X removal ratio on the power consumption of MPC for different wire-to-wire distances. It will be observed from Fig.6 that the NO_X removal ratio increased with increasing power consumption and increasing neighboring wire distance. Typically, the final removal ratio of NO_X for 80 mm is 1.5 times greater than for 40 mm wire-to-wire distance.

Table 2 shows the plasma reactor impedance and the energy transfer efficiency for different wire-to-wire distances. The calculation methods for Z_{Rd} and E_{Td} are the same as in Table 1. From Table 2, it is clear that energy transfer efficiency increased with increasing wire-to-wire distance.

To examine the impedance decrease with decreasing distance between neighboring wires, photographs of pulsed streamer discharges for all wire-to-wire distances were taken. Fig.7 (a) shows a typical photograph for 40 mm wire-to-wire distance. To visualize the differences of the discharges between each wire-to-wire distance, the images were converted into numerical values (Brightness vs. Position) as shown in Fig.7 (b). It will be observed from Fig.7 (b) that the brightness of the streamer discharge spread increased in both directions in vertical axis, which means the discharge emission area increased with increasing wire-to-wire distance. This result agrees with the simulated result for a pulsed corona discharge in a wire-to-plate reactor determined by Kim [6]. Kim suggests that as the adjacent wire electrodes are brought closer, their interference effects on the electric field distribution become stronger and the streamers from adjacent wires consequently shrink to considerably narrow ranges. Kim also recommends that the wire-to-wire spacing should be at least twice the wire-to-plate distance to produce an effective nonequilibrium plasma for enhancing the efficiency of the exhaust gas cleaning process. This recommendation agrees with the experimental results shown in Fig.6.

Table 2. Plasma reactor impedance, Z_{Rd}, and energy transfer efficiency, E_{Td}, for different wire-to-wire distances.

Wire-to-Wire Distance	40 mm	80 mm	120 mm
Z_{Rd}	$\mathbf{Z_{40}}$	$\mathbf{Z_{80}}$ **(Z_{80}<Z_{40})**	$\mathbf{Z_{120}}$ **(Z_{120}<Z_{80}<Z_{40})**
E_{Td}	**28.8 %**	**39.1%**	**41.9%**



(b)

Figure 5. Typical waveforms of the applied voltage (a) and discharge current (b) to the plasma reactor for different wire-to-wire distances.

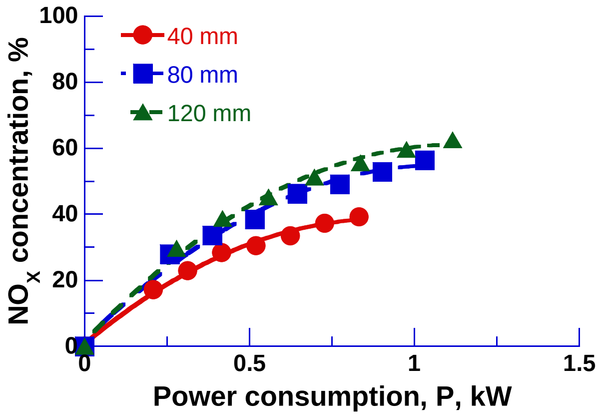
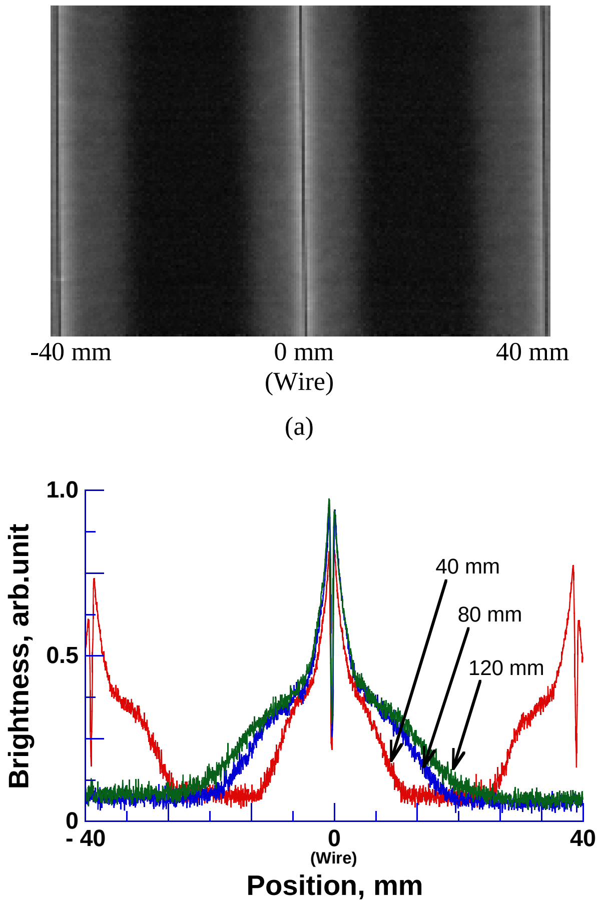


