Sterilization of water soluble cutting fluid by compact air cooled coaxial dielectric barrier discharge reactor with bubbler

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Abstract: Odor and discoloration of water soluble cutting fluid occur due to the growth of microorganisms and putrefying bacteria, which significantly reduces cutting performance and rust prevention. To overcome these drawback, we developed a compact air cooled coaxial dielectric barrier discharge (DBD) with bubbler. bacteria and microorganism thrive in waste water soluble cutting fluids were sterilized, and it was confirmed that more than 99.99% of bacteria were removed. In addition, we analysed the property changes of water soluble cutting fluids by ozone treatment and we found that the composition were unaffected. Meanwhile, turbidity, and odor, which indicate the performance of the waste water soluble cutting fluids, were improved with the effect of bacterial inactivation. We conclude that ozone treatment using a compact air cooled coaxial DBD with bubbler is an effective method for purifying and sterilization of waste water soluble cutting fluids waste.

Keywords: water soluble cutting fluid, sterilization, dielectric barrier discharge, bubbler, ozone treatment.

1. Introduction

The water soluble cutting fluid mainly composed of water has always played an important role in metal processing and it is widely used cutting fluid because they provide excellent cooling effects and offer advantages that can overcome the risks associated with straight cutting oils. However, water soluble cutting fluids in use for a long time may accumulate bacteria, products of bacterial metabolism, products of thermal decomposition and a variety of contaminants derived from human activities in the work place. [1]. These results are related to water soluble cutting fluid decay. The decay of water soluble cutting fluid is due to the propagation of putrefying bacteria and microorganisms. They absorb nutrients such as hydrocarbons, SO_4 ions, sulphur compounds in soluble cutting oil, and generate odors such as hydrogen sulfiede. As a result, odor and discoloration of water soluble cutting fluid occur due to the growth of microorganisms and putrefying bacteria, which significantly reduces cutting performance and rust prevention. This ultimately leads to deterioration of the working environment and is the main reason for the replacement of the water soluble cutting fluid [2,3]. Health problems have been reported among workers exposed to water soluble cutting fluids, and methodologies used to assess health risks from exposure to water soluble cutting fluids have been discussed (National Safety Council, 2002). Previous investigations have shown elevated respiratory, digestive, and skin cancers in exposed popula-tions and increased rates of cough and phlegm. There are also case studies that indicate that these exposures may cause occupational asthma [4]. In recent years, ozone treatment technologies have been developed to purification of pollutants in water [5,6]. Ozone is one of the most well-known strong oxidizing agents and is capable of efficiently inactivating microorganisms. Ozone is a highly effective agent that readily oxidizes organic matter, various microbes, pesticides and chemical residuals, at low concentrations and low contact times compared to chlorine. In addition, it quickly decomposes into oxygen molecules in water without forming any secondary contaminants. As such, ozone treatment is a desirable technique for the sterilization of water-soluble cutting fluids [2]. However, industrial ozone treatment methods have technical and economic limitations, such as high energy consumption, high installation costs, inconsistent treatment efficiency, and the need for a large space. Recently, various ozone generators have been stuied in many industrial field. UV or corona has been used in many studies to gnerate ozone. The UV method has inefficient for ozone production in terms of power consumption. The corona method needs bulky power supply and has high energy consumption and wear of electrode occurs. To overcome these drawback, we developed a compact air cooled coaxial dielectric barrier discharge (DBD). In order to increase, the bacterial inactivation efficiency and reaction rate in cutting fluids, we added bubbler at compact air cooled coaxial DBD. It can efficiently purify water-soluble by using a larege amount bubbles, incliding ozone generated from the plasma at atmospheric pressure. In the DBD system, the use of an AC high-voltage power supply to apply power to the electrodes generates a strong electric field at the discharge node, and the ambient air is broken down to form a discharge. The proposed system features low energy density, a simple structure, low manufacturing cost, and can be easily installed anywhere. In addition, this system uses the air generated in the blower as discharge and as the cooling gas rather than compressed air or oxygen gas, which would decrease the running cost. Futhermore, the most important reaction leading to ozone generation from air at atmospheric pressure is as follows [7, 8]:

$$O + O_2 + M \rightarrow O_3 + M, \quad (1)$$

where M is the third collision partner, which is the nitrogen and oxygen molecules in the air. The optical and electrical properties of a compact air cooled coaxial DBD plasma were characterized and measured the concentration of active species. Addtionally, optimized operating conditions were derived by measuring the flow rate of air. We performed sterilization experiments with various bacteria in waste water soluble cutting fluids, using a compact air cooled coaxial DBD plasma with bubbler under optimized conditions.

