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To cite this article: E Yulianto *et al* 2019 *J. Phys.: Conf. Ser.* **1217** 012011

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Effect of duty cycle on ozone production using DBDP cylindrical reactor

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Abstract: Ozone production using DBDP technology used pulse high voltage to generate ozone. The duty cycle has been used the variations of 10%, 30%, 50%, 60% of the 350 Hz as installed frequency. The DBDP reactor constructed by using cylinder-cylindrical electrode configuration. The inner electrode was made by stainless steel mesh with a length of 19 cm, and the outer electrode was aluminum foil with a length of 19 cm. The barrier was made of tube pyrex glass. Ozone is generated utilizing air as an oxygen-containing gas source with atmospheric pressure and a flow rate of 10 L/minute. The results show that using 10% of the duty cycle produces a maximum output voltage of 5 kV, the resulting ozone concentration of 67 ppm. The 30% cycle produces a maximum output voltage of 7.7 kV and ozone production with a concentration of 115.2 ppm. The 50% duty cycle produces a maximum output voltage of 10 kV with an ozone concentration of 134.4 ppm. The 60% duty cycle is capable of generating a maximum output voltage of 10.77 kV with an ozone concentration generated from 160.8 ppm. We found that using 60% duty cycle is capable of producing high concentrations and ozone capacity.

1. Introduction

Ozone is an unstable oxygen molecule composed of three oxygen atoms [1]. Ozone has strong oxidizing and environmentally friendly. Because of this nature ozone is widely used by industry in the fields of water treatment, food chemistry, and medicine [2]. Ozone application is also applied to fish storage [3], rice storage [4] and chili storage [5]. On this basic research on ozone production is always interesting to discuss [6].

Fang et al. [1], stated that the Dielectric Barrier Discharge Plasma (DBDP) technology is effective for producing ozone. Ozone production using DBD reactors is influenced by several factors including: voltage, power consumption, flow rate [7,8,9,10], temperature [11,12], electrical characteristics and power supply [13], power modulation and pulse polarity [2, 14, 15]. The effect of duty cycle was studied by Miura et al. [16] who used IGBT driven pulse modulator at a frequency of 1 kHz. This study found that the use of low duty cycles can improve energy efficiency in the system. In reference [17], the relationship between the duty cycle and the power consumed applies linearly for low duty cycles, while at high duty



cycles it is non-linear because there is an increase in gas temperature. Reactor configuration used in the volume DBD with high frequency is 5 kHz. Barni et al. [18] also confirmed with the results of the analysis, the use of duty cycles at high frequency (18 - 45 kHz) can reduce power consumption in the plasma formation process, reducing heating due to continuous operation.

In this paper, we study the effect of duty cycle on ozone production using a DBD cylindrical reactor and a medium frequency operation of 350 Hz.

2. Methods

This research uses the DBD reactor cylinder configuration that has been equipped with a cooling system as shown in figure 2. The outer electrode made of aluminum foil with a length of 19 cm and an inner electrode made of stainless steel mesh wire with a length of 19 cm, the protector, is made of PVC, while the cooler uses air is inserted into the gap between the outer electrode and the protector. The research scheme is shown as shown in Figure 1. The power supply uses a high voltage pulse AC with a frequency of 350 Hz and a voltage variation of 0.5, 1, 2, 3, 4 kV to reach the maximum output voltage. The duty cycle is used with variations of 10%, 30%, 50%, and 60%. Ozone production uses air material with a flow rate of 10 L / m. Ozone concentrations can be calculated using the equation [19,20]:

$$C = \frac{24 \times Vt \times M \times 1000}{\text{flow rate} \times t} \quad (1)$$

with Vt is the volume of titran (sodium thiosulfate) in liters, M is molar titran (sodium thiosulfate) in grams / L, t is the time of ozone exposure into KI solution.

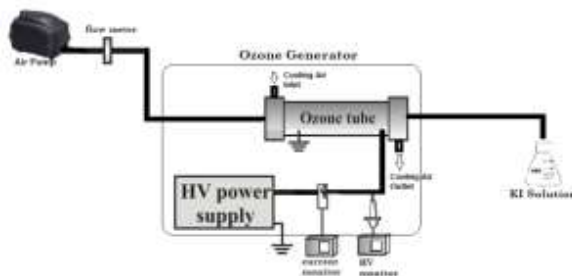


Figure 1. The research scheme

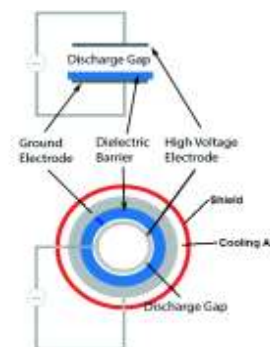


Figure 2. Cross section of DBD reactor

2.1 PWM (Pulse Width Modulation)

PWM is a technique that is commonly used in various applications with the basic idea of regulating the duty cycle of a switch so that it can control the average voltage load. Duty cycle is also defined as the proportion of operating time of components, devices or systems, usually in percentages. Variable duty cycle $D = T_{ON}/(T_{ON} + T_{OFF})$. [17,21].

