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Effective Removal of Air Pollutions by the Electrical Discharge

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Abstract: The objectives of this study were to understand the effects of different electrical and reactor's parameters on the removal efficiency of air pollution and to optimize the parameters to achieve the highest removal efficiency. The surface discharge was applied to dielectric barrier discharge reactors and the voltage, current, frequency and the electrode shape were employed to the reactor as main variables. In general, it has been known that the removal efficiency is decided by the applied power, which is calculated by multiplication of the applied voltage and current. However, the removal efficiency was significantly changed by the composition ratio of the applied voltage and current even though the experimental conditions were not changed with the same applied power. It means that the removal effectiveness should be affected not by the discharge power but by the applied voltage and current separately. From the experimental and statistical analysis, the discharge current was the most important factor to control the removal efficiency regardless of different types of the reactors and the frequency is not the direct function to control the removal rate.

Key words: Dielectric barrier discharge, surface discharge, non-thermal plasma, air pollution, NO_x (Nitrogen Oxides).

1. Introduction

Air pollutants are strongly associated with diseases, such as intrauterine mortality, different pregnancy outcome, low birth weight, respiratory infections and adverse effect on nervous system and so on. Fine PM (Particulate Matter) and ozone are associated with increasing risk of mortality and respiratory morbidity, while exposure to nitrogen oxides, ozone and PM is linked with allergic responses [1].

Especially, GHG (Greenhouse Gases) and fine PM are serious problem in Korea and GHG are still increasing significantly compared with OECD (Organization for Economic Cooperation and Development) average because of higher economic growth and rapid increase of vehicles than other OECD countries in Figs 1, 2 [2].

In early 2000, plasma technology was recognized as new attractive method to control air pollutions and it was expected to change chemical method into eco-friendly method [3]3, 4]. However, without the chemical method, such as bag filters, it was hard to control by-products and to improve the energy efficiency [5, 6].

In spite of some disadvantages of the plasma technology, the electrical discharges as one of the plasma technology has been still applied to the purification of waste water and prevention of malodor from manufacturing processes widely in Korea due to excellent ability of O_3 generation [7].

Previous studies insisted that removal efficiency for the removal of air pollutions or the generation of ozone should be decided by the applied discharge power or discharge voltage because the generation of the discharge mainly depends on the applied voltage and the energy consumption depends on the applied power calculated by multiplication of the applied voltage and current [8, 9].

In this study, it is shown that NO_x reduction and reactant generation are decided not by the discharge power but by multiple combinations of different experimental variables and the individual or mutual effects of the variables.

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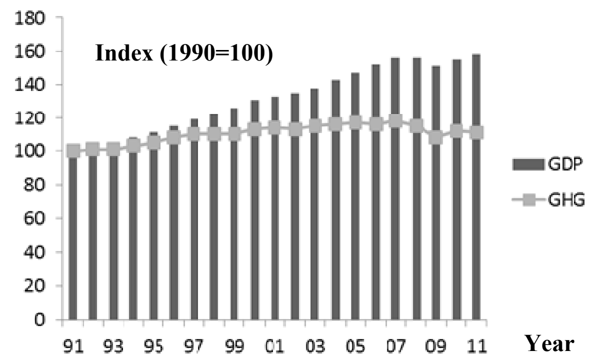

Fig. 1 GHG emission of OECD.

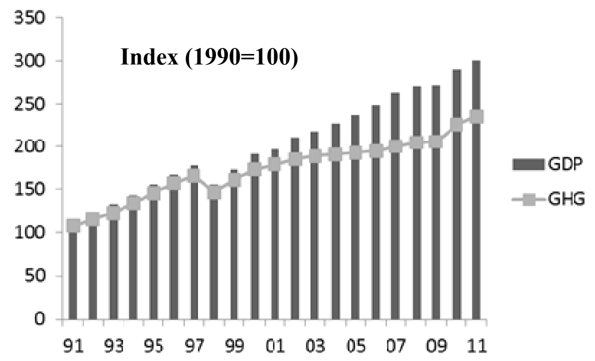

Fig. 2 GHG emission of Korea.

