Ozone production by dielectric barrier discharges plasma of coaxial cylindrical electrodes configuration using oxygen and argon source

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Abstract. A study of ozone production produced by dielectric barrier discharge (DBD) plasma has been done. The DBD reactor used coaxial cylindrical electrodes configuration i.e., a Pyrex glass with diameter of 2.0 cm and length of 30 cm was installed between the two electrodes and served as a barrier material. The outer diameter of electrode was 2.3 cm and the inner electrode was straight conductor wire. Plasma was generated by flowing Oxygen and Argon gas, using AC and DC high voltage up to 16 kV at gas flow rate varied from 2 to 8 L/min. The results show that DBD reactor with oxygen source produces the higher ozone concentration than argon source. In the range 1-13 kV of DC applied voltage for oxygen flow, the ozone concentration increases between 1.0 to 3.8 ppm. In the range 0-2 kV of AC applied voltage for oxygen flow, the ozone concentration fluctuates between 6-7 ppm, and at 3 kV it increases drastically up to 145 ppm at oxygen flow rate of 2 L/min and 4 L/min. The quality of ozone concentration produced by flowing oxygen and argon through this type of reactor could be developed to further investigation and used in various fields of application.

1. Introduction

Today, the development of ozone production using DBD plasma and the possibilities of application in various fields have been investigating by many researchers [1-8]. The quality of ozone production are usually influenced by some parameters, namely, applied voltage, electrodes configuration and gas flow within the reactors. In the references [1-3], the production of ozone from DBD reactor has been studied using spiral-cylindrical electrodes configuration. The production of ozone using DBD has been studied also in relation to the industrial scale [4-5]. Nur et al [6] studied ozone generator due to the energy consumption with various spiral diameter of the electrodes. The radical characteristics of ozone are therefore very useful such as to control fungi for production of good quality of rice [1], and also to be developed in very large rice storage [7]. In the reference [8], an integrated DBD plasma consisted of seven spiral-cylindrical electrodes has been analysed to generate ozone. In the study, copper wire spiral seemed to provide low efficiency of ozone due to its corrosive behaviour.

In this paper we studies the ozone production of DBD reactor from straight wire coaxial cylindrical configuration, where the Pyrex cylinder as dielectric was inserted between cylindrical active electrodes and the surrounding medium in the reactor using oxygen and argon flow.
2. Materials and Methods

2.1. Materials
The plasma discharge in the DBD reactor was produced by flowing oxygen and argon gas at gas flow rate from 2 L/min to 8 L/min. The ozone concentration produced from the process was then measured using ozone meter in part per million (ppm).

The DBD reactor was a Pyrex glass with diameter of 2.0 cm and length of 30 cm as a dielectric barrier material, which was inserted between two iron electrodes using AC and DC high voltage by 16 kV. The diameter of the outer electrode (anode) was 2.3 cm.

2.2. Methods.
Figure 1 shows the design of the DBD reactor at the cross section view and side view. The first step was obtaining current-applied voltage ($I-V$) characteristics of the plasma due to DBD high voltage AC and DC for both of oxygen and argon source. The gas flowed at rate between 2 L/min and 8 L/min while applying high voltage ranging from 0 – 16 kV. The second step was obtaining the ozone concentration due to DBD high voltage AC and DC for both of oxygen and argon source. The AC applied voltage used frequency source of 50-60 Hz. The ozone concentration in ppm was measured using ozone meter.

![Figure 1. the DBD reactor design](image)

3. Result and Discussion

3.1 DBD plasma using argon gas
Figure 2 shows $I-V$ characteristics of DBD plasma using argon gas for AC and DC applied voltage. The current of AC applied voltage measured in the order of mA while the DC voltage was in the order of $\mu$A indicating the higher power dissipation by AC applied voltage. Both of the configuration of the systems provides, respectively, the ozone concentration described in Figure 3.

![Figure 2. $I-V$ characteristics of DBD plasma using argon source](image)
In comparison between applied AC and DC voltage, the DBD configuration using DC voltage provides higher ozone concentration especially for argon flow rate 2 L/min. The concentration of ozone from circa 0.4 to 0.5 ppm at applied AC voltage is relatively low and constant for various argon gas flow rate due to the oscillating argon gas between the electrodes. The inert gas behaviour tends to reduce the number of ozone. The reducing ozone at DC voltage is also found for argon gas flow rate 6 to 8 L/min, indicating that more inert argon gas was colliding the ozone production. The effective argon flow rate at 2 L/min and 4 L/min at DC voltage is shown in figure 4. For high applied DC voltage, the ozone concentration increases at 2 to 4 L/min of argon flow rate, however, the concentration reduces after 6 to 8 L/min of argon flow rate.