2. Materials and methods

2.1 Structure of compact air cooled coaxial DBD reactor with bubbler

Figure 1(a) shows a diagram of a compact air cooled coaxial DBD reactor with bubbler configuration. This DBD device consisted of a power supply (100 W 25 kHz transformer, NT electronics, South Korea), which was connected to a high-voltage electrode and a ground electrode, a batch reactor (200 mm x 80 mm x 250 mm, acrylic) with a capacity of 4 L (of witch we used only 2 L in this study), and DBD reactor with bubbler. The compact air cooled coaxial DBD reactor includes a high-voltage electrode (1/4 inch, SUS tube), an internal insulator (inner diameter, 7 mm; outer diameter, 10 mm, alumina rod) surrounding the high-viltage electrode, and a ground electrode (inner diameter, 13 mm; outer diameter, 27 mm, anodized aluminum rod). The inside and outside of groud electrode was anodized for insulation. As shown in Fig. 1(b), the high-voltage electrode is surrounded by an inner insulator and inner insulator has a structure separated by 3 mm from the anodized ground electrod. Plasma generated in the discharge gap between the inner insulator and inside of the anodized ground electrode contributes to the production of high-concentration ozone. The discharge gas injected into the high-voltage electrode is heated by joule-heating generated from the electrode, so that discharge can occur easily. It also serves to cool the high-voltage electrode. Since ozone is easily decomposed by heat, it is very important to cool the electrode. High-concetration ozone is produced by reducing heat generated from high-voltage electrode.

2.2 Analysis equipment and methods

Figure 1(a) shows a diagram of a compact air cooled coaxial DBD reactor with bubbler configuration. A digital storage oscilloscope was applied to analyze the voltage and current waveforms of the plasma. The concentration of ozone was measured at the gas outlet point of DBD reactor using an O_3 monitor, with a measurement error of 0.01 mg L^{-1} after ozone passed through the water soluble cutting fluids. We analyzed the changes of water soluble cutting fluid turbidity, concentration, pH, and composition by ozone treatment using a turbidity meter with a measurement error of ±0.5 NTU, cutting fluid refractometer with the measurement error of ±0.2%, a pH meter with errors of pH (±0.01), and GC/MS. The initial odor from the sample which is waste water soluble cutting fluids, measured by olfactory methods, was strong due to the degradation by microorganisms, and the dilution rate measured using the air dilution olfactory method of complex odor was 208. The odor-containing gas was collected in a tetra bag through the bubbler containing 2 L of the waste water soluble cutting fluids. Higher values of dilution rate indicate stronger odor. The data of complex odor obtained using the air dilution olfactory method were analyzed by an authorized inspection agency (Dae Sung Environment Research Institute, South Korea) and odor dilution rate was obtained from values averaged over 5-times repeated measurements.

2.3 Analysis of microorganism and bacteria

The experiment of bacterial sterilization was carried out ozone treatment by a compact air cooled coaxial DBD reactor with bubbler to confirm sterilization value of microorganisms in waste water soluble cutting fluid. The experiments of bacterial inactivation were carried out 3 times for analysis each 20 mins. The sample was performed serial dilution, and 100 ul was spread on LB agar (BD, USA) 3 times and cultured at 37℃ for 2 days, and the number of bacterial colony formed was counted for concentration assessment.

