TEMPERATURE PROFILE OF PACKED-BED NON-THERMAL PLASMA REACTOR AND ITS EFFECT ON TOLUENE DECOMPOSITION

NUR ZAZWANI BINTI ROSDI

UNIVERSITI TEKNOLOGI MALAYSIA

TEMPERATURE PROFILE OF PACKED-BED NON-THERMAL PLASMA REACTOR AND ITS EFFECT ON TOLUENE DECOMPOSITION

NUR ZAZWANI BINTI ROSDI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Physics)

Faculty of Science
Universiti Teknologi Malaysia

AUGUST 2017

DEDICATION

To Allah (SWT),
To my beloved parents,
Rosdi Salleh and Che Salbiah bt Awang Mat,
To my husband,
Mohd Akram Mat Deris
To my son,
Muhammad Aqil Hadif
And to my siblings,
Mohd Zulhilmie, Nur Izzati ,Mohammad Zahran, and Muhammad Zulhazreen

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful. First and foremost, I would like to express my feeling of gratitude to Allah (SWT) for giving me strength and His blessing to successfully complete this PhD’s thesis. I would like to thank my dedicated supervisor, Dr. Raja Kamarulzaman Raja Ibrahim for his supervision, mentoring and guidance for the past four years of my PhD’s journey. Your prompt attentions, constructive comments, unending patience, priceless help and suggestions are highly appreciated.

I wish to thank lab staffs of Laser Center of Physics Department, Mr. Sauffie and Mr. Nasir for their technical assistance and not forgotten to my research group members, especially Siti Musliha Aishah Musa, Nursyahirah Mustapha, Elham Mazlan, Mohd Naqiuddin and Mohd Iqbal for their help in completing my lab works and moral support. I would like to acknowledge the financial support from Universiti Teknologi Malaysia to complete the technical work in the lab.

Most importantly, I would like to thank also to my parents for their unending support and love, who instilled in me the importance of education and always support me in all my life decisions. Also, thanks to my husband for always listening and lending your shoulder throughout completing this work. His love and care over four years has been invaluable to me.

ABSTRACT

This study aims to profile real plasma temperature inside the packed-bed (PB) non-thermal plasma (NTP) reactor using a fiber Bragg gratings (FBG) and its effect on toluene decomposition efficiency. PB reactor was designed and fabricated by packing some dielectric material of barium titanate ($BaTiO_3$) pellets between two stainless steel electrodes. The FBG was embedded inside the reactor to measure the plasma temperature within the plasma stream. Plasma temperatures for four carrier gases, helium (He), argon (Ar), nitrogen (N_2), and air were profiled at different applied voltages ranging between 4 and 16 kV based on their breakdown voltage to determine suitable gases for toluene decomposition process that has good temperature stability and no arc formation. For noble gases He and Ar, the plasma temperatures are in the range of 25-80°C and 60-170°C, respectively, while those of N_2 and air are in the range of 28-200°C. Air was selected as carrier gas for toluene decomposition process due to higher plasma temperature, no arc formation and higher free oxygen radicals in the plasma stream. The results show that the plasma temperature increases with the increase in applied voltage, and with the decrease in flow rate and toluene input concentration. The average plasma temperature for toluene decomposition in air is in the range of 100-260°C when measured under applied voltage of 14-19 kV, carrier gas flow rate of 1.0-2.0 L/min and toluene input concentration of 500-8400 ppm. Complete toluene decomposition efficiency has been achieved under plasma parameters of 18 kV, 2.0 L/min and 500 ppm. From this finding, plasma temperature profiling using FBG sensor can be used as plasma diagnostic tool to replace Fourier Transform Infrared spectroscopy (FTIR) instrument and as indicator when toluene decomposition process is complete.

ABSTRAK

Kajian ini bertujuan untuk memprofilkan suhu sebenar plasma di dalam *packed-bed* (PB) reaktor plasma bukan terma (NTP) menggunakan parutan gentian Bragg (FBG) dan kesannya terhadap kecekapan penguraian toluena. Reaktor PB direkabentuk dan difabrikasi dengan memadatkan sejumlah bahan dielektrik barium titanat ($BaTiO_3$) pelet di antara dua elektrod keluli kalis karat. FBG dimasukkan ke dalam reaktor untuk mengukur suhu dalam aliran plasma. Suhu plasma bagi empat gas pembawa, helium (He), argon (Ar), nitrogen (N_2), dan udara telah diprofilkan pada voltan berbeza antara 4 dan 16 kV berdasarkan voltan rosak mereka untuk mencari gas yang sesuai untuk proses penguraian toluena yang mempunyai kestabilan suhu yang baik dan tiada pembentukan arka. Untuk gas lengai He dan Ar, suhu plasma masing-masing berada dalam lingkungan 25-80°C dan 60-170°C, manakala untuk N_2 dan udara berada dalam lingkungan 28-200°C. Udara dipilih sebagai gas pembawa untuk proses penguraian toluena disebabkan faktor suhu plasma yang lebih tinggi, tiada pembentukan arka dan lebih banyak penghasilan radikal oksigen bebas dalam aliran plasma. Keputusan menunjukkan suhu plasma bertambah dengan peningkatan voltan, dan dengan pengurangan kadar aliran dan kepekatan input toluena. Suhu purata plasma untuk penguraian toluena dalam udara berada dalam lingkungan 100-260°C apabila diukur pada voltan antara 14-19 kV, kadar aliran gas pembawa 1.0-2.0 L/min dan kepekatan input toluena 500-8400 ppm. Kecekapan penuh penguraian toluena dicapai pada parameter plasma 18 kV, 2.0 L/ min dan 500 ppm. Daripada dapatan ini, pemprofilan suhu plasma menggunakan penderia FBG boleh digunakan sebagai alat diagnostik plasma untuk menggantikan instrumen spektroskopi inframerah transformasi Fourier (FTIR) dan sebagai penanda apabila proses penguraian toluena lengkap.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ABBREVIATION

A - Absorbance

Ar - Argon

A_e - Area under experimental toluene absorption band

A_s - Area under standard database toluene absorption band

AC - Alternating Current

ATR - Attenuated Total Reflectance

Ar - Argon

APPJ - Atmospheric Pressure Plasma Jet

$BaTiO_3$ - Barium titanate

BTEX - Benzene, Toluene, Ethyl benzene and Xylene

DBD - Dielectric Barrier Discharge

C - Carbon

C.C - Continuous Current

CD - Corona Discharge

CFCs - Chlorofluorocarbons

CH_4 - Methane

CO - Carbon monoxide

CO_2 - Carbon dioxide

C_7H_8 - Toluene

c - Molar concentration

DC - Direct Current

ESP - Elecrostatic precipitators

EPA - Environmental Protection Agency
Ɛ - Molar absorptivity
ē - Electron
FBGs - Fiber Bragg Gratings
FTIR - Fourier Transform Infrared Spectroscopy
GAD - Gliding Arc Discharge
Ge - Germanium
GPIB - General Purpose Interface Bus
HD - High – intensity arc Discharge
HNO_3 - Nitric acid
He - Helium
Hg - Mercury
HV - High Voltage
H_2O - Water
H_2O_2 - Hydrogen peroxide
I - Intensity transmitted light
I_o Intensity of incident light
KBr - Potassium bromide
L - Grating length
L_m - Pathlength experimental
L_s - Pathlength standard gas
LTE - Localized Thermodynamic Equilibrium
l - thickness
MnO_2 - Manganese dioxide
NIST - National Institute of Standards and Technology
NTP - Non-Thermal Plasma
Ne - Neon
NO - Nitrogen oxide
NO_x - Nitrogen oxides

NO_2 - Nitrogen dioxide
N_2 - Nitrogen
N_2O - Nitrous oxide
N_s - Concentration standard database (100 ppm)
n_e - Electron density
n_{eff} - effective refractive index
OH - Hydroxide
OES - Optical Emission Spectrometer
OSA - Optical Spectrum Analyser
O_2 - Oxygen
O_3 - Ozone
PB - Packed- Bed
PD - Pulsed Discharged
PE - Polyethylene
P - Power
PM - Particulate matter
PMT - Photomultiplier tube
PM_{10} - Coarse particle
$PM_{2.5}$ - Fine particle
ROS - Reactive Oxygen Species
RSM - Response Surface Methodology
SD - Surface Discharge
SVE - Soil Vapor Extraction
SO_2 - Sulfur oxide
TP - Thermal Plasma
T - Temperature
T_{avg} - Average temperature
T_e - electron temperature
T_g - gas temperature

T_i - ion temperature
T_o - Heavy particles temperature
T_{rot} - Rotational temperature
T_v - Vibrational temperature
t - Time
TiO_2 - Titanium dioxide
UV - Ultraviolet
VD - Volume Discharge
VOCs - Volatile Organic Compounds
V - Voltage
α - Thermal expansion coefficient
ζ - Thermo – optic coefficient
λ - Wavelength
λ_B - Bragg wavelength
λ_{Bo} - Initial Bragg wavelength
$\Delta\lambda_B$ - Bragg wavelength shift
ΔT - Temperature difference
Λ - Bragg grating period
Ƴ-Al_2O_3 - Gamma alumina