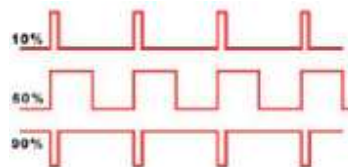


Figure. 3. Percentage of Duty Cycle

Output voltage settings can be obtained by varying the duty cycle, as written in the form of the following equation [21]:

$$D = \frac{V_{out}}{V_{in}} \quad (2)$$

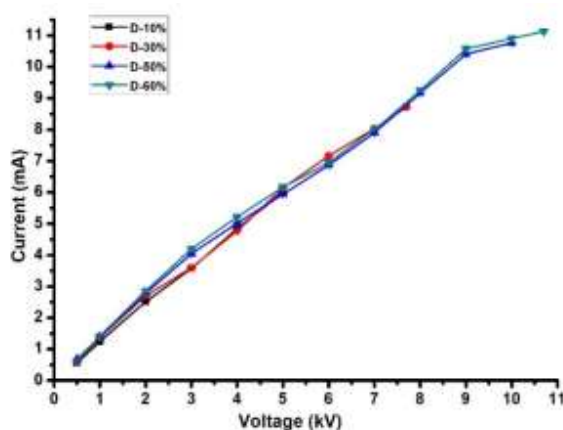
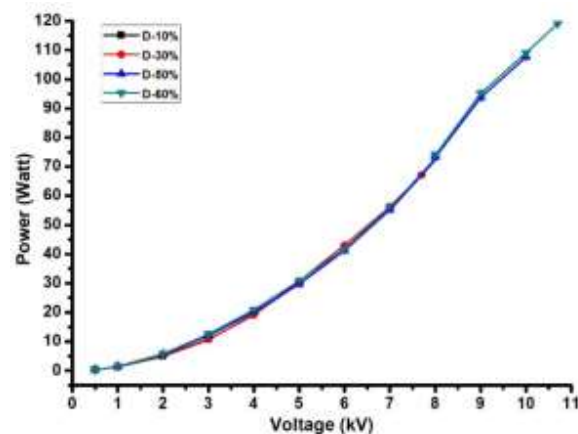
With V_{out} is output voltage, V_{in} is input voltage, and D is duty cycle.

3. Result and Discussion

3.1 Electrical Characteristic

Electrical standards measured include voltage and electric current. Figure 4 is a graph of electric current as a function of voltage, indicating that the electric current produced will be proportional to the voltage applied. This is the accumulation of charge formed in the reactor as a result of the ionization of oxygen molecules due to the impact of the electric field generated in the reactor. The same results were also conveyed by Suraidin et al. [22] in cylinder-cylinder configurations made of galvalume, copper and stainless steel.

Meanwhile, the use of a 10% to 60% duty cycle has the same effect on the increase in electric current. The duty cycle has an effect on the output voltage produced. The output voltage is proportional to the addition of the duty cycle to the same input voltage. This is as stated by Murmu et al. [21] that the output voltage is the result of the multiplication between the duty cycle and input voltage. Figure 5 shows the power relationship as a voltage function. The power consumed is higher along with the addition of voltage for all variations of the duty cycle. The highest power consumption is obtained at a voltage of 10.7 kV with a 60% duty cycle of 119.12 watts. The same research results have also been conveyed by Fang et al. [1] on the variation of the power consumption as a function of voltage with the cylinder-cylinder configuration and the wire-cylinder reactor. These results are also consistent with the analysis of the effect of the duty cycle on the power consumed by Wei et al. [17] in the production of ozone using a Volume Dielectric Barrier Discharge with air and oxygen raw materials.

