Performance Characteristics of a Pin-to-Cylinder Superposed Discharge Type Ozonizer (SDO)

Md. Fayzur Rahman and Kwang Sik Lee

Abstract - This paper presents a model for a pin-to-cylinder discharge type ozonizer, which utilizes the superposition of surface discharge and corona discharge operation. By changing the gas flow rate, the discharge power and the number of SDO units, the characteristics of ozone concentration (O_{3con}), ozone generation (O_{3g}) and ozone yield (O_{3Y}) were investigated. Using one SDO unit the maximum values of O_{3con}, O_{3g} and O_{3Y} were found as 8100[ppm], 1623[mg/h] and 213[g/kWh] respectively. With two SDO units the corresponding values were found as 12800[ppm], 2893[mg/h] and 248[g/kWh] respectively. Hence using two SDO units the efficiency was improved by 16[%].

Keywords - ozone, ozone generation, ozone Concentration, ozone yield, superposed dischange-type ozonizer(SDO)

1. Introduction

Industrial development results in air and water pollution which causes serious deterioration in the environment both nationally and internationally. Ozone is a strong oxidizing agent with no harmful residue and it controls the materials that cause environmental pollution. Also since the production of ozone requires only air and electricity there is no transport of dangerous chemical agents in the application of ozone. These are the main reasons why ozone is increasingly used for oxidizing purposes as well as the elimination of NOx from the flue gases of power plants [1]. A widespread research is going on in the utilization of ozone in different areas including the treatment of industrial exhaust water [2] and drinking water [3]. In the discharge type ozonizer the theoretical efficiency of ozone generation is calculated as 1200[g/kWh] [4]. But only 5-10[%] of the applied energy is utilized in producing ozone and the rest amount is converted into light, sound and heat. With a view to improving the characteristics the researchers have been trying to develop different types of ozonizers[5-12,15]. Some of the researchers developed ozonizer with the ozone yield rate of 170[g/kWh] at normal temperature [13] and of 300[g/kWh] at −60 °C temperature [14].

The efficiency of a hybrid type ozonizer is higher in comparison to that of a conventional type ozonizer[16-17]. Considering all these points we tried to develop an ozonizer which uses the superposed operation of surface and corona discharge. The ozonizer consists of two concentric glass tubes with three types of discharge electrodes: the Central Electrode (CE), the Internal Electrode (IE) and the External Electrode (EE). When high voltage is applied between IE and CE, electric stress developed on the bottom parts of the discharging pins causes surface discharge. Also by applying high voltage between EE and IE corona discharge occurs between the discharging pins and the cylindrical electrode (EE). Since corona discharge is helpful in producing ozone, this design of the ozonizer is very suitable for producing high ozone concentration and ozone yield. Also since pins are used for discharging purpose, there are enough spaces for the occurrence of surface discharge. These spaces are also used for collection of the ozonized gas. Also since the discharge occurs between the tips of the pins and EE, the temperature of the region around the bottom parts of the pins do not rise too much. These are the main causes of obtaining higher ozone concentration (O_{3con}) and ozone yield rate (O_{3Y}). O_2 was used as the source gas. By changing the gas flow rate (Q), the discharge power (W_d), and the number of SDO units, the characteristics of O_3 related different parameters like O_{3con} O_{3g} , and O_{3Y} were investigated. Since the construction is very simple, the manufacturing cost is low in comparison to other ozonizers.

2. Theory of Ozone Generation

The ozonizer is manufactured by using more than one electrode with glass or ceramic as insulator in such a way that a gap of 1~3[mm] is maintained between the electrodes. If ac voltage is applied, ozone is produced by chemical reaction in the oxygen portion of the supplied gas Corona discharges are relatively low power electrical discharges that may take place at different pressures. The corona is invariably generated by strong electric fields associated with small diameter wires, sharp needles, or sharp edges on an electrode. Corona takes its name ("crown")

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from mariners observation of discharges during electrical storms. Corona appears as a faint filamentary discharge radiating outward from the discharge electrode. Corona discharge application process emphasizes one of the two aspects of the discharge: the ions produced or the energetic electrons producing the plasma. The two identities depend on the polarity of the discharge and the characteristics of the gas mixture especially on the electron attracting species. The electron energies depend on the gas characteristics and on the method of generating the corona.

