Exploiting the synergy of a broad spectrum of light & surface dielectric barrier discharge (SDBD) plasma for ozone (O_3) production

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Abstract

Surface Dielectric Barrier Discharge (SDBD) plasma has been combined with UVC and Violet light to investigate the synergy for enhanced production of O_3 and NO_2 radicals at various duty cycle (DC). A two way detection system namely environmental sensors(O_3 and NO_2) and optical absorption (OAS) have been used to validate the realtime concentration of long lived O_3 and NO_2 species. The synergy from coupling UVC and violet lights with DC greater than 25% is observed.

Introduction

In the last few decades, Non Thermal Plasma (NTP) has been widely invesitgated for its unique behaviour of creating an environment where the neutrals and ions remains at ambient temperature as compared to the electrons and ability to degrade very noxious volatile organic compund (VOC) and harmful microorganism. A **broth** of chemically active species, collectively named as RONS (Reactive Oxygen and Nitrogen Species) along with free electrons, radicals, ions are produced due to physico-chemical reaction in gas phase. These plasma constituents includes ozone (O_3), various oxides of nitrogen (NO_x), $OH\cdot, O_2^-, O_2^*, N_2^*$ etc. among which O_3 is very stable species capable of abating various organic pollutant and microorganism, for instance, bacteria, virus, fungi and spores. Ozone (O_3) is one of the powerful oxidants for advanced oxidation process but could pose a threat to human health if the concentration exeeds a certain critical value set by Directive 2008/50/EC.

Among various methods reported by several groups, for the generation of NTP, dielectric barrier discharges (DBDs) is the most widely used techniques where plasma is ignited between two electrodes sperated by a dielectric layer using high voltage and high frequecy AC current or pulsed DC operating at atmospheric pressure. However, another subclass of DBDs, primarilly designed for airflow control in aerodynamic system(Biganzoli et al., 2013). Surface Dielectric Barrier Discharge (SDBD) or plasma actuator where the discharge is confined to the electrode surface has been exploited in this investigation for abating bacterial sample. Incorporation of wide spectrum light sources increase reactivity of the system and therby aid to enhanced production of reactive species and improve deactivation efficacy [(Sheng et al., 2024)]. Herein, a SDBD plasma, wide spectrum light sources, for instance, UVC-275 nm and violet-405nm have been combined together to form a hybrid system for the elevated production of RONS (O_3, NO_2) and the concentration have been estimated by optical absorption spectroscopy and a couple of environmenmtal sensors.

Materials and Methods

The experimental setup used in this investigation combining the SDBD, UVC and Violet light sources is depicted in figure-1. The SDBD equipment has been built with a quartz tube (diameter: 15mm and length: 80mm) having stainless steel mesh (20mm length) surrounded inside and outside of the quartz tube to form a coaxial geometry. The whole arrangement with a high volatge transformer driven by a MOSFET have been housed in a PMMA tube of 118mm length and 32/35 mm diameter. For feeding gas to the system a 40mm DC fan has been attached to the PMMA tube to supply air into the hybrid system. The UVC-275nm and Violet-405nm lights (12 lights each) were also attached inside of a PMMA tube (on bottom) after the SDBD plasma unit.

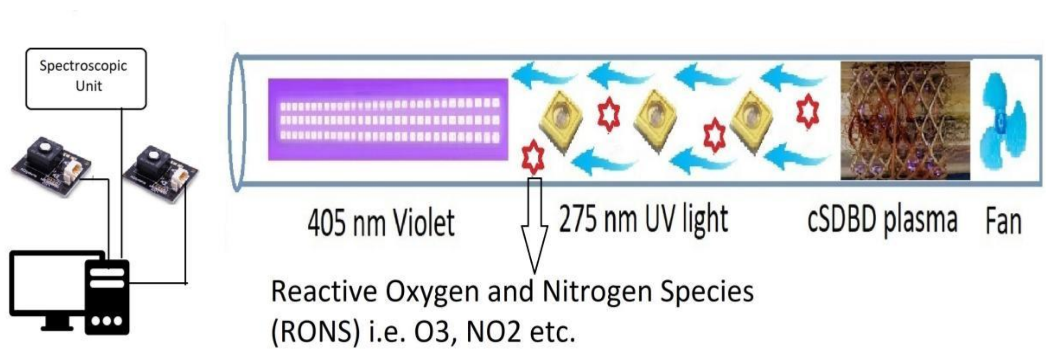

Figure-1: Hybrid SDBD plasma, UVC and Violet lights equipment

For OAS, the spectroscopic unit was placed outside of the PMMA tube in order to pass light (UV lawtranics centered at 253.7) and the measurment of absorption was carried out with different experimental conditions by an optical fiber probe and AvaSpec-ULS4096CL-EVO spectrometer of resolution 0.3 nm and wavelength of 200-1100 nm range. Besides OAS, two individual polymer electrochemical sensors have been used for the measurement of O_3 (TB 600B range: 0~5 ppm and resolution: 0.01ppm) and NO_2 (TB 600B&C range: 0~5 ppm and resolution: 0.01ppm). Humidity and temeprature data were also captured using these sensors. The power measurement was carried out by placing a series capacitor (10nF) using high volatge and current probe attahced to digital storage oscilloscope (RS PRO RSDS1304CFL 4 channel 300 MHz)(Piferi et al., 2021).

