# Temperature Dependent Characteristics of a Combined Discharge Type Ozonizer (CDO)

**Fayzur Rahman*, B. J. Chun**, K. S. Lee** and D. I. Lee****

**Abstract** - A combined discharge type ozonizer was designed and manufactured. The increase or decrease of temperature greatly influences the characteristics of ozone concentration ($O_{3con}$), ozone generation ($O_{3g}$) and ozone yield ($O_{3Y}$) of a discharge type ozonizer. The characteristics of ozone concentration, ozone generation and ozone yield rate were investigated by varying the gas flow rate (Q), the discharge power ($W_d$) and the temperature (T). At T=25[°C] the values of $O_{3con}$ were found as 5632, 4200, 2500 and 1800[ppm] at Q = 1, 2, 4 and 6[l/min] respectively. At the same temperature the corresponding values of $O_{3g}$ were found as 662, 988, 1176 and 1270[mg/h] and those of $O_{3Y}$ were found as 67, 102, 119 and 135[g/kWh] respectively. When the temperature is decreased to –50[°C], the values of $O_{3con}$ were found as 9000, 6700, 4000 and 2800[ppm] respectively at Q = 1, 2, 4 and 6[l/min]. At the same value of temperature the corresponding values of $O_{3g}$ were found as 1220, 1576, 1882 and 2050[mg/h] and those of $O_{3Y}$ were found as 120, 159, 188 and 202[g/kWh] respectively. Hence as the temperature was decreased from 25 to –50[°C], the efficiencies of ozone generation were increased by 79, 55, 58 and 49[%] respectively at Q = 1, 2, 4 and 6[l/min].

**Keywords:** discharge, ozonizer, ozone and temperature

## 1. Introduction

Ozone is a powerful oxidizing agent next to Fluorine and is resolved into the harmless substance of oxygen. So, ozone is widely used not only in sterilization and deodorization of drinking and industrial waste water, but also in various fields of industrial application [1-8]. Since the production of ozone requires only air and electricity, there is no transportation of dangerous chemical elements. These are the most common causes for which ozone is increasingly used day by day. Although many researchers of ozonizer reported so far, tried to improve the efficiency of ozone generation, they emerged with little success. In the discharge process a major portion of the energy is dissipated into heat and light energy. So, a very little portion is utilized in the production of ozone. Theoretical efficiency is about 1200[g/kWh] [9]. But ozonizers with efficiencies of 200-250[g/kWh] using oxygen and 60-80[g/kWh] using air were reported in the literature.

So the researchers are trying to develop different types of ozonizers [10-15]. The efficiency of a hybrid type ozonizer is higher in comparison to that of a conventional type ozonizer [16-17]. Considering all the above mentioned points, in this paper, we tried to develop an ozonizer using the combined operation of surface and silent discharge.

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## 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 high voltage is applied, the electrons gain energy of more than 6-7[eV]. An interaction between the electrons and oxygen molecules can take place to dissociate oxygen molecules into oxygen atoms. The rate of dissociation of oxygen molecules depend on the energy distribution in the discharge channel. Since both silent and surface discharges are caused by narrow pulse type discharges, and because electrons are generated from the different points on the surface of electrodes, both discharges are useful for producing ozone by means of collisions of electrons and oxygen molecules in the supplied gas. In case of using atmospheric air as supplied gas existing Nitrogen affects the production of oxygen which plays an important role in ozone production.

$$O_2 + High\ energy\ electron \rightarrow 2O + Low\ energy\ electron \quad (1)$$

$$N_2 + e \rightarrow N_2^* \quad (2)$$

$$N_2^* + O_2 \rightarrow N_2 + 2O \quad (3)$$

$$O_2 + e \rightarrow 2O + e \quad (4)$$

$$O + O_2 + M \rightarrow O_3 + M \quad (5)$$

Here,
$N_2^*$ represents Nitrogen molecule in the excited state.
$N_2$ represents Nitrogen molecule in the normal state.
$O_2$ represents Oxygen molecule in the normal state.
O represents Oxygen atom in the normal state.
e represents electrons.
M represents third collision partner and may be O, $O_2$ or $N_2$

The decomposition of ozone is mostly represented by (6) - (13) as follows.

