A Design Technology of Ceramic Tube for High Efficiency Ozone

Kook-Hee Cho*, Young-Bae Kim and Dong-Hoon Lee*****

Abstract - An innovative ozonizer has been developed using a high frequency, surface discharge and a high purity Ti-Si-Al ceramic catalyst as a dielectric component. Using a type of thin film, a thin cylindrical compound ceramic catalyst layer was adhered to the outside surface of its inner electrode. An alternating current (AC) exciting voltage with frequencies from 0.6 kHz to 1.0 kHz and peak-to-peak voltages of 4-6 kV was applied between the electrodes to produce a stable high-frequency silent discharge. A substantial reduction of the exciting voltage was also enabled by means of a thin Ti-Si-Al ceramic catalyst tube. As a result, the ozonizer can effortlessly obtain the required ozone concentration (50-60 g/㎥ for oxygen) and high ozone efficiency consumption power (180 g/kWh for oxygen) without the assistance of any particular methods. For purposes of this experiment, oxygen gas temperature was set at 20°c, with an inner reactor pressure of 1.6 atm at 600 Hz and a flow rate of 2 l/min.

Keywords: Ozone, Ceramic, Silent Discharge, Dielectric

1. Introduction

Ozone (O_3) is used to improve the quality of water, air processing and decolorization, chemosynthesis, sterilization, etc. by its strong oxidizing agent. Since the 1970s, research of ozone has been actively in progress. The tendency of present research is to develop a high efficiency ozonizer and ozone generation system as well as to develop a concern forecast program for ozone generation and energy input. In this paper, the relation between ozone efficiency and ozone concentration on the Ti-Si-Al ceramic catalyst discharge tube of cylindrical type was examined. This was essential for observation of surface temperature transformation because surface temperature highly influences gas temperature of the discharge space and ozonic generation of the coated tube on the interior electrode surface by the Ti-Si-Al ceramic catalyst tube in this research. Also, ingredient and illumination parameters were very important in estimating the insulation reliability of the tube.

2. Experiment

Fig. 1 is a schematic diagram for characteristic investigation of the Ti-Si-Al type ceramic catalyst discharge tube. Oxygen was employed as a raw material gas. When AC voltage was applied, ozone concentration was measured. The discharging gap filled with oxygen gas may be supplied evenly. The form of discharge is silent discharge. Ozone generation from the ceramic discharge tube was investigated experimentally by means of flow rate, discharge power, gas pressure and temperature.

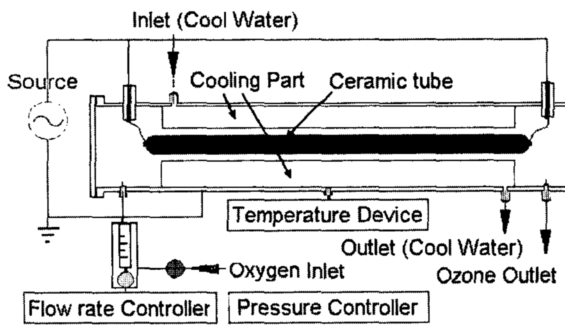


Fig. 1 The experimental schematic diagram.

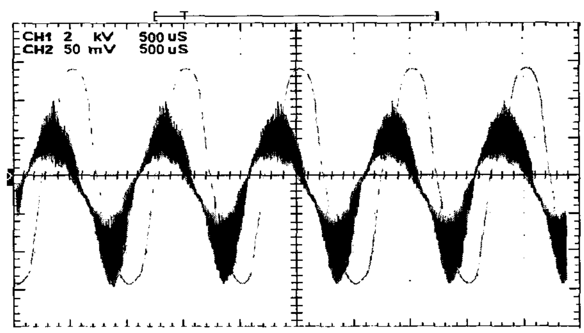


Fig. 2 The voltage and current waveform.