3.2 DBD Plasma using Oxygen gas

Figure 5 shows $I$-$V$ characteristics of DBD plasma using oxygen at applied AC and DC voltage. The ozone concentration production related to the configurations respectively is shown in figure 6.
Figure 6. The ozone production (in ppm unit) at applied AC and DC voltage

Figure 5 shows current measured in the order of mA at applied AC voltage and μA at applied DC voltage indicating more power consumption in applied AC voltage using oxygen flow. However, in figure 6, in the range of applied AC voltage it provides 3 to 145 ppm of ozone concentration, and only 1.0 to 3.8 ppm of applied DC voltage. The more oscillated oxygen at AC voltage tends to increase the development of ozone concentration, and drastically jumps to circa 145 ppm at 3 kV for 2 L/min and 4 L/min of oxygen flow rate. It jumps to circa 145 ppm and 125 ppm at 6 kV for 6 L/min and 8 L/min, respectively. Whereas, at increasing DC voltage, ozone concentration slightly linearly increase in the range 1.0 to 3.8 ppm. This behaviour could be due by homogeneously plasma spread throughout the electrodes and dielectric. Figure 7 shows the fluctuation of ozone concentration between 6-7 ppm at AC voltage and 1-2 ppm at DC voltage of 2 kV. For 3 kV, the ozone concentration drastically increases for 2 L/min and 4 L/min of oxygen flow rate.

Figure 7. The ozone production (in ppm unit) at applied AC and DC voltage at 2 kV and 3 kV

The $I-V$ characteristics considered to the reference [6, 8] is satisfied by modified Robinson relation, i.e. $I \sim V^2$ for free space or air as surrounding medium inside the reactor. In this paper, instead of air as surrounding medium, we used oxygen flow and argon flow. Therefore the whole reactor acts as cylindrical capacitor with cylindrical dielectric inserted between the active electrodes and oxygen or argon dielectric flowing during the measurement. Due to the barrier dielectric, the ion mobility will reduce and give capacitive current close to linear relation to the applied voltage. In figure 2, the relation of $I \sim V^2$ is still hold for AC voltage in the range 1-3 kV for argon flow, but it is almost linear for DC voltage in the range 1-8 kV, and the current drastically increase at 13 kV. In figure 5, for AC voltage between 0-1 kV for oxygen flow, the relation of $I \sim V^2$ is still hold, and between 1-6 kV the relation is almost linear. On the other and for DC voltage, in the range 1-8 kV, the reduced mobility of ions provides to similar ohm’s law behaviour. In the range 8-13 kV the breakdown of ions avalanche provides
significantly increasing current. We suggested that more research to obtain comprehensively $I$-$V$ relation in the range of the condition of AC or DC voltage for this straight coaxial cylindrical electrodes configuration.

In this discussion, there is almost no recent reports for ozone production by DBD reactor of coaxial cylindrical electrodes configuration. The recent comprehensive discussion in the reference [8] related only to integrated seven spiral-cylindrical electrodes configuration using air flow at difference range of applied AC voltage. In that report, the ozone concentration was gradually decreased as the air flow rate increased. In this paper, we called our reactor as straight coaxial cylindrical electrodes configuration, with its special Pyrex dielectric inserted between electrodes and flowed oxygen or argon gas. The whole configuration provides capacitor that consists of Pyrex dielectric and gas dielectric. By applying high AC or DC voltage, non-linear behaviour should appear indicated by $I$-$V$ characteristics above. The ozone production obtained by flowing oxygen or argon gas through the reactor has different quality and may be used in many different application.

4. Conclusion
The $I$-$V$ characteristics of DBD plasma in the range of both of AC and DC applied voltage in this condition were not satisfied by Robinson relation. The use of oxygen flow through the reactor provides clearly more ozone concentration than the use of argon flow. In the range 1-13 kV of DC applied voltage for oxygen flow, the ozone concentration increases between 1.0 to 3.8 ppm. In the range 0-2 kV of AC applied voltage for oxygen flow, the ozone concentration fluctuates between 6-7 ppm, and at 3 kV it increases drastically up to 145 ppm at oxygen flow rate of 2 L/min and 4 L/min. The quality of ozone concentration produced by flowing oxygen and argon through this type of reactor could be developed to further investigation and used in wide many areas of application.

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References
[1] Rachman D A, Nur M and Kusdiyanti E 2014 Berkala Fisika 17 21
[2] Prasetyo A, Nur M, Muhslin Z and Putro S P 2015 Youngster Phys J 4 237
[3] Restiwijaya M, Nur M and Winarni T A 2014 Berkala Fisika 17 1
[4] Hong D, Rabat H, Bauchire J M and Chang 2014 Plasma Chem Plasma Process 34 887
[5] Zhang X, Lee B J, Im H G and Cha M S 2016 IEEE Trans Plasma Sci 44 2288
[6] Nur M, Restiwijaya M, Muhslin Z, Susan A I, Arianto F and Widyanto S A 2016 J Phys: Conf Ser 776 012101
[7] Nur M, Solichin A, Kusdianyanti E, Winarni T A, Susilo, Rachman D A, Restiwijaya M, Teke S, Wuryanti and Muhamad H 2013 IEEE Conf Publ ICICI-BME (New Jersey USA: IEEE) p 221
[8] Nur M, Susan A I, Muhslin Z, Arianto F, Wibawa P J, Gunawan G and Usman A 2017 Bull Chem React Eng Catal 12 24