Walailak J Sci & Tech 2009; 6(2): 283-292.

SHORT COMMUNICATIONS

Characteristics of Ozone Production by Using Atmospheric Surface Glow Barrier Discharge

Mudtorlep NISOA[1,2] and Thammanoon SRINUAM[1,2]

[1]Plasma Agricultural Application Research Unit, Walailak University, Nakhon Si Thammarat 80161, Thailand
[2]ThEP Center, CHE, 328 Si Ayutthaya Rd., Bangkok 10400, Thailand

(E-mail: nmudtorl@wu.ac.th)

ABSTRACT

Ozone is a strong oxidizer that can kill bacteria and other micro-organisms very effectively. In the recent years, ozone has become very important for sterilization of water used in shrimp farming and treatment of wastewater from food industry. However, ozonisers available in the markets are very expensive and have low energy-efficiency. In this work, a highly-efficient and low-cost system that can produce high-concentrations of ozone gas and dissolved ozone in water has been developed. The system consists of a dried air unit, high-voltage rf power supply, ozoniser tubes and venturi injector. The tubes are designed and configured to convert oxygen gas to ozone gas by atmospheric surface glow barrier discharge.

Keywords: Ozone, atmospheric surface glow barrier discharge, oxidizer, sterilization of water, wastewater treatment

INTRODUCTION

Ozone has been known to be very strong oxidizer that can kill *Escherichia coli* bacteria and other micro-organisms effectively [1,2]. Dissolved ozone having a concentration of 0.3 ppm can reduce the amount of *E. coli* by more than 99 % within 2 min. Therefore, in recent years, ozone has become very important for the sterilization of water used in shrimp farming and treatment of wastewater from the food industry. Since ozone is unstable and decomposes to oxygen within *ca*. 10 min without harmful by-products, using ozone is friendly to the environment. Ozone technology is necessary for the sustainability of water use in industries. However, ozonisers available on the market are quite expensive and have low energy-efficiency [3,4]. In this paper, we have developed a highly-efficient and low-cost system that can produce highly concentrated of ozone gas and dissolved ozone in water. Dependence of ozone concentration on rf power and gas flow-rate will be shown.

MATERIALS AND METHODS

Figure 1 shows the schematic diagram of the experimental setup consisting of the ozone generator, a resonant high-voltage high-frequency power supply [9], air dryer unit and ozone venturi injector. The system is composed of dried air unit, high-voltage rf power supply, ozoniser tubes and venturi injector. The configuration of the tube is carefully designed to convert oxygen gas to ozone gas by atmospheric surface glow barrier discharge [3-6]. The discharge occurs at the dielectric surface of the Pyrex glass generating highly active non-equilibrium plasmas at atmospheric pressure. Therefore, ozone is formed during the discharges of air or oxygen gas. Monitoring of the ozone gas and dissolved ozone in water is achieved with a ozone monitor model C-30ZX from ECO Sensors Inc. and the indigo colorimetric method [7,8], respectively. In the ozone generator there are 8 ozoniser tubes connected in series as shown in **Figure 2**.

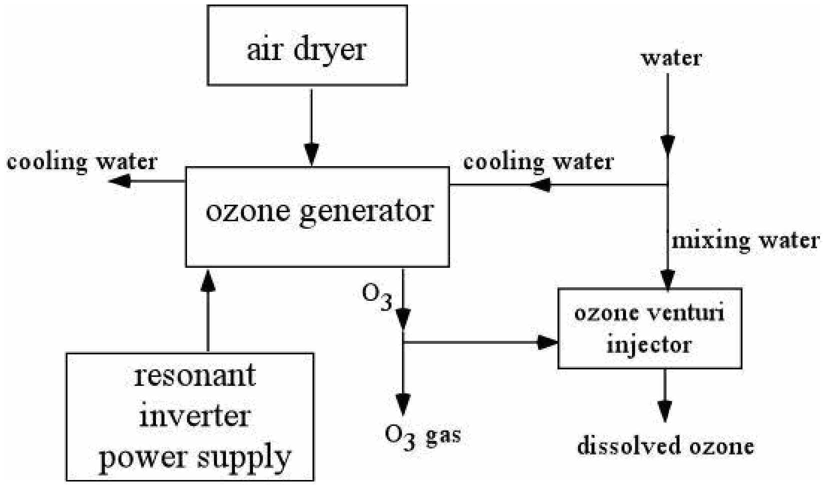


Figure 1 Schematic diagram of the experimental setup.

