OPERATING CHARACTERISTICS AND BIO APPLICATION OF AN ATMOSPHERIC DIELECTRIC BARRIER DISCHARGE

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Lai Chee Kin

July 2011

ABSTRACT

This research project involved the construction of a dielectric barrier discharge (DBD) system capable of producing low temperature plasma at atmospheric pressure. The DBD was characterized for the purpose of investigating the effectiveness of low temperature plasma for inactivation of bacteria such as *Escherichia coli, Salmonella enteritidis,* and *Bacillus cereus.*

The discharge was ignited in the air gap between two parallel copper disc electrodes (3.8cm diameter each) where one of the electrodes was insulated by a dielectric barrier. Glass (ε_r = 7.5, thickness = 2mm) and alumina (ε_r = 9.0, thickness = 1.0mm) were used as the barrier. The DBD was powered by a H.V. generator that utilizes a MOSFET driven car ignition transformer capable of producing up to 25kV peak-to-peak voltage with "unipolar" voltage pulsed mode at frequency of (0.1-2.5)kHz and sinusoidal voltages at 6.5kHz and above.

Electrical characteristics of the discharge were studied for air-gap widths of 0.5mm, 1.5mm, and 3.0mm. At atmospheric pressure, the discharge could be ignited when the average electric field in the air-gap exceeded 3.2kV/mm. The ignition of the discharge was evident from the existence of current spikes occurring at the rising and falling edges of the voltage signal. The current spike with FWHM~20ns corresponds to the short-lived microdischarge typically found in atmospheric air DBD. Alumina barrier (higher ε_r) was found to produce more microdischarges (80000$cm^{-2}s^{-1}$ in sinusoidal voltage mode) in comparison to glass barrier (40000$cm^{-2}s^{-1}$). However, alumina barrier DBD seems to be more filamentary in appearance indicating stronger memory effect in the alumina dielectric. "Unipolar" pulsed DBD operation also appears more diffuse than sinusoidal voltage DBD (higher frequency).

Prominent strong bands (300-400nm) from the second positive system (SPS) of nitrogen molecule and weak bands/lines from OH, O, and O_2 were observed. However, UV-A and UV-B radiation lethal to bacteria is low.

DBD operating conditions for bacteria inactivation were set at 1.5mm air-gap (ease of insertion of bacteria sample) with glass barrier (economical and easily available), and at both voltage excitation modes for comparison. From the measured survival rates for the bacteria; it is found that the 8.5kHz sinusoidal voltage DBD of higher power density was more efficient for sterilization than the 500Hz "unipolar" pulsed mode. A 3-log reduction of bacteria CFU was obtained and complete inactivation was achieved in 1min for most cases. Sterilization rate was highest for *Salmonella enteritidis* and lowest for *Bacillus cereus.* It was deduced that the inactivation of bacteria is contributed by (i) charged particles in the active plasma column (more significant), (ii) reactive species (e.g. O, OH, O_3) (less significant), and (iii) UV radiation (less significant).

ABSTRAK

Projek kajian ini melibatkan pembinaan sistem nyahcas penghalang dielektrik (DBD) yang mampu menghasilkan plasma suhu rendah pada tekanan atmosfera. DBD ini telah dicirikan untuk tujuan mengkaji keberkesanan plasma suhu rendah untuk inaktivasi bakteria seperti *Escherichia coli*, *Salmonella enteritidis*, dan *Bacillus cereus*.

Nyahcas ini dihidupkan di dalam jurang udara antara dua elektrod cakera kuprum selari (3.8cm diameter masing-masing) di mana salah satu elektrod ditebatkan dengan penghalang dielektrik. Kaca (ε_r = 7.5, tebal = 2mm) dan alumina (ε_r = 9.0, tebal = 1.0mm) digunakan sebagai penghalang tersebut. DBD ini dibekalkan kuasa daripada suatu penjana voltan tinggi yang menggunakan transformer pencucuh kereta pacuan MOSFET untuk menghasilkan voltan puncak-ke-puncak sehingga 25kV pada frekuensi (0.1-2.5)kHz bagi mod denyutan voltan "ekakutub" dan 6.5kHz ke atas bagi voltan sinusoid.