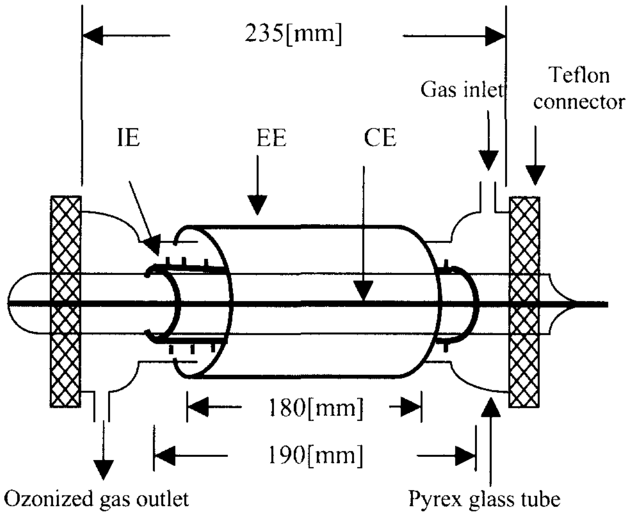

Fig. 1 Schematic diagram of the ozonizer.

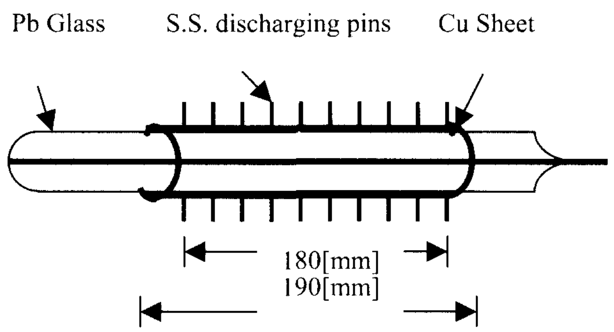

Fig. 2 Schematic Diagram of the inner tube.

Surface discharge occurs by narrow pulse type discharges and because electrons are generated from the different points on the surface of the electrodes, surface discharge is a useful one for the production of ozone caused by collisions of the electrons and oxygen molecules of the supplied gas. When high voltage is applied to a medium, interactions between the electrons and oxygen molecules take place to dissociate oxygen molecules into oxygen atoms. The rate of oxygen dissociation by the electrons depends on the energy distribution in the discharge region.

$$O_2 + e \rightarrow 2O + e \tag{2.1}$$

$$O + O_2 \rightarrow O_3 \tag{2.2}$$

($K = 1.06 \times 10^{-34} \exp(510/T)$ [cm^3/s])

$$O + O_3 \rightarrow 2O_2 \tag{2.3}$$

($K = 1.9 \times 10^{-11} \exp(-2300/T)$ [cm^3/s])

$$e + O_3 \rightarrow e + O + O_2 \tag{2.4}$$

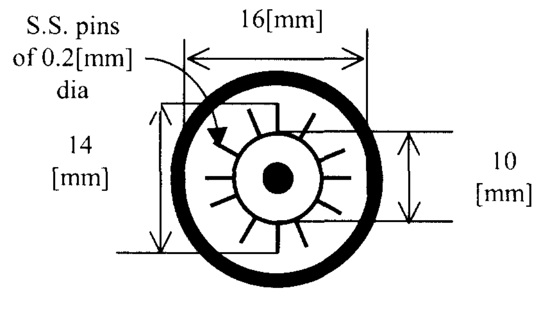

Fig. 3 Cross-section of the ozonizer.

The oxygen atoms generated according to (2.1) by electron ionization react with oxygen molecules to form ozone as shown in (2.2). Here the high speed reaction of (2.2) yields ozone generation and ozone concentration according to the current flowing through the micro discharge channel. But due to the presence of oxygen atoms and ionizing electrons the ozone atoms dissociate according to (2.3) and (2.4). This results in saturation of the ozone generation. In both corona and surface discharge ozone generation takes place mainly in the form of the equation shown below.

$$O + O_2 + M \rightarrow O_3 + M \tag{2.5}$$

where M is the third collision partner and may be O, O_2 and N_2. The decomposing reactions of ozone are mostly represented by (2.6), (2.7) and (2.8) shown below.

$$O_3 + M \rightarrow O + O_2 + M \tag{2.6}$$

$$O + O_2 + O_3 \rightarrow O_3^* + O_3 \tag{2.7}$$

where O_3^* represents a vibrationally excited ozone molecule.