Figure 2 Eight ozoniser tubes connected in series to produce maximum ozone concentration.

Figure 3 shows the schematic detail of the air dryer consisting of 2 columns a desiccant air dryer and a refrigerated air dryer. The 4 solenoid valves are controlled automatically to optimize the working conditions of the air dryer. Therefore dried and cool air having a dewpoint less than −10 ^{o}C can be obtained. Reduction of moisture in the air is very important for highly efficient of ozone production in the discharges [10]. Once the ozone gas is generated, it is fed into the venturi injector to mix with the water, and more than 80 % of the ozone gas is dissolved.

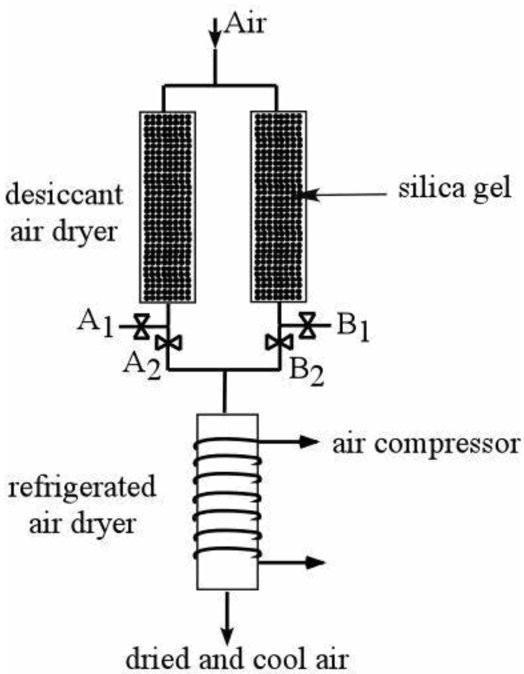


Figure 3 Schematic detail of the air dryer.

Figures 4 and **5** show the schematic details and picture of each ozoniser tube. The tube uses water as a cooling medium and ground electrode. The temperature of the tubes has to be maintained at room temperature during the discharge for effective production of ozone [11], since dissociation of ozone occurs easily at high temperatures. The high voltage electrode made of a stainless mesh is on the inside surface of the Pyrex glass tube. The 2 mm thickness glass tube is used as a dielectric barrier to prevent the transition from glow to arc discharges [12]. The details of the resonant inverter power supply are discussed elsewhere [9]. The concentration of ozone can be controlled easily by variation of frequency and peak voltage of the rf signals.

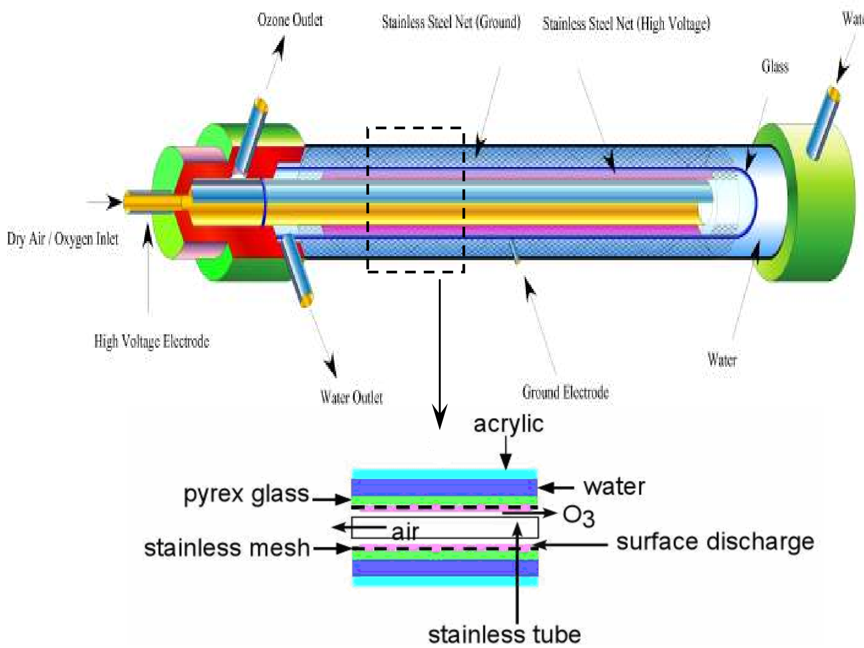


Figure 4 Schematic details of ozoniser tube.

