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Full Length Research Paper

Evaluation of a pilot scale high pressure plasma ozonizer for use in wastewater treatment

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The plasma technique which is used for wastewater treatment is one of the most effective processes for ozone production. In this study, a laboratory scale plasma technique ozonizer designed for treating wastewater was tested under various operation conditions which included voltage (E), current frequency (f), electrical current (I), gas pressure in the system (P), distance of electric dipoles (d), type of electric pole and energy consumption. The optimum configuration for the highest ozone production efficiency was observed using a needle shape electrode when voltage (E) was set at 18,000 volts, f at 1,000 Hz, I at 35 mA, P at 1.3×10^5 N/rn^2 and d at 0.003 m. Using the configuration, the ozonizer efficiency was tested in treatment of domestic and shrimp farm wastewater. Results showed that the ozonizer can significantly improve the quality of wastewater within 60 min of treatment.

Key words: Ozone, ozonizer, oxidizer, plasma, high pressure, plasma system.

INTRODUCTION

Due to strong oxidizing properties, ozone is used for many purposes in the industrial sector including treatment of municipal water supplies and processing of industrial and food wastewater (Yanallah et al., 2006). Several processes such as pulse radio synthesis (Eliassaon and Kogelschatz, 1987), mercury-sensitized photosis (Filippov and Vendillo, 1962), radioactive Co-radiolysis (Bell and Kwong, 1972), flash photolysis (Eliassaon and Kogelschatz, 1987), electrolysis of perchloric acid (Yagi, 1976) and dielectric barriers discharges (Kogelchatz, 1983) had been used for the production of ozone. Ozone can be produced by both physical and chemical processes. The physical processes generate a large amount of ozone which can be directly used for many purposes (Kogelchatz, 1983; Yagi, 1976).

Ozone consisting of three atoms of oxygen is an unstable gas with a strong oxidizing potential. Ozone is formed from the combination of oxygen free radical and oxygen molecule under an excited state. However, as a consequence of electric current breakdown, heat is generated as the current flows through a low energy bond which is easily dissipated (Betrein, 1973; Filippov and Vendillo, 1962). Ozone generation comprises 2 steps namely; dissociation reaction and ozone formation. The factors affecting ozone formation are described below.

Electric field

Electric field can be divided into uniform and non-uniform based on the shape of the electrode. The electric field stress can also influence ozone production. The stress of the electric field decreases with increase in electrode distance. Thus, the ozone production yield of the ozonizer within a uniform electric field rapidly decreases with increase in electrode distance (Betrien, 1973).

Electrode shape

The shape of the electrode affects the types and stress of

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the electric field which can result in a voltage breakdown. For example, in a case of a slightly non-uniform field, the breakdown voltage does not increase with increase in the stress of the electric field (Betrein, 1973; Blair and Whittington, 1975).

Gas density

Under uniform electric field condition, the breakdown voltage increases with increase in gas density. But under non-uniform electric fields, the voltage breakdown is unstable (Crarnaross et al., 1978).

Humidity of the air

H_2O molecules in the air contain a slight negative charge. In highly non-uniform electric field, H_2O or humidity in the air can strongly influence voltage breakdown, especially under direct electric current (Yagi, 1971).

Most ozonizers are designed using a cylindrical tube configuration with the coordinate central point of electric poles inside and outside the tube. The dielectric pole is made of glass containing a high dielectric value. Between cathode and anode, dielectric is located on either side of the poles. Moist or dry gas or oxygen flows through the gap between these electrodes and results in electricity discharge at the poles. During operation, the outside of the ozonizer is lubricated by a cool liquid in order to reduce temperature (Yagi, 1976). However, most ozonizers use a large amount of energy at high pressure under alternating current at frequency of 50 Hz.

In this study, a laboratory scale ozonizer (high pressure plasma system) was designed and constructed to evaluate ozone production under various conditions. The operation parameters namely; energy consumption, current frequency, gas pressure, distances of electric dipolar and types of electric pole were tested in order to identify the conditions for optimal ozone production. The experimental data was used for the development of a physical equation for maximum output of the ozonizer.

MATERIALS AND METHODS

The laboratory ozonizer was constructed and the ozone production yield tested under alternating electrical current (AC) for various operational conditions as shown in Figure 1. The ozonizer reactor was cylindrical in shape. The case was constructed of stainless steel pipe (25.0 cm in diameter). The ozonizer components included an energy generation source, moving coil, frequency kit, heat resistant glass tube, heat resistance PVC tube, electrode pole (Figure 2), air pump, humidity and nitrogen removing component (Eliasson and Kogelschatz, 1987), oxygen and ozone gas tubes and pressure meter, etc.

