Power analysis of ozone generator for high capacity production

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Abstract. Research on the power analysis of ozone generator for high capacity production has been done. We used an ozone generator with capacity of 100 grams/hour. The ozone generator was developed by providing dielectric barrier discharge (DBD) plasma reactor. DBD reactor was made of a glass tube as dielectric material and stainless-steel mesh wire as electrodes. An AC high voltage was used as a power supply. The pure oxygen and free air were used as source of gas. The produced ozone was measured at some variation of voltage, i.e. 2.5-5.7 kV with constant flowrate of 20 L/min and dissolving duration into KI solution of 2 min. The ozone concentration was measured by reacting ozone to potassium iodide (KI), as an ozone scavenger solution. The results showed that ozone capacity increase with increasing of applied voltage. The minimum and maximum capacity of ozone with pure oxygen input obtained at voltage of 2.5 kV and 3.6 kV, while with free air input obtained at voltage of 2.5 kV and 5.7 kV.

Furthermore, ozone capacity of 100 gr/h with pure oxygen input obtained at power of 6.2 watt while with free air input obtained at power of 17.6 watt.

1. Introduction

Ozone has a chemical symbol and is composed of oxygen atoms. Ozone is an unstable oxygen molecule [1]. Ozone is a powerful oxidizing agent and can be a non-chemical disinfectant [2]. Ozone can serve as sterilization, deodorization, decolorization, and degradation. Ozone as sterilization because it can kill microorganisms, viruses, bacteria, and spores. Ozone is also capable of removing odor as a deodorizing function. Ozone also has a degradation function that is able to shed organic compounds and oxidize heavy metals. Ozone is also capable of removing organic colorants [3].

Ozone technology is an environmentally friendly technology because if reacting with other elements will produce oxygen, so ozone can be called green chemistry in the future [4]. Application of ozone utilization has been done a lot. Sectors utilizing ozone technology include drinking water treatment, water treatment for aquariums, disinfection for bottled drinking water, infected liquid waste treatment [5]. Utilization of ozone in the field of food, among others: fish storage [6,7], rice storage [8], ozone effect for chili [9,10,11].

Ozone can be formed naturally as a result of radiate ultraviolet rays from the beam that is by decomposing oxygen gas in the air. The oxygen molecules break down into two oxygen atoms and react oxygen to form ozone [12]. Ozone can also be produced using the dielectric barrier discharge plasma (DBDP) method, as has been done by Siemens [13]. This DBDP method is a fairly effective
method for producing ozone [1]. The dielectric material will serve as a current limiter capable of preventing the occurrence of sparks and helps to distribute uniform discharges on the electrode [14]. Inherited discharge plasma (DBDP) includes nonthermal plasma category. DBD reactors are generally composed of two electrodes separated by a narrow gap and a dielectric barrier. The high-voltage AC source is connected to both electrodes.

Research on ozone production using DBDP technology has been widely applied, among others by Nur, et al [15] which emphasizes ozone production using DBD spiral-cylinders. Haverkamp, et al [16] conducted a study of high-frequency ozone production in DBD. Boonduang, et al. [17] has also examined the effects of oxygen pressure and oxygen flow rate as the raw material of ozone with DBD cylinder-reactor reactors. Another study conducted Bourdet, et al [18] emphasizes the effect of the wavefronts voltage at DBD ozone production efficiency. Restiwijaya, et al [19]; Suraidin, et al [20], also conducts research on the production of ozone technology with DBDP using pure oxygen and air free gas feedstocks, by varying the length of the reactor and the gas flow rate. However, the study was not much to discuss parameter physical parameters on the ozone generator capable of producing ozone with a high capacity.

Based on the background, then conducted a study on the power analysis of an ozone generator capable of producing ozone with high a site hood. The ozone generator used using DBDP technology configures cylinders with tubular glass dielectrics. The raw material is oxygen gas and free air. Ozone generated ozone generators will be compared and analyzed the power consumption required to produce ozone with a capacity of 100 grams/hour. The concentration of ozone formed is determined by using titration method.

2. Methods
Ozone is produced by using pure oxygen gas and free air. Produced ozone is calculated concentration by titration method using KI solution as ozone and sodium thiosulfate as its titrant. Ozone flows into an Erlenmeyer containing 50 ml of a 0.2 M KI solution with a 2-minute ozonation time. KI solution will change color and titrated with 0.4 M Sodium Thiosulfate solution uses buffet. Measurement of the ozone concentration was calculated using the stoichiometric equation, the number of moles of iodide formed would be proportional to the number of moles of ozone used to oxidize.