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Plasma, also referred to as ‘ionized gas’ is generated when thermal, electrical or light energy reacts with a gas. An electron is moved out from the gas atom outermost shell, and thus forms a collection of free-moving ions and electrons. Plasma is divided into two general categories, namely, thermal plasma (TP) and non-thermal plasma (NTP). In thermal plasma, all species of particles, including neutral atoms, neutral molecules, ions and electrons, are in thermal equilibrium. Meanwhile, in NTP, most of the discharged energy is transformed into the production of high energetic electrons, instead of heating the neutral and ions that remain at or near room temperature. Therefore, the electrons, ions and neutrals are not in thermal equilibrium. This NTP technology with a high production of energetic electrons leads to a higher production of active chemical species, and thus becomes a promising tool for numerous applications, including surface treatment, plasma actuators, biomedical domain, sterilization, plasma medicine, as well as environmental and industrial pollutant abatement [1–5]. This NTP technology is widely used to treat various environmental pollutants such as diesel exhaust cleaning [6], water treatment [1,7] , air pollutants [8–10] and Volatile Organic Compounds

(VOCs) [11–16]. VOCs are carbon-based chemicals that can easily evaporate to vapor or gas at room temperature, due to their low boiling point. Some examples of VOCs include benzene, toluene, xylene (BTEX), styrene, methane, ethane, methyl chloride and formaldehyde. VOCs are widely released by residential areas, pharmaceuticals industries, high-tech and commercial industries, petrochemical industries, as well as household products such as solvent and paint thinner, lubricants, gasoline, oil refineries, detergents and dry cleaning fluids [17,18].

The conventional techniques available to control VOCs emission include adsorption, absorption, condensation and membrane separation technology, which is only categorized as a recovery process [19–21]. These techniques do not destroy VOCs, but are able to be recovered and reused. Conversely, NTP technology is an abatement process which destructs VOCs. VOCs should be controlled and treated because short and long term exposure to VOCs has adverse health effects on humans, animals and the surrounding environment [22–24]. The long exposure might cause kidney failure, child birth defects and even death.

NTP process for VOCs pollutant removal could be generated by methods including an electron beam and electrical discharges such as pulse power discharge [25], corona discharge [26] and dielectric barrier discharge (DBD) [27–30]. In this study, DBD with a designed packed-bed (PB) reactor was constructed using a several basic elements including two electrodes, a high voltage power supply, a discharge gap between the electrodes, and dielectric materials and a carrier gas.

Previous studies in the related literature mostly focused on plasma properties such as energy density [31–34] and electron temperature [35–37], but there is a lack of related studies on real plasma temperature within plasma streams inside the plasma reactor. Real plasma temperature measurement plays an important role in chemical reactions and in-situ measurement, mainly because it is temperature-dependent. This study focuses on monitoring the real plasma temperature using established optical tools, Fiber Bragg Grating (FBGs) which is a fast response technique to profile the plasma temperature during the entire VOCs decomposition process using an NTP system. FBGs are embedded inside the PB reactor and is monitored in real-time via the installed LabVIEW software application. Three plasma parameters, including applied voltage, carrier gas flow rates and VOCs (toluene) input concentrations were varied to examine the impact on the plasma temperature profile. The correlation regarding plasma temperature behavior, toluene decomposition rate and its by-product formation, were thoroughly investigated.

1.2 Problem Statement

The fundamental study of temperature is crucial in the NTP decomposition process because it plays a vital role for chemical reactions during gas phase analysis and plasma diagnostic, especially for in-situ measurements. The increment of temperature enhances the chemical reaction rate by breaking and dissociating more VOCs molecular bonding and enhances the VOCs decomposition. To date, information regarding real plasma temperature behavior inside plasma reactors remains undiscovered, since studies on temperature monitoring techniques within the plasma streams are lacking. The conventional technique commonly employed in NTP technology to measure the plasma temperature is using a thermocouple, but this is limited to the outer plasma reactor wall due to metal based component leads to electrical field interruption.

In addition, the temperature measured outside the plasma reactor does not indicate the actual plasma temperature because the nature of plasma is strongly localized. A laser gun technique is also inappropriate for plasma temperature measurement inside the PB reactor due to the presence of dielectric beads within the plasma stream. Therefore, the real plasma temperature monitoring inside the plasma reactor is necessary to study the temperature within the plasma stream.

FBGs seem to offer an alternative method to measure the real plasma temperature within the plasma streams inside the plasma reactor, since they are highly temperature sensitive, small, flexible, able to operate at temperatures up to and beyond 1000°C [38], have a fast response technique, and are free from electrical fields and electromagnetic field interruption, since FBGs are insulator-based components. Besides, FBGs optical sensing is able to be placed in between tight packed dielectric beads without affecting the dielectric properties of the beads. This FBGs sensor is connected via the LabVIEW program in order to allow the actual real plasma temperature profiling.

1.3 Objectives

The objectives for this research are as follows:

1) To design and fabricate atmospheric pressure non-thermal packed-bed plasma reactor system for VOCs decomposition
2) To profile plasma temperature within plasma streams inside packed-bed reactor through an in-situ and real-time temperature measurement using FBGs
3) To determine the impact of applied voltage, carrier gas flow rate and toluene input concentration on plasma temperature profile
4) To investigate the behavior of plasma temperature profile with toluene decomposition efficiency and its by-products from the decomposition process

1.4 Scope of Study

In this study, the NTP system was developed with a self-designed and fabricated PB reactor. This system was tested for the PB reactor, which consists of barium titanate ($BaTiO_3$) dielectric pellets in between the discharged electrodes, and is suitable to be operated within the applied plasma parameters range. The FBGs is embedded inside the plasma reactor to allow plasma temperature to be monitored within the plasma stream via in-situ and real-time process. The plasma temperature profile is monitored by observing Bragg wavelength shift, $\Delta\lambda_B$ from Optical Spectrum Analyser (OSA), and is displayed using the LabVIEW program via GPIB connector. Emitted radiation from plasma generation is collected simultaneously with the recorded plasma temperature using special grade fibre, Optical Emission Spectrometer (OES) by monitoring the profiles of peaks intensity stability. When applied voltage is higher, the emission of intensity peaks is increased and since FBGs are made up of Ge–doped based fiber it could absorb UV radiation when reached maximum operated voltage and permanently altered the refractive index. Thereby, monitoring the profiles of peaks intensity stability using OES indicate and ensure harmless UV emission range, which is safe for FBGs temperature measurement without permanently altering the refractive index.

The plasma temperature profiles are investigated under the influence of plasma operating parameters including applied voltage (14 – 19 kV), carrier gas flow rates (1.0 – 2.0 L/min) and toluene initial concentration (500 – 8400 ppm). By varying the plasma parameters, the behavior of plasma temperature profile is thoroughly investigated and correlated with the decomposition efficiency of toluene and its by-products.

1.5 Significance of Study

The information of the real plasma temperature is significant in the NTP decomposition process, since the chemical reaction process and quantitative analysis used such as Fourier Transform Infrared (FTIR) spectroscopy and laser spectroscopy for in-situ measurement are very dependent on temperature. For quantitative measurement using FTIR, Beer-Lambert Law is strongly recommended and the absorbance is temperature dependent parameter. Since the analysis dependent on standardly-acquired temperature database, hence calculation referring at inaccurate temperature database influenced to the error in temperature measurement and thereby causes inaccuracy in the quantitative analysis of VOCs decomposition efficiency. The fast response technique of FBGs provides novel knowledge, since it is able to monitor and profile the real plasma temperature within the plasma stream inside the plasma reactor. Therefore, FBGs can be applied to investigate the impact of the plasma parameters on the plasma temperature behavior, and can be performed as a suitable technique to measure VOCs decomposition efficiency.

REFERENCES

1. Hashim, S. A., binti Samsudin, F. N. D., San Wong, C., Bakar, K. A., Yap, S. L., and Zin, M. F. M. (2016). Non-Thermal Plasma for Air and Water Remediation. *Archives of Biochemistry and Biophysics*, *605,* 34-40.
2. Xiao, G., Xu, W., Wu, R., Ni, M., Du, C., Gao, X., ... and Cen, K. (2014). Non-Thermal Plasmas for VOCs Abatement. *Plasma Chemistry and Plasma Processing*, 34(5), 1033–1065.
3. Van Durme, J., Dewulf, J., Leys, C., and Van Langenhove, H. (2008). Combining Non-Thermal Plasma with Heterogeneous Catalysis in Waste Gas Treatment: A Review. *Applied Catalysis B: Environmental*, 78(3), 324–333.
4. Vandenbroucke, A. M., Morent, R., De Geyter, N., and Leys, C., (2011). Non-Thermal Plasmas for Non-Catalytic and Catalytic VOC Abatement. *Journal of Hazardous Materials*, 195, 30–54.
5. Khacef, A., Cormier, J. M., Pouvesle, J. M., and Van, T. L. (2008). Removal of Pollutants by Atmospheric Non Thermal Plasmas.
6. Manivannan, N., Balachandran, W., Beleca, R., and Abbod, M. (2014). Non-Thermal Plasma System for Marine Diesel Engine Emissions Control.
7. Magureanu, M., Piroi, D., Mandache, N. B., David, V., Medvedovici, A., Bradu, C., and Parvulescu, V. I. (2011). Degradation of Antibiotics in Water by Non-Thermal Plasma Treatment. *Water Research*, 45(11), 3407–3416. Elsevier Ltd.
8. Schmid, S., Jecklin, M. C., and Zenobi, R. (2010). Degradation of Volatile Organic Compounds in a Non-Thermal Plasma Air Purifier. *Chemosphere*, 79(2), 124–130.

