NOx Removal by Corona Plasma Generated by Nanosecond Pulse Modulator

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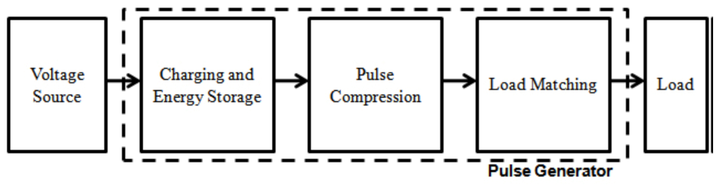
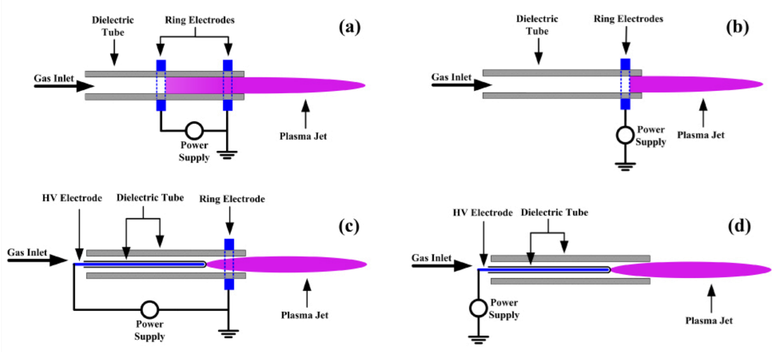
Ⅰ. Backgrounds

Nanosecond Pulsed Discharge



- Pulsed discharge : Uses high-power electrical energy obtained by storing high-voltage for a relatively long time and then releasing it momentarily
  - ✓ Nanosecond pulse : High power in very short rise time
- Overall power & energy consumption of the discharge could be saved because of the short duration of power input
- By-products : radiations, high-pressure pulse, **reactive species**

Plasma Reactor for Radical



Non-thermal Plasma (NTP)

- Plasma in which particles do not reach thermal equilibrium
- Generates high-energy electrons : 1 to 25 eV (10,000 - 250,000 K)
- Other particles maintain low temperature
  → No energy efficiency degradation by overall gas heating

Mechanism of Forming Reactive Species by NTP

- Electric field creates high-energy electrons
- High-energy electrons collide with the air molecules
- Energy transfers to molecules and excites the energy states
- Ionization occurs and reactive species are created
  - ✓ Reactive oxygen species (ROS)
  - ✓ Reactive nitrogen species (RNS)
- Reactive species oxidizes other substances (VOC, NOx, ...)

Corona Discharge & Ozone

- Usually occurs at sharp edges or thin wires (where the electric field is large enough)
- Strong ionization & luminescence appear near electrodes
- Ozone gas is generated from oxygen gas around the electrode ($O_2 \rightarrow 2O,\ O + O_2 \rightarrow O_3$)

Nitrogen oxides (NOx)

- Generated by oxidations of nitrogen at high temperatures
- Harmful to living organisms + cause pollution (Photochemical smog and acid rain)

- NO and NO_2 are oxidized by O3 in the following subsequent steps
  - ➢ $NO + O_3 \rightarrow NO_2 + O_2$
  - ➢ $NO_2 + O_3 \rightarrow NO_3 + O_2$
  - ➢ $NO_2 + NO_3 \rightarrow N_2O_5$

- N_2O_5 can be easily removed by contact with water to form Nitric acid
  - ➢ $N_2O_5(g) + H_2O \rightarrow 2HNO_3(aq)$

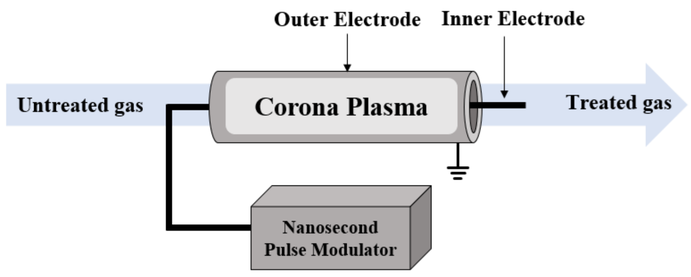
Ⅱ. Objectives

- Present a method that reduces NOx by utilizing the corona plasma generated by nanosecond pulsed discharge.

- ✓ Design and a pulse modulator capable of applying high-voltage pulses in tens of nanoseconds.
- ✓ Fabricate a corona plasma reactor that can discharge input NOx gases.
- ✓ Confirm the effect of reducing NOx concentration by pulsed corona discharge by measuring the NOx concentration over time.

Ⅲ. Experimental Setup

NOx Reduction Device

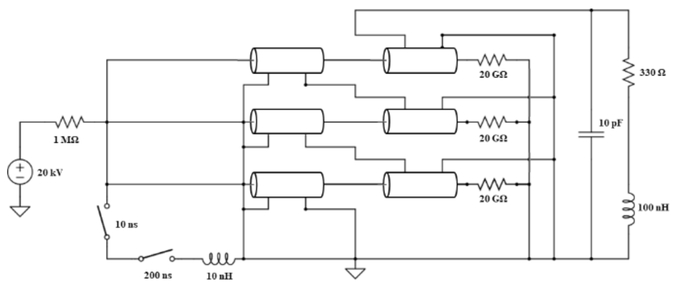


- Nanosecond pulse modulator + Corona plasma reactor
- ✓ Plasma reactor connects to the exhaust of the diesel vehicle
- ✓ Gas from the exhaust vent passes through the corona plasma formed by high-voltage pulsed discharge

Nanosecond Pulse Modulator

PFL (Pulse Formation Line)

