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개선된 램프형 오존발생기에 관한 연구

(A Study on the Improved Lamp Type Ozonizer(ILO))

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요 약

본 논문에서는 환경개선 및 건강증진 설비로써 활용되고 있는 Ultraviolet(U.V.) 광화학 반응을 이용한 lamp형 오존발생기(LO)의 특성을 개선할 목적으로 LO 에 연면방전을 중첩시킨 개선된 형태의 오존발생기(ILO)를 설계·제작하였다. 제작된 오존발생기는 전압인가 방식에 따라서 2가지 형태의 오존발생기(LO 및 ILO)가 구성되고, 이들 각 오존발생기에 대하여 전력, 원료가스의 유량에 따른 오존생성농도, 오존발생량 및 오존생성수율 특성을 연구 검토하였다. 이때, 오존생성농도, 오존발생량 및 오존생성수율 등이 ILO 가 LO 보다 우수한 것으로 나타나서, LO 의 오존생성특성을 향상시킬 수 있었다. 그 결과, 방전전력이 19[W]로 일정한 경우 ILO 가 LO 보다 오존생성농도, 오존발생량 및 오존생성수율이 원료가스의 유량이 1[ℓ/min]일 때 124 [%], 6[ℓ/min]일 때 143[%] 상승하였으며 본 연구에서 최대 712[ppm]의 오존생성농도, 128[mg/h]의 오존발생량과 6750[mg/kWh]의 오존생성수율을 얻을 수 있었다.

Abstract

In this paper, improved lamp type ozonizer(ILO), which utilizes the superposition of lamp type ozonizer(LO) and surface discharge operation, is designed and manufactured for the purpose of characteristic improvement of an LO employed for installation of environment improvement and good health using Ultraviolet(U.V.) photochemical reactions methods. The ozonizer consists of 2 types(LO and ILO), and ozone concentration, ozone generation and ozone yield were investigated in accordance with discharge power and quantity of supplied gas. The results of ozone concentration, ozone generation and ozone yield were ILO > LO. So, ozone generation characteristics of the lamp type ozonizer were improved. At a discharge power of 19[W], ozone concentration, ozone generation, and ozone yield of the ILO are each improved than LO 124[%] at the gas flow 1[ℓ/min] and 143[%] at the gas flow 1[ℓ/min]. The maximum values of ozone concentration, ozone generation and ozone yield were found as 712[ppm], 128[mg/h] and 6750[mg/kWh] respectively.

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1. Introduction

In an industrial society, environmental problems like air and water pollution have been the vital point of concern to health. O_3 is widely used for the purpose of environmental improvement[1~6]. The environmental problems like acid rain, global warming, oxygen depletion and smog are NO_x, SO_x, CO_2 and volatile organic compound(VOC's). It has already been demonstrated that nonthermal plasma techniques offer an innovative approach to a cost-effective solution to these problems[7~9]. In general ozone(O_3) is a powerful oxidizing agent and it decays without residues, which can be harmful to the environment.

Werner Von Siemens developed primarily a silent discharge type ozonizer for the first time in 1857 using the principle of using dielectric between dischargers, so as to obtain streamer discharge[10]. Scheneller produced the same in 1894 but without dielectric. Since then the problem of low efficiency has become the burden of all researchers.

The lamp type ozonizers(LO) using uv photochemical reaction methods have low efficiency. These are very important in ozone area as they perform a role of lighting source as well as ozonizer that is used in sterilizing E.coli(Escherichia coli) bacteria.

So it has become very important to increase the efficiency of LO. Sufficient improvements on efficiency were observed by using improved operation.

In this paper, by using LO under consideration we designed and manufactured new type ozonizer, improved lamp type ozonizer(ILO), using superposed surface discharge operation. The ILO utilizes the superposition of LO and surface discharge operation. Ozone concentration, ozone generation, and ozone yield were investigated in accordance with discharge power and quantity of supplied gas.