Ciri-ciri elektrik bagi nyahcas ini dikaji pada jarak ruang udara 0.5mm, 1.5mm, dan 3.0mm. Pada tekanan atmosfera, nyahcas boleh dihidupkan bila medan elektrik purata dalam ruang udara melebihi 3.2kV/mm. Pencucuhan nyahcas adalah jelas dengan kewujudan arus tercacak yang berlaku pada bahagian isyarat voltan yang menaik dan menurun. Arus tercacak dengan FWHM~20ns adalah sepadan dengan mikro-nyahcas berhayat pendek yang biasanya diperhatikan dalam DBD udara atmosfera. Penghalang alumina (ε_r lebih tinggi) boleh menghasilkan lebih mikro-nyahcas ((80000cm^{-2}s^{-1} dalam mod voltan sinusoid) berbanding dengan penghalang kaca (40000cm^{-2}s^{-1}). Namun demikian, DBD penghalang alumina nampaknya lebih berfilamen dan ini menandakan kesan memori lebih tinggi dalam dielektrik alumina. Operasi DBD denyutan "ekakutub" juga nampaknya lebih resap berbanding dengan DBD voltan sinusoid (frekuensi lebih tinggi).

Jalur terang yang paling menonjol (300-400nm) daripada sistem positif kedua (SPS) molekul nitrogen dan jalur/garis lemah daripada OH, O, dan O_2 telah diperhatikan. Namun begitu, sinaran UV-A dan UV-B yang membunuh bacteria adalah rendah.

Keadaan pengendalian DBD untuk pentakaktifan bakteria ditetapkan pada jurang udara 1.5mm air-gap (mudah untuk menyelitkan sampel bacteria) dengan penghalang kaca (berekonomi dan mudah diperolehi), dan pada kedua-dua mod voltan pengujaan untuk perbandingan. Daripada kadar kemandirian bakteria yang diukur, didapati DBD voltan sinusoid pada 8.5kHz dengan ketumpatan kuasa lebih tinggi adalah lebih berkesan dalam inaktivasi bakteria berbanding dengan mod denyutan ”ekakutub” pada 500Hz. Pengurangan 3-log dalam unit pembentuk koloni (CFU) bacteria diperolehi dan pensterilan dicapai dalam 1min bagi kebanyakan kes. Kadar pensterilan adalah paling tinggi bagi *Salmonella enteritidis* dan paling rendah bagi *Bacillus cereus.* Disimpulkan bahawa pentakaktifan bakteria disebabkan oleh (i) zarah bercas dalam turus plasma aktif (peranan utama), (ii) spesies reaktif (misalnya O, OH, O_3) (kurang peranan), dan (iii) sinaran UV (kurang peranan).

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K	kelvin
eV	electron volt
ns	nano-second
A	ampere
cm	centimeter
nC	nano Coulomb
µm	micrometer
kA	kiloampere
pF	pico farad
MHz	megahertz
MΩ	mega-ohm
Å	angstrom
^{o}C	degree celcius
H	henry
L	inductance
I	current
E	electric field
e	electron
α	first Townsend ionization coefficient
γ	secondary emission coefficient
d	air-gap
f	function / frequency
p	pressure
v_d	drift velocity of electron

ε_r	dielectric constant
C	capacitance
A	area of the electrode
d	thickness of the dielectric layer
DBD	dielectric barrier discharge
UV	ultra violet
OAUGDP	One Atmosphere Uniform Glow Discharge Plasma
RF	radio frequency
H.V.	high voltage
IF	inactivation factor
SEM	scanning electron microscope
AC	alternating current
USB	universal serial port
SLR	single len reflex
CCD	charge-coupled device
FWHM	full width half maximum
TNTC	too numerous to count
SPS	second positive system
RMS	root mean square
CFU	Colony Forming Unit