$$O_3 + N \rightarrow O_2 + NO \quad (6)$$

$$O_3 + NO \rightarrow O_2 + NO_2 \quad (7)$$

$$NO_2 + O_3 \rightarrow O_2 + NO_3 \quad (8)$$

$$M + O_3 + O \rightarrow O_2 + M \quad (9)$$

$$H_2O + O_3 \rightarrow O_2 + H_2O_2 \quad (10)$$

$$H_2O_2 \rightarrow HO_2 + H \quad (11)$$

$$HO_2 + O_3 \rightarrow 2O_2 + OH \quad (12)$$

$$OH + O_3 \rightarrow O_2 + H\,O_2 \quad (13)$$

Equations (10)-(13) show the reactions of ozone decomposition by moisture. The ozone concentration, ozone generation and ozone yield rate of the ozonizer can be improved by controlling the temperature and moisture content of the supplied gas. The proposed ozonizer has a configuration of improving ozone yield rate by controlling both the temperature and moisture content of the supplied gas.

## 3. Construction of Ozonizer

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 electrodes, electric stress developed on the surface cause surface discharge of the inner tube. Also by applying high voltage between CE and EE electrodes silent discharge is occurred between the gap of the two glass tubes. Also by applying high voltage between CE and EE electrodes silent discharge is occurred between the gap of the two glass tubes. 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 glass 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 external tube is made of pyrex glass of 1.5[mm] thickness. The outer diameter is 19[mm] and the length is 235[mm]. Stainless Steel (S.S.) bars of 1[mm] × 1[mm] cross-section are placed in parallel on the surface of the internal tube as shown in Fig. 1. A connection is brought out for using as IE terminal. The EE is a wire of 1[mm] diameter, which is made of an alloy of $SiO_2$ and Cu. The schematic diagram is shown in Fig. 2. The cross-sectional view is shown in Fig. 3.

