Finding parameters relationship for disinfectant gas production

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Abstract. Water purifying is an important process to get fresh water for human needs. Several treatments such as advanced filtering using activated carbon and chlorine have been done to get clean water. However, most of the previous treatments required complex maintenance and left a by product. The choice for disinfectant gas is going to ozone gas because it has a minor harmful impact on the environment. This work is to find related parameters and to formulate those parameters in the equation to predict disinfectant gas production in the silent discharge process. The theoretical analysis provides a general approach for the equation models and experimental results complete the required data for the regression technique to determine constants and terms in equation model at the saturated region. Finally, a proposed equation model has successfully produced a prediction curve that is matched with experimental results.

1. Introduction
Water is an important substance for humankind. Many efforts are carried out to get fresh and clean water taken from any resources. The membrane bioreactor removed the only heavy organic component. Advanced filtering has given impact to eliminate soft and silky organics and components i.e. bacteria and viruses less than 1–5 $\mu$m. The implementation of activated carbon was reported to implement, but short life and frequent replacement become the burden of using activated carbon. Oxidation treatment for water was also reported by using chlorine and chloride oxide, but they produce a by product in the form of unpleasant taste and smell. The choice for disinfectant gas is going to ozone gas because it has a minor harmful impact on the environment. The most economical technique of ozone generation is a silent discharge [1,2] and the mechanism of discharge has been investigated [3]. The production of ozone as disinfectant gas is interesting work by determining the related parameters and then to formulate them in a mathematical model properly. Previous models in the pulse streamer discharge process have been developed for ozone generation [4,5]. It is also recorded for double dielectric carrier discharge the relationship parameters was revealed as the function of current and voltage during generation [6,7]. However, no record is found for the silent discharge process in production ozone as a disinfectant gas.

2. Theoretical and experimental analysis
There are a number of parameters that significantly influence on disinfectant production in the form of ozone concentration. Based on the evidence available in the literature [1-6], the most significant factors influencing the ozone concentration are the applied voltage V, the feed gas flow rate fr, the power needed W, the pressure P, and the applied frequency f. In the high frequency silent discharge
approach, the chamber capacitance $C_{\text{cap}}$ is also important, and this is determined by the permittivity of the dielectric material, the width of the air gap inside the chamber and the area of the dielectric layer covering the electrodes. The power required by the chamber is proportional to $C_{\text{cap}}$ [1,3].

The relationship between the ozone production in term of concentration and the above parameters can be written in general as

$$O_3 = (O_3)(V, f, C_{\text{cap}}, f, P, W, f)$$

(1)

where the symbols and the dimensions associated with the quantities in Equation (1) are ozone concentration $(O_3)$ in ppm or g/m$^3$ or L$^{-3}$M$^{-1}$, voltage $(V)$ in volts or L$^2$MT$^{-2}$A$^{-1}$, the flow rate $(f_r)$ in litres per minute or L$^3$T$^{-1}$, capacitance $(C_{\text{cap}})$ in Farads or L$^{-2}$M$^{-1}$T$^4$A$^2$, frequency $(f)$ in Hertz or T$^{-1}$, pressure in Pascals (Pa) or L$^{-1}$MT$^{-2}$, the power needed $(W)$ in watt or L$^2$M$^1$T$^{-1}$.

The Buckingham theorem [8] is also referred to enables the dimensionless matrix in Equation (2). The determinant of the first four rows and the last four columns of the matrix in Equation (2) is non zero with rank four because only seven variables in this matter then the number of dimensionless products ($\pi$) characterizes the system only in three set i.e. $\pi_1, \pi_2, \pi_3$.

|          | $O_3$ | $f_r$ | $(V)$ | $C_{\text{cap}}$ | $f$ | $P$ | $W$ |
|----------|-------|-------|-------|------------------|----|-----|-----|
| L        | -3    | 2     | 3     | -2               | 0  | -1  | 2   |
| M        | 1     | 1     | 0     | -1               | 0  | 1   | 1   |
| T        | 2     | -3    | -1    | 4                | -1 | -2  | -3  |
| A        | 0     | -1    | 0     | 2                | 0  | 0   | 0   |
| $\pi_1$  | 1     | 0     | 0     |                  |    |     |     |
| $\pi_2$  | 0     | 1     | 0     |                  |    |     |     |
| $\pi_3$  | 0     | 0     | 1     |                  |    |     |     |

When

$$A = \begin{bmatrix}
-2 & 0 & -1 & 2 \\
-1 & 0 & 1 & 1 \\
4 & -1 & -2 & -3 \\
2 & 0 & 0 & 0
\end{bmatrix}$$

(3)

$$B = \begin{bmatrix}
-3 & 2 & 3 \\
1 & 1 & 0 \\
0 & -3 & -1 \\
0 & -1 & 0
\end{bmatrix}$$

(4)

and $D$ is

$$D = \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix}$$

(5)