Ozone production yield and energy consumption of the ozonizer was measured under various voltages (E), frequency (f), electrical current: direct current (I), gas pressure in the system (P), distance of electric dipolar (d) and type of electrodes. Ozone production yield of the designed ozonizer under various operation conditions were quantified with potassium iodide using standard method of the chemical reactions (Moris, 1977).

In these experiments, the optimum ozone production was determined by varying five factors (E, f, I, P, and d):

a) Experimental set up: varying the coil volt (E) from 3,000 to 18,000 volt with fixed frequency (f) at 50 Hz, electrical current (I) at 10 mA, pressure (P) at 1.0×10^{5} N/m^2, and discharge gap (d) at 0.006 cm. The tests were also performed with different electrode shapes. Ozone production with changing coil volt (E) for different electrode shapes was recorded and data plotted.
b) Experimental set up: varying current frequency (f) from 50 to 1,000 Hz with a fixed moving coil voltage (E) which generated the maximum ozone production from the test at (a), electrical current (I) at 10 mA, pressure (P) at 1.0×10^{5} N/m^2, discharge gap (d) at 0.006 cm. The tests were also performed using different electrode shapes. Data of ozone production and current frequency (f) with different electrode shapes was recorded and graphed.
c) Experimental set up: varying electrical current (I) from 10 mA to 35 mA with fixed moving coil voltage (E) at maximum ozone production from test (a) and optimum current frequency (f) from the test (b), pressure (P) at 1.0×10^{5} N/m^2 and discharge gap (d) at 0.006 cm. The tests were also performed using different electrode shapes. Result of ozone production and electrical current (I) with different electrode shapes was recorded.
d) Experimental set up: varying gas pressure (P) from 1.0×10^{5} to 1.5×10^{5} N/m^2 with fixed moving coil voltage (E) at the maximum ozone production from test (a), optimum current frequency (f) from test b), optimum electrical current (I) from the test in c, and discharge gap (d) at 0.006 cm. The tests were also performed using different electrode shapes. Result of ozone production and pressure (P) with different electrode shapes was recorded and graphed.
e) Experimental set up: varying discharge gap (d) from 0.001 to 0.006 m with fixed moving coil volt (E) at the maximum ozone production from the test a, optimum current frequency (f) from the test b), optimum electrical current (I) from the test in c, and optimum pressure (P) from the test in d. The tests were also performed with different electrode shapes. Result of ozone production and discharge gap (d) with different electrode shapes was recorded and graphed.

Quantity of ozone produced was measured using Iodometric method (Moris, 1977). The ozone was trapped by potassium iodide solution (KI) and the amount of ozone determined by titration of solution with sodium thiosulfate ($Na_2S_2O_3$). The amount of ozone produced was calculated using the following equation:

$$O_3 / L = \frac{(A - B) \times M \times 26400}{mL} \quad \text{(mg)}$$

Where A = mL of sodium thiosulfate used for sample, B = mL of sodium thiosulfate used for blank, M = concentration of sodium thiosulfate (mole), mL = volume of sample (mL), and L = litter.

RESULTS AND DISCUSSION

Effect of voltage on the ozone production yield

For the determination of the effect of voltage, the system was operated under fixed current frequency of 50 Hz, electric current of 10 mA, discharge gap of 0.006 m, gas pressure of 1.0×10^5 N/m^2 and voltages of 3,000, 6,000, 8,000, 10,000, 12,000 and 18,000 volts. The ozone production yield increased with increase in voltage for all