Figure 5 Picture of ozoniser tube when the discharge occurred and ozone is produced.

RESULTS AND DISCUSSION

The threshold rf peak voltage for ozone production occurs at about 2 kV as shown in **Figure 6**. The highest concentration of ozone at each supplied rf peak voltage value is produced at the resonant frequency of the LC oscillator of the ozoniser tube and compensated inductor. Since the tube will behave as a capacitor in parallel with a resistor during the discharge, the inductance of the compensated inductor has been designed carefully for resonant frequencies between 10 kHz and 800 kHz.

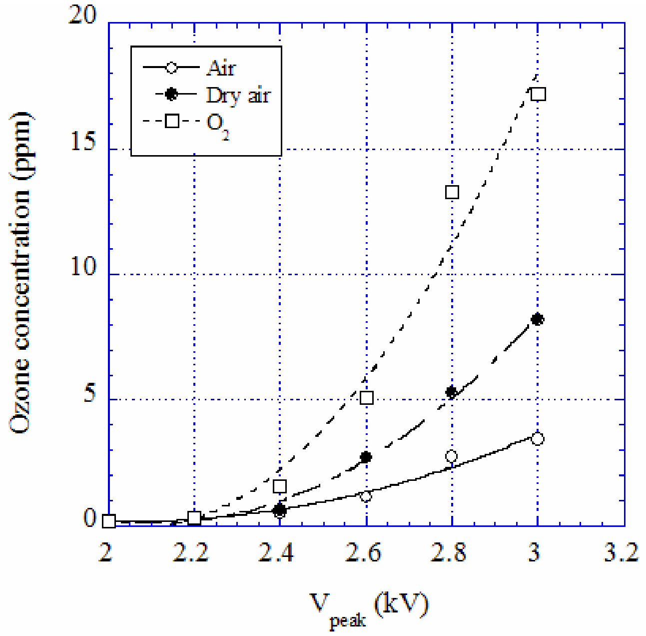
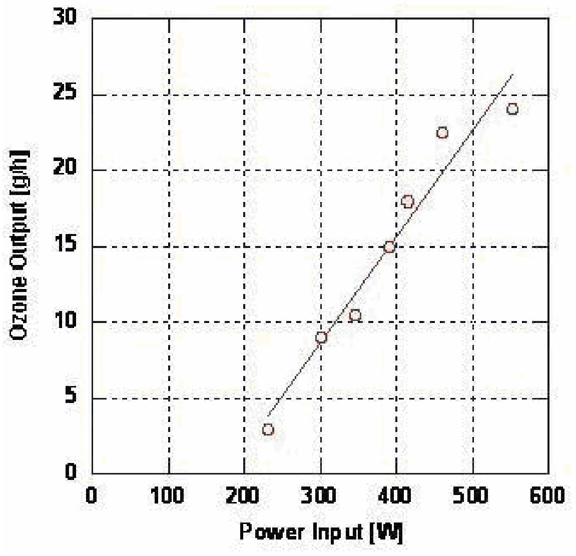
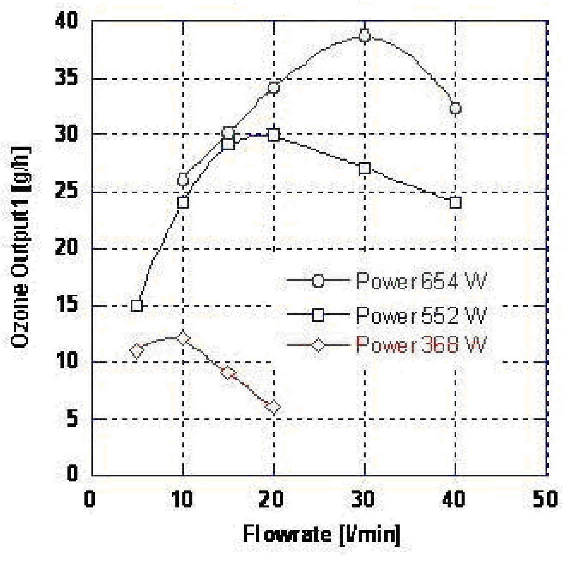


Figure 6 Dependence of ozone concentration on the rf peak voltage, gas flow rate is 40 l/min.