2. Theory

2.1 Ozone generation mechanism by uv photochemical reaction methods

The important reaction of ozone generation and decomposition by photochemical reaction methods are as per given in equation (1) through (7) [11~12]. Fig. 1 shows the diagram for the basic principle of lamp type ozonizer in photochemical reaction methods.

$$O_2 + h\nu \rightarrow O^* + O \quad \text{......} (1)$$
$$(\lambda = 130 \sim 175[nm])$$
$$O_2 + h\nu \rightarrow O + O \quad \text{......} (2)$$
$$(\lambda = 175 \sim 242[nm])$$
$$O + O_2 + M \rightarrow O_3 + M \quad \text{......} (3)$$

where M = O, O_3 or O_2, which is a third collision partner

$$O_3 + h\nu \rightarrow O_2^* + O \quad \text{......} (4)$$
$$(\lambda = 310 \sim 374[nm])$$
$$O_3 + h\nu \rightarrow O^* + O_2 \quad \text{......} (5)$$
$$(\lambda = 210 \sim 300[nm])$$
$$O_3 + h\nu \rightarrow O_2 + O \quad \text{......} (6)$$
$$(\lambda = 550 \sim 610[nm])$$
$$O_3 + O \rightarrow 2O_2 \quad \text{......} (7)$$
$$O_2 + e \rightarrow 2O + e \quad \text{......} (8)$$

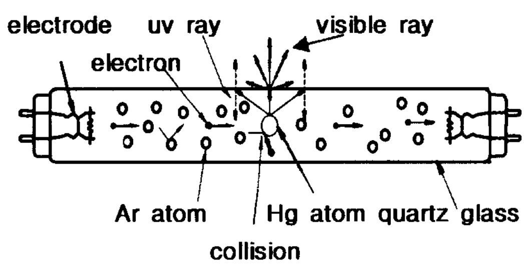


Fig. 1. The basic principle diagram of the LO in photochemical reaction methods

Equations (1) through (3) show the reactions in the ozone generation process. In the uv photochemical reaction methods the principle of ozone generation is based on the fact that if uv ray is radiated onto oxygen molecule in a gaseous medium, the oxygen molecules are dissociated into oxygen atoms which are then coupled with oxygen molecules to yield ozone.

If uv ray of wavelength 130 ~ 175[nm] is radiated onto oxygen atoms in the discharge region, the atoms are dissociated into excited oxygen atoms and normal state oxygen atoms, as shown in equation (1). If the uv wavelength lies in the range of 175 ~ 245[nm], then molecules are dissociated into two similar normal state oxygen atoms. This is represented in equation (2). The oxygen atoms thus produced in the process are combined with other oxygen molecules along with 3rd coexisting materials to yield O_3. This is shown in equation (3). Here if the energy required for an oxygen molecule to dissociate is 5.08[eV], it is radiated into wavelength of 244[nm]. Furthermore if O_3 absorbs uv ray "Hartley" of wavelength 210 ~ 300[nm] and/or "Huggins" of wavelength 300 ~ 374 [nm], then it results a strong dissociation of O_3. This is shown in equation (4) and (5). Similar thing happens if O_3 absorbs uv rays "Chapplus" of wavelength 550 ~ 610[nm] as shown in equation (6). In this case O_3 is dissociated into oxygen atom and oxygen molecule. The oxygen atom thus produced reacts further with O_3 to dissociate O_3 into oxygen as shown in equation (7).

2.2 O_3 generation mechanism by surface discharge

Surface discharge is a breakdown of the medium in which the solid insulator is immersed. If process continues as long as voltage is applied, it is called surface discharge. copious electrons in surface discharge are produced and accelerated to cause the plasma-chemical reaction for O_3 generation[1]. Fundamental mechanism of O_3 production is the same as other discharge process.

O_3 formation is a two step process such as in equation (3) and (8) that starts with micro-discharge.

3. Experimental Apparatus and Methods

3.1 Experimental apparatus

Fig. 2 shows the schematic diagram of theimproved lamp type ozonizer(ILO), which is a superposition of a lamp type ozonizer(LO) and surface discharge operation.