2. Experimental Set Up

The chemical reactions are carried out in tubular dielectric barrier discharge reactors with different arrangements of electrodes.

For the surface discharge reactor in Fig. 3, the tungsten wire is attached on the outside surface of the inside tube, which is activated as a dielectric barrier and filled with metal balls. The use of a Pyrex tube allows inspection of the inside of a discharge reactor. The effective discharge length is 115 mm.

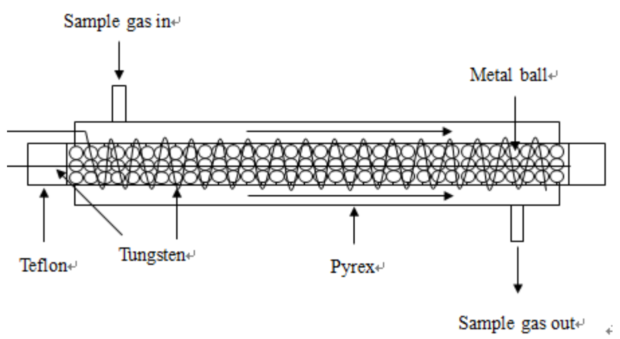

Fig. 3 Surface discharge reactor.

Number of turn of the tungsten wire is decided by the distance between wires and varies from 4, 9 and 20 turns. The applied frequency is raised from 1 kHz up to 9 kHz and the voltage is applied from several hundred voltage up to 5 kV. A gas flow rate is set at 1 L/min creating a residence time of 0.83 s. NO_x 1,000 ppm balanced by N_2 is employed.

3. Experimental Results

3.1 NO_x Removal Rate

Different frequencies (1-9 kHz) are applied to three different reactors, which are classified by the number of electrode turns, to investigate their effects on NO_x removal. Experimental results are compared in Figs. 4-6.

It is shown that the increase of the applied frequency improves the removal rate at the similar applied power even though their effects seem to level off after 7 kHz.

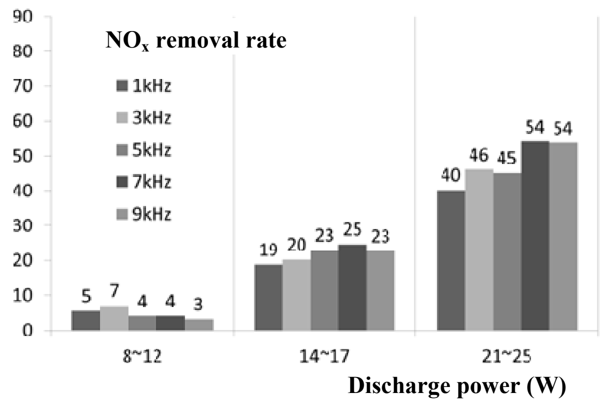

Fig. 4 NO_x removal of 4 turn reactor.

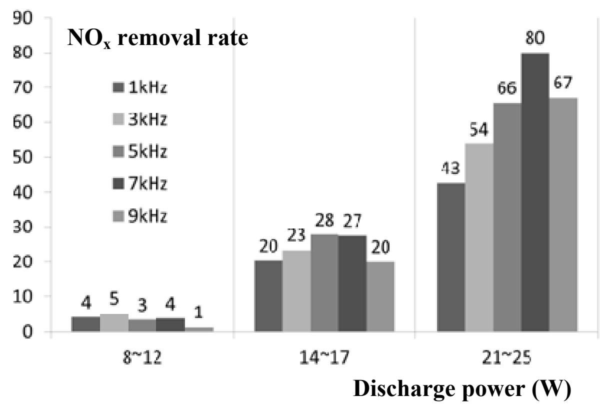

Fig. 5 NO_x removal of 9 turn reactor.