![Research Scheme](image1)

![DBD reactor](image2)

The ozone generator used has the high capacity with DBDP configuration technology of cylinder-cylinder. Electrodes made of stainless-steel mesh wire and dielectric pyrex glass tube. The ozone generator power supply uses high-voltage AC and varies by 2.5 kV, 3.0 kV, 3.3 kV, 3.6 kV, 3.8 kV, 4.7 kV and 5.7 kV. Sources of raw materials use pure oxygen gas and free air. The gas flow is adjusted using a flowmeter of 20 L/min. Measurement of electric current using amperemeter or current monitor. High voltage measurements using a voltmeter or HV monitor equipped with an HV probe.
3. Results and Discussion
3.1 Measurement of ozone concentration

The concentration of ozone is determined indirectly using the titration method. The amount of ozone can be determined on the basis of the reaction $I^-$ with $O_3$ which yields $I_2$. The equivalent amount of $I_2$ can be determined by titration with sodium thiosulfate. Ozone generated ozone generator flows into a sealed container containing KI solution. KI solution will change color from clear to amber indicating $O_3$ oxidizing KI. This color of $I_2$ formed by oxidation reaction $I^-$ [21]

$$ O_3 + 2I^- + H_2O \rightarrow I_2 + 2OH^- + O_2 $$  \hspace{1cm} (1)

The above reaction equation shows that mole $I_2$ is proportional to mole $O_3$ which can be used to oxidize KI so that mole $I_2$ can be used in calculating the ozone mol of generator production. The determination of mole $I_2$ is done by titrating the solution using sodium thiosulfate.

$$ O_3 + 2I^- + H_2O \rightarrow I_2 + 2OH^- + O_2 $$  \hspace{1cm} (2)

$$ O_3 + H_2O + 2Na_2S_2O_3 \rightarrow 2OH^- + S_4O_6^{2-} + O_2 $$  \hspace{1cm} (3)

$$ I_2 + 2Na_2S_2O_3 \rightarrow 2NaI + Na_2S_4O_6 $$  \hspace{1cm} (4)

Titration using sodium thiosulfate is carried out until the amount of $I_2$ is proportional to sodium thiosulfate, ie by the color indicator of the clear solution. From the equation of the reaction above the number of moles of ozone will be proportional to half the number of moles of sodium thiosulfate used. Calculation of ozone concentration can use the equation [21, 22].

$$ C_o = \frac{R \times V_t \times N_t}{V_{gas}} $$  \hspace{1cm} (5)

$C_o$ is the concentration of ozone (gram / L), $R$ is the ratio of the analytical mol and the reactant of a balanced chemical equation (the number of moles of ozone is proportional to half the number of moles of sodium thiosulfate ie, $O_3$ is 48 times multiplied by half'), $N_t$ is the normality of sodium thiosulfate (mol / L), $V_t$ is the volume of titrant (L) and $V_{gas}$ is the gas volume of input (L). The volume of gas ($V_{gas}$) can be obtained:

$$ V_{gas} = flow \times \left( \frac{L}{\text{minute}} \right) \times \text{time(minute)} $$  \hspace{1cm} (6)

While the normality ($N$) of sodium thiosulfate can be obtained:

$$ N = M \times e $$  \hspace{1cm} (7)

With $M$ is molar and $e$ is equivalent, sodium thiosulfate value of $e$ is 1 so that the value of normality ($N$) will be the same as the molar ($M$). Molar ($M$) can be described as follows:

$$ M = \frac{m}{BM} \times \frac{1}{V_p} $$  \hspace{1cm} (8)

With $M$ being the molar (gram / L), $m$ is the mass of sodium thiosulfate (gram), $BM$ is the molecular weight or Mr., and $V_p$ is the volume of aquades (liters). If in the dissolution of sodium thiosulfate we use aquades in order ml, then equation (8) becomes:

$$ M = \frac{m}{BM} \times \frac{1000 \left( \frac{ml}{V_p} \right)}{ml} $$  \hspace{1cm} (9)

$$ M = \frac{m}{BM} \times \frac{1}{V_p} \times 1000 $$  \hspace{1cm} (10)

If equation (6) and equation (10) are substituted into equation (5), then the calculation of ozone concentration becomes:

$$ C = \frac{24 \times V_t \times M \times 1000}{flowrate \times \text{time}} $$  \hspace{1cm} (11)

The ozone production capacity can be calculated using the formula [23]:

Ozone capacity (grams / hour) = ozone concentration (grams / L) x gas flow rate (L / hour)

From the research results obtained ozone concentration and ozone capacitance as follows:
Table 1. Result of calculation of ozone concentration and ozone capacity

| Voltage (kV) | Titrants (ml) | Concentration ozone (ppm) | Capacity (grams/hour) |
|-------------|---------------|----------------------------|----------------------|
|             | Source Oxygen | Source Oxygen | Source Air | Source Oxygen | Source Air |
| 2.5         | 0.15          | 0.05           | 36         | 12           | 43.2       | 14.4       |
| 3.0         | 0.35          | 0.10           | 84         | 24           | 100.8      | 28.8       |
| 3.3         | 0.50          | 0.15           | 120        | 36           | 144        | 43.2       |
| 3.6         | 0.65          | 0.25           | 156        | 60           | 187.2      | 72         |
| 3.8         | 0.65          | 0.25           | 156        | 60           | 187.2      | 72         |
| 5.7         | 0.65          | 0.45           | 156        | 108          | 187.2      | 129.6      |