$$O_3^* + O \rightarrow 2O_2 \tag{2.8}$$

3. Construction of Ozonizer

The ozonizer consists of two concentric glass tubes. The internal tube is made of Pb glass of 1[mm] thickness with the CE placed at the center. The outside diameter is 10[mm] and length is 250[mm]. After washing and drying the tube, it is sealed with the CE wire at the two ends and is evacuated by vacuum pump down to a pressure of 10^{-1} [torr]. The CE wire is 300[mm] long and one end is used for ground connection. A Cu sheet of about 0.2[mm] thickness was wrapped upon the surface and Stainless Steel (S.S.) pins of about 2[mm] length and 0.2[mm] diameter were inserted on the surface of the Cu sheet. A connection was brought out from the Cu sheet for using as IE electrode. The schematic diagram is shown in Fig. 2. The external tube is made of pyrex glass of 1.2[mm] thickness. The outer diameter is 19[mm] and the length is 235[mm]. A Cu sheet of about 0.2[mm] thickness was wrapped on the surface of the external tube. A wire was welded to the Cu sheet for using as EE electrode. The schematic diagram is shown in Fig. 1. The cross-sectional view is shown in Fig. 3. The measurements have been shown on the diagram.

4. Experimental Apparatus and Methods

4.1 Experimental Apparatus

Fig. 4 shows the block diagram representation of the overall measurement process. The mechanical system connection has been shown by dotted lines and electrical connections have been shown by solid lines. Commercial oxygen gas of 99.99[%] purity was used as the supplied gas. The discharge voltage (V_d) and the discharge current (I_d) were measured by means of digital storage oscilloscope (500[MHz], 1[Gs/s]). The quantity of supplied gas was controlled by a flow meter (0 ~ 24[l/min]). The ozone concentration of ozonized gas was measured by ozone monitor (0 - 110,000[ppm]). O_{3g} was calculated from O_{3con}. O_{3Y} was calculated by using O_{3g} and W_d. Experiments were carried out by applying high voltage (HV) to IE and EE with CE connected to ground.

