A Study on Plasma Chemistry for Human Health & Waste Management

Dr. Ramesh Baboo
Asst. Prof., Dept. of Chemistry
Govt. Girls P. G. College, Fatehpur, (U.P.) India

Received Dec. 09, 2017 Accepted Jan. 15, 2018

ABSTRACT *Plasma chemistry of materials makes use of high energy content of partially ionize gas, commonly referred to as the fourth state of matter. Plasma consists of charged excited and neutral partial ionization of atom or molecules of a gas and therefore, is an electrical conductor. Plasma provides convenient sources of energetic ions and activated atoms which are now widely employed in disinfection, densification and synthesis, and decomposition of materials. Thermal plasmas are use in the medical field for various purposes, such as sterilization, in the last few decades. Combination of Transition metal based nanomaterials and non equilibrium plasma have been used to detoxify volatile organic compound polluted gas streams. Recently, direct or indirect application of non-thermal plasma, also known as cold plasma, is under investigation for its ability to disinfect and sterilize biomaterial or the surfaces likely to be damaged by thermal plasma. Non-thermal plasma has been employed widely for production of ozone, which can be used to oxidize organic molecules and kill bacteria, a realization that lead to the development of a new field-plasma Medicare.*

Keywords: *Plasma chemistry, Nanomaterials, Sterilization, Synthesis and Plasma Medicare.*

Introduction

Plasma [1] chemistry of materials makes use of high energy content of partially ionize gas, commonly referred to as the fourth state of matter. Plasma consists of charged excited and neutral partial ionization of atom or molecules of a gas and therefore, is an electrical conductor. Plasma can be seen as a particular ionized gas, which retains some unique features which distinguish it from an (ideal) gas. One of the main differences is that plasma particles do interact, because of the electromagnetic coupling between charged particles and electric and magnetic collective perturbations which constitute the plasma itself. Another important difference from an ideal gas is found in nonthermal plasmas in which quite different temperatures are associated with different species, due to the out-of-equilibrium thermodynamic regime. Indeed, in cold plasmas, neutrals and ions may be at ambient temperature whereas electrons may reach temperatures close to 105 K.

It is estimated that more than 99.9% of the apparent universe is in the plasma state: gaseous nebulae, interstellar gas [2], stars, including our sun [3], have extremely high surface temperatures (from 2000 to 22000 K) and they consist entirely of plasma. Our planet is not an exception to the presence of the plasma state. The earth's atmosphere (in the altitude range between 90 and 500 km, the thermosphere), is continuously bombarded by intense cosmic rays and solar wind radiation and as a consequence its components become electrically charged species leading to the formation of an atmospheric shell, called the '*ionosphere*' [4–5]. The solar UV radiation is almost completely absorbed by the ionosphere, producing the electrically charged particles (especially electrons) which are deflected and funneled by the magnetic field of the earth to the poles, which results in the northern hemisphere in the formation of spectacular 'northern lights' known as *Aurora Borealis* [6]. Lightning developed during thunderstorms is a natural plasma state as well. It is estimated that about 100 cloud–ground and cloud–cloud lightning strikes happen every second over the whole earth. Lightning is an intense transient electric discharge of extremely long path-length (often many kilometers). The plasma state can be produced in laboratories and by raising the energy content of matter regardless of the nature of the energy source. Thus plasmas can be generated by mechanical (close to adiabatic compression), thermal (electrically heated furnaces), chemical (exothermic reactions), radiant (high energy electromagnetic and particle radiations, e.g., electron beams) and electromagnetic (arcs, coronas, direct current, and radio frequency, microwave, electron cyclotron resonance discharges) energies, and by the combination of them, as in an explosion, in which mechanical and thermal energies are present.

Discussion

Plasma processing is a technology used in a large number of industries, and it is equally important in other sectors such as sanitation and waste management, medicare, automotive, textile, food packaging, biomedical, polymers, and solar energy. Plasma is an environmentally friendly process technology, producing an extremely low level of industrial by-products, especially when compared to more traditional wet chemical treatments. Types of plasma and their involvement in health and sanitation were discussed step by step.

Thermal Plasmas

Hot plasmas, such as electrical arcs, plasma jets of rocket engines, plasmas generated by thermonuclear reactions, and so on, have an extremely high energy content, which induces fragmentation of all organic molecules to atomic levels. The thermal plasma is obtained by generating an arc discharge in a gas submitted to electric fields of varied frequency. The bundle of gas ionized at very high temperature is able to remove, fuse or to thermally modify a material. The bundle can be compared to a tool, it is easily controllable and not in direct contact with the treated surface. The applications of thermal plasmas depend on temperature, gaseous reagents and tiny particles injected into the plasma (plasma spraying, synthesis) or exposed to plasma in the form of 'bulk materials' (fusion and refining in metallurgy).

The potential applications of thermal plasma processing technology cover a wide range of activities, such as the extraction of metals, the refining/alloying of metals/alloys, the synthesis of fine ceramic powders, spray coatings, and the consolidation and destruction of hazardous waste. In particular cases the thermal plasma finds applications in complicated chemical processes, for instance fast quenching chemistry or synthesis of nanoparticles.