3.2 Characteristic of current - voltage

Figure 3 shows the electric current as a function of voltage, along with the addition of voltage, the current obtained is also higher. This is due to the intensification of the active electrode inside the reactor. The increased use of electric voltage will produce a strong electric field around the active electrode. A powerful electric field will accelerate the movement of ionic particles and electrons and particle particles are subsequently subjected to collisions between particles. The collision between particles generates ionization, dissociation and also electrical charge. Changes in electrical charges that change in units of time will produce an electric current. At a voltage of 3.3 kV to 5.7 kV seen a fairly high rise of current caused given voltage has been able to accelerate the movement of particles and the intensity of the collision more often so that the accumulation of charge formed in greater time changes.

![Figure 3. Flow and power consumption of DBD reactor as a function of voltage](image)

Besides affecting the current, the voltage also affects the amount of power consumed by the reactor. The addition of voltage affects the increase in power consumption calculated from the multiplication of the input voltage with the resulting current. At a voltage of 3.3 kV to 5.7 kV, there is an increase in power consumption is quite rapid. The rapid increase in power does not mean the power consumed is great. Consumption power in DBD reactor is quite low, at 5.7 kV high voltage consumed less than 30 watts.

3.3 Effect of voltage on ozone concentration

The effect of voltage on ozone concentration is presented in Figure 4 for two types of ozone raw materials ie oxygen and air. The use of oxygen raw materials, ozone concentration is higher than the use of air raw materials. While the ozone capacity calculated from a multiplication of ozone constants with flow rate, the use of pure oxygen produces greater ozone capacity than air as the raw material for ozone production. At a voltage of 2.5 kV to 3.6 kV, the concentration and ozone capacity increase with the addition of voltage. Both apply to oxygen and air gas sources. At a voltage of 3.6 kV to 5.7 kV
kV, the concentration and ozone capacity generated from the air feedstock still shows the linear stress effect, whereas the oxygen-based raw material has been saturated.

Figure 4. Ozone concentration and ozone capacity as a function of voltage

3.4 Effect of power consumption on ozone production

The influence of the amount of power consumed by the DBD reactor is shown in Figure 5. The amount of energy consumed per unit time reactor influence the outcome of both the concentration and the ozone production and its capacity. When the reactor consumes 4.8 W to 9.72 W, the amount of ozone concentration produced is greater for both types of raw material use. The resulting ozone capacity also has the same trend. While the power consumption of 11.33 W to 28.03 W, ozone production experienced a difference in trend. Ozone production using oxygen raw materials has been saturated while the air raw material still tends to linear.

Figure 5. The concentration of ozone and ozone capacity as a function of power consumption

Production of raw material oxygen-ozone trends has always been higher than using raw material air. This is because the side compound the virgin was away nitrogen and oxygen and a small portion of other elements such as argon, carbon dioxide, neon, helium, methane, krypton [24]. The ionization energy and dissociation of the oxygen molecules are lower than the nitrogen molecules so that the oxygen molecules will more easily ionize and dissociate than the nitrogen molecules. The ionization energy of oxygen molecules is 12 eV, meaning that if the oxygen molecule gets 12 eV energy it can ionize oxygen. Because in ionized conditions, the oxygen molecule is in unstable condition and will tend to recombination again to the normal state. Oxygen and ions are capable of capturing the electrons to be accompanied by emitting 12 eV of energy. This also occurs for nitrogen molecules that have an ionization energy of 15 eV. The process of ozone formation requires two steps, starting with the separation of oxygen molecules by electrons in micro discharges [13], \( e + O_2 \rightarrow 2O + e \), and the subsequent reaction is \( O + O_2 + M \rightarrow O_3 + M \), with M is another molecule in a reactor such as \( N_2, O_3 \), dll [15,24,25].
According to S Stanley [26], the final product after $10^3$ seconds from the production of micro-discharge in the DBD reactor using dry air feedstock is a nitrogen oxide compound such as NO$_2$, NO$_3$, N$_2$O$_5$, N$_2$O, and O$_3$. The results of Stanley's research are shown in figure 6. This is also the reason ozone production results using air feedstock is always smaller than ozone production using oxygen raw materials. Figure 5 also shows that in order to obtain an ozone capacity of 100 grams/hour, the DBD reactor requires a power consumption of 6.2 watts at a voltage of 3 kV with a source of oxygen feedstock. When using air source raw materials, the power consumption required by the DBD reactor is 17.6 watts and the voltage is 4.7 kV.

4. Conclusion
Ozone production using DBD reactors using oxygen feedstock produces ozone concentrations and ozone capacity is higher than using air raw materials. Ozone production capacity of 100 grams/hour was obtained at a voltage of 3 kV and power consumption of 6.2 watts for the raw material oxygen. When using air feedstock, the ozone capacity of 100 grams/hour is obtained at a voltage of 4.7 kV and power consumption of 17.6 watts.

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