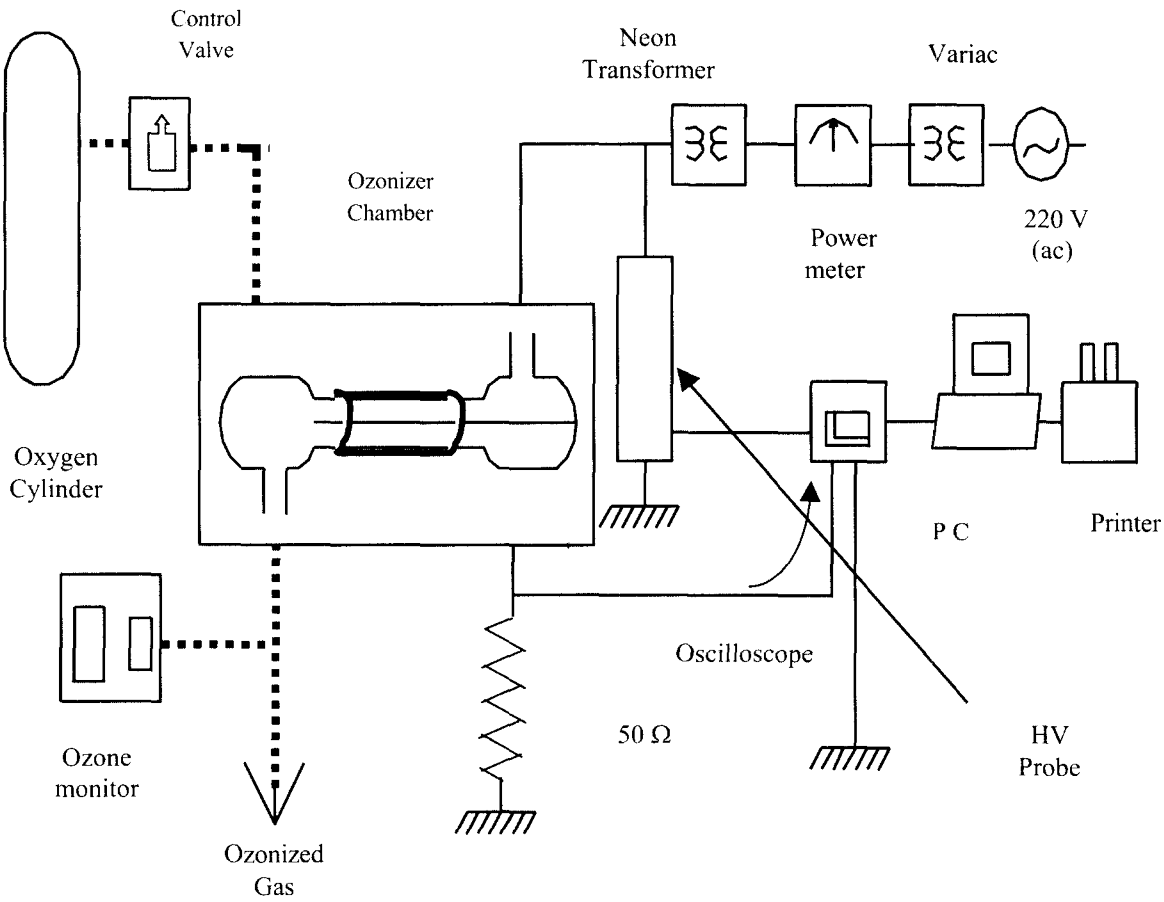

Fig. 4 Block diagram representation of the overall system.

4.2 Experimental Methods

The CE electrode was made of a wire of S.S. The amount of discharge power was varied by varying the supply voltage from 0 to a maximum of 15[kV]. The different parameters like O_{3con}, O_{3g} and O_{3Y} were recorded for each value of the applied voltage.

Two identical SDO units were prepared and connected in such a way that the ozonized gas from one unit enters into the other unit as the source gas. O_{3Y} was measured.

5. Experimental Results and Discussion

Fig. 5 and Fig. 6 show the characteristics of O_{3con} and O_{3g} with the variations of discharge power (W_d) and gas flow rate (Q). As seen from the figures both ozone concentration and ozone generation increase continuously with W_d . When W_d exceeds a value of 6.5[W], the increasing rate becomes low. This means that up to a value of 6.5[W] of W_d the discharge within the discharge region is activated and depending on the increase of electrons produced in the discharge the number of collisions between the electrons and oxygen atoms becomes very high. The reactions take place according to (2.1), (2.2) and (2.5). Hence the rate of ozone generation becomes very high. When the discharge power exceeds 6.5[W] the discharge becomes stronger. The ozone generating reactions become more active as explained. So, O_{3con} becomes very high. Due to this high value of O_{3con} decomposition of ozone takes place at a higher rate according to (2.3), (2.4), (2.6), (2.7) and (2.8). This results in a lower increasing rate of O_{3con}. As long as the discharge power increases, the temperature within the discharge chamber increases. With this high temperature and increased value of O_{3con} the oxygen atoms, molecules and electrons participate in decomposing ozone.

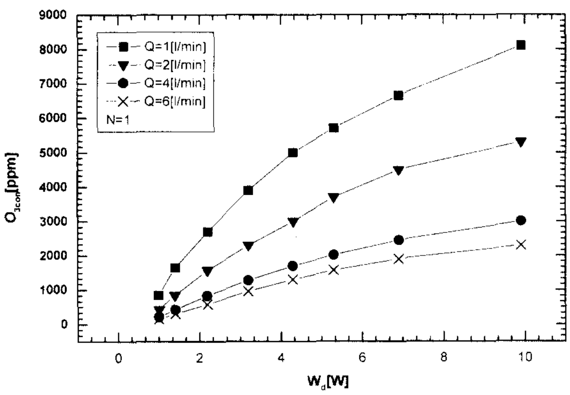

Fig. 5 Characteristics of O_{3con} with the variation of Q

The curves of Fig. 5 show that O_{3con} increases as Q decreases and vice versa. When Q decreases, the duration of stay of oxygen molecules in the discharge area increases, i.e., the reaction time increases. This gives high value of O_{3con}. Using one ozonizer unit this maximum values of O_{3con} were found as 8100[ppm] at Q=1[l/min], 5300[ppm] at Q=2[l/min], 3000[ppm] at Q=4[l/min], and 2300[ppm] at Q=6[l/min].

Furthermore from Fig. 6 it is seen that the value of ozone generation (O_{3g}) increases with W_d. Here it is considered that as long as W_d increases the electron density in the discharge region increases. So, both the corona and surface