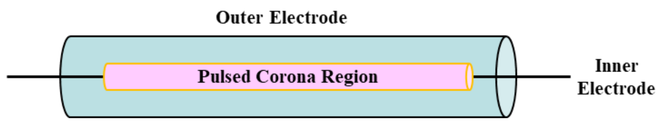
- High-voltage power supply + Switches + Transmission lines + Resistors (or inductors) → **Impedance matching**



3-stage Blumlein Pulse Modulator

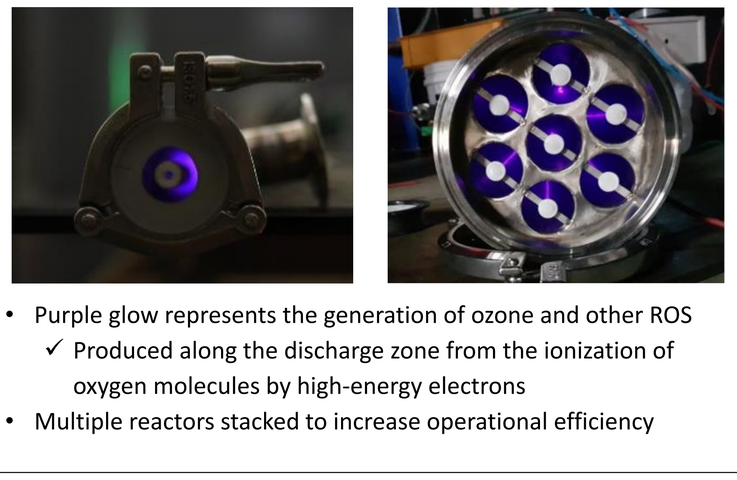
- Stacked three Blumlein PFL in series
  → Increase the output voltage (10 kV * 3)
- Spark-gap switch perform the repetitive operation of the PFL

Corona Plasma Reactor



Coaxial Electrode Structure

- Cathode : Cylindrical stainless pipe
  - ➢ Radius : 47 mm, Length : 1 m
- Anode : Straight stainless wire
  - ➢ Radius : 1.5 mm, Length : 1 m

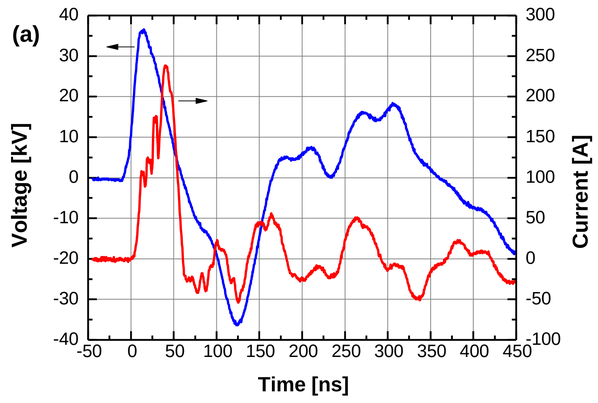


- Purple glow represents the generation of ozone and other ROS
  - ✓ Produced along the discharge zone from the ionization of oxygen molecules by high-energy electrons
- Multiple reactors stacked to increase operational efficiency

Ⅳ. Results

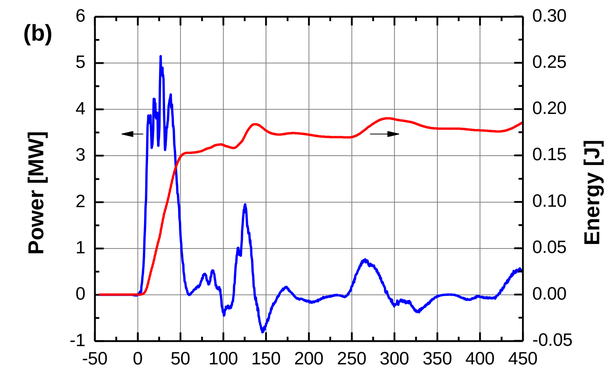
Performance of Nanopulse Plasma Reactor

- Transient waveforms of voltage and current



Ⅳ. Results (cont.)

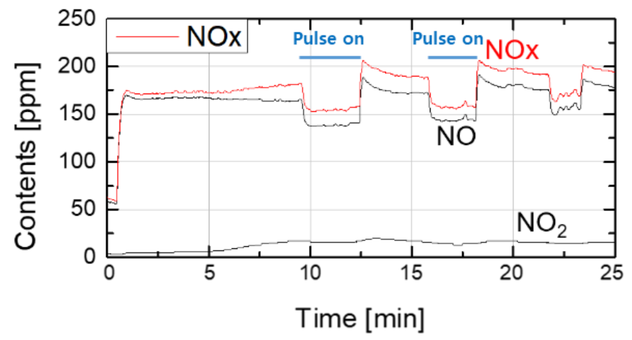
- Electrical power & energy → calculated from voltage and current



- ✓ Charging voltage : 20 kV
- ✓ Max. output voltage : 37 kV
- ✓ Pulse width : 36 ns
- ✓ Pulse repetition rate : 100 Hz
- ✓ Peak power : about **5 MW**
- ✓ Average power : **15 W**
- ✓ Deposited energy : **0.15 J**

→ **Low average power & total energy compared to high peak power**

Performance of NOx Treatment



- The discharge is repeated at approximately 3-minute intervals
- NOx concentration reduces by approximately 20%
- Apparent changes in NOx concentration with or without pulse are observed

Ⅴ. Summary

- Benefits of nanosecond pulse modulator in NOx removal → high peak power but low average power
- ✓ High peak power : effective production of high-energy electrons
- ✓ Low average power : good energy efficiency in long-term operations

- If this technology is combined with the conventional SCR (selective catalyst reduction) technique, the overall efficiency for NOx reduction is expected to be increased further

Ⅵ. References

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Ⅶ. Acknowledgements

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