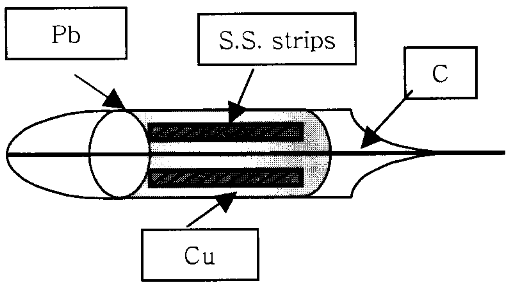


**Fig. 1** Schematic diagram of the Internal tube of CDO.

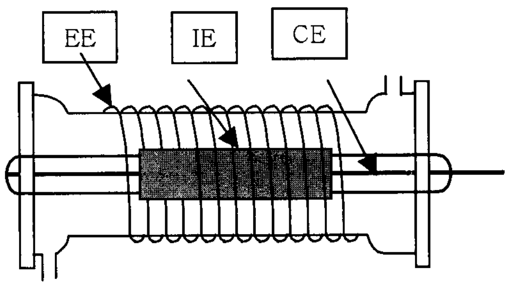


**Fig. 2** Schematic diagram of the Outer tube of CDO.

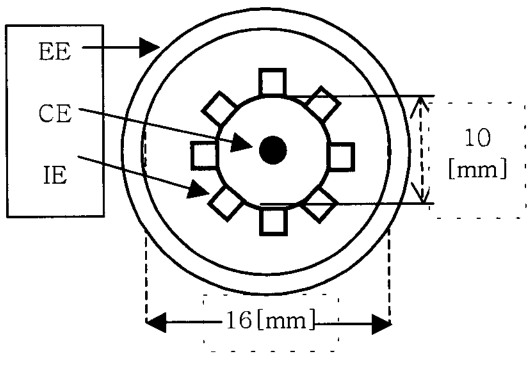


**Fig. 3** Cross section of the ozonizer.

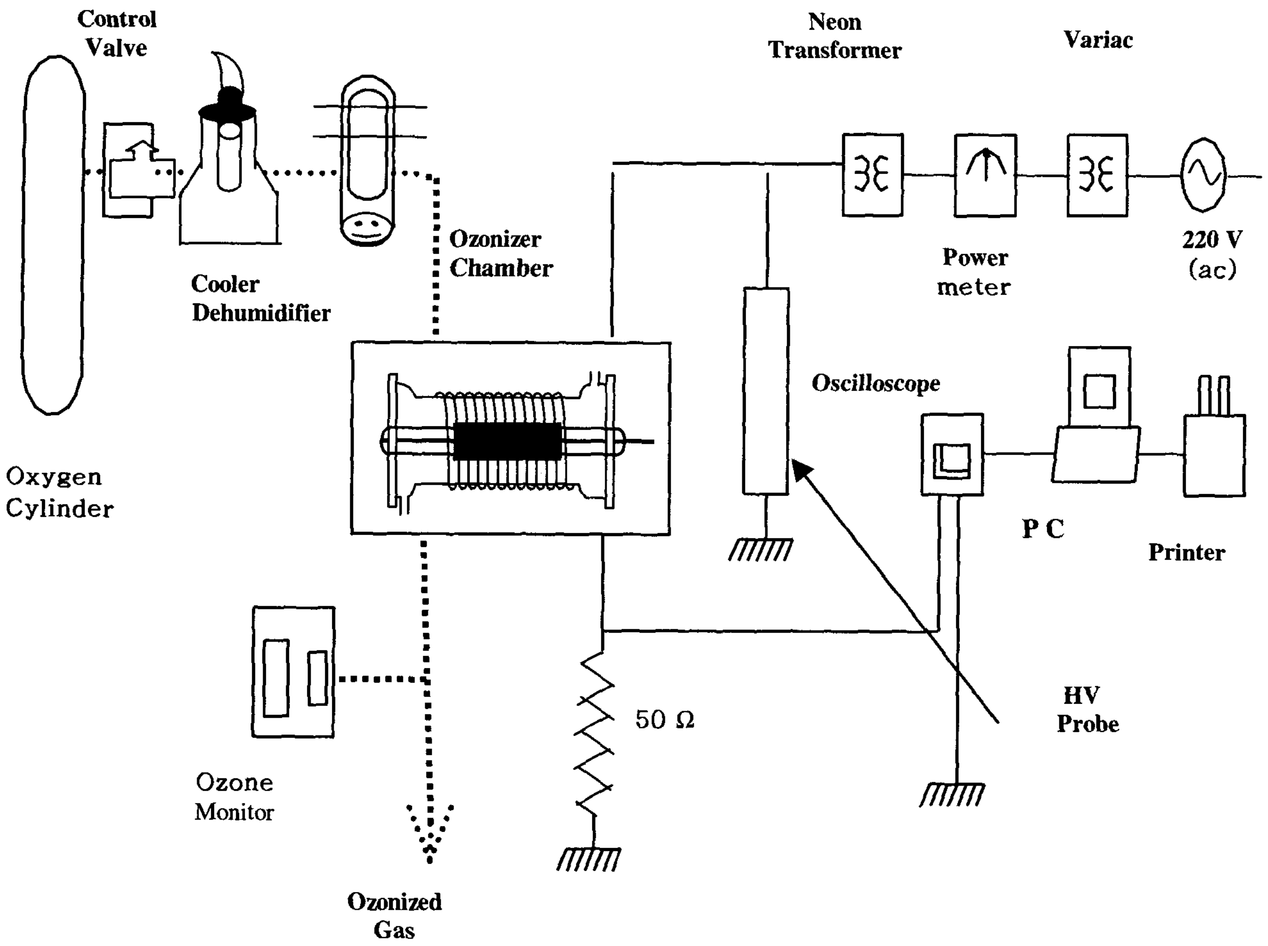


**Fig. 4** Block diagram representation of the overall system.

## 4. Experimental Setup and Methods

### 4.1 Experimental Set Up

Fig. 4 shows the block diagram representation of the overall measurement process. The discharge voltage $V_d$ and 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 the ozonized gas was measured by ozone monitor (0-110,000[ppm]). The system is equipped with the combined discharge type ozonizer, cooler and dehumidifier. The gas flow line is shown with dotted line and this shows the $O_2$ supply system and the flow of ozonized gas passing through the measuring apparatus. The cooling system was implemented by using liquid Nitrogen gas cylinder. One end of the cooling trap was connected to the Nitrogen gas cylinder and the other end was connected to the ozonizer. The circuit of power supply source and measuring apparatus are shown with solid line in the schematic diagram.

### 4.2 Experimental Methods

Experiments were carried out by applying high voltage between EE and IE with CE connected to ground. The amount of discharge power was varied by varying the supply voltage from 0 to 16[kV]. By varying the flow rate of the supplied gas (Q : 1, 2, 4, and 6[l/min]) and the temperature of the supplied gas (T), the discharge voltage ($V_d$), discharge current ($I_d$) and discharge power ($W_d$) were measured to investigate the characteristics of the proposed combined discharge type ozonizer (CDO). The different parameters like ozone concentration ($O_{3con}$), the ozone generation ($O_{3g}$) and and ozone yield ($O_{3Y}$) were measured and calculated for variable values of Q, T and $W_d$.