9. Delagrange, S., Pinard, L., and Tatibouët, J. M. (2006). Combination of a Non-Thermal Plasma and a Catalyst for Toluene Removal from Air: Manganese Based Oxide Catalysts. *Applied Catalysis B: Environmental*, *68*(3), 92-98.

10. Oda, T. (2003). Non-Thermal Plasma Processing for Environmental Protection: Decomposition of Dilute VOCs in Air. *Journal of Electrostatics*, *57*(3), 293-311.

11. Gandhi, M. S., and Mok, Y. S. (2014). Non-Thermal Plasma-Catalytic Decomposition of Volatile Organic Compounds Using Alumina Supported Metal Oxide Nanoparticles. *Surface and Coatings Technology*, 259, 12 - 19.

12. Allah, Z. A., Sawtell, D., Kasyutich, V. L., and Martin, P. A. (2009). FTIR and QCL Diagnostics of the Decomposition of Volatile Organic Compounds in an Atmospheric Pressure Dielectric Packed Bed Plasma Reactor. *Journal of Physics: Conference Series*, (Vol. 157, No. 1, p. 012001. IOP Publishing.

13. Abd Allah, Z. (2012). Non-Thermal Atmospheric Pressure Plasma for Remediation of Volatile Organic Compounds.

14. Zhu, T., Wan, Y. D., Li, J., He, X. W., Xu, D. Y., Shu, X. Q., ... and Jin, Y. Q. (2011). Volatile Organic Compounds Decomposition Using Nonthermal Plasma Coupled with a Combination of Catalysts. *International Journal of Environmental Science & Technology*, 8(3), 621–630.

15. Ramaraju, B., Karuppiah, J., Linga Reddy, E., Manoj Kumar Reddy, P., and Subrahmanyam, C. (2012). Removal of Mixture of VOCs by Nonthermal Plasma. *Composite Interfaces*, *19*(3-4), 271-277.

16. Urashima, K., and Chang, J. S. (2000). Removal of Volatile Organic Compounds from Air Streams and Industrial Flue Gases by Non-Thermal Plasma Technology. *IEEE Transactions on Dielectrics and Electrical Insulation*, 7(5), 602–614.

17. Environmental Protection Agency, (2011). Volatile Organic Compounds Emissions.

18. British Columbia, (2004). Indoor Air Quality :Volatile Organic Compunds (VOCs). *65D*. HealthLinkBC.

19. Wijmans, J. G. (2003). *Membrane System for Recovery of Volatile Organic*

Compounds from Remediation Off-Gases. Membrane Technology and Research, Inc.(US).

20. Ghoshal, A. K., and Manjare, S. D. (2002). Selection of Appropriate Adsorption Technique for Recovery of VOCs: An Analysis. *Journal of Loss Prevention in the Process Industries*, *15*(6), 413-421.

21. Khan, F. I., and Ghoshal, A. K. (2000). Removal of Volatile Organic Compounds from Polluted Air. *Journal of Loss Prevention in the Process Industries*, *13*(6), 527-545.

22. Parmar, G. R., and Rao, N. N. (2008). Emerging Control Technologies for Volatile Organic Compounds. *Critical Reviews in Environmental Science and Technology*, *39*(1), 41-78.

23. Villanueva, F., Tapia, A., Amo-Salas, M., Notario, A., Cabañas, B., and Martínez, E. (2015). Levels and Sources of Volatile Organic Compounds Including Carbonyls in Indoor Air of Homes of Puertollano, the Most Industrialized City in Central Iberian Peninsula. Estimation of Health Risk. *International Journal of Hygiene and Environmental Health*, *218*(6), 522-534.

24. Sarigiannis, D. A., Karakitsios, S. P., Gotti, A., Liakos, I. L., and Katsoyiannis, A. (2011). Exposure to Major Volatile Organic Compounds and Carbonyls in European Indoor Environments and Associated Health Risk. *Environment international*, *37*(4), 743-765.

25. Guo, H., Lee, S. C., Chan, L. Y., and Li, W. M. (2004). Risk Assessment of Exposure to Volatile Organic Compounds in Different Indoor Environments. *Environmental Research*, *94*(1), 57-66.

26. Wang, H., Li, D., Wu, Y., Li, J., and Li, G. (2009). Removal of Four Kinds of Volatile Organic Compounds Mixture in Air Using Silent Discharge Reactor Driven by Bipolar Pulsed Power. *Journal of Electrostatics*.

27. Ajo, P., Kornev, I., and Preis, S. (2015). Pulsed Corona Discharge in Water Treatment: The Effect of Hydrodynamic Conditions on Oxidation Energy Efficiency. *Industrial & Engineering Chemistry Research*, *54*(30), 7452-7458.

28. Zhu, T., Wan, Y., Li, H., Chen, S., and Fang, Y. (2011). VOCs

Decomposition via Modified Ferroelectric Packed Bed Dielectric Barrier Discharge Plasma. *IEEE Transactions on Plasma Science*, *39*(8), 1695-1700.

29. Guo, Y. F., Ye, D. Q., Chen, K. F., He, J. C., and Chen, W. L. (2006). Toluene Decomposition Using a Wire-Plate Dielectric Barrier Discharge Reactor with Manganese Oxide Catalyst in Situ. *Journal of Molecular Catalysis A: Chemical*, *245*(1), 93-100.
30. Indarto, A. (2012). Decomposition of Dichlorobenzene in a Dielectric Barrier Discharge. *Environmental Technology*, *33*(6), 663-666.
31. Yu-fang, G., Dai-qi, Y., Ya-feng, T., and Ke-fu, C. (2006). Humidity Effect on Toluene Decomposition in a Wire-Plate Dielectric Barrier Discharge Reactor. *Plasma chemistry and plasma processing*, *26*(3), 237-249.
32. Van Laer, K., and Bogaerts, A. (2015). Fluid Modelling of A Packed Bed Dielectric Barrier Discharge Plasma Reactor. *Plasma Sources Science and Technology*, *25*(1), 015002.
33. Liang, W. J., Ma, L., Liu, H., and Li, J. (2013). Toluene Degradation by Non-Thermal Plasma Combined With A Ferroelectric Catalyst. *Chemosphere*, *92*(10), 1390-1395.
34. Kim, D. H., and Mok, Y. S. (2011). Decomposition of Sulfur Hexafluoride by Using a Nonthermal Plasma-Assisted Catalytic Process. *Journal of the Korean Physical Society*, *59*(6), 3437-3441.
35. Chen, H. L., Lee, H. M., Chen, S. H., and Chang, M. B. (2008). Review of Packed-Bed Plasma Reactor for Ozone Generation and Air Pollution Control. *Industrial & Engineering Chemistry Research*, *47*(7), 2122-2130.
36. Lim, M., Jayapalan, K. K., Zulkifli, A. Z. S., Hassan, H., Lai, K., and Chin, O. (2017). Characterization of an Atmospheric Air Non-thermal Plasma Device in Relation to Ozone Production. *International Journal of Environmental Science and Development*, *8*(1), 50.
37. Koirala, S. P., Awaah, I., Burkett, S. L., and Gordon, M. H. (2011). Correlation of Plasma Characteristics to Etch Rate and Via Sidewall Angle In A Deep Reactive Ion Etch System Using Langmuir Probe and Optical Emission Spectroscopy. *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*, *29*(1), 011008.

38. Sarani, A., Nikiforov, A. Y., and Leys, C. (2010). Atmospheric Pressure Plasma Jet in Ar and Ar/H_2O Mixtures: Optical Emission Spectroscopy and Temperature Measurements. *Physics of Plasmas*, *17*(6), 063504.

39. Mihailov, S. J. (2012). Fiber Bragg Grating Sensors for Harsh Environments. *Sensors*, *12*(2), 1898-1918.

40. Conrads, H., and Schmidt, M. (2000). Plasma Generation and Plasma Sources. *Plasma Sources Science and Technology*, *9*(4), 441.

41. Plasma State of Matter. Retrieved July 2, 2017, from http://chemistry.tutorvista.com/physical-chemistry/plasma-state-of-matter.html

42. Plasmas Explained. Retrieved July 02, 2017, from https://www.sciencelearn.org.nz/resources/238-plasmas-explained

43. P. Mulser and D. Bauer, (2010). High Power Laser-Matter Interaction. *Springer Tracts in Modern Physics*, 238 .

44. Offermann, D. T., Welch, D. R., Rose, D. V., Thoma, C., Clark, R. E., Mostrom, C. B., ... and Link, A. J. (2016). Transition from Beam-Target to Thermonuclear Fusion in High-Current Deuterium Z-Pinch Simulations. *Physical Review Letters*, *116*(19), 195001.

45. Chen, Z., Donnelly, V. M., Economou, D. J., Chen, L., Funk, M., and Sundararajan, R. (2009). Measurement Of Electron Temperatures and Electron Energy Distribution Functions In Dual Frequency Capacitively Coupled CF 4/O 2 Plasmas Using Trace Rare Gases Optical Emission Spectroscopy. *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*, *27*(5), 1159-1165.