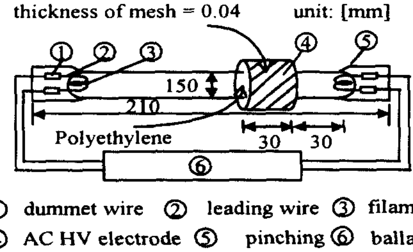


Fig. 2. Schematic diagram of ILO

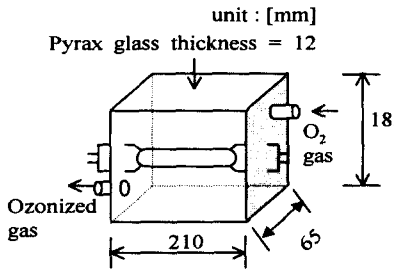


Fig. 3. Schematic diagram of ILO chamber

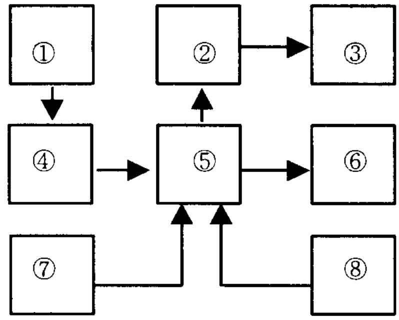
In Fig. 2, discharge tube is made by a clear quartz glass of thickness 1[mm] which is melted in SiO_2(99.1[%]) and B_2O_2(0.1[%]). The dummet wire is made of an alloy of Ni(41[%]), Mn (0.75 ~ 1.25[%]) and Si. The leading wire is made of Ni(99.9[%]).

After washing and drying the lamp, it is evacuated by vacuum pump unto 10^{-3}[torr] through a whole made at the mid point of the tube. As shown in the figure there is a mesh of 0.04[mm] thickness wound upon polyethylene. AC High voltage is applied between the mesh and one of the filament. The lengths of the mesh and the discharge path are both 30[㎜]. Fig. 3 shows the schematic diagram of the ILO chamber, which is made by pyrex glass in the form of the inner compartment of a rectangle for the sake of research purpose. Thickness is 12[㎜] and the size is Length×Width×Height = 210×65×185[㎣]. In the experiment only one tube was used. Commercial oxygen gas(99.99[%] purity) was used as supplied gas. The voltage sources of the ILO are : (1) AC H.V source for surface discharge and (2) AC 220[V] commercial voltage source for uv photochemical reaction. The discharge voltage(V_d), discharge current(I_d) were recorded by means of a digital storage oscilloscope(500[㎒], 1[Gs/s]). The quantity of supplied gas(Q) is controlled by the flowmeter(0 ~ 25[ℓ/min]).

The ozone concentration(O_{3con}) of ozonized gas for gaseous phase was measured by using ozone monitor(0 ~ 110,000[ppm]). The ozone generation(O_{3g}) is calculated by using O_{3con} and Q, and the ozone yield(O_{3Y}) is calculated by O_{3g} and discharge power(W_d). Fig. 4 shows the block diagram of the ILO system.

3.2 Experimental methods

The LO's circuit was supplied by a variable low voltage source. By varying both the Q and the applied voltage, the values of O_{3con} were recorded for different values of W_d. These data were used for the LO. AC high voltage was applied between the mesh and one of the filaments for surface discharge operation. The LO's circuit is also energized. By varying the applied voltage and Q, the values of O_{3con} were recorded for different values of W_d. These data were used for the ILO. In all cases O_{3g} were calculated by Q and O_{3con}. O_{3Y} were calculated by O_{3g} and W_d.

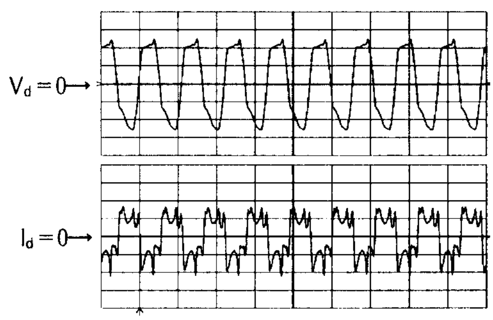


① chamber of supplied gas ② oscilloscope
③ PC ④ flowmeter ⑤ ILO ⑥ O_3 monitor
⑦ AC high voltage for surface discharge
⑧ AC 220[V] for the LO

Fig. 4. Block diagram of the ILO system

4. Experimental results and discussions

Fig. (5) to (11) show the characteristics of the two ozonizers LO and ILO. Fig. 5 shows the waveforms of discharge voltage(V_d), and discharge current(I_d) of the LO. The fluctuating nature of the current wave in each half cycle is due to the presence of the choke in the lamp circuit. The maximum value of V_d was 95[V] at the discharge power of 19[W]. The maximum value of I_d was 95[mA].



