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ULTRAVIOLET PLASMA FOR CYANOBACTERIA TREATMENT APPLICATION

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ABSTRACT

Plasma has been used widely in health and science application as deactivator agent. One of the plasma applications in health is in water treatment. The study was focused on generating ultraviolet (UV) plasma to substitute the method of chlorination in water treatment due to harmful effect of chlorination toward living things. UV plasma was successfully generated via Dielectric Barrier Discharge (DBD) in mercury-free electrodeless discharge tubes filled with non-toxic element such as argon and nitrogen gases. This is an alternative material as most of commercially available UV lamp is the one from mercury radiation, and mercury is known as a toxic material. Other than that, by using DBD as one type of electrodeless discharge (without internal electrode), the lamp lifetime can be improved as there is no chemical reaction between the electrodes and filling material as being applied in conventional type of discharge lamp. The study is conducted to observe the effectiveness of UV plasma radiation as an agent in deactivating cyanobacteria (Oscillatoria sp.) in a fresh water ecosystem. The effect of UV radiation on cyanobacteria (Oscillatoria sp.) was qualitatively observed. The UV plasma that produced need to meet the effective range of UV radiation which is thought at wavelength between 200 nm and 400 nm, and has higher intensity in order to help in deactivate the cyanobacteria (Oscillatoria sp.) effectively. The effect of UV plasma exposed towards the algae of cyanobacteria (Oscillatoria sp.) is studied morphologically at certain period of exposure. Experimental results showed that the UV plasma using mercury-free material give well-higher intensity and affect the most in deactivation of cyanobacteria (Oscillatoria sp.) compared to mercury-based lamp.

Keywords: ultraviolet, cynobacteria, dielectric barrier discharge (DBD), glow discharge.

INTRODUCTION

Many researchers, in the control of pathogenic microorganisms, are seriously considering the use of photochemistry and molecular dissociation involving ultraviolet (UV) for the disinfection of water and sterilization of surfaces [1-4]. One of the simplest and most effective sources for UV radiation is a low-pressure discharge in argon and mercury vapor that allows effective generation of radiation in the biologically active wavelength range of 240–280 nm, specifically at 254 nm that is responsible for modification of DNA (genetic material) and ultimately killing of biological entities such as bacteria [5]. Mercury-free sources by using inert gases mixture with halogen element such as Xe-I and Kr-Cl also show an interesting results as an alternative to mercury-based source [6-8].

Plasma is the fourth state of matter. In a simple word, plasma is an ionized gas, a gas into which sufficient energy is provided to free electrons from atoms or molecules and to allow species, ions and electrons, to coexist. Plasma is a partially ionized gas containing an equal number of positive and negative charges, as well as some other number of none ionized gas particles. Plasma can be seen as a collection of particles that is (at least partially) charged and sensitive to electromagnetic forces. The plasma that being used for this study is a cylindrical glass tube that filled with different kind of gases and pressure such as nitrogen, argon and mercury at 1 Torr and 10 Torr. The research is being conducted as trying to make some different compared to others UV water treatment because the inert gaseous that will be used which are more environmental friendly compared to mercury. The research is applying Dielectric Barrier Discharge (DBD) which is a type of electrodeless (without internal electrode) in order to develop a long lifetime UV lamp.

Harmful Algae Blooms (HABs) such as blue-green algae (Oscillatoria sp.) have become a serious major problem in aquatic environment all over the world. Algae blooms are a common occurrence in aquatic environments. A subset of these blooms poses environmental or human health threats, and it is therefore referred to as “harmful algae blooms,” or HABs. Some of them are harmful by virtue of their sheer biomass, whereas others are capable of producing toxins [9-10]. Due to this, many scientists have focused on ways to control HABs but the present ways lead to few disadvantages such as high manufacturing cost and low environmental friendly. Effect of nature UV from solar radiation on cyanobacteria has been studied by Nadeau *et al* [11], where the impact of radiation and temperature on cyanobacteria activities has been reported. In this study, the inhibition effect of the artificial UV plasma to the growth of Oscillatoria sp. has been investigated.

