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The comparison of ozone production with dielectric barrier discharge plasma reactors series and parallel at atmospheric pressure

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Abstract. Ozone that was generated by using dielectric barrier discharge plasma (DBDP) reactor has been investigated. In this study, we compared ozone production with reactor series and parallel at atmospheric pressure. The reactor used models of a wire mesh - aluminum foil configuration. The first reactor uses a series circuit with two reactors and the second reactor uses a parallel circuit with two reactors. Ozone was produced by DBDP reactor using AC high Voltage. Oxygen that source of ozone has been taken from the pure oxygen and natural gas. Some analysis conducted including the variation of voltage, the flow rate of gas and type of source gas which affect produced concentration. Some parameters varied including voltage from 0 - 10 kV and the flow rate of gas 4 - 12 L / min. The results showed that ozone concentration in the series reactor is higher than that of the parallel reactor. The series reactor could produce ozone with a concentration of 348 ppm at a voltage of 10 kV. Then the parallel reactor of ozone could produce with a concentration of 240 ppm at a voltage of 10 kV. We found that series reactor could produce more high ozone concentration at the same voltage.

1. Introduction

Research on ozone production is currently a topic that has always attracted the attention of researchers [1]. This is because the ozone function can be used as sterilization, and degradation [2]. One technology that can be used effectively to produce ozone is a plasma dielectric barrier discharge (DBDP) [3]. This technology utilizes plasma flares that occur between active electrodes and dielectric barriers. Air flowing in the gap will be pounded by electrons so that oxygen molecules are ionized, recombined and dissociated [4]. Generally, the factors that influence ozone production are voltage, electrode material, reactor geometry, reactor configuration, gas flow rate, and a gas source in the reactor [1-9]. Ozone production using the DBDP cylinder-cylinder electrode configuration has been studied in reference [6,7]. Li et al.



[10] also studied DBDP ozone generator with various positions of the parallel reactor made from ZrO₂ with Double Surface Dielectric Barrier Discharge (DSDBD) configuration and single surface dielectric barrier discharge. In this study, it was found that DSDBD configuration is better than single surface DBD.

In this paper, we study the performance of two DBDP reactors arranged in series and parallel. We also examine the effect of flow rate with input sources in the form of oxygen and air. Ozone produced will be compared and analyzed for the power consumption needed to produce ozone with high concentrations. The ozone concentration was calculated using the volumetric method.

2. Methods

Dielectric barrier Discharge plasma using a cylindrical configuration reactor is equipped with a power supply of high voltage AC pulses. Experiment set-up is shown in Figure 1. Electrodes in stainless steel wire mesh with a length of 19 cm and outer electrodes using aluminum foil with a length of 19 cm, while pyrex glasses with an inner diameter of 2.7 cm and an outer diameter of 3.1 cm, function as a barrier.

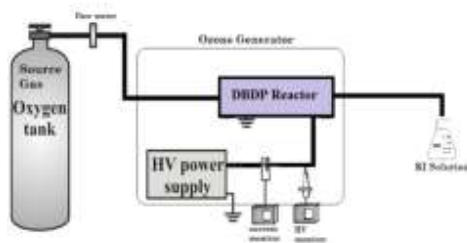


Figure 1. Scheme of research

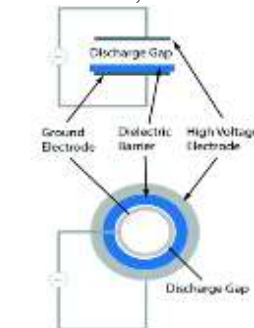


Figure 2. Cross section of DBD reactor

Pulse high voltage AC varies from 0 to 10kV. The gas source uses oxygen and free air with a flow rate of 4, 8, 12 L / min. Ozone production uses two DBDP reactors arranged in series and parallel as shown in Figure 3. Measurement of ozone concentration using the titration method. The ozone concentration can be calculated using the equation [11,12]:

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

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

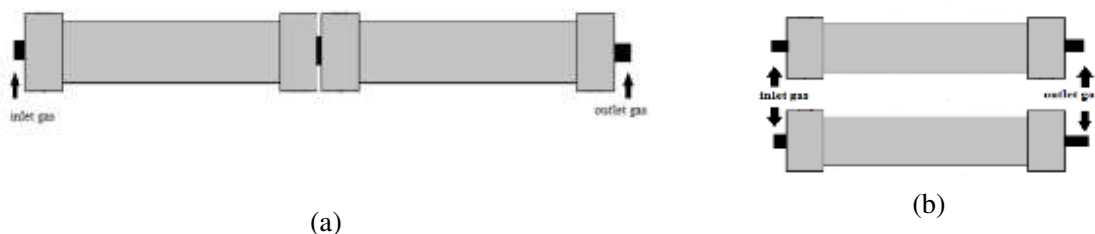


Figure 3. Structure of reactors DBDP: (a) series, (b) parallel

3. Results and Discussion

3.1 Electrical Characteristic

Ozone can be produced by DBDP reactor. DBDP reactor in which a small gap is formed for gas flow by inserting a dielectric layer on the surface of one of the electrodes has always been considered as a reliable way to generate ozone. Normally, ozone generation is mainly produced by three-body collision as follows:



Where M mainly stands for O, O₂, N₂, and O₃ in the air. Figure 4. is a graph of electrical current characteristics as a voltage function of the DBDP reactor arranged in series and parallel with the oxygen input gas and air. An increase in electric current is proportional to the increase in operating voltage on the system. This applies to all reactor arrangement models and input gas sources. The higher operating voltage can produce a strong electric field, which in turn accelerates the movement of electrons accumulating at the inner electrode. Collisions accompany this electron movement with oxygen molecules which causes ionization and dissociation, so the number of changes in charge in units of time will increase [7].

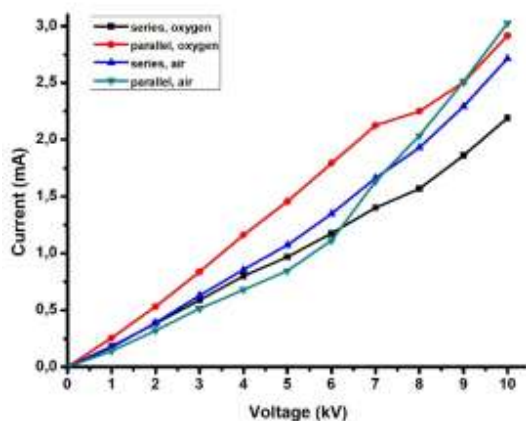


Figure 4. Electric current as a voltage function

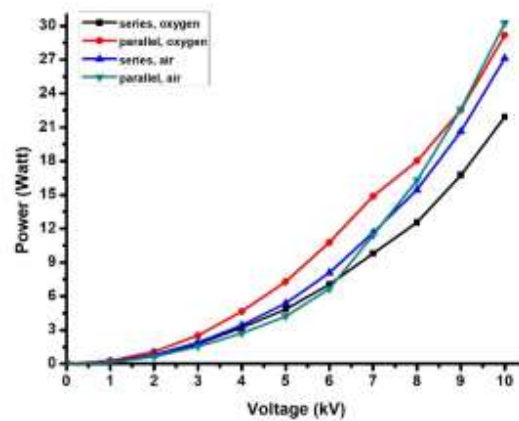


Figure 5. Power as a voltage function

The magnitude of the electric current generated by the reactor arranged in parallel with the gas input of pure oxygen is always more significant than the series arrangement for the same input gas. The results are slightly different when using air input gas, at a voltage of 0-7 kV the amount of electric current with a parallel reactor arrangement is lower than the series arrangement. At voltages above 7 kV, starting to show a more significant increase in current occurs in generators with parallel reactor arrangements. Air gas has an oxygen composition of 20%, Nitrogen 79% and other gases 1%. At voltages above 7 kV allows electrons to have enough energy to ionize nitrogen gas so that the amount of charge formed increases [8]. With increasing applied voltage, ozone decomposition is enhanced with the rise in gas temperature brought by the rise in specific input power energies. Besides, plasma could also affect the response of discharge current to the power source with a different composition of the input gas [13,14].

Figure 5. is a graph of power as a voltage function. The power consumed is the result of multiplying electric current and operating voltage provided. The addition of power increases polynomially to the addition of voltage. Nassour et al. [15], have confirmed that the addition of voltage will increase the power consumption on the surface DBD cylinder-cylinder configuration. Figure 5 also shows that both series and parallel reactor arrangements only require relatively small power consumption of fewer than 30 watts.

3.2 Effect of voltage, flow rate and residence time

The generated concentration of ozone as a function the applied voltage is shown in Figure 6. Results show that ozone concentration increases with the increase of applied voltage, similar to the results in many researchers [16]. Figure 6 shows the results of ozone production as a voltage function. Ozone concentration increases with increasing stress. High voltages provide enough energy for electrons to ionize and dissociate oxygen molecules into oxygen atoms. In ozone generators with series reactors, it always produces ozone with a higher concentration than parallel arranged. This is related to the length of time the oxygen molecules stay in the reactor. Ozone production using oxygen gas sources can produce high ozone compared to using air as a source of gas. This is because oxygen ionization energy is lower than nitrogen so that it is easier to experience dissociation into ozone-forming oxygen atoms [8,17]. According to Stanley et al. [18], the final product of micro-discharge in a DBDP reactor that uses air input gas is a nitrogen oxide compound. This is also the reason why ozone production using pure oxygen raw materials is always high.