Figure 6. Dependence of the NO_X removal ratio on the power consumption of the MPC for different wire-to-wire distances.



(b)

Figure 7. Typical image of a pulsed streamer discharge for a 40 mm wire-to-wire distance (a), and dependence of the discharge emission brightness on position for different wire-to-wire distances.

IV. CONCLUSIONS

Pulsed streamer discharges using a MPC in a wire-to-plate discharge plasma reactor has been used to remove NO_X from diesel generator exhaust gases. The following conclusions have been deduced.

1) For a fixed peak pulsed voltage applied to the plasma reactor, the peak of current and energy input per pulse into the discharges increases with increasing number of wires and increasing wire-to-wire distance of the plasma reactor.
2) The impedance of the plasma reactor decreases with increasing number of wires, because a larger number of streamers are produced.
3) The impedance of the plasma reactor decreases with increasing wire-to-wire distance. It is confirmed that the influence of electric field distribution overlap becomes weaker for longer wire-to-wire distance by obtaining a larger discharge emission area, as seen in streamer discharge images.
4) The NO_X removal ratio increases with increasing numbers of wires and increasing wire-to-wire distance in the plasma reactor.
5) The energy transfer efficiency from the MPC to the plasma reactor increases with decreasing plasma reactor impedance. Since the lower plasma reactor impedance has better impedance matching with the MPC, it can improve the energy efficiency of the NO_X removal.
6) For efficient diesel exhaust control using a MPC, it is important to obtain a low impedance in the plasma reactor by employing large numbers of wires and long wire-to-wire distances.

REFERENCES

[1] R. Hackam and H. Akiyama, "Air pollution control by electrical discharges", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 7, No. 5, pp. 654-683, 2000.

[2] B. M. Penetrante, M. C. Hsiao, B. T. Merritt, G. E. Vogtlin, and P. H. Wallman, "Comparison of electrical discharge techniques for non-thermal plasma processing of NO and NO_2", IEEE Transactions on Plasma Science, Vol. 23, pp. 679-687, 1995.

[3] T. Namihira, D. Wang, S. Katsuki, R. Hackam, H. Akiyama, "Propagation velocity of pulsed streamer discharges in atmospheric air", IEEE Transactions on Plasma Science, 2003. (In print)

[4] E. M. van Veldhuizen, W. R. Rutgers, and V. A. Bityurin, "Energy efficiency of NO removal by pulsed corona discharges", Plasma Chemistry and Plasma Processing, Vol. 16, pp. 227-247, 1996.

[5] T. Namihira, S. Tsukamoto, D. Wang, H. Hori, S. Katsuki, R. Hackam, H. Akiyama, M. Shimizu, and K. Yokoyama, "Influence of gas flow rate and reactor length on NO removal using pulsed power", IEEE Transactions on Plasma Science, Vol. 29, No. 4, pp. 592-598, 2001.

[6] Y. H. Kim and S. H. Hong, "Two-dimensional simulation images of pulsed corona discharge in a wire-plate reactor", IEEE Transactions on Plasma Science, Vol. 30, No. 1, pp. 168-169, 2002.