46. Shirakawa, T., and Sugai, H. (1993). Plasma Oscillation Method for Measurements of Absolute Electron Density in Plasma. *Japanese Journal of Applied Physics*, *32*(11R), 5129.

47. P. P. Lecture, 3. Plasma Ionization. Saha Equation. (2),. 382–390.

48. K. Wiesemann, (2012). A Short Introduction to Plasma Physics. 1.

49. J. V. R. Heberlein, (1992). Generation of Thermal and Pseudo-Thermal Plasmas. 64 5629–636

50. Samal, (2017). Thermal Plasma Technology: The Prospective Future in Material Processing. *Journal of Cleaner Production*, 142 3131–3150.

51. S. D. Popov, (2007). Alternating Current Electric Arc Plasma Generators 1. 05–08.

52. Li, J. G., Kamiyama, H., Wang, X. H., Moriyoshi, Y., and Ishigaki, T. (2006). TiO 2 Nanopowders via Radio-Frequency Thermal Plasma Oxidation of Organic Liquid Precursors: Synthesis and Characterization. *Journal of the European Ceramic Society*, *26*(4), 423-428.

53. Xu, J. L., Khor, K. A., Dong, Z. L., Gu, Y. W., Kumar, R., and Cheang, P. (2004). Preparation and Characterization of Nano-Sized Hydroxyapatite Powders Produced in A Radio Frequency (Rf) Thermal Plasma. *Materials Science and Engineering: A*, *374*(1), 101-108.

54. D. Szabó and S. Schlabach, (2014). Microwave Plasma Synthesis of Materials—From Physics and Chemistry to Nanoparticles: A Materials Scientist's Viewpoint. *Inorganics*, 2 3468–507.

55. S. Choi, T. Watanabe, and T. Li, (2012). Discharge Characteristics of DC Arc Water Plasma for Environmental Applications. *Plasma Science and Technology*, 14 121097–1101.

56. M. F. Zhukov and I. M. Zasypkin, (2006). Thermal Plasma Torches - Design, Characteristics, Applications.

57. T. Iwao and M. Yumoto, (2006). Portable Application of Thermal Plasma and Arc Discharge for Waste Treatment, Thermal Spraying and Surface Treatment. *IEEJ Transactions on Electrical and Electronic Engineering*, 1 2163–170.

58. E. Gomez, D. A. Rani, C. R. Cheeseman, D. Deegan, M. Wise, and A. R. Boccaccini, (2009). Thermal Plasma Technology for the Treatment of Wastes: A Critical Review. *Journal of Hazardous Materials*, 161 2–3614–626.

59. J. Heberlein and A. B. Murphy, (2008). Thermal Plasma Waste Treatment. *Journal of Physics D: Applied Physics*, 41 553001.

60. Wang, Q., Yan, J., Tu, X., Chi, Y., Li, X., Lu, S., and Cen, K. (2009). Thermal Treatment of Municipal Solid Waste Incinerator Fly Ash Using DC Double Arc Argon Plasma. *Fuel*, *88*(5), 955-958.

61. Huang, H., and Tang, L. (2007). Treatment of Organic Waste Using Thermal Plasma Pyrolysis Technology. *Energy Conversion and Management*, *48*(4), 1331-1337.

62. Shenton, M. J., and Stevens, G. C. (2001). Surface Modification of Polymer Surfaces: Atmospheric Plasma versus Vacuum Plasma Treatments. *Journal of Physics D: Applied Physics*, *34*(18), 2761.

63. Heimann, R. B. (2008). Plasma-Spray Coating: Principles and Applications. John Wiley & Sons.

64. I. Boulos, (1996). New Frontiers in Thermal Plasma Processing. (68). 51007–1010.

65. M. I. Boulos, (1991). Thermal Plasma Processing. (19). 61078–1089.

66. Ferrell, J. R., Galov, A. S., Gostev, V. A., Banks, B. A., and Weeks, S. P. (2013). Characterization, Properties and Applications of Nonthermal Plasma: A Novel Pulsed-Based Option. *J Biotechnol Biomater*, *3*(155), 2.

67. Fridman, A. (2008). *Plasma Chemistry*. Cambridge University Press.

68. Nehra, V., Kumar, A., and Dwivedi, H. K. (2008). Atmospheric Non-Thermal Plasma Sources. *International Journal of Engineering*, *2*(1), 53-68.

69. Ighigeanu, D., Martin, D., Zissulescu, E., Macarie, R., Oproiu, C., Cirstea, E., ... and Iacob, N. (2005). SO_2 and NOx Removal by Electron Beam and Electrical Discharge Induced Non-Thermal Plasmas. *Vacuum*, *77*(4), 493-500.

70. Matsumoto, T., Wang, D., Namihira, T., and Akiyama, H. (2012). Non-Thermal Plasma Technic For Air Pollution Control. In *Air Pollution-A Comprehensive Perspective*. InTech.

71. Valinčius, V., Grigaitienė, V., and Tamošiūnas, A. (2012). Report on The Different Plasma Modules for Pollution Removal MO 03. *Plasma For Environ Protect*.

72. Béquin, P., Joly, V., and Herzog, P. (2013). Modeling of a corona discharge microphone. *Journal of Physics D: Applied Physics*, *46*(17), 175204.

73. Antao, D. S. (2009). *A study of Direct Current Corona Discharges in Gases and Liquids for Thin Film Deposition* (Doctoral dissertation, Drexel University).

74. A. Mizuno, (2000). Electrostatic Precipitation. *IEEE Transactions on Dielectrics and Electrical Insulation*, 7 5615–624.

75. Jeong, J. Y., Babayan, S. E., Tu, V. J., Park, J., Henins, I., Hicks, R. F., and Selwyn, G. S. (1998). Etching Materials with An Atmospheric-Pressure Plasma Jet. *Plasma Sources Science and Technology*, *7*(3), 282.

76. Schutze, A., Jeong, J. Y., Babayan, S. E., Park, J., Selwyn, G. S., and Hicks, R. F. (1998). The Atmospheric-Pressure Plasma Jet: A Review and Comparison to Other Plasma Sources. *IEEE Transactions on Plasma Science*, *26*(6), 1685-1694.

77. Oh, J. S., Kakuta, Y., Yasuoka, Y., Furuta, H., and Hatta, A. (2014). Localized DLC Etching By A Non-Thermal Atmospheric-Pressure Helium Plasma Jet In Ambient Air. *Diamond and Related Materials*, *50*, 91-96.

78. Morent, R., & De Geyter, N. (2011). Inactivation of Bacteria by Non-Thermal Plasmas. In *Biomedical Engineering-Frontiers and Challenges*. InTech.

79. El-Aragi, G. M. (2009). Gliding Arc Discharge (GAD) experiment. *Plasma Physics and Nuclear Fusion Dept., Nuclear Research Center, AEA, PO, 13759*.

80. Du, C. M., Yan, J. H., Li, X. D., Cheron, B. G., You, X. F., Chi, Y., ... and Cen, K. F. (2006). Simultaneous removal of polycyclic aromatic hydrocarbons and soot particles from flue gas by gliding arc discharge treatment. *Plasma chemistry and plasma processing*, *26*(5), 517-525.

81. Diatczyk, J., Komarzyniec, G., and Stryczewska, H. D. (2011). Power consumption of gliding arc discharge plasma reactor. *Int. J. Plasma Environ. Sci. Technol*, *5*(1), 12-16.

82. J. H. Yan, Z. Bo, X. D. Li, C. M. Du, K. F. Cen, and B. G. Chron, (2007). Study of Mechanism for Hexane Decomposition with Gliding Arc Gas Discharge. *Plasma Chemistry and Plasma Processing*, 27 2115–126.

83. Lee, H., and Sekiguchi, H. (2011). Plasma–Catalytic Hybrid System using Spouted Bed with A Gliding Arc Discharge: CH4 Reforming as A Model Reaction. *Journal of Physics D: Applied Physics*, *44*(27), 274008.

84. Kogelschatz, U. (2003). Dielectric-Barrier Discharges: Their History, Discharge Physics, and Industrial Applications. *Plasma Chemistry and Plasma Processing*, *23*(1), 1-46.

85. Liang Chen, H., Ming Lee, H., and Been Chang, M. (2006). Enhancement of Energy Yield for Ozone Production via Packed-Bed Reactors. *Ozone: Science and Engineering*, *28*(2), 111-118.

86. Matsumoto, T., Wang, D., Namihira, T., and Akiyama, H. (2012). Non-Thermal Plasma Technic for Air Pollution Control. In *Air Pollution-A Comprehensive Perspective*. InTech.

87. Pal, U. N., Soni, J. S., Kr, S., Kumar, M., Sharma, A. K., and Frank, K. (2008, June). Discharge Analysis and Electrical Modeling of a Coaxial Dielectric Barrier Discharge (DBD) Lamp. In *Plasma Science, 2008. ICOPS 2008. IEEE 35th International Conference on* (pp. 1-1). IEEE.

88. Kogelschatz, U., Eliasson, B., and Egli, W. (1997). Dielectric-Barrier Discharges. Principle And Applications. *Le Journal de Physique IV*, *7*(C4), C4-47.

89. Tendero, C., Tixier, C., Tristant, P., Desmaison, J., and Leprince, P. (2006). Atmospheric Pressure Plasmas: A Review. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *61*(1), 2-30.