A major advantage of UV treatment is the UV disinfection which is capable of disinfecting water faster than chlorine without cumbersome retention tanks and harmful chemical disinfectants. UV radiation is an alternative to chlorination for deactivation or kills microorganisms in water treatment application. In this age, normally investor will use chemical such as copper sulphate for water treatment. The research is introducing

mercury-free UV source for another source of light as most of light contains mercury which is very harmful.

As mentioned above, focus of the research is to determine the level of effectiveness of UV plasma for cyanobacteria (Oscillatoria sp.) treatment application. The study is on the UV plasma which the main aimed is to identify the effect of UV plasma at wavelength range from 200 nm to 400 nm. In order to produce the UV plasma, DBD has been applied. Once the plasma is produced, the UV radiation from plasma emission will be used to be tested for water treatment. The water treatment involved the samples of Oscillatoria sp., one of the families of cyanobacteria blue-green algae and the samples are being exposed under the UV plasma radiation for a certain period of hours to see the morphology effect on the algae surface.

EXPERIMENTAL SETUP

Experimental setup covers from the selection of discharge tube, plasma generation (electrical setup), optical properties measurement (emission spectra), followed by biological part (culturing cyanobactreria) and evaluation part (UV treatment).

Discharge tube

Commercially available mercury UV lamp with diameter and length of 15 mm and 300 mm respectively was used. For mercury-free lamp, a custom-made N_2 and Ar-N_2 lamps were used with different gas pressure at 1 Torr and 10 Torr. N_2 and the mixture of AgrN_2 were used due to strong near UV emission can be obtained from those gases. Tube diameter and length are 10 mm and 200 mm respectively. Aluminium tape was used as a medium to transfer the electric energy across the glass tube.

Discharge circuit

Connection diagram is shown in Figure-1. DC power supply is connected to the ballast which act as converter (from DC to AC), amplifier (increase the voltage up to few hundreds volt) and also as a controller to control the current flow. The voltage input to the discharge tube can be controlled by adjusting the value of DC voltage range from 5 V to 15 V which can produce an output voltage up to 800 V.

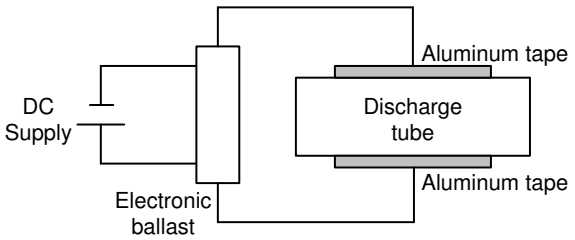

Figure-1. Diagram of the discharge circuit.

Electrical and optical measurement

The circuit is connected with the oscilloscope in order to measure voltage, current and frequency. Discharge and current voltages were recorded for each condition of the measurements. In order to obtain power consumption of the lamp, Ohm's law is applied. Emission spectra measurement is important in order to know spectral distribution and output wavelength from each discharge condition. This is important to ensure the UV radiation is produced and its intensity can be recorded. For emission spectra emission, Ocean Optics Spectrometer model USB4000-UV-VIS, capable to measure spectral distribution from 200 nm to 900 nm has been used.

Cyanobacteria culture

In preparing BG-11 (medium for blue-green algae) agar media, 7.5 g of 1.5% bacteriological agar was dissolved into 300 ml of distilled water inside 1 L bottle. Then, the mixture was autoclave at 121 ˚C (20 min, 1atm). In 500 ml of sterile volumetric flask, the mixture was transferred and 10 ml of BG-11 stock media was added. Sterile distilled water was added into the solution until final volume of 500 ml was achieved. The media was poured onto sterile petri dish and allowed to cool. For preparing BG-11 liquid media 980 ml of distilled water was autoclaved at 121 ˚C (20 min, 1atm). Then, 20 ml of BG-11 stock media was added. The media was then kept in the refrigerator. The cultures were incubated and maintained under continuous illumination of cool fluorescent light at 20 °C. After 3-5 days, the growth of blue-green strain of Oscillatoria sp. will be obviously observed by naked eye on the agar medium. Using a sterile forceps, the strain was isolated and transferred onto new agar plate. Isolation step was taken until pure culture was obtained.