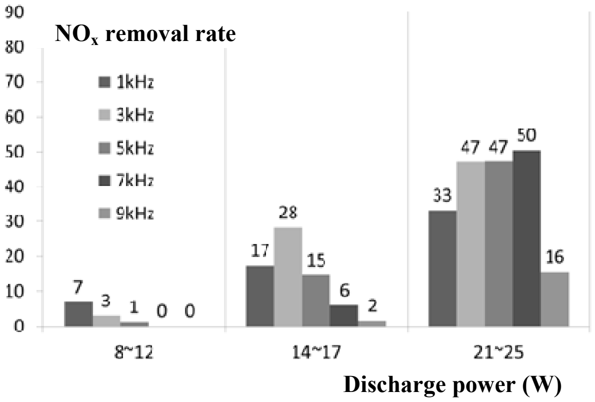

Fig. 6 NO_x removal of 20 turn reactor.

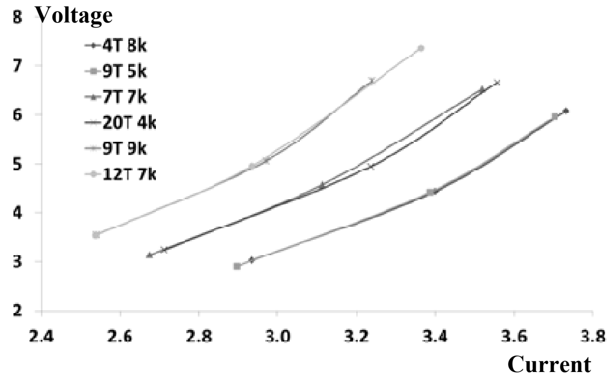

Fig. 7 Application of similar power, voltage and current to different reactors.

At the beginning of the discharge, it seems that higher removal is expected with low frequencies. That's why the beginning of the discharge is decided by the discharge voltage and high voltage can be applied with low frequency.

It is observed that the highest removal rate is obtained with the application of 7 kHz. After 7 kHz, NO_x removal effect is deteriorated because large current is applied compared with the applied voltage due to low impedance and high frequency.

The role of the applied frequency changes the impedance of the dielectric barrier reactor and the ratio of the applied voltage and current.

From the experimental result, it is known that the removal rate is significantly affected by the combination of the applied voltage and current because the removal is controlled not by the frequency but by the applied power by multiplication of the applied voltage and current.

3.2 Effect of Frequency and Design of the Reactor on NO_x Removal

All discharge V-I obtained by experimental results are compared and three groups, which show the same applied power, voltage and current, are found in Fig. 7. *T* and *k* means the number of the electrode turn and applied frequency respectively.

This comparison removes the effect of the voltage and current and makes to focus the effect electrode configuration on NO_x removal.

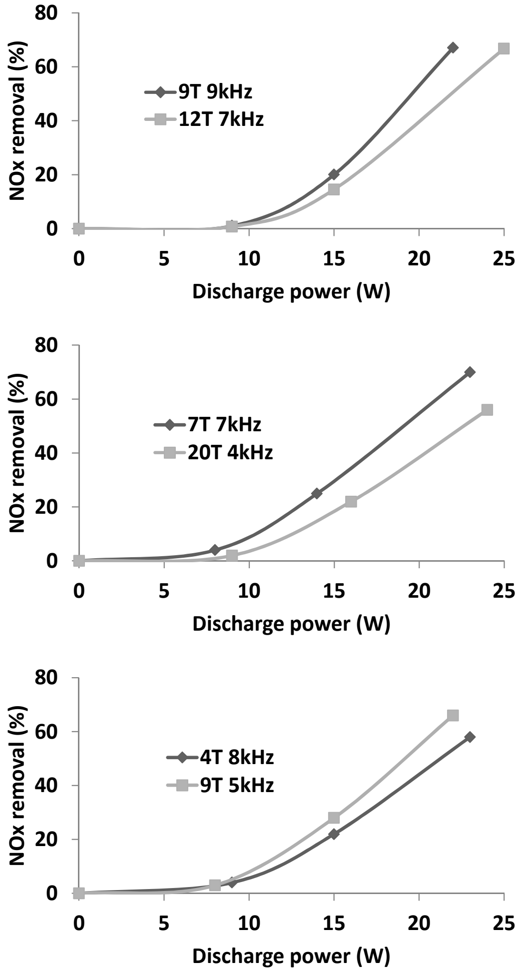

Fig. 8 Comparison of NO_x removal rate focused on the effect of the frequency and electrode configuration.