50[V/div], 2[mA/div], 50[μs/div]

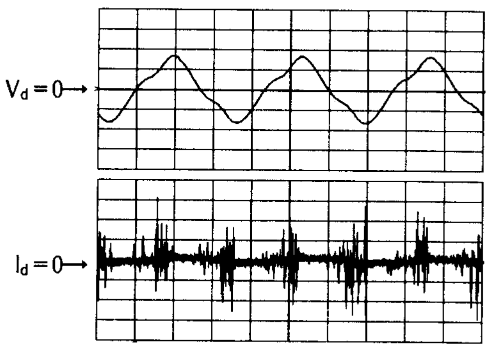
Fig. 5. Waveforms of discharge voltage and current of LO

Fig. 6 shows the waveforms of V_d and I_d

for surface discharge. The discontinuous pattern of the current waveform indicates the brush discharge.

The streamers developed by the application of high voltage can easily penetrate into the discharge region. But since the glass is acting as dielectric barrier, only a short current spike can propagate and no arc can develope.

The dielectric thus prevents the arc formation in the discharge process. So the discharge current is spike in nature. The maximum values of V_d and I_d were 1.1[kV] and 9.9[mA] respectively at a W_d of 19[W].



1000[V/div], 0.4[mA/div], 5[ms/div]

Fig. 6. Waveform of discharge voltage and current of the surface discharge

Fig. 7(a) and 7(b) show the O_{3con} and O_{3g} characteristics for the LO and ILO respectively against W_d.

In all cases the value of O_{3con} is high for lower value of Q. At a lower value of Q the oxygen molecules stay in the discharge chamber for a longer duration. So, reaction time is high. This yields more O_{3con} value which results equations (1) through (3) to occur more frequently. At Q = 1[ℓ/min] the rising slopes of O_{3con} curves are higher than those for higher values of Q. As W_d rises from 9[W] to 19[W], O_{3con} rises from 150 to 575[ppm] in fig. 7(a) and from 322 to 712[ppm] in fig. 7(b). At Q = 6[ℓ/min] and at the same increase of W_d O_{3con} rises from 0 to 75[ppm] in fig. 7(a) and from 70 to 182[ppm] in fig. 7(b).

For the same reason stated before, at lower Q O_{3g} characteristics curves always start from higher values than those at higher values of Q. At Q = 1[ℓ/min] as W_d rises from 9[W] to 19[W] O_{3g} rises from 18 to 68[mg/h] in fig. 7(a) and from 38 to 84[mg/h] in fig. 7(b). At a higher flow rate of Q = 6[ℓ/min] and for the same increase of W_d, O_{3g} rises from 0 to 53[mg/h] in fig. 7(a) and from 50 to 128[mg/h] in fig. 7(b).

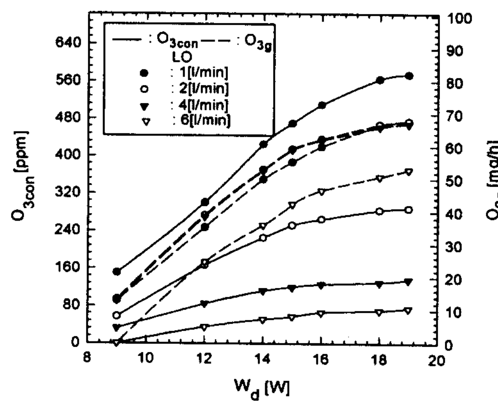


Fig. 7(a). O_{3con}-O_{3g} characteristics of LO

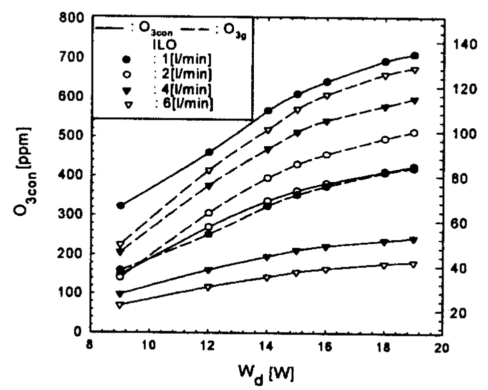


Fig. 7(b). O_{3con}-O_{3g} characteristics of ILO

Fig. 8 shows the O_{3Y} characteristics for two ozonizers. O_{3Y} attains the highest value for Q = 2 [ℓ/min] in LO, whereas in the ILO O_{3Y} is highest for Q = 6[ℓ/min] and lowest for Q = 1[ℓ/min]. In every case starting from a lower value O_{3Y} increases continuously upto a certain value of W_d, where O_{3Y} becomes maximum. With the further increase of W_d it falls down. As W_d increases from a lower value the discharge becomes stronger