Ozone production uses a 10 kV operating voltage with reactors arranged in series and using oxygen raw materials to produce the highest ozone of 348 ppm. This result has the same trend as previous researchers [3] with a maximum production of 55 mg / L at a 15 kV operating voltage using a cylindrical DBD reactor.

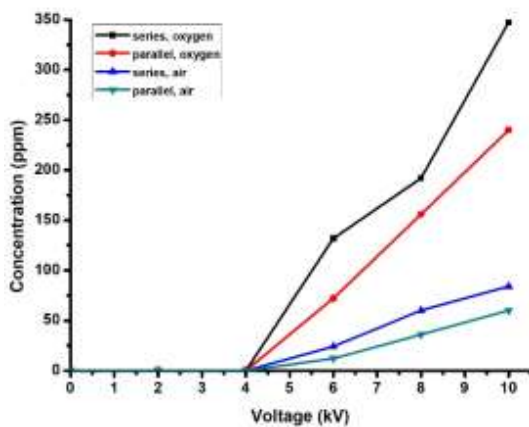


Figure 6. Ozone concentration as a voltage function

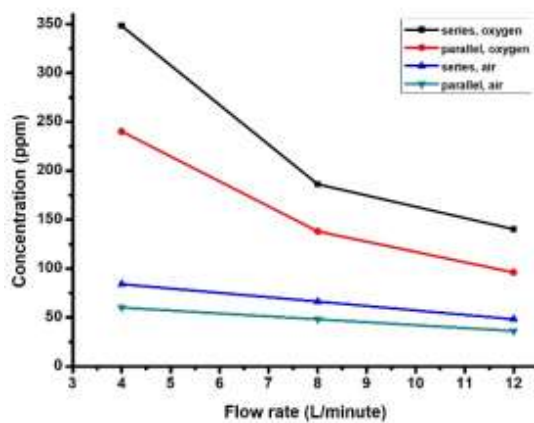


Figure 7. Ozone concentration as a flowrate function

Variations in input gas flow rate also affect ozone production, as shown in Figure 7. High flow rate causes ozone formation to decrease both with series and parallel reactors, raw oxygen, and air. Flowrate is closely related to the residence time of oxygen molecules in the reactor. The higher the flow rate of the input gas, the faster the oxygen molecules are pushed out so that, the shorter the residence time of the molecule in the reactor. Low flowrate will cause oxygen molecules to stay longer in the reactor so that the number of oxygen molecules that are ionized and experience more dissociation and then ozone formation also increases [6].

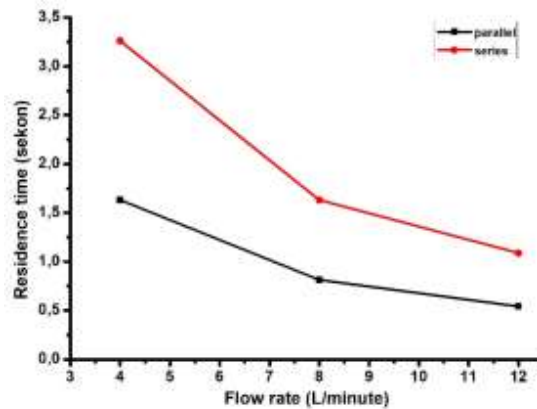


Figure 8. Residence time as of function flowrate

Figure 8 shows the relationship between flow rate and residence time. The residence time is the result of the reactor volume with a flow rate [19]. The residence time has a decreasing trend along with the addition of flowrate. The arrangement of the reactor also affects the residence time; it appears that the series arrangement is two times longer than the parallel arrangement. Figures 7 and eight show linkages and confirmations between the two, that with low flowrate and structured reactors the series has proven to be useful for producing ozone with high concentrations.

4. Conclusions

Ozone production using a DBDP reactor which is arranged in series at a voltage of 10 kV and an oxygen flow rate of 4 L / min can produce a concentration of 348 ppm ozone when using air, it produces ozone with a concentration of 84 ppm. Ozone production uses parallel reactor arrangement at 10 kV operating voltage and 4 L / minute oxygen flowrate can produce ozone with a concentration of 240 ppm, when using air raw materials, ozone is produced with a concentration of 60 ppm. We found that series reactor could produce more high ozone concentration at the same voltage.

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