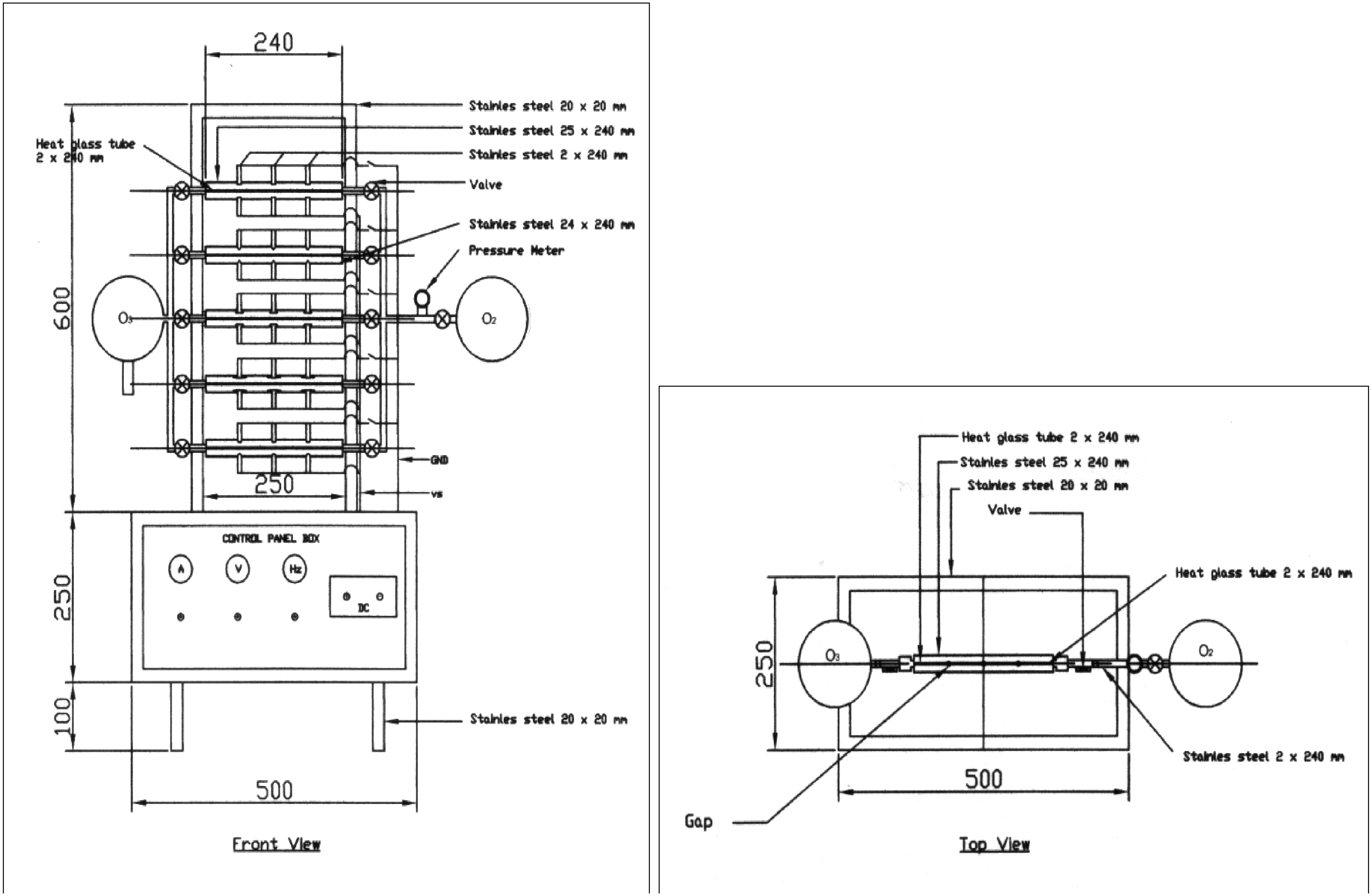


Figure 1. Schematic diagram of a pilot scale ozonizer.

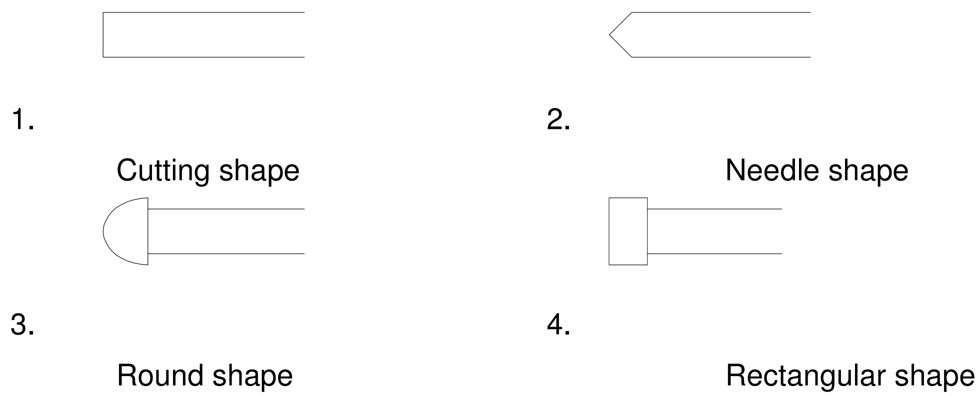


Figure 2. Type of electrodes use in ozonizer; 1) cutting shape, 2) needle shape, 3) round shape, and 4) rectangular shape.

Table 1. Effect of voltage on ozone production in the pilot scale ozonizer for various types of electrodes.