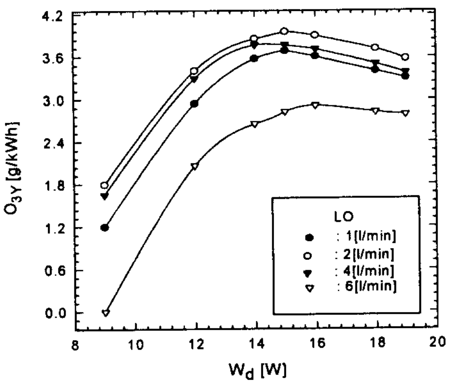


Fig. 8(a). O_{3Y} characteristics of LO

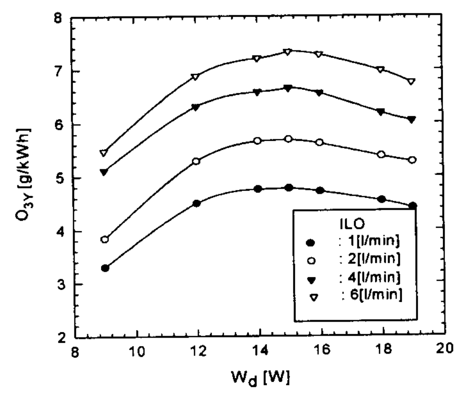


Fig. 8(b). O_{3Y} characteristics of ILO

giving more O_{3con}. After 15[W] power dissipation, owing to both temperature rise and high value of O_{3con} decomposition of O_3 takes place more rapidly. This results in equation (4), (5), (6), and (7) to occur more frequently. So, before W_d = 15[W] equations (1), (2), (3), and (8) are dominant and after W_d = 15[W] equations (4), (5) (6) and (7) are dominant. At W_d = 15[W], O_{3Y} attains a maximum value of 4[g/kWh] in LO at Q = 2[ℓ/min] and 7[g/kWh] in ILO at Q = 6 [ℓ/min].

Fig. 9(a) and 9(b) show the O_{3con} and O_{3g} characteristic comparison of the two ozonizers for Q = 1 and 6[ℓ/min] respectively. At any value of discharge power, both O_{3con} and O_{3g} are higher in the ILO and lower in the LO. In the ozonizers both O_{3con} and O_{3g} have rising characteristics as W_d increases. In the LO there is a ballast used in the circuit. Almost 50[%] of the applied power is consumed in the ballast.

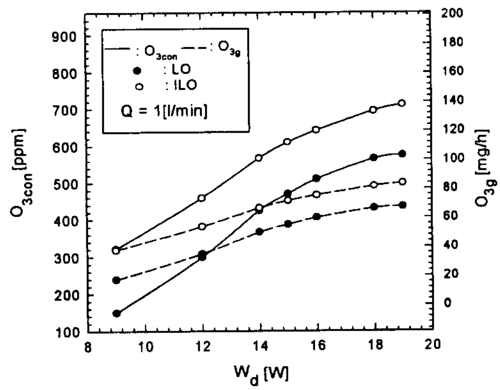


Fig. 9(a). O_{3con}-O_{3g} characteristic comparison for Q = 1 [ℓ/min]

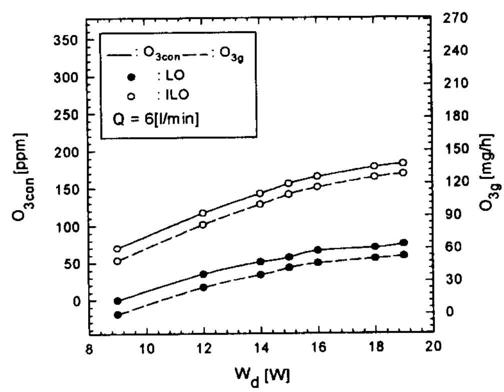


Fig. 9(b). O_{3con}-O_{3g} characteristic comparison for Q = 6[ℓ/min].