Treatment of oscillatoria sp.

As the physical parts and biological part is done, the method is followed by final step of treat the Oscillatoria sp. agar media samples under UV radiation. The treatment is being carried out in a room that turn on the air conditioning system where the temperature is kept at 20 °C, and with lighting system for 24 hours in order to keep the algae at best condition. The treatment was done in a transparent box so that the algae able to receive light. The distance between the UV plasma discharge tube and the sample is being fixed at 4 cm. For each tube, there are two samples used in each time. One of the samples is being exposed under UV radiation while the other one is left without UV exposure under room condition.

RESULTS AND DISCUSSION

The results is discussed based on the electrical and optical characteristics that have been obtained, and how effective the produced UV radiation on cyanobacteria.

Electrical and optical parameters

Input voltage, discharge current, power consumption and frequency applied are shown in Table-1 below. For lamp filled with argon, nitrogen, and mixture of both gases, the voltage needed is higher than mercury

lamp. This is due to breakdown voltage for argon and nitrogen is higher than mercury. Those gases are non-reactive gas, thus they need high energy to be ionized. However, discharge current for mercury lamp is higher. This can be thought because mercury need low voltage to be discharged, thus their gas resistivity is low that can allow more current flow across the tube. Frequency value is same due to the same ballast was used. The frequency is control by the ballast to be same even input voltage is adjusted.

Table-1. List of electrical values for each lamp.

Lamp type	Voltage V_{pp} (V)	Current I_{pp} (mA)	Power (W)	Frequency (kHz)
N_2 (1 Torr)	410	3	1.2	42
N_2 (10 Torr)	390	2	0.8	42
Ar-N_2 (1 Torr)	430	3	1.3	42
Ar-N_2 (10 Torr)	520	10	5.4	42
Fluorescent (Hg-Ar)	240	11	2.75	42

Emission spectra for each condition are show from Figure-2 to Figure-6. As can be seen from the figures, strong UV emission range from 300 nm to 400 nm (near UV region) for nitrogen-based discharge. For mercury discharge, strong emission line at 254 nm can be observed. Emission spectra range from 700 nm to 850 nm which mainly laid on infra-red (IR) region is from argon radiation. Argon act as buffer gas to apply Penning effect on the discharge in order to reduce ionization voltage. The effect of UV on bacteria is strongly depend on what wavelength of UV emission can be obtained from the source and from the present results, UV radiation at around 350 nm give a better inactivation effect of algae. From the results, for mercury-free lamp UV emission for Ar-N_2 (10 Torr) discharge produced the highest intensity and this also contribute on the effect of the system. However, as in terms of input voltage and power consumption, higher value is needed. The optimization of

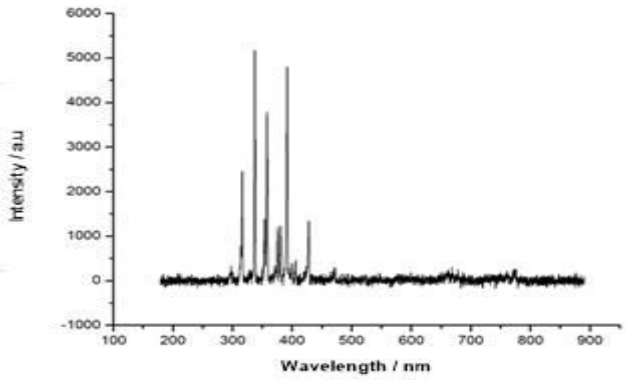

Figure-2. Emission spectra for N_2 discharge at 1 Torr.