3. Results and discussion

3.1 Generation of air DBD plasma

Figure 1(b) shows the stable plasma generation at air flow rate of 25 L/min. The suggested a compact air cooled coaxial DBD was capable of generating a high concentration of ozone with a simple structure and low power consumption by a simple power supply 100W. The ozone generated in a compact air cooled coaxial DBD DBD is formed via a three-body reaction of oxygen atoms [9, 10] as shown below:

$$e + O_2 \rightarrow O + O + e \quad (2)$$

$$O + O_2 + O_2/N_2 \rightarrow O_3 + O_2/N_2 \quad (3)$$

Figure 2 shows the concentration of ozone generated from a compact air cooled coaxial DBD according to the flow rate, measured in deferent power. The averaged concentrations at flow rates of 15, 20, 25, and 30 L/min were 420, 410, 400, and 320 ppm, at power of 60W, respectively. At a flow rate below 15 L/min, the gas velocity was low such that the gas temperature increased rapidly. At high temperatures, ozone decomposes rapidly. The developed DBD is specially optimized to generate ozone at the conditions of 60W and flow rate of 25 L/min because, ozone generation is stable even at high power. The developed DBD is specially optimized to generate ozone at the conditions of power of 60W and flow rate of 25 L/min.

3.2 Sterilization of microorganims in water soluble cutting fluids

Fig. 3(a) shows the sterilization of bacteria from the sample cutting fluid according to the ozone treatment. Bacteria was decreased by about 99.99% after treated 60 min to ozone generated in the plasma. Addtinally, Fig. 3(b) shows the odor generated from the sample cutting fluid according to the ozone treatment. Odor decreased by about 30% after 60 min of exposure to ozone generated in the plasma. we found that odor, which indicate the performance of the waste water soluble cutting fluids were improved with the effect of bacterial sterilization. It indicates that the odor of waste water soluble cutting fluid is improved due to the sterilizatio effect.

3.3 Analysis of water soluble cutting fluid properties by ozone treatment

For sterilization of waste water soluble cutting fluids, it is important to analyze bacterial inactivation rate as well as property changes after ozone treatment. We analyzed the changes of turbidity, concentration, pH, and composition of cutting fluids by using a turbidity meter, the cutting fluid refactometer, a pH meter, and GC/MS, depending on the ozone treatment time. The concentration of fresh cutting fluid was 7.1%. The concentrations of fresh cutting fluids treated by ozone treatment for 10 min per 1 hour for 5 days were 8.40%, 8.36%, 8.36%, 8.40, 8.40 and 8.40%, respectively. The pH of fresh cutting fluid was 9.37. The pH of fresh cutting fluids treated by ozone treatment for 10 min per 1 hour for 5 days were 9.37%, 8.36%, 8.36%, 8.40, 8.40 and 8.40%, respectively. It shows that the concentration and pH of oil components was almost not changed after ozone treatment. The composition changes of waste cutting fluid by ozone treatment were measured through qualitative analysis of GC/ MS. Mainly, two intense peaks in the retention time of 13.56 min and 16.54 min were detected. We analyzed the retention time and peak intensity that the peaks were almost unchanged. We confirmed from the results that the concentration of ozone generated from the developed DBD was not enough high to dissociate the molecules. The turbidity was confirmed to improve with the removal of dissolved impurities and microorganisms in cutting fluid after ozone treatment.

4. Conclusion

We suggested an ozone treatment using a compact air cooled coaxial DBD with bubbler in which a high concentration of ozone could be stably generated and injected into waste water soluble cutting fluids. The bubbler was applied to efficiently inject the generated ozone into the cutting fluids with impurities and microorganisms. An optimized condition of flow rate was determined based on ozone concentration. Bacteria and microorganism thrive in waste water soluble cutting fluids were sterilized, and it was confirmed that more than 99.99% of bacteria were removed. In addition, we analysed the property changes of water soluble cutting fluids by ozone treatment and we found that the composition were unaffected. Meanwhile, turbidity, and odor, which indicate the performance of the waste water soluble cutting fluids, were improved with the effect of bacterial sterilization. The results show that the ozone treatment was effective. We conclude that ozone treatment using a compact air cooled coaxial DBD with bubbler is an effective method for purifying and sterilization of waste water soluble cutting fluids waste. We believe that this method contributes towards the improvement of the working environment of the metalworking industry and prolonging the lifetime of cutting fluids.