Fig. 2 shows the voltage and current waveforms for silent discharge of 1000Hz that has been used in this experiment. In one cycle of AC waveform, we can see that a discharge and non-discharge section appears. As the discharge current flows, the voltage reached its maximum point,

* Korea Electrotechnology Research Institute, Changwon, Kyungnam, Korea. (khcho@keri.re.kr)
** Korea Electrotechnology Research Institute, Changwon, Kyungnam, Korea. (ybkim@keri.re.kr)
*** Dept. of Electric Engineering, Kyungnam University, Masan, Kyungnam, Korea. (2323444@hanmail.net)
Received: April 24, 2003 ; Accepted: July 30, 2003

where it was observed that the current decreased sharply. The presence of an electric field between the outer electrode (metal) and the inner electrode (ceramic dielectric surface) caused a streamer discharge to be formed. In the end, the streamer discharge disappeared. The amount of ozone obtained during these processes is determined as functions of voltage and frequency.

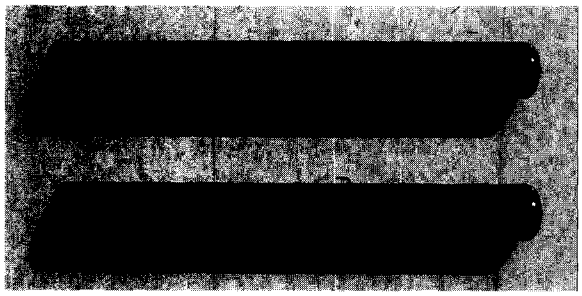


Fig. 3 A typical photo of a Ti-Si-Al ceramic tube

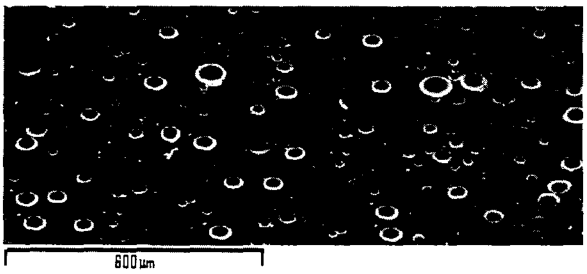


Fig. 4 A surface image of a Ti-Si-Al ceramic tube by SEM

Fig. 3 is an actual photo of a Ti-Si-Al ceramic tube. The result of the Ti-Si-Al ceramic tube surface as analyzed by SEM is shown in Fig. 4. A Ti-Si-Al ceramic tube having a relative dielectric constant (εr ≥ 100) is adhered to the inner surface of the electrode. This tube, which consists of Si (45%), Ti (24%), and Al (14%) shows superior dielectric characteristic as compared to normal pyrex glass (εr ≅ 5). Furthermore, the thermal consumption of discharge energy can be reduced in the Ti-Si-Al ceramic tube because of the higher dielectric material (εr ≥ 100) with a thinness of about 700um. As a result, ozone efficiency is increased.

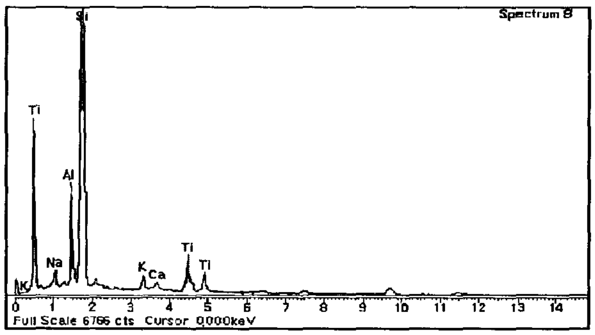


Fig. 5 Component analysis of ceramic tube using SEM

Fig. 5 is a graph that shows the mass analysis of the Ti-Si-Al ceramic tube using SEM. The lines in this graph indicate the actual Ti-Si-Al ceramic tube materials used in this experiment.

3. Experimental Results

Fig. 6 is a graph that shows the ozone concentration vs. input voltages at 600-1000Hz, 20 °C, 1.6 atm and 2 l/min.

As voltage increased, ozone concentration also increased and the slant of the curve showed an increasing tendency. It is interesting to see that the ozone concentration demonstrated a higher value at higher frequencies throughout the applied voltage.