**Figure. 4.** Electric current as Voltage function**Figure. 5.** Power as voltage function

3.2 Ozone Production

Figure 7 shows the effect of voltage on ozone production for variations in duty cycle. Addition of voltage correlates with the strength of the electric field around the active electrode. This electric field strength accelerates the movement of charged particles and then collides between particles. The air flows into the

reactor; the oxygen molecule will ionize and dissociate due to the high voltage applied to both electrodes [7,8]. The process of ozone production through a collision mechanism will occur as shown in the figure 6 [23]. Ozone production begins with the separation (dissociation) of oxygen molecules by electrons in micro discharge $e + O_2 \rightarrow e + O(^3P) + O(^3P)$ at 6.0 eV and $e + O_2 \rightarrow e + O(^3P) + O(^1D)$ at 8.4 eV, the next reaction is $O(^3P) + O_2 + M \rightarrow O_3 + M$, with M is another molecule in the reactor like N_2 , O_2^- , etc [1,2,7,8,14,15,17, 23]. The addition of operating voltage correlates with the high concentration of ozone produced [14,17]. Figure 7 also shows that the production of new ozone starts at 3 kV for all duty cycle variations. According to Zhang et al. [24], the formation of ozone will be preceded by a first discharge at a certain voltage called an ignition voltage. At this voltage, the power from the power supply will be absorbed by electrons at 19.35%, and 41.09% of the power absorbed by electrons will turn into heat due to reactions in ozone production.

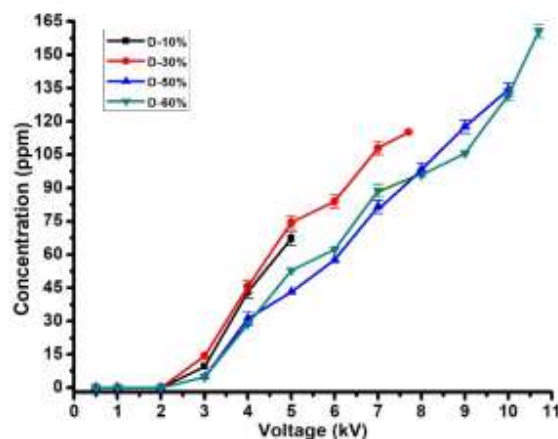
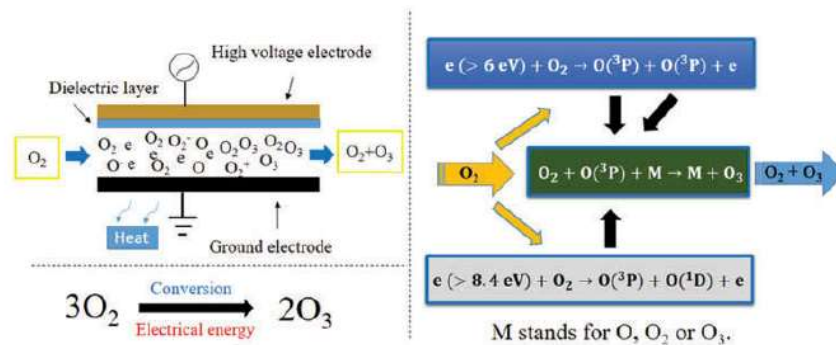


Figure. 6. Scheme of ozone production

Figure. 7. Concentration as a voltage function

The effect of the duty cycle also shows, the higher the duty cycle, the higher the output voltage and the increasing ozone production. PWM with a 10% duty cycle, means that the signal will be ON for 10% of all periods and OFF for 90% of the period. The 50% duty cycle shows the signal ON for 50% of the

period and OFF on the remaining 50%. PWM output with a 60% duty cycle will mean the signal is ON for 60% of the period and OFF at 40% of the period. PWM output with a duty cycle of 10%, 30%, 50%, and 60% encodes four different analog voltages that is at 10%, 30%, 50%, 60% of the value of its full strength. The 10% duty cycle can produce a 5 kV output voltage with a maximum ozone concentration of 67.2 ppm. The 30% of the duty cycle produces a maximum output voltage of 7.7 kV and the ozone concentration of 115.2 ppm. The 50% duty cycle produces a maximum output voltage of 10 kV with the ozone concentration of 134.4 ppm while using a 60% duty cycle can produce ozone concentration of 160.8 ppm with an output voltage of 10.7 kV. The influence of the duty cycle on ozone concentration has also been observed by previous researchers [17], using a volume of dielectric barrier discharge made from air gas. The result is that at 100% duty cycle, the ozone concentration is 90 ppm. While other researchers [14] also confirmed that increasing the duty cycle will also increase the production of ozone using Surface Dielectric Barrier Discharge with an oxygen gas source.

4. Conclusion

The use of duty cycles in ozone generators using DBD reactor cylinder-cylinder configurations has proven to be successful in increasing ozone production. An ozone generator with high production capacity is obtained at a voltage of 10.7 kV with the use of a 60% duty cycle, which is 160.8 ppm.

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