(a)



(b)

Figure 7 Dependence of ozone gas output on (a) rf power and (b) flow rate of oxygen at various rf powers. In (a) the rf frequency and oxygen flow rate are 36 kHz and 10 l/min, respectively.

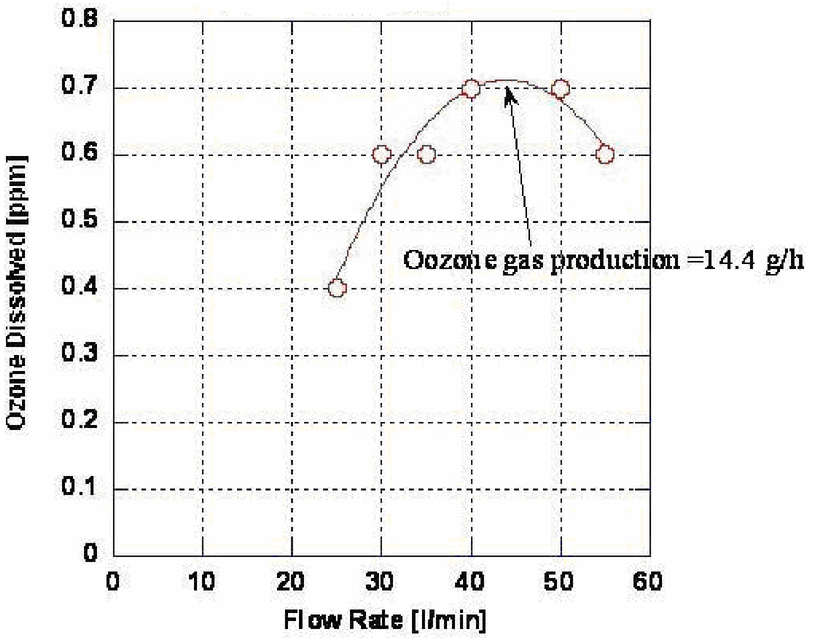


Figure 8 Dependence of dissolved ozone on flow rate of dried air, when the water flow rate is 50 l/min, rf power and frequency are 667 W and 34 kHz, respectively.

Figure 7a shows that ozone output is increased with rf input power. That is because more energetic electrons are generated and more oxygen molecules are dissociated into oxygen atoms. Therefore interaction among atoms and molecules of oxygen to form ozone is increased. **Figure 7b** shows the dependence of the ozone output upon the oxygen gas flow rate for different rf input powers. They have similar characteristics to have peak of ozone output. However, the gas flow rate corresponding to the peak is increased with the rf power. The results have suggested that a higher ozone output capacity can be obtained by increasing the gas flow rate and input rf power. At the peaks, the residence time of oxygen atoms and molecules is optimized with the number of the particles produced in the rf field, so that the highest reaction rate for ozone production occurs [11]. In **Figure 8** dried air is used to feed into the ozone tubes. The ozone output capacity is reduced by about 50 % as compared to production when using oxygen gas. As the ozone gas is injected into the venturi, dissolved ozone of a concentration greater than 0.7 ppm will be obtained.

CONCLUSIONS

The system has a maximum ozone capacity of 40 g/h and 15 g/h when oxygen gas and dried air are used respectively. Consequently, a dissolved ozone concentration greater than 0.7 ppm can be obtained when dried air is used. The ozone production system studied in this paper has the potential for development for commercial use in the shrimp industry. To achieve that, high power electronics for high power rf generators and discharge physics during ozone production have to be investigated carefully.

ACKNOWLEDGEMENTS

We would like to thank the Office of Commission on Higher Education and Institute of Research and Development, Walailak University for their financial support.

REFERENCES

[1] MV Selma, A Allende, F Lopez-Galvez, MA Conesa and MI Gil. Disinfection potential of ozone, ultraviolet-C and their combination in wash water for the fresh-cut vegetable industry. *Food Microbiol.* 2008; **25**, 809-14.
[2] MBH Najafi and MHH Khodaparast. Efficacy of ozone to reduce microbial populations in date fruits. *Food Control* 2009; **20**, 27-30.
[3] MAT Alsheyaba and AH Muñozb. Optimisation of ozone production for water and wastewater treatment. *Desalination* 2007; **217**, 1-7.