Results and Discussion

The duty cycle (1~25%) of the plasma generating circuit was varried to finetune the RONS concentrations. The typical on period of the pulse was kept constant at 1 ms and off time was varried (99~3 ms) in order to tailor the optimum condition for ozone and nitrite concentration. Power dissipated in the SDBD discharge is geometrically calculated as the area covered inside of the Lissajous figure and is summerised in Table-1. The concentration of O_3 and NO_2 determined from environmental sensors were also presented in the same table.

Duty cycle (%)	1	1*	2	2*	3	3*	4	4*	5	5*	10	10*	25	25*
Power (mW)	14		26		33		52		59		128		324	
O_3 (ppb)	54	61	131	137	182	197	251	263	360	378	698	736	**1096**	**1310**
NO_2 (ppb)	110	111	234	240	349	365	464	459	679	727	1382	1459	**1825**	**2565**

Table-1: Power dissipataion, O_3 and NO_2 concentration as a fucntion of duty cycle [* SDBD plasma, UVC and Violet light were combined]

Both ozone and nitrite concentration increased with increasing duty cycle. For each duty cycle (DC) two sets of experiments were conducted plasma only and plasma, UVC and Violet combined*. From 1~20% DC the concentrations were nearly similar for both the conditions but a synergy is present when the DC is 25% as can be seen from the concentration presented in the table. To prove this phenomena OAS experiments have been conducted where absorption were measured at 253nm for O_3 and 365nm for NO_2. Futher the intensities absorbed from the spectrometer were used to estimate the coresponding concentration by beer-lambert law. A considerable increase in the concentration in $molecules/cm^3$ were observed for both ozone and nitrite.

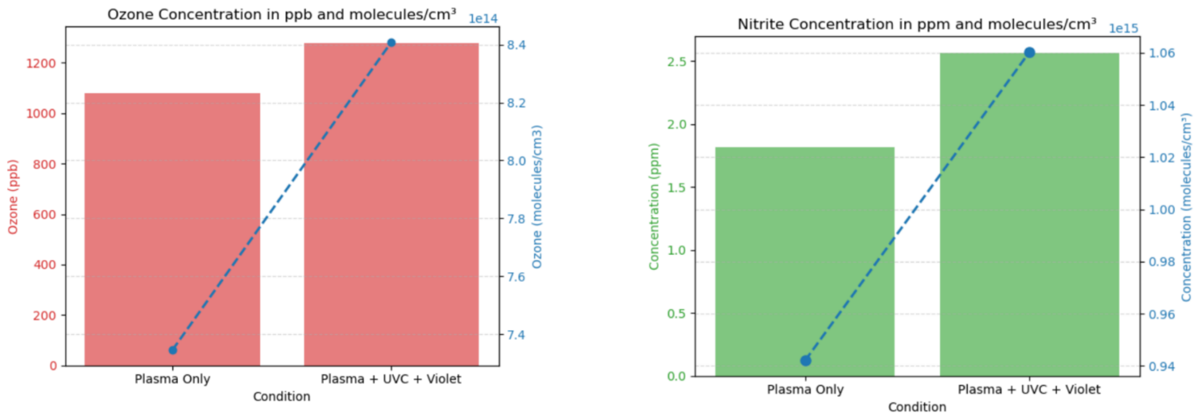

Figure-2: Ozone and Nitrite concentration at 25% duty cycle measured with OAS (lines) and sensors (bars).

The synergistic effect may arise from the fact that, UVC and violet light could produce photon strong enough to increase the population of vibrationally excited atomic oxygen at downstream where the oxygen molecules recombine with atomic or excited group to increase the overall concentration (Brown and Vaida, 1996). The reaction pathway could be followed as (1) $(O_2)_2 \xrightarrow{h\nu} O_3 + O$, (2) $O_2 + O = O_3$, and (3) $NO + O \xrightarrow{h\nu} NO_2$. Both measurement techniques, sensors and OAS, show similar trend with 25% DC and may happen due to the absorption of light energy by vibrationally excited molecules to assits in more O_3 and NO_2 formation.

Conclusions

An enhanced production of ozone and nitrite have been achieved with hybrid SDBD plasma, UVC and violet light sources at an specific duty cycle (~25%). In short, SDBD plasma with UVC and Violet light induced photons may contribute to this noble synergistic phenomena .

Acknowledgments

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