## 5. Experimental Result and Discussion

Fig. 5 shows the ozone concentration ($O_{3con}$) characteristics against the variation of temperature (T). The discharge voltage ($V_d$) was kept at 16[kV] and the temperature of the supplied gas was increased slowly from –50 to 20[°C]. It is seen from the figure that when the temperature increases from –50 to 20[°C], the ozone concentration ($O_{3con}$) decreases from 9000 to 5632[ppm] at Q = 1[l/min], from 6700 to 4200[ppm] at Q = 2[l/min], from 4000 to 2500[ppm] at Q=4[l/min] and from 2800 to 1800[ppm] at Q=6[l/min]. This is due to the result of decreasing the moisture content of supplied gas in accordance with the decreasing temperature. So, the dissociation reaction of ozone was greatly decreased and the reactions of the equations (6) through (13) happen to occur less. So ozone concentration decreases with temperature and vice versa.

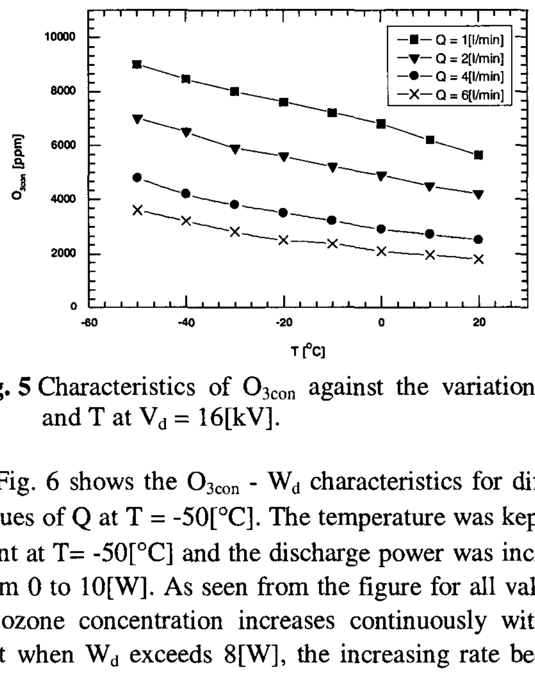


**Fig. 5** Characteristics of $O_{3con}$ against the variation of Q and T at $V_d$ = 16[kV].

Fig. 6 shows the $O_{3con}$ - $W_d$ characteristics for different values of Q at T = -50[°C]. The temperature was kept constant at T= -50[°C] and the discharge power was increased from 0 to 10[W]. As seen from the figure for all values of Q ozone concentration increases continuously with $W_d$. But when $W_d$ exceeds 8[W], the increasing rate becomes low. This means upto a value of 8[W] of $W_d$, the discharge is activated within the discharge chamber and depending on the increase of the electrons produced in the discharge chamber, the number of collisions between the electrons and the oxygen atoms becomes very high. This leads the equations (1) – (5) to happen more vigorously. Hence the rate of ozone generation becomes very high. When the discharge power exceeds 8[W], the discharge becomes stronger and hence $O_{3con}$ becomes high. Due to this high value of $O_{3con}$ decomposition of ozone takes place at a higher rate resulting in the occurrence of (6) – (13) more and more. The oxygen atoms, molecules, electrons and excited atoms participate in decomposing ozone.

According to the curves of figures 5 and 6 it is seen that $O_{3con}$ increases as Q decreases and vice versa. When Q decreases, the duration of the oxygen molecules in the discharge chamber will increase. This gives high value of $O_{3con}$. The maximum values of $O_{3con}$ were found as 9000 [ppm] at Q = 1[l/min], 6700[ppm] at Q = 2[l/min], 4000[ppm] at Q = 4[l/min] and 2800[ppm] at Q = 6[l/min] respectively.

Fig. 7 shows the characteristics of $O_{3g}$ against the variation of Q and T. Here $O_{3g}$ decreases for all values of Q as T increases and vice versa. As T increases