90. Kostov, K. G., Honda, R. Y., Alves, L. M. S., and Kayama, M. E. (2009). Characteristics of Dielectric Barrier Discharge Reactor for Material Treatment. *Brazilian Journal of Physics*, *39*(2), 322-325.

91. Vertriest, R., Morent, R., Dewulf, J., Leys, C., and Van Langenhove, H. (2003). Multi-Pin-To-Plate Atmospheric Glow Discharge for the Removal of Volatile Organic Compounds in Waste Air. *Plasma Sources Science and Technology*, *12*(3), 412.

92. Moon, J., and Jung, J. (2007). A Wire-Plate Type Nonthermal Plasma Reactor Utilizing A Slit Dielectric Barrier And A Third Electrode. *Int. J. Plasma Environ. Sci. Technology*, *1*(1), 21-27.

93. Kim, H. S., Kang, W. S., Kim, G. H., and Hong, S. H. (2009). Plasma Flow Characteristics In A Spray-Type Dielectric Barrier Discharge Reactor. *IEEE Transactions on Plasma Science*, *37*(6), 773-784.

94. Pekárek, S. (2003). Non-Thermal Plasma Ozone Generation. *Acta Polytechnica*, *43*(6).

95. Van Laer, K., and Bogaerts, A. (2015). Fluid Modelling Of A Packed Bed Dielectric Barrier Discharge Plasma Reactor. *Plasma Sources Science and Technology*, *25*(1), 015002.

96. Mizuno, A., Yamazaki, Y., Ito, H., and Yoshida, H. (1992). AC energized ferroelectric pellet bed gas cleaner. *IEEE Transactions on Industry Applications*, *28*(3), 535-540.

97. Park, M. K., Ryu, S. G., Park, H. B., Lee, H. W., Hwang, K. C., and Lee, C. H. (2004). Decomposition of *processing*, *24*(1), 117-136.Cyanogen Chloride by Using a Packed Bed Plasma Reactor at Dry and Wet Air in Atmospheric Pressure. *Plasma chemistry and Plasma*

98. Kim, H. H. (2004). Nonthermal Plasma Processing For Air-Pollution Control: A Historical Review, Current Issues, and Future Prospects. *Plasma Processes and Polymers*, *1*(2), 91-110.

99. Harling, A. M., Wallis, A. E., and Whitehead, J. C. (2007). The Effect of Temperature on the Removal of DCM using Non-Thermal, Atmospheric-Pressure Plasma-Assisted Catalysis. *Plasma Processes and Polymers*, *4*(4), 463-470.

100. Blin-Simiand, N., Jorand, F., Belhadj-Miled, Z., Pasquiers, S., and Postel, C. (2007). Influence of Temperature on the Removal of Toluene by Dielectric Barrier Discharge. *International Journal of Plasma, Environmental Science and Technology*, *1*(1).

101. Zhang, R., Yamamoto, T., and Bundy, D. S. (1996). Control of Ammonia and Odors in Animal Houses by a Ferroelectric Plasma Reactor. *IEEE Transactions on Industry Applications*, *32*(1), 113-117.

102. Evuti, A. M. (2014). *Treatment of Toluene and Xylene Compounds from Wastewater Using Air Stripping and Non Thermal Plasma System* (Doctoral dissertation, Universiti Teknologi Malaysia).

103. Prieto, G., Okumoto, M., Takashima, K., Katsura, S., Mizuno, A., Prieto, O., & Gay, C. R. (2003). Nonthermal Plasma Reactors For The Production Of Light Hydrocarbon Olefins From Heavy Oil. *Brazilian Journal of Chemical Engineering*, *20*(1), 57-61.

104. K. I. Osman, (2011). Synthesis and Characterization of BaTiO3 Ferroelectric Material. 176.

105. Xu, X. (2001). Dielectric Barrier Discharge—Properties and Applications. *Thin Solid Films*, *390*(1), 237-242.

106. Chen, H. L., Lee, H. M., Chen, S. H., and Chang, M. B. (2008). Review of Packed-Bed Plasma Reactor for Ozone Generation and Air Pollution Control. *Industrial & Engineering Chemistry Research*, *47*(7), 2122-2130.

107. Eliasson, B., Hirth, M., and Kogelschatz, U. (1987). Ozone Synthesis From Oxygen In Dielectric Barrier Discharges. *Journal of Physics D: Applied Physics*, *20*(11), 1421.

108. Chen, H. L., Lee, H. M., Chen, S. H., Chang, M. B., Yu, S. J., &and Li, S. N. (2009). Removal of Volatile Organic Compounds By Single-Stage And Two-Stage Plasma Catalysis Systems: A Review Of The Performance Enhancement Mechanisms, Current Status, And Suitable Applications. *Environmental science & technology*, *43*(7), 2216-2227.

109. H. Luo, Z. Liang, X. Wang, Z. Guan, and L. Wang, (2010). Homogeneous Dielectric Barrier Discharge in Nitrogen at Atmospheric Pressure. *Journal of Physics D: Applied Physics*, 43.

110. Shrestha, R., Tyata, R. B., and Subedi, D. P. (2013). Effect of Applied Voltage in Electron Density of Homogeneous Dielectric Barrier Discharge at Atmospherice Pressure. *Himalayan Physics*, *4*, 10-13.

111. Pal, U. N., Kumar, M., Tyagi, M. S., Meena, B. L., Khatun, H., and Sharma, A. K. (2010). Discharge Analysis and Electrical Modeling for the Development Of Efficient Dielectric Barrier Discharge. In *Journal of physics: Conference series* (Vol. 208, No. 1, p. 012142). IOP Publishing.

112. Kogelschatz, U., Eliasson, B., and Egli, W. (1997). Dielectric-Barrier Discharges. Principle and Applications. *Le Journal de Physique IV*, *7*(C4), C4-47.

113. Smith, D., and Adams, N. G. (1984). Elementary Interactions between Charged and Neutral Species in Plasmas. *Pure and Applied Chemistry*, *56*(2), 175-188.

114. Petitpas, G., Rollier, J. D., Darmon, A., Gonzalez-Aguilar, J., Metkemeijer, R., and Fulcheri, L. (2007). A comparative study of non-thermal plasma assisted reforming technologies. *International Journal of Hydrogen Energy*, *32*(14), 2848-2867.

115. Xiao, D., Cheng, C., Shen, J., Lan, Y., Xie, H., Shu, X., ... and Chu, P. K. (2014). Electron density measurements of atmospheric-pressure non-thermal N2 plasma jet by Stark broadening and irradiance intensity methods. *Physics of Plasmas*, *21*(5), 053510.

116. Zhu, X. M., Chen, W. C., and Pu, Y. K. (2008). Gas Temperature, Electron Density and Electron Temperature Measurement in a Microwave Excited Microplasma. *Journal of Physics D: Applied Physics*, *41*(10), 105212.

117. Bolouki, N., Tomita, K., Hassaballa, S., Yamagata, Y., and Uchino, K. (2014). Temporal Evolution of Electron Density and Electron Temperature Profiles In A Non-Thermal Atmospheric-Pressure Plasma Measured By Laser Thomson Scattering. *Japanese Journal of Applied Physics*, *54*(1), 016101.

118. Sornsakdanuphap, J., Suanpoot, P., Hong, Y. J., Ghimire, B., Cho, G., Uhm, H. S., ... and Choi, E. H. (2017). Electron Temperature and Density Of Non-Thermal Atmospheric Pressure Argon Plasma Jet By Convective Wave Packet Model. *Journal of the Korean Physical Society*, *70*(11), 979-989.

119. Kim, D. H., Mok, Y. S., and Lee, S. B. (2011). Effect Of Temperature On The Decomposition Of Trifluoromethane In A Dielectric Barrier Discharge Reactor. *Thin Solid Films*, *519*(20), 6960-6963.

120. Sobacchi, M. G., Saveliev, A. V., Fridman, A. A., Gutsol, A. F., and Kennedy, L. A. (2003). Experimental assessment of pulsed corona discharge for treatment of VOC emissions. *Plasma Chemistry and Plasma Processing*, *23*(2), 347-370.

121. Kirkpatrick, M. J., Finney, W. C., and Locke, B. R. (2004). Plasma–catalyst interactions in the treatment of volatile organic compounds and NO x with

pulsed corona discharge and reticulated vitreous carbon Pt/Rh-coated electrodes. *Catalysis Today*, *89*(1), 117-126.

122. S. M. A Musa, R. K. Raja Ibrahim, and A.I. Azmi, (2014). Development of Fiber Bragg Grating (FBG) as Temperature Sensor Inside Packed-Bed Non-Thermal Plasma Reactor. *Jurnal Teknologi*, 68(3), 139–142.

123. De Geyter, N., and Morent, R. (2012). Non-Thermal Plasma Surface Modification Of Biodegradable Polymers. In *Biomedical Science, Engineering and Technology*. InTech.

124. Bolbasov, E. N., Rybachuk, M., Golovkin, A. S., Antonova, L. V., Shesterikov, E. V., Malchikhina, A. I., ... and Tverdokhlebov, S. I. (2014). Surface Modification Of Poly (L-Lactide) And Polycaprolactone Bioresorbable Polymers Using RF Plasma Discharge With Sputter Deposition Of A Hydroxyapatite Target. *Materials Letters*, *132*, 281-284.