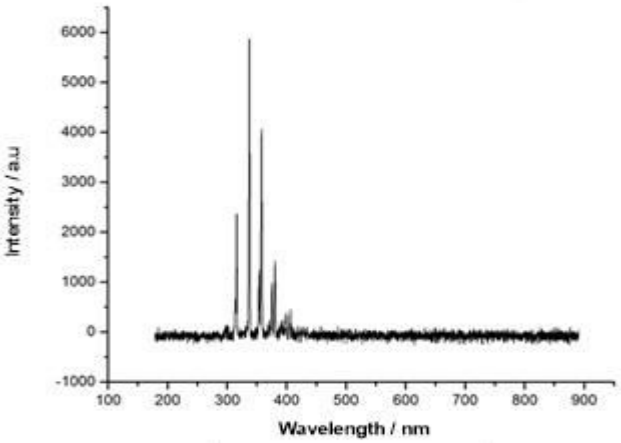

Figure-3. Emission spectra for N_2 discharge at 10 Torr.

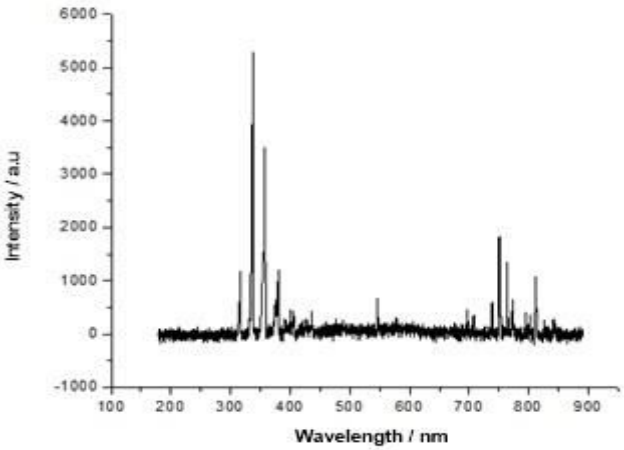

Figure-4. Emission spectra for Ar-N_2 discharge at 1 Torr.

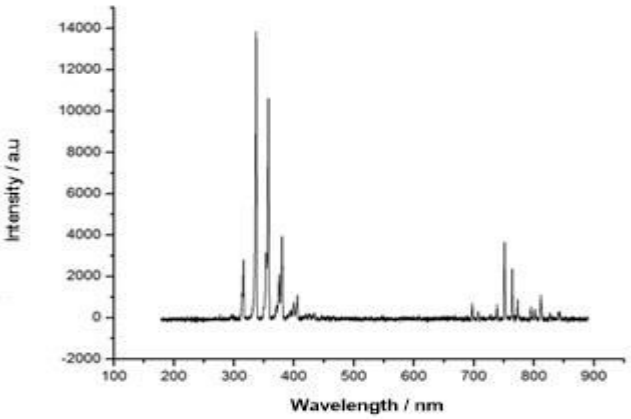

Figure-5. Emission spectra forAr- N_2 discharge at 10 Torr.

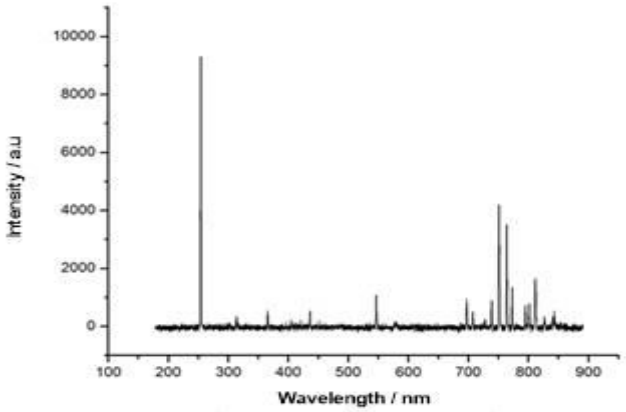

Figure-6. Emission spectra for commercial Hg lamp discharge.