Electrode		Operation parameter		
Type	**Surface area (cm^2)**	**Voltage (Volts)**	**Energy consumption (kWh)**	**Ozone production (mg/h)**
Cutting shape	7.60	3,000	0.030	2.500±0.020
		6,000	0.060	8.933±0.040
		8,000	0.080	18.930±0.025
		10,000	0.100	58.237±0.015
		12,000	0.120	79.800±0.020
		18,000	0.180	112.533±0.032
Needle shape	8.72	3,000	0.030	3.113±0.015
		6,000	0.060	9.403±0.015
		8,000	0.080	22.446±0.025
		10,000	0.100	68.510±0.026
		12,000	0.120	90.183±0.025
		18,000	0.180	150.377±0.036
Round shape	7.12	3,000	0.030	2.580±0.020
		6,000	0.060	7.900±0.030
		8,000	0.080	17.403±0.022
		10,000	0.100	49.350±0.020
		12,000	0.120	68.506±0.031
		18,000	0.180	98.300±0.020
Rectangular shape	6.88	3,000	0.030	2.093±0.025
		6,000	0.060	8.157±0.021
		8,000	0.080	18.243±0.047
		10,000	0.100	52.136±0.047
		12,000	0.120	78.713±0.025
		18,000	0.180	109.170±0.037

Frequency (Hz) = 50; Current (mA)= 10; Gas pressure (N/m^2) = 1.0×10^5; Electrode distance (m) = 0.006

types of electrodes tested (Table 1). Moreover, the needle shape electrode showed the highest ozone production with yield of 150.377±:0.036 mg/h at the voltage of 18,000. However, the energy consumption also increased with the increase in voltage of the system. The energy consumption was about 0.180 kWh for 18,000 volts. This likely was a result of the increase in voltage of the system. When the voltage was increased, the kinetic energy of

Table 2. Effect of current frequency on ozone production in the pilot scale ozonizer for various types of electrodes.

Electrode		Operation parameter	
Type	**Surface area (cm^2)**	**Frequency (Hz)**	**Ozone production (mg/h)**
Cutting shape	7.60	50	112.560±0.031
		80	115.340±0.071
		140	128.450±0.020
		260	138.580±0.044
		520	149.570±2.350
		1000	167.430±0.071
Needle shape	8.72	50	150.490±0.021
		80	150.820±0.021
		140	161.150±0.153
		260	178.300±0.047
		520	189.580±0.047
		1000	201.600±0.046
Round shape	7.12	50	98.293±0.032
		80	110.440±0.173
		140	115.300±0.051
		260	120.470±0.040
		520	124.787±0.012
		1000	138.367±0.015
Rectangular shape	6.88	50	109.210±0.035
		80	115.290±0.206
		140	212.400±0.026
		260	127.410±0.026
		520	132.510±0.051
		1000	142.530±0.021

Voltage (Volts) = 18,000; Current (mA) = 10; Gas pressure (N/m^2) = 1.0×10^5; Electrode distance (m) = 0.006; Energy consumption (kWh) = 0.180

oxygen molecule also increased which resulted in an increase in ozone production yield (Bell and Kwong, 1972; Blair and Whitington, 1973).

Effect of current frequency on the ozone production yield

For the determination of the effect of current frequency, the system was operated under a constant voltage of 18,000 volts, electric current of 10 mA, discharge gap of 0.006 m, gas pressure of 10×10^5 N/m^2 and current frequencies of 50, 80, 140, 260, 520 and 1,000 Hz. The ozone production yield of the system increased with increase in current frequency for each type of electrode (Table 2). The maximum ozone production of the system with needle type electrode was reached at 201.60 ± 0.046 mg/h under the highest electric current frequency (1,000 Hz). This suggest that when current frequency increased, the number of electron particles also increased due to an increase in the collision rate of electron particles, oxygen molecules and ionization rate of the oxygen molecules (Bell and Kwong, 1972; Filippov and Vendillo, 1962).

Effect of electrical current on the ozone production yield

To determine the effect of current, the system was operated at a fixed voltage of 18,000 volts, current frequency of 1,000 Hz, discharge gap of 0.006 m and gas pressure of 1.3×10^5 N/m^2 at various electric current (10, 15, 20, 25, 30, 35 mA). The ozone production yield of the system increased with the increase in electrical current for all electrodes (Table 3). The energy consumption of the system also increased with increase in electrical current. The energy consumption of the system at 35 mA was the highest (0.630 kWh) when operated at the highest electrical current (1000 Hz) rate. The ozone production of the system with needle shape electrode at 35 mA was 252.210 ± 1.117 mg/h with an energy consumption of 0.630kWh. This demonstrated that when electrical current was increased, the number of electron particle also

Table 3. Effect of electrical current on ozone production of the pilot scale ozonizer for various types of electrodes.