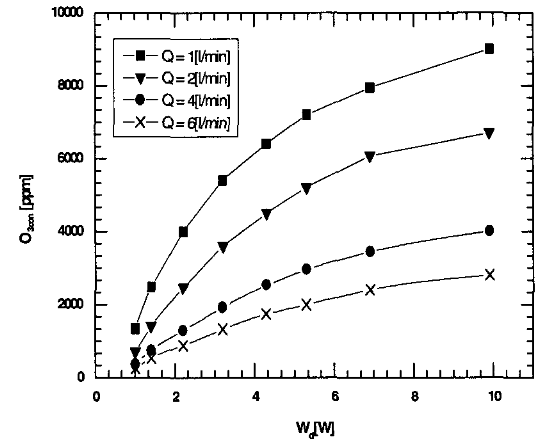


**Fig. 6** Characteristics of $O_{3con}$ against the variation of Q and $W_d$ at T = -50[°C].

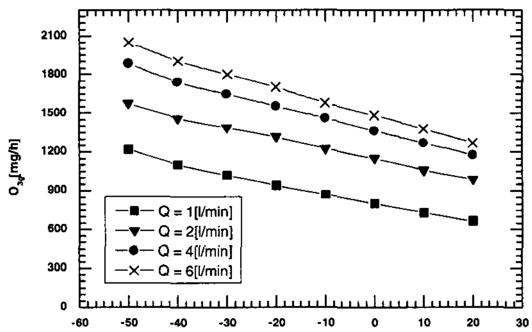


**Fig. 7** Characteristics of $O_{3g}$ against the variation of Q and T at $V_d$ = 16[kV].

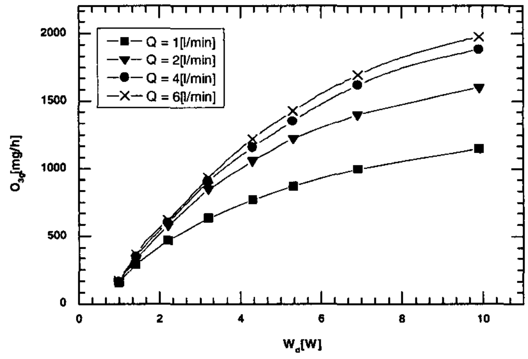


**Fig. 8** Characteristics of $O_{3g}$ against the variation of Q and $W_d$ at T = -50[°C].

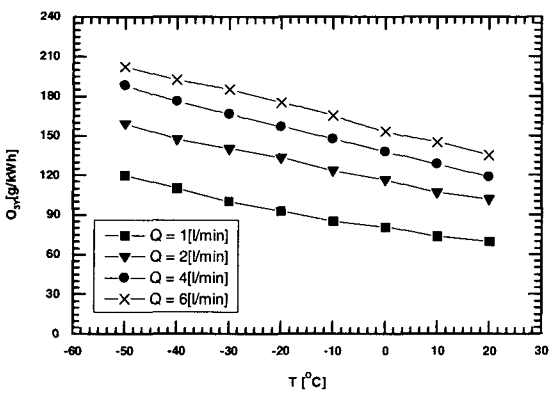


**Fig. 9** Characteristics of $O_{3Y}$ against the variation of Q and Tat $V_d$ = 16[kV].

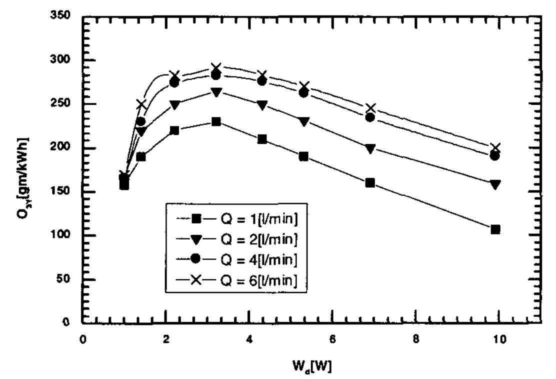


**Fig. 10** Characteristics of $O_{3Y}$ against the variation of Q and $W_d$ at T = -50[°C].

from –50[°C] to 20[°C], $O_{3g}$ decreases from 1220 to 662[mg/h] at Q= 1[l/min], from 1576 to 988[mg/h] at Q= 2[l/min], from 1882 to 1176[mg/h] at Q= 4[l/min] and from 2050 to 1270[mg/h] at Q= 6[l/min] respectively.

Fig. 8 shows the $O_{3g}$ characteristics against the variation of Q and $W_d$. Ozone generation increases with $W_d$ for all values of Q. Hence it is considered that as long as $W_d$ increases the electron density in the discharge chamber increases. So both silent and surface discharges become stronger. The number of collisions among the electrons, oxygen atoms and molecules and excited oxygen atoms become larger, which leads $O_{3g}$ to be proportional to $O_{3con}$. At a constant value of $W_d$ the value of $O_{3g}$ decreases with Q. As Q increases the ozone producing oxygen molecules also increase, but their duration of stay in the discharge chamber become short. This results in small number of collisions among the generated electrons and oxygen molecules. The rate of increase of $O_{3con}$ thus reduces. As a result $O_{3g}$ is determined under such a condition that the reduction of $O_{3con}$ is greater than the increase of the number of oxygen atoms. The maximum values of $O_{3g}$ were found as 1220[mg/h] at Q = 1[l/min], 1576[mg/h] at Q = 2[l/min], 1882[mg/h] at Q = 4[l/min] and 2050[mg/h] at Q = 6[l/min] respectively.