Thermal Plasma in Waste Management

Approximately 2.6 billion people on earth currently lack access to safe and affordable sanitation. The negative health impact of poor sanitation is enormous. To change this situation the toilet has to be reinvented. The sanitation problems have posed a challenge to researchers worldwide to develop toilet solutions that do not require water, energy, or sewage infrastructure, and are affordable for people in developing countries. By employing a small-scale processing facility that gasifies the biomass in a microwave generated plasma. The gasification step is preceded by a pre-treatment stage to create optimal feed quality. In order to create a self-sustained process that does not depend on pre-existing infrastructure, the produced off-gas is fed to a gas cleaning unit and then to a solid oxide fuel cell to recover the energy expended for microwave field generation. In plasma waste treatment, the major advantages of using thermal plasmas are the fast heating rates, the high processing temperatures allowing the formation of stable vitrified slugs, and the low off-gas flow rates. The extreme temperatures generated by plasma, when applied to materials such as waste, result in many possible reactions such as combustion, pyrolysis, gasification and vitrification. The end result depends on the nature of the material and on the surrounding conditions, such as the amount of oxygen in the atmosphere where the plasma treatment is occurring.

Industrial cleaning with solvents produces large volumes of waste. Often the purpose of the solvent cleaning process is to remove organic oils, fluxes or polymers from surfaces either to promote adhesion or to mitigate corrosion. A typical production-scale cleaning process can generate very large volumes of solvents tainted with various contaminants. Some of the solvents can be recycled, but the majority must be disposed of by incineration or landfill. One such alternative method for organic removal is plasma cleaning. If an object is immersed in a glow discharge plasma of a suitable gas, the bombardment of the surface with energetic ions and molecules results in the removal of surface contaminants. Many industrial reactors use an oxygen or argon plasma to remove trace amounts of organic contaminant. Although both gasses are adequate for plasma cleaning, alone they are not very effective, removing only a few micrometer per hour. One study shows that the effects of adding a fluorine containing gas such as sulfur hexafluoride to an oxygen plasma is very high in the process of cleaning of industrial wastes.

Thermal Plasma in Human Health and Medicare

Heat and high temperature have been exploited in medicine for a long time for the purpose of tissue removal, sterilization and cauterization (cessation of bleeding) [7]. Warriors have cauterized wounds by bringing them in contact with red hot metal objects since ancient times. Electrocautery is a more modern technique which applies controlled heat to surface layers of tissue by passing sufficiently high current through it. However, contact of tissue with metal surface of a cautery device often results in adhesion of charred tissue to the metal. Subsequent removal of the metal can peel the charred tissue away re-starting bleeding. Some of the earlier applications of plasma in medicine provided an alternative to metal contact electrocautery. In Argon Plasma Coagulation (also called Argon Beam Coagulation) highly conductive plasma replaced the metal contacts in order to pass current through tissue avoiding the difficulties with tissue adhesion. Hot plasma is also being employed to cut tissue [7, 8-11], although the exact mechanism by which this cutting occurs remains unclear. Heat delivered by plasma has also been employed recently for cosmetic re-structuring of tissue [12-14].

Non Thermal Plasma

Cold plasmas, including low-pressure Direct Current and Radio Frequency discharges (silent discharges), discharges from fluorescent (e.g., neon) illuminating tubes, dielectric discharge-barrier plasma may be found both at low pressure or atmospheric pressure. Electrons, which are small and light particles, cannot heat the large and heavy molecules very efficiently, so in many cases the background gas remains almost at room temperature. In such nonequilibrium systems (often called *nonthermal plasmas* or *cold plasmas*), the complex plasma chemistry is driven by electrons. They perform ionization, necessary to sustain the plasma; in addition, they are responsible for atomic/molecular excitation, dissociation, and production of radicals and metastable molecular states. The result is an active gaseous medium that can be safely used without thermal damage to the surrounding materials.

There are several methods to generate cold plasmas. When charged particles are in the minority, heating of neutral molecules is limited. The effect of low pressure is double: in a rare gas ionization events are scarce, which keeps the charge density low. Moreover, the frequency of elastic collisions between electrons and atoms/molecules is low, so electrons do not have much chance to convey their energy to the gas.

Non Thermal Plasma in Waste Management

The phosphates and the nitrates are the pollutants having generally an agricultural origin via the use of the chemical manures. The nutrition and the physiological dismissals of the animals slaughtered in the slaughterhouses are at the origin of their presence in wastewaters of these structures. These pollutants have ominous and varied effects on the environment: water illnesses, eutrophication of the water bodies etc. In the closed surroundings, as the lakes, the ponds, the phosphates provoke with the nitrates, a deadly dystrophication for fauna and flora as well as for men [15-16]. For the treatment, the cold plasma gotten by gliding electric discharge named glidarc was used. After 20 min exposure time to gliding discharge process, the pollutants mentioned above are abated by 41.55% for phosphates and 86.24% for nitrates.