Electrode		Operation parameter		
Type	Surface area (cm^2)	Current (mA)	Energy consumption (kWh)	Ozone production (mg/h)
Cutting shape	7.60	10	0.180	167.410±0.025
		15	0.270	171.310±0.050
		20	0.360	184.530±0.031
		25	0.450	192.550±0.041
		30	0.540	201.300±0.045
		35	0.630	218.400±0.023
Needle shape	8.72	10	0.180	201.480±0.020
		15	0.270	210.600±0.038
		20	0.360	221.390±0.252
		25	0.450	230.400±0.032
		30	0.540	240.470±1.117
		35	0.630	252.210±1.117
Round shape	7.12	10	0.180	138.420±0.025
		15	0.270	145.220±0.025
		20	0.360	153.500±0.025
		25	0.450	162.190±0.020
		30	0.540	178.520±0.030
		35	0.630	138.420±0.025
Rectangular shape	6.88	10	0.180	142.550±0.026
		15	0.270	150.340±0.026
		20	0.360	158.380±0.452
		25	0.450	165.350±0.045
		30	0.540	183.410±0.029
		35	0.630	186.720±0.025

Voltage (Volts) = 18,000; Frequency (Hz) = 1,000; Gas pressure (N/m^2) = 1.0×10^5; Electrode distance (m) = 0.006

increased due to an increase in the collision rate of electron particles and oxygen molecules (Bell and Kwong, 1972; Honda and Naito, 1955).

Effect of gas pressure of the system on the ozone production yield

For the determination of the effect of gas pressure, the system was operated under constant voltage of 18,000 V, current frequency of 1,000 Hz, discharge gap of 0.006 m and electrical current of 35 mA and at various gas pressures that ranged from 1.0×10^5-1.5×10^5 N/m^2. Ozone production yield increased with increase in gas pressure for all types of electrodes (Table 4). The highest ozone production yield of 272.340 ± 0.31 mg/h was detected with a needle shape electrode at a power consumption of 0.630 kWh and at an air pressure level of 1.3×10^5 N/m^2. When the gas pressure increased above $l.3 \times l0^5$ N/m^2, the ozone production yield decreased. This can be explained by the fact that when the system was maintained under a constant electric field, breakdown voltage was dependent on gas density. When the electric field was non-uniform, the breakdown voltage fluctuated and increased proportionally with increase in gas pressure (Bell and Kwong, 1972; Narowed, 1975; Kogelchatz, 1983).

Effects of discharge gap on the ozone production yield

To determine the effect of discharge gap, the system was operated at a fixed voltage of 18,000 V, current frequency of 1,000 Hz, electrical current of 35 mA and gas pressure of 1.3×10^5 N/m^2 with the discharge gap from 0.001-0.006m. The ozone production yield increased with decrease in discharge gap but not less than 0.003 m (Table 5). The maximum ozone production (295.280 ± 0.059 mg/h) was observed for the system with a needle shape at a discharge gap of 0.003 m. However, at a discharge gap of less than 0.003 m, the ozone production yield decreased with decrease in discharge gap. This

Table 4. Effect of gas pressure on ozone production of the pilot scale ozonizer for various types of electrodes.

Electrode		Operation parameter	
Type	**Surface area (cm^2)**	**Gas pressure (N/m^2)**	**Ozone production (mg/h)**
Cutting shape	7.60	1.0×10^5	218.390±0.049
		1.1×10^5	230.420±0.029
		1.2×10^5	240.500±1.129
		1.3×10^5	251.490±0.030
		1.4×10^5	250.470±0.040
		1.5×10^5	249.330±0.027
Needle shape	8.72	1.0×10^5	252.210±0.017
		1.1×10^5	260.280±0.012
		1.2×10^5	271.290±0.020
		1.3×10^5	272.340±0.031
		1.4×10^5	270.370±0.015
		1.5×10^5	269.370±0.255
Round shape	7.12	1.0×10^5	182.630±11.585
		1.1×10^5	190.230±0.052
		1.2×10^5	196.120±0.004
		1.3×10^5	196.200±0.046
		1.4×10^5	195.180±0.027
		1.5×10^5	193.220±0.032
Rectangular shape	6.88	1.0×10^5	184.760±0.040
		1.1×10^5	190.113±0.015
		1.2×10^5	193.210±0.026
		1.3×10^5	196.280±0.031
		1.4×10^5	195.250±0.046
		1.5×10^5	194.770±0.042

Voltage (Volts) = 18,000; Frequency (Hz) = 1,000; Current (mA) = 35; Electrode distance (m)=0.006; Energy consumption (kWh) =0.630

could be explained by the fact that when the discharge gap was increased, the number of electron particles that reached the other end of electrode decreased resulting in a decrease in the ozone production. However, when the discharge gap was less than 0.003 m, the collision rate of electron particles and oxygen molecules likely decreased due to the number of the oxygen molecules between the electrodes (Kogelchatz, 1983). The voltage energy frequency alternating current was 50-60 Hz. The electric breakdown was equal to a current breakdown in the air gap when the distance was less than 150cm, but decreased when the air gap increased. This means that electric breakdown between electrodes in the air of d distance occurred at standard IEC (760 torr, 20℃ and 11 gH_2O/m^3) (Yagi, 1976; Sugimitsu and Okazaki, 1982).