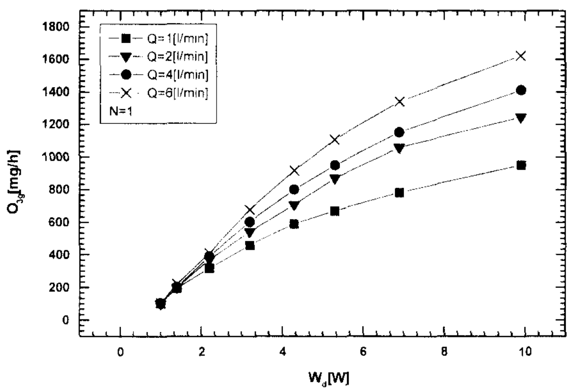

Fig. 6 Characteristics of O_{3g} with the variation of Q

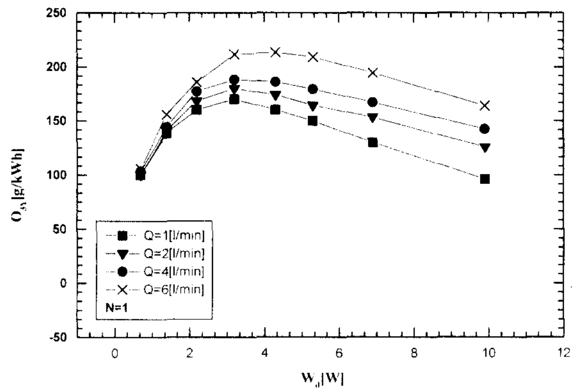

Fig. 7 Characteristics of O_{3Y} with the variation of Q

discharge become stronger. The number of collisions among the electrons, oxygen atoms, molecules and excited oxygen atoms become higher, which causes O_{3g} to be proportional to O_{3con}. At a constant value of W_d the value of O_{3g} is higher at higher Q. As Q increases the number of ozone producing oxygen molecules also increase, but their duration of stay in the discharge chamber become less. This results in fewer number of collisions among the generated electrons and oxygen molecules. The rate of increase of O_{3con} thus reduces. In result O_{3g} is determined by the number of increased oxygen atoms and decreased value of O_{3con}. The maximum value of O_{3g} is attained under such a situation that the increase of the number of oxygen atoms is greater than the reduction of O_{3con}. The maximum values of O_{3g} were found as 952[mg/h] at Q=1[l/min], 1247[mg/h] at Q=2[l/min], 1411[mg/h] at Q=4[l/min] and 1623[mg/h] at Q= 6[l/min].

Fig. 7 shows the characteristics of ozone generation yield rate (O_{3Y}) with the variation of discharge power and Q. As seen from the figure for all values of Q at lower value of W_d ozone generation yield rate rises continuously until W_d reaches 3.5[W]. After this it continuously falls. The rising portion of the curves may be explained as follows. With the increase of W_d the electron density increases. So, the number of collisions among the generated electrons, oxygen atoms, and excited oxygen molecules

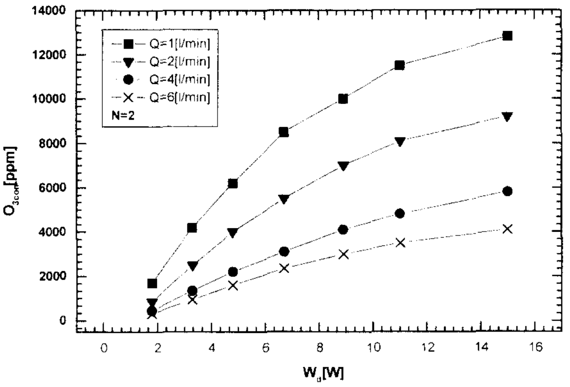

Fig. 8 Characteristics of O_{3con} with the variation of Q

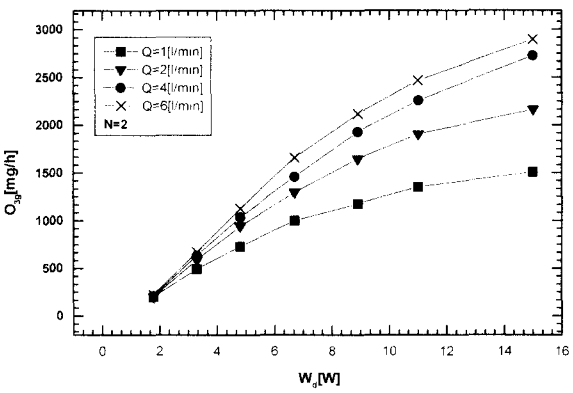

Fig. 9 Characteristics of O_{3g} with the variation of Q and W_d for N=2.