Effect of UV plasma on cyanobacteria

The treatment process took time for about at least two hours before Oscillatoria sp. react towards the plasma radiation. Basically, the treatment process is to observe the changes in the color of Oscillatoria sp. after certain period or the morphologically effect on Oscillatoria sp. The treatment is being carried out up to 12 hours. The UV plasma slowly deactivated the Oscillatoria sp. where the treatment process took time for about at least two hours before Oscillatoria sp. react towards the plasma radiation. Basically, the treatment process is to observe the changes in the color of Oscillatoria sp. after certain period or the morphologically effect on Oscillatoria sp. The deactivation of Oscillatoria sp. is said to be succeed as the effect on the surface can be clearly seen. However, how much percentage of the bacteria that has been deactivated cannot be count as the sample is in agar media and not in a liquid form. Thus, the effect is just qualitatively counted for this treatment. The treatment has been done in transparent box in order to let the algae still get light and keep in good humidity. Biologically, algae is considered inactive if it did not get enough supply of light and humidity. Therefore, insufficient of light and humidity will not be the factor of the algae inactivation but the UV plasma itself. Comparison of UV plasma produced via DBD for discharge tube and UV commercial lamp can be seen in Figure-5 and Figure-6. From the emission spectra results, the intensity of UV radiation of discharge tube Ar-N_2 (10 Torr) is higher, thus it helps in deactivation process during treatment compared to UV commercial lamp. Result of deactivated Oscillatoria sp. samples of both ultraviolet plasma as shown in Figure-7 and Figure-8 below for before and after treatment. Sample that has being exposed to discharge tubes of Ar-N_2 (10 Torr) qualitatively look deactivated at most of the surface but the one treated under UV commercial lamp was not even though both of it were exposed at same period of time for eight hours. It shows that intensity of plasma also affect the treatment of Oscillatoria sp. Another reason would be UV emission from Ar-N_2 discharge which is strong at 300 nm – 400 nm is more effective compared to emission line at 254 nm of commercial UV lamp. However, effect on which particular wavelength that most effective need a further study.

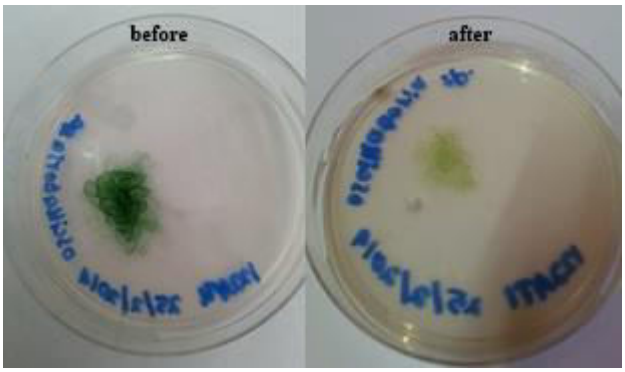

Figure-7. Sample of Oscillatoria sp. before and after treated under Ar-N_2 (10 Torr) discharge.

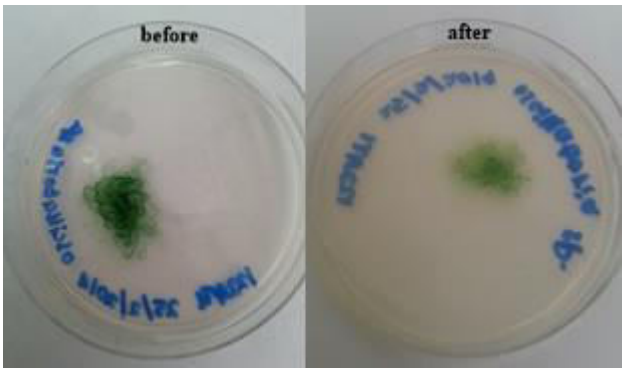

Figure-8. Sample of Oscillatoria sp. before and after treated under commercial UV lamp discharge.

CONCLUSIONS

This novel approach of UV plasma radiation effects toward blue-green algae has proved its effectiveness. This will give great interest for future research and further development of this system as the water treatment agent instead of conventional chlorine treatment. Development of this type of environmental-friendly plasma treatment is still new in algae inactivation, still lot of work need to be done. However from this present work, the initial results has shown a potential of the algae treatment using this method. The work is ongoing.

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