Fig. 9 shows the ozone yield rate characteristics with the variation of both temperature and gas flow rate. The discharge power was kept constant at $W_d$ = 9.9[W]. The temperature was increased slowly from –50 to 20[°C] and the value of $O_{3Y}$ was recorded each time. The cause of improving the ozone yield rate with the temperature reduction is exactly the same which was explained in figure 5. As the temperature increases from –50 to 20[°C], $O_{3Y}$ reduces from 120 to 67[g/kWh] at Q = 1[l/min], from 159 to 102[g/kWh] at Q = 2[l/min], from 188 to 119[g/kWh] at Q = 4[l/min] and from 202 to 135[g/kWh] at Q = 6[l/min] respectively.

Fig. 10 shows $O_{3Y}$ characteristics against the variation of $W_d$ and Q at T = -50[°C]. As seen from the figure for all values of Q ozone yield rate continuously rises until $W_d$ = 3[W]. As $W_d$ exceeds 3[W] the curves go downward. As the discharge power starts increasing the electron density increases. So, the number of collisions among the generated electrons, oxygen atoms and excited oxygen molecules increase giving higher values of $O_{3g}$. After the time when $O_{3Y}$ reaches peak value the temperature rises slightly. Due to this ozone decomposing, reactions happen to increase more yielding (6) – (13). This reduces the value of $O_{3g}$. Since $O_{3Y}$ is determined by $O_{3g}$ and $W_d$, ozone yield rate after reaching peak value decreases continuously 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 chamber is less, which results in a low value of $O_{3con}$. The increase 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 230[g/kWh] at Q = 1[l/min], 264[g/kWh] at Q = 2[l/min], 282[g/kWh] at Q = 4[l/min] and 291[g/kWh] at Q = 6[l/min] respectively.

## 6. Conclusions

The effect of temperature on the performance characteristics of the proposed CDO has been studied in this paper. The ozone concentration was found inversely proportional to the gas flow rate.

As the temperature is reduced from T = 25 to -50[°C] the values of $O_{3con}$ increases from 5632 to 9000[ppm] at Q = 1[l/min], from 4200 to 6700[ppm] at Q = 2[l/min], from 2500 to 4000[ppm] at Q = 4[l/min] and from 1800 to 2800[ppm] at Q = 6[l/min] respectively. With the same temperature decrease $O_{3g}$ increases from 662 to 1220 [mg/h] at Q = 1[l/min], from 988 to 1576[mg/h] at Q = 2[l/min], from 1176 to 1882[mg/h] at Q = 4[l/min] and from 1270 to 2050[mg/h] at Q = 6[l/min] respectively. Under the same condition of temperature change $O_{3Y}$ also increases from 67 to 120[g/kWh] at Q = 1[l/min], from 102 to 159[g/kWh] at Q = 2[l/min], from 119 to 188[g/kWh] at Q = 4[l/min] and from 135 to 202[g/kWh] at Q = 6[l/min] respectively.

The maximum values of ozone yield rate were found at T = 20[°C] as 67[g/kWh] at Q = 1[l/min], 102[g/kWh] at Q = 2[l/min], 119[g/kWh] at Q = 4[l/min] and 135[g/kWh] at Q = 6[l/min]. When T was reduced to -50[°C], correspond values of ozone yield rate were recorded as 120, 159, 188 and 202[g/kWh] respectively. Hence the values of efficiency were improved by 79[%], 55[%], 58[%] and 49[%] at Q = 1, 2, 4 and 6[l/min] respectively. The maximum values of ozone concentration and ozone generation were recorded as 9000[ppm] and 2050[mg/h] respectively. Because of the simplicity in design the manufacturing cost is less. The proposed ozonizer can be applied to the improvement of environmental pollution such as the treatment of industrial exhaust water.

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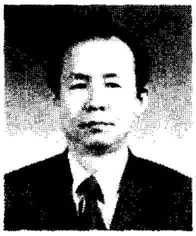

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