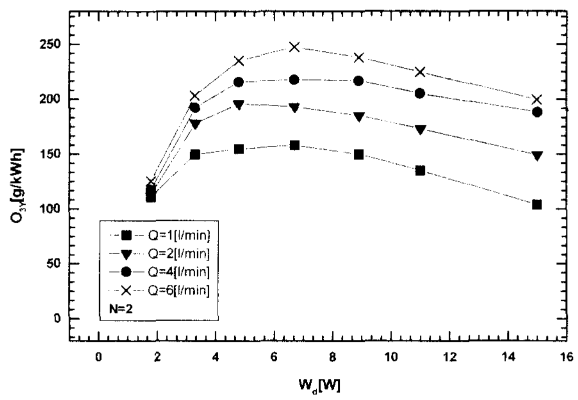

Fig. 10 Characteristics of O_{3Y} with the variation of Q

increases giving higher value of O_{3g}. After the time when O_{3Y} reaches its peak value the temperature within the discharge chamber rises. Due to this high temperature the O_3 decomposing reactions occur more yielding (2.3), (2.4), (2.6), (2.7) and (2.8). This reduces the value of O_{3g}. Since O_{3Y} is determined by O_{3g} and W_d, O_{3Y} decreases continuously after its peak value for all values of Q.

At the same value of W_d the value of O_{3Y} is seen to be higher at higher Q. At higher Q the number of oxygen atoms is larger. But the duration of their stay in the discharge

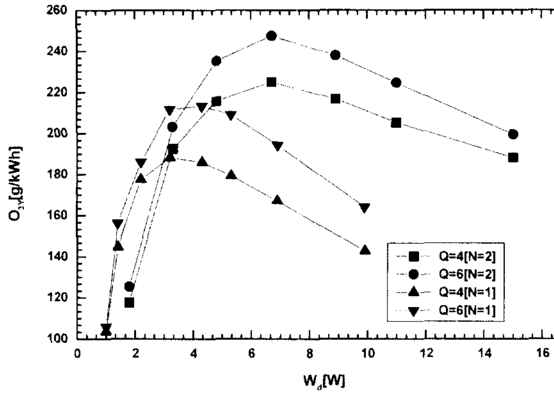

Fig. 11 Comparison of the O_{3Y} characteristics for N=1

chamber is less, which results in a low value of O_{3con}. So, the value of O_{3g} is determined by the large number of oxygen molecules and low amount of O_{3con}. The increase of the number of oxygen atoms is dominant over the reduction of O_{3con}. So, O_{3Y} is higher with higher Q. For different values of Q the maximum values of O_{3Y} were found as 170[g/kWh] at Q=1[l/min], 180[g/kWh] at Q = 2[l/min], 188[g/kWh] at Q=4[l/min] and 213[g/kWh] at Q = 6[l/min].

Fig. 8, Fig. 9 and Fig. 10 show the characteristics of O_{3con}, O_{3g} , and O_{3Y} respectively for two ozonizer units connected in series (N=2). Previous explanation can be adopted for analyzing the characteristics of the ozonizer using two units.

For different flow rates the maximum values of O_{3con} with N=2 were found as 12800[ppm] at Q=1[l/min], 9200[ppm] at Q=2[l/min], 5800[ppm] at Q=4[l/min], and 4100[ppm] at Q=6[l/min]. The maximum values of O_{3g} were found as 1505[mg/h] at Q=1[l/min], 2164[mg/h] at Q=2[l/min], 2728[mg/h] at Q=4[l/min] and 2893[mg/h] at Q= 6[l/min]. The maximum values of O_{3Y} were found as 158[g/kWh] at Q=1[l/min], 196[g/kWh] at Q = 2[l/min], 218[g/kWh] at Q=4[l/min] and 248[g/kWh] at Q = 6[l/min]. Fig. 11 shows the comparison of the O_{3Y} characteristics of the ozonizer for N=1 with that for N=2. As seen from the figure the maximum value of the ozone yield rate was found as 213[g/kWh] for N=1. Using two units this value was found as 248[g/kWh] under the same condition of gas flow rate. Hence an improvement of 16[%] of the efficiency was possible.

6. Conclusions

1. Using one ozonizer unit the maximum values of ozone concentration, ozone generation, and ozone yield were found as 8100[ppm], 1623[mg/h] and 213[g/kWh] respectively. Using two ozonizer units the corresponding values were found as 12800[ppm], 2893[mg/h] and 248[g/kWh] respectively.

2. Ozone concentration was found to be nearly inversely

proportional to the gas flow rate.

3. When two ozonizer units are connected, the efficiency was improved by 16[%].

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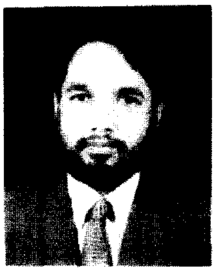

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