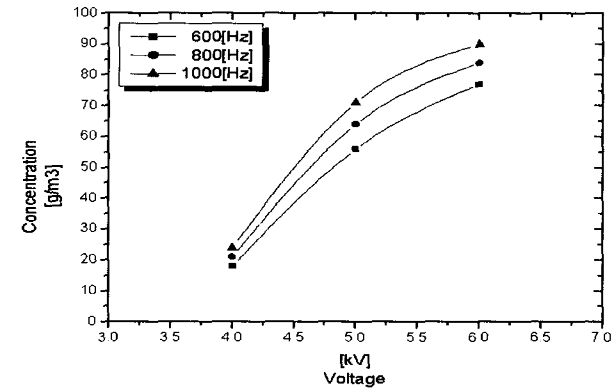


Fig. 6 Ozone concentration vs. voltage at 2 l/min.

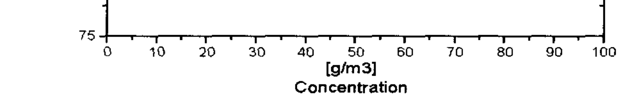


Fig. 7 Ozone efficiency vs. ozone concentration at 2 l/min.

Fig. 7 is a graph that showed a relation between the ozone concentration and efficiency using the conditions of Fig. 6. When frequency is 1000Hz, ozone concentration is high. But if we consider the relative energy efficiency aspect, the lower frequency (600Hz) is more superior than high frequency (1000Hz). As can be seen in Fig. 7, when we applied the lower frequency (600Hz), the maximum ozone efficiency was 180 g/kWh. This data is superior than that of ordinary ozone generation tubes.

Fig. 8 is a graph that shows the ozone concentration vs.

input voltages at 600-1000Hz, 20°C, 1.6 atm and 6 l/min. It was found that the tendency of ozone concentration decreases to increasing flow rate at the same voltage. As well, ozone concentration looked tendency of saturation curve as input voltage increase continuously.

Fig. 9 is a graph that displays the relation between ozone concentration and ozone efficiency under the condition of Fig. 8. The ozone efficiency per input energy is decreased when the flow rate is higher than the condition of Fig. 6. The ozone efficiency did not show the proportionate ratio to inflow oxygen gas rate.

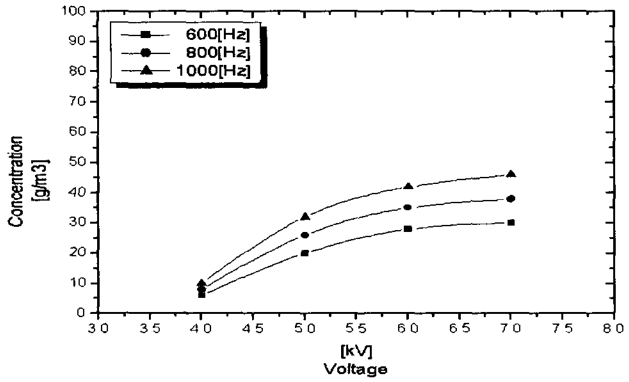


Fig. 8 Ozone concentration vs. voltage at 6 l/min.

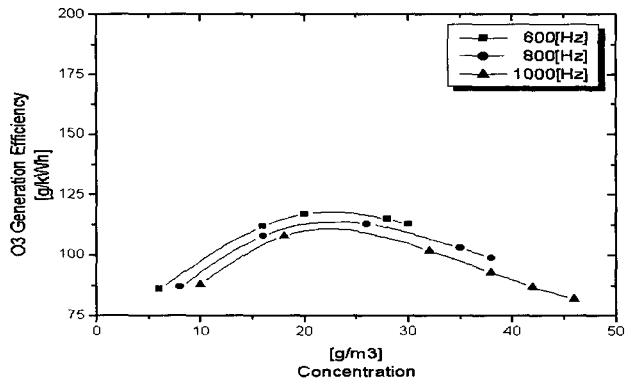


Fig. 9 Ozone efficiency vs. ozone concentration at 6 l/min.