Equation model derivation

Based on the above results, it can be concluded that the production of ozone increased with increase in voltage, current frequency, electric current, gas pressure and decreased discharge gap. The phenomenal of the increase in ozone production can be explained by the first order equation as follows.

Current Frequency

Electromotive force increases with increase in current frequency. When the electromotive force of the system was increased, the electric potential between electrodes also increased. As a result, the collision rate of the electron particles and oxygen molecules also increased which resulted in an increase in ozone production yield (Bell and Kwong, 1972; Blair and Whittington, 1975).

Air pressure

Density of the gas or oxygen in the chamber of the system increased with increase in pressure. When the density of gas in the chamber increased, the collision rate of the electron particles and oxygen molecules increased

Table 5. Effect of discharge gap (electrode distance) on ozone production of the pilot scale ozonizer for various types of electrodes.

Electrode		Operation parameter	
Type	**Surface area (cm^2)**	**Electrode distance (m)**	**Ozone production (mg/h)**
Cutting shape	7.60	0.006	235.990±0.025
		0.005	259.590±0.025
		0.004	281.310±0.044
		0.003	291.330±0.025
		0.002	280.230±0.025
		0.001	260.330±0.044
Needle shape	8.72	0.006	269.350±0.040
		0.005	278.490±0.040
		0.004	287.490±0.020
		0.003	295.280±0.059
		0.002	275.270±0.023
		0.001	248.640±0.036
Round shape	7.12	0.006	193.220±0.031
		0.005	202.400±0.017
		0.004	215.350±0.020
		0.003	240.500±0.044
		0.002	218.390±0.030
		0.001	217.520±0.032
Rectangular shape	6.88	0.006	194.750±0.021
		0.005	201.880±0.028
		0.004	217.400±0.047
		0.003	238.480±0.047
		0.002	230.140±0.047
		0.001	229.520±0.036

Voltage (Volts) = 18,000; Frequency (Hz) = 1,000; Current (mA) = 35; Gas pressure (N/m^2) = 1.3×10^5; Energy consumption (kW.h) = 0.630

resulting in an increase in ozone production (Narowed, 1975; Kogelchatz, 1983).

Discharge gap

When the discharge gap increased, the amount of electron particle that reached the other end of the electrode decreased. This resulted in a decrease in collision rate of electron particles and oxygen molecules. This in turn decreased ozone production yield (Crarnaross et al, 1978).

Electrical current

Number of electron particles increased with increase in electric current which also resulted in an increase in the collision rate of electron and oxygen particles. This resulted in an increased ozone production yield (Narowed, 1975).

For the formulation of an equation and determination of the equation coefficient, experiments were carried out in a designed ozonizer with needle type electrode which yielded the highest ozone production. The relationship between ozone production yield and voltage, current frequency, electrical current, gas pressure and discharge gap were determined as shown in Figure 3. The square of correlation coefficient (R^2) of the relationship between ozone production and voltage, current frequency, electrical current, gas pressure and discharge gap were 0.925, 0.8686, 0.9986, 0.9251 and 0.9468, respectively. Results suggested a linear correlation (Kutner et al, 2005). The equation was formulated as follows:

$O_3 \infty V \quad \therefore O_3 = k_1 V$ (1)

$O_3 \infty f \quad \therefore O_3 = k_2 f$ (2)

$O_3 \infty I \quad \therefore O_3 = k_3 I$ (3)

$O_3 \infty P \quad \therefore O_3 = k_4 P$ (4)

$O_3 \infty d \quad \therefore O_3 = k_5 d^{-1}$ (5)

$(1)\times(2)\times(3)\times(4)\times(5) \quad O_3 \infty Vf\, IPd$ (6)

The experiments were conducted using an ozonizer with needle type electrodes under various conditions of voltage, current frequency, electrical current, gas pressure and distance of electric pole, to observe the ozone production yields. The ozone production yield under various conditions of voltage, current frequency, electrical current,