125. Thirumdas, R., Sarangapani, C., and Annapure, U. S. (2015). Cold Plasma: A Novel Non-Thermal Technology for Food Processing. *Food Biophysics*, *10*(1), 1.

126. Rød, S. K., Hansen, F., Leipold, F., and Knøchel, S. (2012). Cold Atmospheric Pressure Plasma Treatment of Ready-To-Eat Meat: Inactivation Of Listeria Innocua And Changes In Product Quality. *Food microbiology*, *30*(1), 233-238.

127. Stoffels, E., Flikweert, A. J., Stoffels, W. W., and Kroesen, G. M. W. (2002). Plasma Needle: A Non-Destructive Atmospheric Plasma Source for Fine Surface Treatment Of (Bio) Materials. *Plasma Sources Science and Technology*, *11*(4), 383.

128. Fridman, G., Peddinghaus, M., Balasubramanian, M., Ayan, H., Fridman, A., Gutsol, A., & Brooks, A. (2006). Blood coagulation and living tissue sterilization by floating-electrode dielectric barrier discharge in air. *Plasma Chemistry and Plasma Processing*, *26*(4), 425-442.

129. Fridman, G., Friedman, G., Gutsol, A., Shekhter, A. B., Vasilets, V. N., & Fridman, A. (2008). Applied plasma medicine. *Plasma Processes and Polymers*, *5*(6), 503-533.

130. Odén, H. (2010). *Treatment Technology for VOC Emissions from Oil Refineries: Case study of measures taken to minimize VOC emissions at Swedish petrochemical companies to be appiled at Chineses Refineries*.

131. Jones, A. P. (1999). Indoor air quality and health. *Atmospheric environment*, *33*(28), 4535-4564.

132. Cape, J. N. (2003). Effects of airborne volatile organic compounds on plants. *Environmental Pollution*, *122*(1), 145-157.

133. Worch, E. (2012). *Adsorption technology in water treatment: fundamentals, processes, and modeling*. Walter de Gruyter.

134. Sui, H., Zhang, T., Cui, J., Li, X., Crittenden, J., Li, X., & He, L. (2016). Novel Off-Gas Treatment Technology To Remove Volatile Organic Compounds With High Concentration. *Industrial & Engineering Chemistry Research*, *55*(9), 2594-2603.

135. Picazo, E., D’Amico, E., Boatwright, W., Chavez, R., Davis, J., Doherty, J., ... and Basabilvazo, G. Carbon Tetrachloride Attenuation in the WIPP Underground Ventilation Air Using a Granulated Activated Carbon (GAC) Volatile Organic Compound (VOC) Removal System-11374.

136. Ahmad, U. K., Mechor, W. H., Mohamed, M., and Omar, R. Enhancement of Natural Organic Removal from Raw Water and Treated Water using Zeolite.

137. Shepherd, A. (2001). Activated Carbon Adsorption For Treatment Of VOC Emissions. *13th Annual EnviroExpo, Boston, Massachusetts (May 2001, 4 pages)*.

138. Liotta, L. F. (2010). Catalytic oxidation of volatile organic compounds on supported noble metals. *Applied Catalysis B: Environmental*, *100*(3), 403-412.

139. Wang, S., Ang, H. M., & Tade, M. O. (2007). Volatile organic compounds in indoor environment and photocatalytic oxidation: state of the art. *Environment international*, *33*(5), 694-705.

140. Scire, S., Minico, S., Crisafulli, C., Satriano, C., & Pistone, A. (2003). Catalytic combustion of volatile organic compounds on gold/cerium oxide catalysts. *Applied Catalysis B: Environmental*, *40*(1), 43-49.

141. Huang, K. C., Zhao, Z., Hoag, G. E., Dahmani, A., & Block, P. A. (2005). Degradation of volatile organic compounds with thermally activated persulfate oxidation. *Chemosphere*, *61*(4), 551-560.

142. Van der Vaart, D. R., Spivey, J. J., Vatavuk, W. M., and Wehe, A. H. (1996). *Thermal and Catalytic Incinerators*. US Environmental Protection Agency.

143. An, H. T. Q., Huu, T. P., Le Van, T., Cormier, J. M., and Khacef, A. (2011). Application of Atmospheric Non Thermal Plasma-Catalysis Hybrid System for Air Pollution Control: Toluene Removal. *Catalysis Today*, *176*(1), 474-477.

144. Chae, J. O., Moon, S. I., Sun, H. S., Kim, K. Y., Vassiliev, V. A., & Mikholap, E. M. (1999). A study of volatile organic compounds decomposition with the use of non-thermal plasma. *Journal of Mechanical Science and Technology*, *13*(9), 647-655.

145. Gandhi, M. S., & Mok, Y. S. (2014). Non-thermal plasma-catalytic decomposition of volatile organic compounds using alumina supported metal oxide nanoparticles. *Surface and Coatings Technology*, *259*, 12-19.

146. Abdullahi, M. E., Abu Hassan, M. A., Zainon Noor, Z., & Raja Ibrahim, R. K. (2016). Integrated air stripping and non-thermal plasma system for the treatment of volatile organic compounds from wastewater: statistical optimization. *Desalination and Water Treatment*, *57*(34), 16066-16077.

147. Mista, W., & Kacprzyk, R. (2008). Decomposition of toluene using non-thermal plasma reactor at room temperature. *Catalysis Today*, *137*(2), 345-349.

148. A. M. Evuti, (2016). Qualitative By-Products Analysis of Non-Thermal Plasma Decomposition of Toluene and Xylene from Wastewater Using Fourier Transform Infrared Spectroscopy, 3(4), 90–99.

149. Hill, K. O., Fujii, Y., Johnson, D. C., & Kawasaki, B. S. (1978). Photosensitivity in optical fiber waveguides: Application to reflection filter fabrication. *Applied physics letters*, *32*(10), 647-649.

150. Kreuzer, M. (2006). Strain measurement with fiber Bragg grating sensors. *HBM, Darmstadt, S2338-1.0 e*.

151. N. Jamaludin, (2012). Edith Cowan University Copyright Warning. *Thesis: Individual retirement savings behavior: Evidence From Malaysia*

152. Zhu, Y. H., Qi, H., & Wang, G. X. (2011, August). Temperature characteristic of fiber bragg grating. In *Electronic and Mechanical Engineering and Information Technology (EMEIT), 2011 International Conference on* (Vol. 8, pp. 4020-4022). IEEE.

153. Tatsuda (2013). FBG. Retrieved July 06, 2017, from http://www.tatsuta.com/products/photoe/local_fbg.html

154. Kersey, A. D., Davis, M. A., Patrick, H. J., LeBlanc, M., Koo, K. P., Askins, C. G., ... and Friebele, E. J. (1997). Fiber grating sensors. *Journal of lightwave technology*, *15*(8), 1442-1463.

155. Cui, J., Hu, Y., Feng, K., Li, J., and Tan, J. (2015). FBG Interrogation Method with High Resolution and Response Speed Based on a Reflective-Matched FBG Scheme. *Sensors*, *15*(7), 16516-16535.

156. Jonghun, L. (2011). Characteristics of Fiber Bragg Grating Temperature Sensor using Thermal Strain of an External Tube. *Journal of Korean Physical Society*, *59*, 3188.

157. Rao, Y. J., Webb, D. J., Jackson, D. A., Zhang, L., and Bennion, I. (1997). In-Fiber Bragg-Grating Temperature Sensor System for Medical Applications. *Journal of Lightwave Technology*, *15*(5), 779-785.

158. Cazo, R. M., Barbosa, C. L., Hattori, H. T., Rabelo, R. C., Lisbôa, O., and Ferreira, J. L. (2009). Fiber Bragg Grating Temperature Sensor. *Photonics Div., IEAv, São José dos Campos-SP-Brazil, e-mail: carmi@ ieav. cta. br*.

159. Rao, Y. J. (1999). Recent Progress in Applications of In-Fibre Bragg Grating Sensors. *Optics and Lasers in Engineering*, *31*(4), 297-324.

160. Chen, W. P., Shih, F. H., Tseng, P. J., Shao, C. H., and Chiang, C. C. (2015). Application of a Packaged Fiber Bragg Grating Sensor To Outdoor Optical Fiber Cabinets For Environmental Monitoring. *IEEE Sensors Journal*, *15*(2), 734-741.

161. Jung, J., Nam, H., Lee, B., Byun, J. O., and Kim, N. S. (1999). Fiber Bragg Grating Temperature Sensor with Controllable Sensitivity. *Applied optics*, *38*(13), 2752-2754.

162. Yu, Q., Zhang, Y., Dong, Y., Li, Y. P., Wang, C., and Chen, H. (2012, May). Study on Optical Fiber Bragg Grating Temperature Sensors for Human Body Temperature Monitoring. In *Photonics and Optoelectronics (SOPO), 2012 Symposium on* (pp. 1-4). IEEE.

163. Pereira, G., McGugan, M., and Mikkelsen, L. P. (2016). Method for Independent Strain and Temperature Measurement in Polymeric Tensile Test Specimen Using Embedded FBG Sensors. *Polymer Testing*, *50*, 125-134.

164. Y. Zhou *and others,* (2015). The Study on the Temperature Measurement for the 35 kV Dry-Type Air-Core Reactor with the Embedded Optical Fiber Bragg Grating. *Diangong Jishu Xuebao/Transactions of China Electrotechnical Society*, 30 5142–146. Chinese Machine Press.