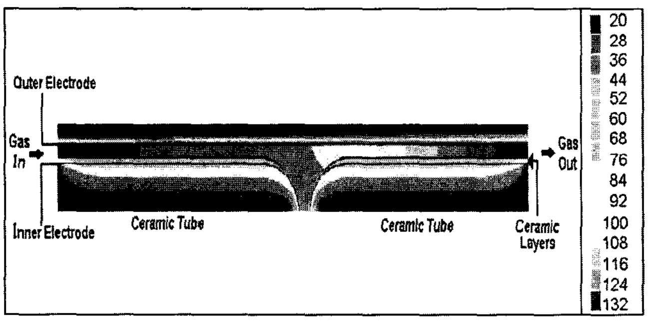
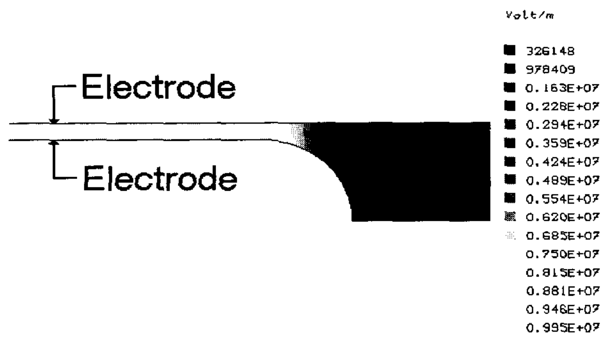
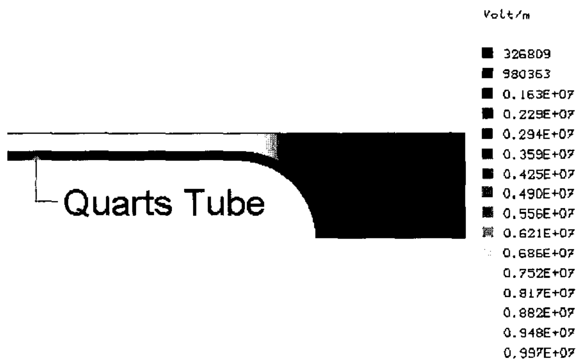


Fig. 10 Simulation to gas temperature transformation in the ceramic tube at 2 l/min, 20 °C, 1.6 atm, 600Hz and 40W.

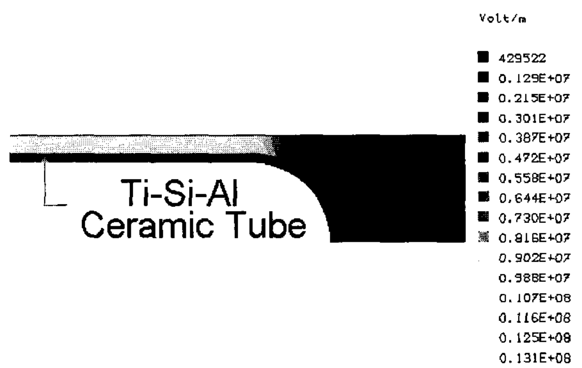
Fig. 10 shows the simulation result for the oxygen gas temperature change in the interior of the Ti-Si-Al ceramic tube at a maximum ozone efficiency point in the graph of Fig. 7. At this time, discharge power is 40W. Considering the simulation result, the initial gas (oxygen) temperature of 20°C at the inlet was increased dramatically to 132 °C at the outlet of the discharge tube. Maintaining the lower temperature would be helpful in promoting beneficial ozone generation and preservation. Thus, the cooling of the discharge tube will be advantageous to higher ozone efficiency.



(a) Electric field simulation of an electrodes space.



(b) Electric field simulation of a quartz tube.



(c) Electric field simulation of a Ti-Si-Al ceramic tube.

Fig. 11 Simulation results of electric field distribution in a tube with applied voltages.

Fig. 11 (a), (b) and (c) are the simulation results of the electric field distribution in a tube as the applied voltage of 10 kV between positive and negative electrodes is applied. Fig. 11 (a) is the electric field analysis result when the distance between electrodes is 1 mm. In this case, no dielectric substance is provided on positive and negative electrodes. Fig. 11 (b) is the electric field analysis result when the positive metal electrode (lower part) is replaced by a quartz tube. Fig. 11 (c) is the electric field analysis result when the positive metal electrode (lower part) is replaced by a dielectric substance of Ti-Si-Al ceramic with high dielectric constant ($\varepsilon r \geq 100$). As seen in Figure 11, when the positive metal electrode is replaced by a Ti-Si-Al ceramic tube, a maximum electric field (0.131E+08 V/m) appears, and the initial discharge voltage becomes low. Therefore, the Ti-Si-Al type ceramic catalyst structure is considered to assist the improvement of ozone concentration and ozone efficiency.