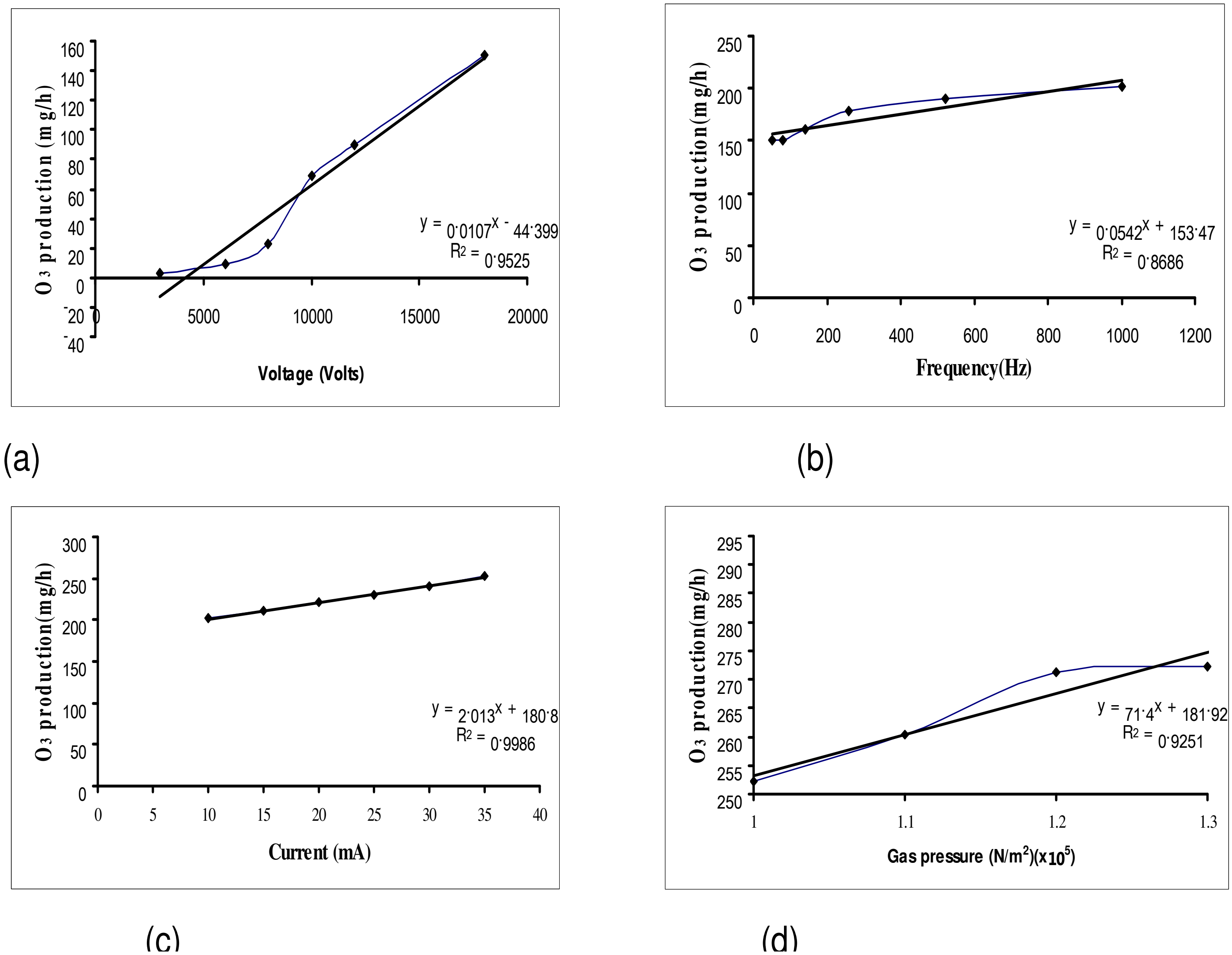


Figure 3. Influence of selected factors on ozone production; a) voltage (volt), b) current frequency (Hz), c) electrical current (mA), d) gas pressure (N m^{-2}), and e) electrode distance (m).

gas pressure and distance of electric pole were plotted. The coefficient constant of each equation was analyzed as followed:

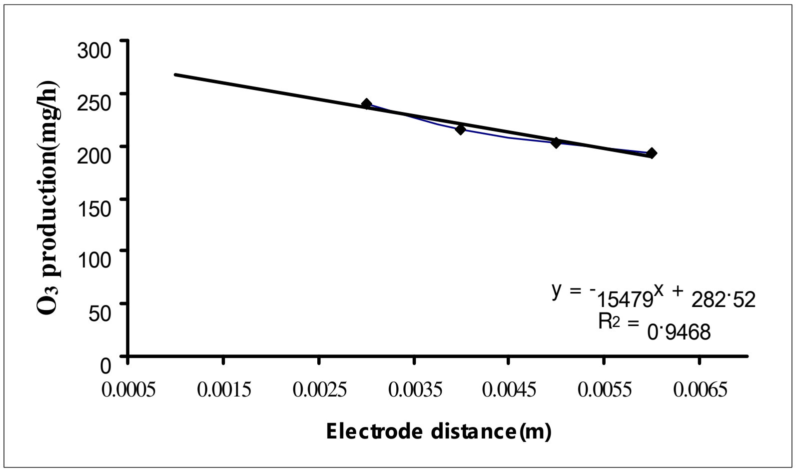
k_1 was determined from slope of the curve of ozone production yield vs voltage as shown in Figure 3a.
$k_1 = 0.0107$ mg/mV
k_2 was determined as the slope from the curve of ozone production yield VS current frequency as shown in Figure 3b.
$k_2 = 0.0542$ mg/Hz
k_1 was determined as the slope from the curve of ozone production yield VS electrical current as shown in Figure 3c.
$k_3 = 2.013$ mg/mA
k_4 was determined as the slope from the curve of ozone production yield VS gas pressure as shown in Figure 3d.
$k_4 = 71.4$ mg/N·m^2
k_5 was determined as the slope from the curve of ozone production yield VS distance of pole (in the range of 0.003-0.006 m) as shown in Fig 3e.

$$k_5 = \frac{1}{15479} \text{ mg/m}$$

But from the equation (6) $K = \sqrt[5]{k_1 k_2 k_3 k_4 k_5}$

Then $$O_3 = K\left(\frac{VIfP}{d}\right)^{1/5}$$

For the Hoartree-Fock Theory (Kutner et al., 2005): The



(e)

Figure 3. Continued.

Table 6. Efficiency of the pilot scale ozonizer on wastewater treatments at the flow rate of 10 L min^{-1}.

Parameter	Domestic wastewater		Shrimp farm water	
	Before treated	60 min treated	Before treated	60 min treated
Dissolve Oxygen (D.O.)	0	7.1±0.5	2.5±0.1	7.6±0.6
Chemical Oxygen Demand (COD)	110±7	74±5	119±7	84±7
Biological Oxygen Demand (BOD)	119±9	72±7	138±7	79±8

coefficient constant (K) could be analysis as followed:

$$K = \sqrt[5]{\frac{0.0107 \times 0.0542 \times 2.013 \times 71.4}{15479}} \ \text{kg/V·Hz·A·N·m}^{-3}$$

Then, $K = 0.0884$ kg/V·Hz·A·N·m^{-3}

Application Efficiency

The ozonizer efficiency was determined based on the above equation configuration associated with the optimum performance factor. The efficiency for increasing dissolved oxygen (DO), removing chemical oxygen demand (COD) and biological oxygen demand (BOD) are showed in Table 6. The results were recorded after 60 min of operation for laboratory scale ozonizer under a controlled flow rate at 10 L/min. DO significantly increased in both the domestic wastewater (0 to 7.1 mg/L) and shrimp farm water (2.5 to 7.6 mg/L). COD of domestic wastewater decreased by 32.7% (110 to 74 mg/L) and decreased by 29.4% (119 to 84 mg/L) in the shrimp farm water. In addition, BOD of domestic wastewater decreased by 39.5% (119 to 72 mg/L) and shrimp farm water decreased by 42.8% (138 to 79 mg/L).

Conclusion

The ozone production of the designed ozonizer increased with increase in voltage, current frequency, electrical current and gas pressure and decrease in discharge gap (when the discharge gap was not less than 0.003 m). However, when the discharge gap was less than 0.003 m, the ozone production yield decreased. The shape of electrode influenced ozone production yield, with needle shaped showing the highest ozone production yield. The highest ozone production yield of 295.280±0.059 mg/h was generated with low energy consumption of 0.630 kWh, voltage of 18,000 volts, f of 1,000 Hz, I of 35 mA, P of 1.3×10^5 N/m^2 and d of 0.003 m with the needle shape type pole.

The ozone production equation was derived as follows:

Ozone production yield $O_3 \alpha (\frac{VIfP}{d})^{1/5}$ or

$$O_3 = K(\frac{VIfP}{d})^{1/5} \qquad \frac{\text{V·A·Hz·N}}{\text{mm}^2}$$

The constant coefficient of equation (K) was 0.0884kg/ V·Hz·A·N·m^{-3}.

At the configuration above, the performance of the laboratory scale ozonizer improved water quality by increasing DO and significantly reducing COD and BOD in the wastewaters tested.

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