A portion of the rest 50[%] power is converted into light and heat energy. So only a very small amount of power is utilized for ozone generation. Whereas in the surface discharge operation, inspite of converting a portion of the applied power into heat, the remaining power is utilized for ozone generation. So, at the same value of W_d the values of both O_{3con} and O_{3g} of the ILO are very high in compared to those of LO. In the ILO, the uv rays are produced in the lamp and high energy electrons are produced in the discharge process. Both the uv rays and high energy electrons take part in the ozone generation process. Although a portion of the applied power is converted into heat and light, the combined effect of the two process results in higher values of both O_{3con} and O_{3g} in compared to those in LO.

Fig. 10(a) and 10(b) show the O_{3Y} characteristic comparison of the two ozonizers for Q = 1 and 6 [ℓ/min] respectively. For the reason stated above the values O_{3Y} of the ILO were greater than those of the LO under the same condition of W_d and Q.

At Q = 1[ℓ/min] the maximum values of O_{3Y} are 4[g/kWh] in LO and 5 in ILO. The corresponding values of O_{3Y} at Q = 6[ℓ/min] are 3 and 7[g/kWh] respectively.

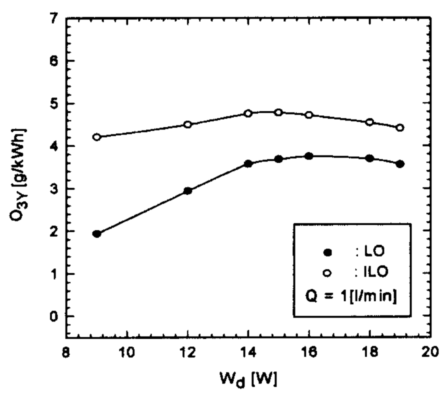


Fig. 10(a). O_{3Y} characteristic comparison for Q = 1 [ℓ/min]

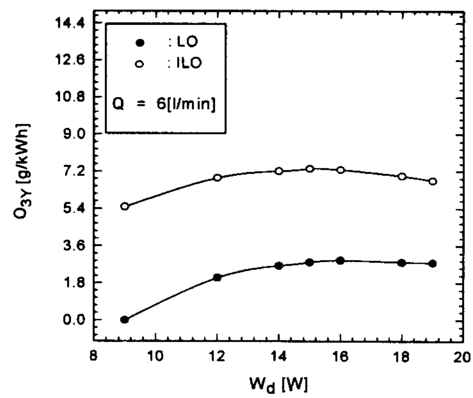


Fig. 10(b). O_{3Y} characteristic comparison for Q = 6 [ℓ/min]

Fig. 11 shows the curve for the increase factor, F, which is defined as equation (9)

$$F\ [\%] = \frac{O_{3Y}\ \text{of ILO} - O_{3Y}\ \text{of LO}}{O_{3Y}\ \text{of LO}} \times 100 \quad (9)$$

The curves of F have been shown for two values of Q. As discharge power increases, F decreases in value and vice versa. As W_d increases from 9[W] to 19[W], F decreases from 117[%] to 24[%] for Q = 1[ℓ/min] and from 241[%] to 143[%] for Q = 6[ℓ/min]. The highest values of F are 117[%] for Q = 1[ℓ/min] and 241[%] for Q = 6[ℓ/min]. Hence depending on the gas flow rate, from 117[%] to 241[%] increase in the efficiency was observed at W_d = 9[W].

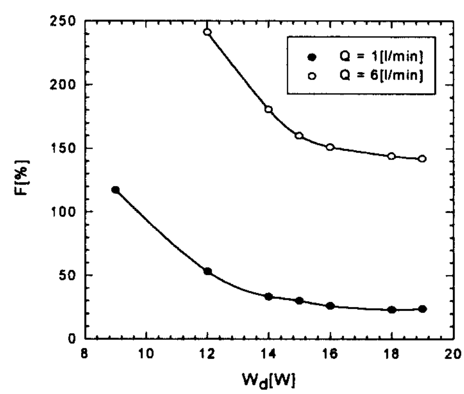


Fig. 11. F characteristic of the ILO

5. Conclusion

In this paper, with a view to improving the characteristics of a lamp type ozonizer(LO), an improved lamp type ozonizer(ILO) is designed and manufactured by utilizing the superposition of the lamp type ozonizer with surface discharge operation. The results of the discharge and ozone generation characteristics were possible to conclude as follows.