165. Musa, S. M. A., Ibrahim, R. R., and Azmi, A. I. (2014). Development of Fiber Bragg Grating (FBG) as Temperature Sensor Inside Packed-bed Non-thermal Plasma Reactor. *J. Teknol*, *68*(3), 139-142.

166. Harilal, S. S. (1997). Optical Emission Diagnostics of Laser Produced Plasma From Graphite And Yba2cu3o7.

167. Laux, C. O., Spence, T. G., Kruger, C. H., and Zare, R. N. (2003). Optical Diagnostics Of Atmospheric Pressure Air Plasmas. *Plasma Sources Science and Technology*, *12*(2), 125.

168. Nawarange, A. V. (2011). Optical Emission Spectroscopy During Sputter Deposition Of Cdte Solar Cells And Cute-Based Back Contacts.

169. Machala, Z., Janda, M., Hensel, K., Jedlovský, I., Leštinská, L., Foltin, V., ... and Morvova, M. (2007). Emission Spectroscopy of Atmospheric Pressure Plasmas For Bio-Medical And Environmental Applications. *Journal of Molecular Spectroscopy*, *243*(2), 194-201.

170. . Philipp and R. Von Rohr, (2007). Transport Processes and Reactions Laboratory Spectroscopic Quantification of Electron Temperature and Density in High Pressure Plasmas. 40, (5) 936.

171. Glow Discharge Dot Com - Glow Discharges. (2016). *Glow Discharge dot Com*,

172. Anghel, S. D., and Simon, A. (2010). Preliminary Investigations of a Very Low Power Atmospheric Pressure Helium Plasma. *Rom. Journ. Phys*, *55*(1-2), 185-193.

173. Bradley. M (2017). FTIR Basics. ThermoFisher Scientific. Retrieved July 06, 2017,fromhttp://www.thermofisher.com/my/en/home/industrial/spectroscopy-elemental-isotope-analysis/spectroscopy-elemental-isotope-analysis-learning-center/molecular-spectroscopy-information/ftir-information/ftir-basics.html

174. Nicolet, T., and All, C. (2001). Introduction to Fourier Transform Infrared Spectrometry. *Thermo Nicolet Corporation*.

175. Ries, D., Robert, E., Dozias, S., Vandamme, M., Sarron, V., and Pouvesle, J. M. (2011, July). Characterisation of Plasma Sources for Biomedical Applications. In *Proceedings of the 20th International Symposium on Plasma Chemistry*.

176. Pandiyaraj, K. N., and Selvarajan, V. (2008). Non-Thermal Plasma Treatment For Hydrophilicity Improvement Of Grey Cotton Fabrics. *Journal of Materials Processing Technology*, *199*(1), 130-139.

177. Huang, Y. (2011). Non-thermal Plasma Inactivation of Bacillus Amyloliquefaciens Spores.

178. Nair, S. A., Nozaki, T., and Okazaki, K. (2007). In situ Fourier Transform Infrared (FTIR) Study of Nonthermal-Plasma-Assisted Methane Oxidative Conversion. *Industrial & Engineering Chemistry Research*, *46*(11), 3486-3496.

179. Gallon, H. J., and Whitehead, C. (2011). *Dry Reforming of Methane Using Non-Thermal Plasma-Catalysis* (Doctoral dissertation, University of Manchester).

180. Hammer, T. (2000). Non-Thermal Plasma Treatment of Automotive Exhaust Gases. In *Proceedings of the International Symposium on High Pressure Low Temperature Plasma Chemistry, Greifswald, Germany* (Vol. 2, pp. 234-241).

181. Zhu, T., Wan, Y. D., Li, J., He, X. W., Xu, D. Y., Shu, X. Q., ... and Jin, Y. Q. (2011). Volatile Organic Compounds Decomposition Using Nonthermal Plasma Coupled With A Combination Of Catalysts. *International Journal of Environmental Science and Technology: (IJEST)*, *8*(3), 621.

182. Schmidt, M., Schiorlin, M., and Brandenburg, R. (2015). Studies on the Electrical Behaviour and Removal of Toluene with A Dielectric Barrier Discharge. *Open Chemistry*, *13*(1).

183. Tang, X., Wang, M., Feng, W., Feng, F., and Yan, K. (2011). VOCs Degradation with Non-Thermal Plasma and Ag-Mnox Catalysis. In *International Symposium on Plasma Chemistry* (Vol. 20).

184. Becker, K. H., Kogelschatz, U., Schoenbach, K. H., and Barker, R. J. (Eds.). (2004). *Non-Equilibrium Air Plasmas at Atmospheric Pressure*. CRC press.

185. Veerapandian, S. K., Leys, C., De Geyter, N., and Morent, R. (2017). Abatement of VOCs Using Packed Bed Non-Thermal Plasma Reactors: A Review. *Catalysts*, *7*(4), 113.

186. Hensel, K., Matsui, Y., Katsura, S., and Mizuno, A. (2004). Generation of Microdischarges in Porous Materials. *Czechoslovak Journal of Physics*, *54*, C683-C689.

187. Urashima, K., Kostov, K. G., Chang, J. S., Okayasa, Y., Iwaizumi, T., Yoshimura, K., and Kato, T. (2001). Removal of C/Sub 2/F/Sub 6/From A Semiconductor Process Flue Gas by A Ferroelectric Packed-Bed Barrier Discharge Reactor with An Adsorber. *IEEE Transactions on Industry Applications*, *37*(5), 1456-1463.

188. Lin, C. H., & Bai, H. (2001). Energy-effectiveness of nonthermal plasma reactors for toluene vapor destruction. *Journal of environmental engineering*, *127*(7), 648-654.

189. Chang, J. S., Chakrabarti, A., Urashima, K., and Arai, M. (1998, October). The effects of barium titanate pellet shapes on the gas discharge characteristics of ferroelectric packed bed reactors. In *Electrical Insulation and Dielectric Phenomena, 1998. Annual Report. Conference on* (Vol. 2, pp. 485-488). IEEE.

190. Takaki, K., Urashima, K., & Chang, J. S. (2006). Scale-Up of Ferro-Electric Packed Bed Reactor For C 2 F 6 Decomposition. *Thin solid films*, *506*, 414-417.

191. Azmi, N. F. S. N., Evuti, A. M., Abu Hassan, M. A., & Ibrahim, R. K. (2016). Optimization of Non Thermal Plasma Reactor Performance for the Decomposition of Xylene. *Jurnal Teknologi*, *78*(8), 165-171.

192. Wu, J., Huang, Y., Xia, Q., and Li, Z. (2013). Decomposition of Toluene in A Plasma Catalysis System With Nio, Mno2, Ceo2, Fe2O3, And Cuo Catalysts. *Plasma Chemistry and Plasma Processing*, *33*(6), 1073-1082.

193. Kim, H. H., Kobara, H., Ogata, A., and Futamura, S. (2005). Comparative Assessment of Different Nonthermal Plasma Reactors on Energy Efficiency and Aerosol Formation from The Decomposition Of Gas-Phase Benzene. *IEEE transactions on industry applications*, *41*(1), 206-214.

194. Ogata, A., Ito, D., Mizuno, K., Kushiyama, S., Gal, A., and Yamamoto, T. (2002). Effect of Coexisting Components on Aromatic Decomposition in a Packed-Bed Plasma Reactor. *Applied Catalysis A: General*, *236*(1), 9-15.

195. Ogata, A., Shintani, N., Yamanouchi, K., Mizuno, K., Kushiyama, S., and Yamamoto, T. (2000). Effect of Water Vapor on Benzene Decomposition Using a Nonthermal-Discharge Plasma Reactor. *Plasma Chemistry and Plasma Processing*, *20*(4), 453-467.

196. Hourdakis, E., Simonds, B. J., and Zimmerman, N. M. (2006). Submicron Gap Capacitor for Measurement of Breakdown Voltage in Air. *Review of Scientific Instruments*, *77*(3), 034702.

197. Berzak, L. F., Dorfman, S. E., and Smith, S. P. (2006). Paschen's Law in Air and Noble Gases. *Lawrence Berkeley National Laboratory*.

198. T. P. Table and A. Properties, “Metals and Nonmetals Metals and Nonmetals Correlations between electronic configuration and properties,” pp. 1–9.

199. SCRIBD, “Periodic Trends | Periodic Table | Sets Of Chemical Elements.”[Online].Available:https://www.scribd.com/document/85568965/Periodic-Trends. [Accessed: 10-Jul-2017]

200. Panicker, P. K. (2004). Ionization of Air by Corona Discharge.

201. Rosdi, N. Z., Ibrahim, R. R., Musa, S. M. A., Hosseinian, R., Azmi, A. I., and Ahmad, N. (2016). Reactor Temperature Profiles of Non-Thermal Plasma Reactor Using Fiber Bragg Grating Sensor. *Sensors and Actuators A: Physical*, *244*, 206-212.

202. Holtzhausen, J. P., and Vosloo, W. L. (2003). High Voltage Engineering Practice and Theory.

203. Whiteley, M. (2002). Power Dissipation in Resistors. Retrieved July 11, 2017,fromhttp://info.ee.surrey.ac.uk/Teaching/Courses/ee1.cct/circuittheory/section1/powerdis.html

204. Tu, X., Gallon, H. J., and Whitehead, J. C. (2011). Transition Behavior of Packed-Bed Dielectric Barrier Discharge In Argon. *IEEE Transactions on Plasma Science*, *39*(11), 2172-2173.