It is shown in Fig. 8 that the removal rate is significantly different depending on the applied frequency and electrode configuration even though the applied power, voltage and current are not different.

Therefore, the combination of the applied voltage and current should be investigated to reach the top of the removal efficiency whenever the configuration of the electrode and the reactor is modified. Based on the investigation, the right decision of the design of the electrode and reactor is important to improve NO_x removal.

From the experimental results:

- The applied power should be divided into the voltage and current to investigate their individual effects on NO_x removal because different removal rates are observed even though the same power is applied to the same reactor;
- The role of the applied frequency changes the impedance of the dielectric barrier reactor and the ratio of the applied voltage and current;
- Right decision of the applied voltage, current and frequency should be done carefully to improve the removal efficiency because they are closely connected each other.

4. Statistical Analysis

4.1 Voltage, Current, Frequency and Electrode Configuration

Based on the experimental results, main functions are decided as the applied V (Voltage), I (Current), F (Frequency) and T (Electrode Configuration). Three hundred and forty eight experimental samples are statistically analyzed to investigate individual effects of the functions on the removal and to understand the most important factor for the removal efficiency.

It is shown in Table 1 that the discharge voltage and current have positive correlation to NO decomposition but the negative correlation of DeNO is indicated by the increase of the electrode turn.

It is statistically confirmed that the frequency has no correlation to DeNO directly but has strong relation to the voltage and current as expected.

From this analysis, it is expected that the most important factor to control NO removal is the discharge current.

Model summary by MLR (Multiple Linear Regression) with VIFT (Voltage, Current, Frequency and Electrode Configuration) is shown in Table 2. A stepwise multiple regression analysis, which applies significant variables in order and then rejects non-significant variables, is applied.

Four models are proposed by the stepwise method and the fourth model, which has four predictors, explains

Table 1 Correlation analysis of variances.

		V	I	F	T	DeNO
	Pearson correlation	1	-.234**	-.757**	-.183**	.320**
V	Sig. (2-tailed)		.000	.000	.001	.000
	N	348	348	348	348	348
	Pearson correlation	-.234**	1	.503**	.205**	.738**
I	Sig. (2-tailed)	.000		.000	.000	.000
	N	348	348	348	348	348
	Pearson correlation	-.757**	.503**	1	-.129*	.002
F	Sig. (2-tailed)	.000	.000		.016	.963
	N	348	348	348	348	348
	Pearson correlation	-.183**	.205**	-.129*	1	-.116*
T	Sig. (2-tailed)	.001	.000	.016		.031
	N	348	348	348	348	348
	Pearson correlation	.320**	.738**	.002	-.116*	1
DeNO	Sig. (2-tailed)	.000	.000	.963	.031	
	N	348	348	348	348	348

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 2 Model summary[e].

Model	R	R square	Adjusted R square	Std. error of the estimate
1	.738[a]	.545	.544	146.738
2	.896[b]	.803	.801	96.797
3	.919[c]	.844	.843	86.166
4	.947[d]	.896	.895	70.462

a. Predictors: (Constant), Current.

b. Predictors: (Constant), Current, Voltage. c Predictors: (Constant), Current, Voltage, Turn.

d. Predictors: (Constant), Current, Voltage, Turn, Frequency.

e. Dependent: $DeNO_x$.

Table 3 Coefficient with VIFT[a].