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Figure Captions

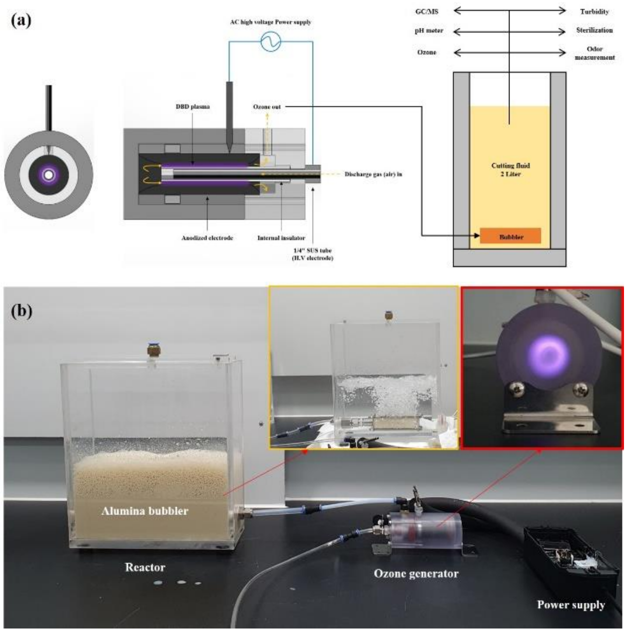


Figure 1. Schematic diagram of a compact air cooled coaxial DBD reactor with bubbler configuration.

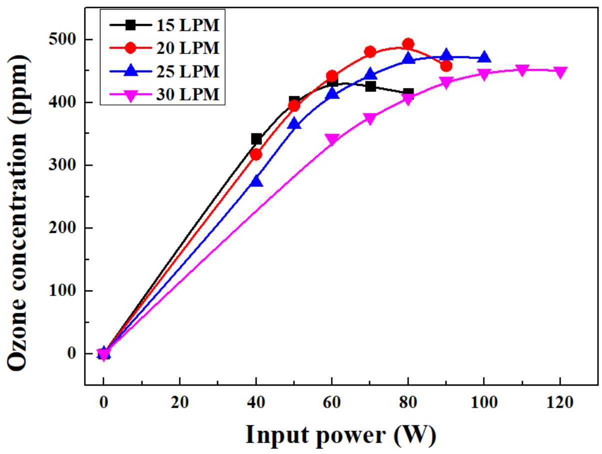
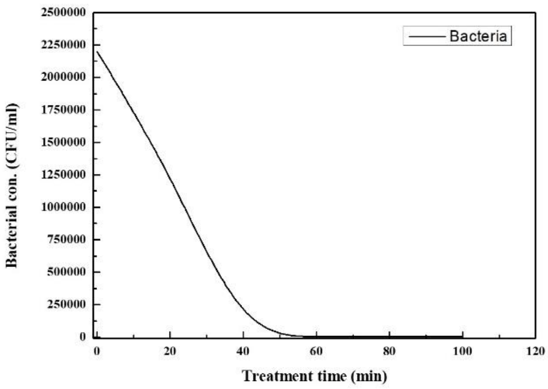


Figure 2. the concentration of ozone generated from a compact air cooled coaxial DBD according to the flow rate, measured in deferent power.

(a)



(b)

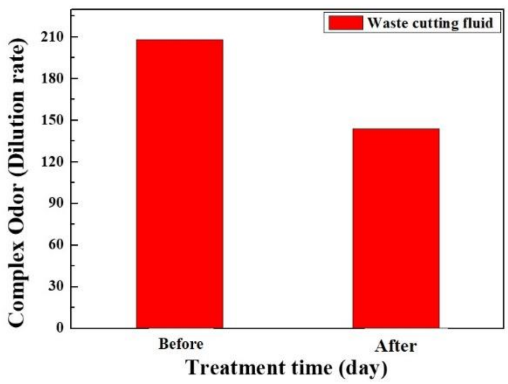


Figure 3. (a) sterilization value of microorganisms in waste water soluble cutting fluid and (b) the odor generated from the sample cutting fluid according to the ozone treatment.