205. Yousfi, M., Merbahi, N., Sarrette, J. P., Eichwald, O., Ricard, A., Gardou, J. P., ... and Benhenni, M. (2011). Non Thermal Plasma Sources of Production of Active Species For Biomedical Uses: Analyses, Optimization And Prospect. In *Biomedical Engineering-Frontiers and Challenges*. InTech.

206. Russ, H., Neiger, M., and Lang, J. E. (1999). Simulation of Micro Discharges for the Optimization of Energy Requirements for Removal of NO/Sub X/From Exhaust Gases. *IEEE Transactions on Plasma Science*, *27*(1), 38-39.

207. Chirokov, A., Gutsol, A., Fridman, A., Sieber, K., Grace, J., and Robinson, K. (2005). Self-Organization of Microdischarges in Dielectric Barrier Discharge Plasma. *IEEE Transactions on Plasma Science*, *33*(2), 300-301.

208. Wagner, H. E., Brandenburg, R., Kozlov, K. V., Sonnenfeld, A., Michel, P., and Behnke, J. F. (2003). The Barrier Discharge: Basic Properties and Applications To Surface Treatment. *Vacuum*, *71*(3), 417-436.

209. Penetrante, B. M., Vogtlin, G. E., Bardsley, J. N., Vitello, P. A., And Wallman, P. H. (1993, January). Application of Non-Thermal Plasmas to Pollution Control. In *Proc. 2nd Int. Plasma Symp. World Progress in Plasma Appl., Palo Alto, California* (Pp. 1-11).

210. Musa, S. M. A. (2015). *Packed-bed Non-thermal Pl asma Reactor Tempreature Profiling Using Fiber Bragg Grating Sensor* (Doctoral dissertation, Universiti Teknologi Malaysia).

211. Wu, H., Sun, P., Feng, H., Zhou, H., Wang, R., Liang, Y., ... and Fang, J. (2012). Reactive Oxygen Species in a Non-thermal Plasma Microjet and Water System: Generation, Conversion, and Contributions to Bacteria

Inactivation—An Analysis by Electron Spin Resonance Spectroscopy. *Plasma Processes and Polymers*, *9*(4), 417-424.

212. Ding, H. X., Zhu, A. M., Yang, X. F., Li, C. H., and Xu, Y. (2005). Removal of Formaldehyde from Gas Streams via Packed-Bed Dielectric Barrier Discharge Plasmas. *Journal of Physics D: Applied Physics*, *38*(23), 4160.

213. Abedi, K., Ghorbani-Shahna, F., Jaleh, B., Bahrami, A., and Yarahmadi, R. (2014). Enhanced Performance of Non-Thermal Plasma Coupled With Tio 2/GAC for Decomposition of Chlorinated Organic Compounds: Influence of a Hydrogen-Rich Substance. *Journal of Environmental Health Science and Engineering*, *12*(1), 119.

214. Magureanu, M., Mandache, N. B., Parvulescu, V. I., Subrahmanyam, C., Renken, A., and Kiwi-Minsker, L. (2007). Improved Performance of Non-Thermal Plasma Reactor during Decomposition of Trichloroethylene: Optimization of the Reactor Geometry and Introduction Of Catalytic Electrode. *Applied Catalysis B: Environmental*, *74*(3), 270-277.

215. Li, S., Ma, X., Liu, L., and Cao, X. (2015). Degradation Of 2, 4-Dichlorophenol In Wastewater By Low Temperature Plasma Coupled With Tio 2 Photocatalysis. *RSC Advances*, *5*(3), 1902-1909.

216. Martin, J., Rakotomalala, N., Talon, L., and Salin, D. (2009). Measurement of the Temperature Profile of an Exothermic Autocatalytic Reaction Front. *Physical Review E*, *80*(5), 055101.

217. Jiang, L., Zhu, R., Mao, Y., Chen, J., and Zhang, L. (2015). Conversion Characteristics and Production Evaluation of Styrene/O-Xylene Mixtures Removed By DBD Pretreatment. *International Journal of Environmental Research and Public Health*, *12*(2), 1334-1350.

218. Kim, D. H., Mok, Y. S., and Lee, S. B. (2011). Effect of Temperature on the Decomposition Of Trifluoromethane In A Dielectric Barrier Discharge Reactor. *Thin Solid Films*, *519*(20), 6960-6963.

219. Xia, J. F., Gao, X. X., Kong, J. Y., Hui, H. X., Cui, M., and Yan, K. P. (2000). By-Products Nox Control and Performance Improvement of a Packed-Bed Nonthermal Plasma Reactor. *Plasma Chemistry and Plasma Processing*, *20*(2), 225-233.

220. Mi, T., Han, J., He, X., and Qin, L. (2015). Investigation of HFC-134a Decomposition by Combustion and Its Kinetic Characteristics in A Laboratory Scale Reactor. *Environment Protection Engineering*, *41*(4), 143-150.

221. Using Non-Thermal Plasma to Control Air Pollutants Using Non-Thermal Plasma to Control Air Pollutants.

222. Oda, T., Nakagawa, Y., Ono, R., and Fujisawa, H. (2008). Non-Thermal Plasma Decomposition of Dilute Trichloroethylene in Air-Catalyst Effect. *International Society for Electrostatic Precipitation*.

223. Indarto, A. (2010). *Chemical Reactions Using Gliding Arc Plasma*. Lulu. Com.

224. Blanksby, S. J., and Ellison, G. B. (2003). Bond Dissociation Energies of Organic Molecules. *Accounts of Chemical Research*, *36*(4), 255-263.

225. Iijima, S., Nakayama, K., Kuchar, D., Kubota, M., and Matsuda, H. (2009). Optimum Conditions for Effective Decomposition of Toluene as VOC Gas by Pilot-Scale Regenerative Thermal Oxidizer. *International Journal of Chemical and Biological Engineering*, *2*(1), 38-43.

226. Ciuprina, F., Andrei, L., Panaitescu, D., and Zaharescu, T. (2016, July). Temperature Influence on Dielectric Properties of PP-Sio 2 Nanocomposites. In *Dielectrics (ICD), 2016 IEEE International Conference on* (Vol. 1, Pp. 112-115). IEEE.

227. Oda, T., Yamaji, K., And Takahashi, T. (2004). Decomposition of Dilute Trichloroethylene by Nonthermal Plasma Processing-Gas Flow Rate, Catalyst, and Ozone Effect. *IEEE Transactions on Industry Applications*, *40*(2), 430-436.

228. Bito, H., and Ikeda, K. (1995). Effect of total flow rate on the concentration of degradation products generated by reaction between sevoflurane and soda lime. *BJA: British Journal of Anaesthesia*, *74*(6), 667-669.

229. Sultana, S., Vandenbroucke, A. M., Leys, C., De Geyter, N., and Morent, R. (2015). Abatement of Vocs with Alternate Adsorption and Plasma-Assisted Regeneration: A Review. *Catalysts*, *5*(2), 718-746.

230. Xu, G. M., Ma, Y., and Zhang, G. J. (2008). DBD Plasma Jet in Atmospheric Pressure Argon. *IEEE Transactions on Plasma Science*, *36*(4), 1352-1353.

231. Talebizadeh, P., Rahimzadeh, H., Babaie, M., Anaghizi, S. J., Ghomi, H., Ahmadi, G., and Brown, R. (2015). Evaluation of Residence Time on Nitrogen Oxides Removal in Non-Thermal Plasma Reactor. *PloS one*, *10*(10).

232. Bo, Z., Yan, J. H., Li, X. D., Chi, Y., Cen, K. F., and Cheron, B. G. (2007). Effects of Oxygen and Water Vapor on Volatile Organic Compounds Decomposition Using Gliding Arc Gas Discharge. *Plasma Chemistry and Plasma Processing*, *27*(5), 546-558.

233. Kim, J. C. (2002). Factors Affecting Aromatic VOC Removal by Electron Beam Treatment. *Radiation Physics and Chemistry*, *65*(4), 429-435.

234. Kalpathi, V. (2005). *Destruction Of Volatile Organic Compounds In A Dielectric Barrier Discharge Plasma Reactor* (Doctoral dissertation, Oklahoma State University).

235. Chang, C. L., and Lin, T. S. (2005). Decomposition of Toluene and Acetone in Packed Dielectric Barrier Discharge Reactors. *Plasma Chemistry and Plasma Processing*, *25*(3), 227-243.

236. Machala, Z., Hensel, K., and Síc, J. (2009). Ráhe'lJ.: Chemical Activity Of Coplanar DBD With Al2O3 And Tio2 Electrodes Tested On VOC Decomposition. In *29th International Conference on Phenomena in Ionized Gases (ICPIG)*.

237. Cal, M. P., & Schluep, M. (2000). Destruction of VOCs Using Non-Thermal Plasmas.

238. Guo, Y., Liao, X., Fu, M., Huang, H., and Ye, D. (2015). Toluene Decomposition Performance and Nox By-Product Formation during a DBD-Catalyst Process. *Journal of Environmental Sciences*, *28*, 187-194.