(1) Ozone concentration was found to be inversely proportional to the gas flow rate Q.

(2) The maximum values of ozone concentration in the improved lamp type ozonizer at 19[W] of discharge power were found to be 712 and 182[ppm] at the gas flow rate 1 and 6[ℓ /min] respectively.

(3) The maximum values of the ozone yield in the improvement lamp type ozonizer were found at discharge power 15[W], which were 5 and 7[g/kWh] at the gas flow rate 1 and 6[ℓ/min] respectively. The corresponding values in the LO at the same discharge power were 4 and 3[g/kWh] respectively.

(4) The maximum values of ozone generation at discharge power 19[W] in the improved lamp type ozonizer were found as 84 and 128[g/kWh] at the gas flow rate 1 and 6[ℓ/min] respectively. At the same value of discharge power the corresponding values of ozone generation in the lamp type ozonizer were found as 68 and 53[mg/h] respectively.

(5) At discharge power 19[W], the values of ozone concentration, ozone generation and ozone yield are each improved by 24[%] at gas flow rate 1[ℓ/min] and 143[%] at gas flow rate 6[ℓ/min].

According to the above mentioned results, in the lamp type ozonizer, there is a great power loss in the ballast. Also power is lost into light and heat energy. But in the improve lamp type ozonizer, although a portion is converted into light and heat energy, the superposition effect of the surface discharge and the lamp type ozonizer results in higher output at the same amount of discharge power. This results in higher efficiency and better performance of the improved lamp type ozonizer.

REFERENCES

[1] Senichi Masuda, " Ceramic based ozonizer for high speed sterilization ", IEEE transactions, Vol. 2, No. 88, pp. 164 1~ 1646, 1998

[2] Gary R. Peyton, " Destruction of Pollutants in Water with Ozone in Combination with Ultraviolet Radiation " Environment Science Technology, vol. 22, No. 7, 1988

[3] Roman Morar, Radu Munteanu, Emil Simion, Iuliu Munteanu, and Lucian Dascalescu, " Electrostatic Treatment of Bean Seeds ", IEEE Transaction, vol. 35, No. 1, 1999

[4] Johannes Staehelln and Jurge Holgne, " Decomposition of O_3 in water : Role of ignition by Hydroxide ions and Hydrogen peroxide, Environment Science Technology " Vol. 16, pp. 676~681, 1982

[5] Md. Fayzur Rahman., Hyun-Jig Song, Kwang-Sik Lee, and Dong-In Lee, " Characteristic analysis of a new superpose discharge type ozonizer ", Proceeding on Electrical Discharge and High Voltage Engineering Conference, pp. 358~361, 1999

[6] Md. Fayzur Rahman., Hyun-Jig Song, Kwang-Sik Lee, and Dong-In Lee, " Improvement of the efficiency of a uv lamp type ozonizer ", Proceeding of the Korean Institute of Illuminating and Electrical Installation Engineers, pp. 2 3~26, Nov. 14, 1998

[7] G. Dinelli, L. Civitano, " Industrial experiments on pulse corona simultaneous removal of NOx, and SO2 from the flue gas " IEEE Transaction, vol. 26, pp. 535~541, 1990

[8] A. Mijuno, R. H. Davis, " A method for the removal of sulphur dioxide from exhaust gas utilizing pulsed streamer corona electron energization " IEEE Transaction, vol. 22, pp. 516~522, 1986

[9] G. Dinelli and M. Rea, " Pulse power electrostatic technologies for the control of flue gas emissions ", Journal Electrostatics, vol. 25, pp. 23~24, 1990

[10] A. Vosmaer, " O_3, it's manufacture, properties and uses ", D. Van Nostrand company 25 park place, 1916

[11] Chun-Sou Kang, " A study on the lamp type ozonizer " MS thesis, Electrical Engineering, Yeungnam University, 1995

[12] Hyun-Jig Song, Kwang-Sik Lee, and Dong-In Lee, " A study on the trial manufacture and characteristics of lamp type ozonizer ", Korea-Japan Joint Symposium on Electrical Discharge and High Voltage Engineering, 1996

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