From references [5,8], C is determined by

$$C = -D(A^{-1}, B)^T$$

(6)
then the complete dimensional matrix is

\[
\begin{array}{cccccc}
O_x & f_x & (V) & C_p & f & P & W \\
L & -3 & 2 & 3 & -2 & 0 & -1 & 2 \\
M & 1 & 1 & 0 & -1 & 0 & 1 & 1 \\
T & 2 & -3 & -1 & 4 & -1 & -2 & -3 \\
A & 0 & -1 & 0 & 2 & 0 & 0 & 0 \\
\pi_1 & 1 & 0 & 0 & 0 & \frac{1}{3} & \frac{2}{3} & \frac{1}{3} \\
\pi_2 & 0 & 1 & 0 & \frac{1}{2} & \frac{3}{2} & 0 & \frac{1}{2} \\
\pi_3 & 0 & 0 & 1 & 0 & 0 & 1 & -1 \\
\end{array}
\]

(7)

From which it follows that

\[
\pi_1 = \frac{O_x f_x W^2}{P^2}
\]

(8)

\[
\pi_2 = \frac{V C_p^2 f_r^2}{W^2}
\]

(9)

\[
\pi_3 = \frac{f_r P}{W}
\]

(10)

Dimensionless products can be described by using of Buckingham π theorem [8] as

\[
\pi_1 = \text{function}(\pi_2, \pi_3)
\]

(11)

Equation (11) is considered as monomial form [8] and leads to the relationship

\[
\pi_1 = D_c \pi_2^{m_2} \pi_3^{m_3}
\]

(12)

where \(D_c\) is a dimensional constant. Setting Equations (8)–(10) into Equation (12) enables the ozone concentration to be expressed as

\[
O_x = D_c \left( \frac{P^2}{f_r^2 W^2} \right)^{m_2} \left( \frac{V C_p^2 f_r^2 W^2}{W^2} \right)^{m_3} \left( \frac{f_r P}{W} \right)^{m_3}
\]

(14)

The evidence available in the literature [1,2,6,7] enables Equation (14) to be simplified. Since the ozone concentration is proportional to \(V, f_r, W\), and \(C_p\), it is also inversely proportional to \(f_r\) and \(P\), hence \(m_2\) and \(m_3\) in (14) are replaced by +3 and –3 respectively. Equation (14) rewrite as:

\[
O_x = D_c \left( \frac{V^3 \sqrt{C_p^3 f_r^3 W^3}}{f_r^3 P^2} \right)
\]

(15)

where the value of \(D_c\) is determined by regression techniques.

The flow rate, frequency, capacitance, and pressure are held constant throughout the duration of measurement of voltage and power, so it is convenience to be written as:

\[
K = \left( \frac{\sqrt{C_p^3 f_r^3}}{f_r^3 P^2} \right) (V^3 W^3)
\]

(16)

The equation for ozone concentration in Equation (16) is rewritten as:

\[
O_x = D_c K
\]

(17)

To consider the destruction factor \((D_F)\), Equation (17) is written as:
The determination of $D_F$ is carried out through experimental work up to the saturated region. The form DF equation is investigated by using rational function and polynomial regression. The experimental set up to verify the prediction equation model is shown in Figure 1. A high frequency high voltage power supply was constructed from the regulated rectifier and high frequency inverter. A high frequency high voltage transformer transformed low voltage fed by the inverter to high voltage in high frequency to the discard chamber. A discard chamber is constructed in a planar chamber made from aluminium mesh and copper plate with air and mica sheet as dielectric materials. The maximum breakdown voltage of the dielectric of the chamber is 1.4 kilo Volt Discharge air gap is set into 0.75 mm with 1.0 L/m flow rate to get the effect of a destructed factor in the saturated region. The environmental pressure was 1.01325 x 10^5 Pa. The electric power supply delivered variable voltage from 0.7 – 1.38 kV rms and 2.0 – 8.2 Watt with 27.5 kHz constant frequency. Pure oxygen gas was used as input gas and ozone as disinfectant gas was measured by ozone meter at the output of the discard chamber.

Based on rational function as the best result in curve fitting in Figure 2, the ozone destruction factor is written as:

$$D_F = \frac{66.41 + 822.2 \left( \frac{VW}{V_o W_o} \right)}{1 - 0.16 \left( \frac{VW}{V_o W_o} \right) + 0.0073 \left( \frac{VW}{V_o W_o} \right)^2}$$

Combining Equation (18) and (19) with $D_c$ is kept to be constant 9.0, gives the equation of ozone concentration at 1 L/m of flow rate as:

$$O_3 = (9.0) \left( \frac{V^3 \sqrt{C_p f^3 W^5}}{f^3 D^3} \right) \left[ \frac{66.41 + 88.47 \left( \frac{VW}{V_o W_o} \right)}{1 - 0.16 \left( \frac{VW}{V_o W_o} \right) + 0.0073 \left( \frac{VW}{V_o W_o} \right)^2} \right]$$

The comparison of these regression techniques to fit with experimental data is shown in Figure 2.
In Figure 2, the predicted curve using rational function has $R^2$ that close to 1.0 and it is the nearest among regression techniques. The use of dimensional analysis has been demonstrated for predicting the ozone concentration for a high frequency silent discharge disinfectant gas generator. It was found that good agreement was obtained between prediction results and those obtained through experiments.

3. Conclusion
Based on literature reviews and experimental results, several parameters affecting ozone production in terms of disinfectant gas concentration at high frequency alternating current generation are found. Those parameters are voltage, frequency, power in Watt, flow rate, the permittivity of dielectric material, air gap and capacitance of the discard chamber. A predicted model in the mathematical equation for gas concentration has successfully produced curve which is in good conformity with the results of experimental measurements.

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