[4] Z Fang, Y Qiu, Y Sun, H Wang and K Edmund. Experimental study on discharge characteristics and ozone generation of dielectric barrier discharge in a cylinder-cylinder reactor and a wire-cylinder reactor. *J. Electrostat.* 2008; **66**, 421-6.

[5] K Takaki, Y Hatanaka, K Arima, S Mukaigawa and T Fujiwara. Influence of electrode configuration on ozone synthesis and microdischarge property in dielectric barrier discharge reactor. *Vacuum* 2009; **83**, 128-32.

[6] X Lei, Z Rui, L Peng, D Li-Li and Z Ru-Juan. Sterilization of *E. coli* bacterium with an atmospheric pressure surface barrier discharge. *Chin. Phys.* 2004; **13**, 913-7.

[7] P Baroch, N Saito and O Takai. Special type of plasma dielectric barrier discharge reactor for direct ozonization of water and degradation of organic pollution. *J. Phys. D: Appl. Phys.* 2008; **41**, 1-6.

[8] JD Fortner, DI Kim, AM Boyd, JC Falkner, S Moran, VL Colvin, JB Hughes and JH Kim. Reaction of water-stable C_{60} aggregates with ozone. *Environ. Sci. Technol.* 2007; **41**, 7497-502.

[9] M Nisoa, D Srinoum and P Kerdthongmee. Development of high voltage high frequency resonant inverter power supply for surface glow barrier discharges. *Solid State Phenom.* 2005; **107**, 81-6.

[10] R Ono and T Oda. Dynamics of ozone and OH radicals generated by pulsed corona discharge in humid-air flow reactor measured by laser spectroscopy. *Appl. Phys.* 2003; **93**, 5876-82.

[11] AA Garamoon, FF Elakshar, AM Nossair and EF Kotp. Experimental study of ozone synthesis. *Plasma Sci. Technol.* 2002; **11**, 254-9.

[12] EE Kunhardt. Generation of large-volume atmospheric-pressure nonequilibrium plasmas. *IEEE T. Plasma Sci.* 2000; **28**, 189-200.

บทคัดย่อ

หมุดตอเล็บ หนิสอ[1,2] และ ธรรมนูญ ศรีน่วม[1,2]

ลักษณะเฉพาะของการกำเนิดโอโซนด้วยเทคนิค Atmospheric Surface Glow Barrier Discharge

โอโซนเป็นตัวออกซิไดซ์ที่รุนแรงสามารถฆ่าแบคทีเรียอีโคไลและจุลินทรีย์อื่นๆได้อย่างมีประสิทธิภาพสูง ในปัจจุบันโอโซนมีบทบาทสำคัญมากในการพัฒนาเทคโนโลยีสำหรับบำบัดน้ำเพื่อใช้ในอุตสาหกรรมการเลี้ยงกุ้งและการบำบัดน้ำเสียจากโรงงานอุตสาหกรรมอาหาร แต่ในปัจจุบันระบบกำเนิดโอโซนที่มีขายอยู่ในท้องตลาดยังมีราคาแพงและประสิทธิภาพต่ำ ในงานวิจัยนี้จะนำเสนอการพัฒนาระบบกำเนิดก๊าซโอโซนและน้ำโอโซนที่มีประสิทธิภาพสูงและราคาไม่แพง โดยระบบดังกล่าวจะประกอบด้วยชุดทำอากาศแห้ง ชุดกำเนิดสัญญาณวิทยุความต่างศักย์สูง หลอดโอโซน และชุดการผสมโอโซนกับน้ำโดยการไหลแบบเว็นจูรี โครงสร้างของหลอดโอโซนจะทำให้ก๊าซออกซิเจนถูกเปลี่ยนเป็นก๊าซโอโซนโดยกระบวนการดิจชาร์จที่ทำให้เกิดพลาสมาเย็นที่ผิวของวัสดุไดอิเลคตริค

[1]หน่วยวิจัยพลาสมาประยุกต์เพื่อการกสิกรรม มหาวิทยาลัยวลัยลักษณ์ อำเภอท่าศาลา จังหวัดนครศรีธรรมราช 80161
[2]ThEP Center สำนักงานคณะกรรมการการอุดมศึกษา เลขที่ 328 ถนนศรีอยุธยา เขตราชเทวี กรุงเทพมหานคร 10400