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-166.719	23.673		-7.042	.000
	Current	101.198	4.972	.738	20.354	.000
2	(Constant)	-648.022	27.541		-23.529	.000
	Current	117.973	3.374	.861	34.968	.000
	Voltage	113.913	5.369	.522	21.216	.000
3	(Constant)	-558.686	26.237		-21.294	.000
	Current	122.932	3.048	.897	40.336	.000
	Voltage	107.391	4.828	.492	22.243	.000
	Turn	-8.890	.930	-.210	-9.559	.000
4	(Constant)	-90.838	41.679		-2.179	.030
	Current	150.927	3.284	1.101	45.962	.000
	Voltage	27.262	7.283	.125	3.743	.000
	Turn	-16.271	.947	-.385	-17.188	.000
	Freq	-42.004	3.208	-.506	-13.093	.000

a. Dependent: DeNO.

Table 4 Coefficient with PFT[a].

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	-224.797	15.150		-14.838	.000
	Power	34.965	.931	.953	37.561	.000
2	(Constant)	-342.261	18.583		-18.418	.000
	Power	35.212	.761	.960	46.272	.000
	Turn	17.323	2.044	.176	8.474	.000
3	(Constant)	-385.686	18.980		-20.321	.000
	Power	35.088	.699	.957	50.192	.000
	Turn	17.753	1.879	.180	9.449	.000
	Freq	9.359	1.792	.100	5.222	.000

a. Dependent: DeNO.

the relation between the dependent and independent variables better than others.

R-square for this model is 0.896 which means that X variables can explain about 89.6% of the change in Y.

It is indicated in 4th model of Table 3 that the increase of 1 mA or 1 kV removes NO 151 ppm or 27 ppm respectively but the increase of the frequency or electrode turn deteriorates NO removal.

It is observed that the effect of the voltage is significantly reduced at the 4th model compared with the 3rd model and only difference between two models is the existence of the frequency.

This happens because of the negative correlation between the frequency and the voltage. The regression equation is shown:

$$Y = -94.4 + (153.2 \times \text{Current}) + (27.0 \times \text{Voltage}) - (16.5 \times \text{Turn}) - (42.2 \times \text{Frequency})$$

4.2 Comparison of VIFT and PFT

Statistical analysis is conducted in Table 4 with the discharge power instead of the voltage and current.

It is shown that the most important factor is the discharge power for the improvement of the removal. It is also shown that the increase of the applied frequency and electrode turn increase the removal efficiency.

However, it is shown from the experimental results, that there is the limitation to increase the removal efficiency with increasing the frequency and electrode turn and the removal is seriously deteriorated after the limitation. Therefore, the effect of the frequency can be overestimated or distorted.

From the statistical results:

- The discharge current is the most important factor to control the removal rate regardless of different types of the reactor;
- The frequency is not the direct function to control the removal rate but is the indirect function to control the applied voltage and current;
- The discharge power is applied to express the energy efficiency. However, to maximize the removal and energy efficiency and to set the ideal design for the reactor or electrode, it is necessary that the applied voltage and current should be investigated respectively instead of the applied power.

5. Discussion

Experiments and statistical analysis are conducted to find out the ideal conditions for the effective removal of air pollutions. In most of previous studies, the discharge power has been widely applied to compare the removal efficiency, to prove the removal abilities and to design the effective reactor.

However, it is confirmed that the discharge power should be divided into the discharge voltage and current to investigate to improve the removal efficiency and to design the ideal reactor. Without the investigation of the voltage and current respectively, it is impossible to make the reactor work well.

6. Conclusions

The applied power should be divided into the voltage and current to investigate their individual effects on NO_x removal even though the discharge power can be to express the energy efficiency.

Right decision of the value of the applied voltage, current and frequency is important to maximize the removal efficiency.

The discharge current is the most important factor to control the removal rate regardless of different types of the reactor.

The frequency is not the direct function to control the removal rate but is the indirect function to control the removal rate through the effect on the applied voltage and current.

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