4. Conclusion

In this paper, we investigated the ozone generation characteristic of the Ti-Si-Al ceramic tube. Ozone concentration at the frequency of 1000Hz was higher than that at 600Hz. In addition, when we compared the aspect of energy efficiency, the results showed that the lower frequency scenario (600Hz) was superior to the high frequency scenario (1000Hz). Further, we found that the temperature of discharge space (gap between a metal electrode and dielectric material) is increased from an initial gas temperature of 20°C to a maximum gas temperature of 132°C at the tube outlet when we obtained the simulation result of fluid at experimental conditions such as flow rate (2 l/min), pressure of inner tube (1.6 atm), gas temperature (20°C) and discharge power (40W). As seen in Figure 11, when the positive metal electrode is replaced by a Ti-Si-Al ceramic tube, a maximum electric field (0.131E+08 V/m) appears and the initial discharge voltage becomes lower. Therefore, the Ti-Si-Al type ceramic catalyst structure is considered to aid the improvement of ozone concentration and ozone efficiency.

References

[1] Kook-Hee Cho, Young-Bae Kim, Dong-Hoon Lee, "A Study on the Characteristics of Ceramic Tube for Ozone Generation", *2002 Joint Conference of ACED & K-J Symposium on ED and HVE*, pp. 610-612, Nov. 17-20, 2002.

[2] Kook-Hee Cho, Young-Bae Kim, and Kil-Soo Seo, "Improvement of Ozone Concentration and Efficiency by a Superposition-silent in Discharge Ozonizer", *ICEE 2K, The International Conference on Electrical Engineering 2000*, pp. 228-231, July 2000.

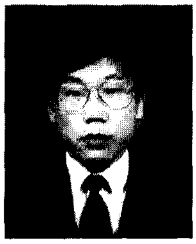
[3] Kook-Hee Cho and Young-Bae Kim, "Development of Ozone System with Multiple Discharge Gap for Clean Environment", *2000 Korea-Japan Joint Symposium on Electrical Discharge and High Voltage Engineering*, pp. 1041-1043, October, 2000.

[4] Rip G. Rice, "Century 21-Pregnant with Ozone", *Proceedings of the 15^{th} Ozone World Congress, Oral Presentation Volume I, London, U.K.*, 11^{th} – 15^{th}, pp. 1-27, Sep. 2001.

[5] U. Kogelschatz, "Advanced Ozone Generation", *Process Technologies for Water Treatment, Edited by Samuel Stucki, Plenum Publishing Corporation*, pp. 87-100, 1988.

[6] R. Peyrous, "The Effect of Relative Humidity on Ozone Production by Corona Discharge in Oxygen or Air", *Ozone science and Engineering*, Vol. 12, pp. 19-40, 1990.

[7] H. Sugimitsu, "Measurement of the Rate of Formation in an Ozonizer", *Journal de Chemie Physique*, Vol. 79, No. 9, pp. 655-660, 1982.



Kook-Hee Cho
He received B.S, M.S and Ph.D degrees in electric engineering from Soongsil University in 1987, 1989 and 1998, respectively. He is currently working in the applied electro-physics group at the Korea Electro-technology Research Institute (KERI). His research interests include ozone generation, pulse power, plasma and diagnosis of power systems.

Young-Bae Kim
He received B.S degree in electric engineering from Busan Industrial College in 1978. He is currently working in the applied electro-physics group at the Korea Electro-technology Research Institute (KERI). His research interests include ozone generation, IPS and VRAC Switch.

Dong-Hoon Lee
He received B.S and M.S degrees in electric engineering from Kyungnam University in 1996 and 1998, respectively. He is progressing towards a Ph.D in electric engineering from Kyungnam University, Korea. His research interests include treatment of harmful water and oil cracking using high voltage discharge plasma, NOx and SOx removal technology, ozone generation, vacuum switch, impulse generation and electrochemistry.