The vehicle exhaust gas is one of the major causing environmental pollution. It contains a mass of Volatile Organic Compounds and NO_x, which is very harmful to human body. In order to remove pollutants from automotive exhaust, many studies about plasma-driven catalysis for Volatile Organic Compounds or NO_x gas purification have been done. The technology of low temperature plasma driven catalysis of nano-titanium dioxide and Au/Al2O3 catalysts were effective to the clearance of the vehicle exhaust gas.

Non Thermal Plasma in Human Health and Medicare

Non-thermal effects of plasma are quite interesting and promising. The main reason is that non-thermal plasma effects can be tuned for various sub-lethal purposes such as genetic transfection [17], cell detachment [18-19], wound healing [20, 21], and others (i.e.). Moreover, non-thermal effects can be selective in achieving a desired result for some living matter, while having little effect on the surrounding tissue. This is the case, for example, with recent plasma blood coagulation and bacteria deactivation which does not cause toxicity in the surrounding living tissue [20]. Most of research focusing on the use of non-thermal plasma effects in medicine can be fit into two major categories: that are *direct* plasma treatment and *indirect* plasma treatment [22]. In direct plasma treatment living tissue or organs play the role of one of the plasma electrodes. In many cases voltage does not need to be directly connected to this living tissue electrode, but some current may flow through living tissue in the form of either a small conduction current, displacement current or both.

A variety of water-containing solutions have been tested so far including pure water and water with various organic compounds. Our method of application of dielectric discharge-barrier plasma, reported previously, is unique and known as floating electrode dielectric discharge-barrier plasma [23]. This discovery led us to develop this application to create an antimicrobial solution that can possibly be used to flush the contaminated surfaces of indwelling catheters to eradicate bacterial/fungal cells [24].

Conclusion

Plasma is well suited for use in the sanitation and waste treatment in society as well as in industry. It requires only electricity and inert gases to operate as opposed to the fossil fuel used in incinerators. The very high temperatures allow for almost any type of waste to be destroyed, regardless of its own heating value. This makes plasma system very interesting for the treatment of hazardous waste, medical waste and incinerator ash. During the process the off-gasses are produced which may be used as fuel for production energy or electricity.

Treatment of various skin diseases by thermal plasmas and related afterglow plasma systems have been employed in a hospital setting for a long time; however, these treatments can be quite destructive. Depending on thermal capacity of the plasma flow there can be pyrolysis, coagulation, and destruction of biological tissue during the procedure. Non-equilibrium plasmas were shown to be able to initiate, promote, control, and catalyze various complex behaviors and responses in biological systems. More importantly, it was shown that plasma can be *tuned* to achieve the desired medical effect, especially in medical sterilization and treatment of different kind of skin diseases. Wound healing and tissue regeneration was achieved following various types of plasma treatment of a multitude of wound pathologies. The non-equilibrium plasma was shown to be non-destructive to tissue, safe, and effective in inactivation of various parasites and foreign organisms.

Acknowledgement
Authors acknowledge the immense help received from the scholars whose articles are cited and included in references of this manuscript. The authors are also grateful to authors/ editors / publishers of all those articles, journals and books from where the literature of this article has been reviewed and discussed.

References

1. Tonks, L. and Langmuir, I. (1929) Oscillations in ionised gases. Phys. Rev., 33, 195.
2. Sweet, P.A. (1958) Electromagnetic phenomena, in Cosmical Physics, (ed. B. Lehnert), Cambridge University Press, London.
3. Priest, E.R. (1981) Solar Flare Magnetohydrodynamics, Gordon and Breach Science Publishers, UK.
4. Gloeckler, G., Hamilton, D., Kremser, G. and Hovestadt, D., et al. (1985) Composition of the thermal and super thermal ions in the Near Earth Plasma Sheet, Proceedings on the Chapman Conference on Magnetotail Physics.
5. Bame, S.J., Aderson, R.C., Asbridge, J.R., and Zwickl, R.D., et al. (1983) Plasma regimes in the deep geomagnetic Field Tail: ISEE 3. Geophys. Res. Lett., 10, 912.
6. Bryant, D.A. (1993) Space plasma physics, in Plasma Physics, Chapter 9 (ed. R. Dendy), Cambridge University Press.
7. Ginsberg, G.G., et al., (2002), the argon plasma coagulator. Gastrointestinal Endoscopy, 55(7), 807-810.
8. Vargo, J.J., (2004) Clinical applications of the argon plasma coagulator. Gastrointestinal Endoscopy, 59(1), 81-88.
9. Watson, J.P., et al., (1997) Colonoscopic argon plasma coagulation for benign and malignant rectal tumors. Gut, 40, 156.
10. Colt, H.G. and S.W. Crawford, (2006) In vitro study of the safety limits of bronchoscopic argon plasma coagulation in the presence of airway stents. Respirology, 11(5), 643-647.
11. Raiser, J. and M. Zenker, (2006) Argon plasma coagulation for open surgical and endoscopic applications: state of the art. Journal of Physics D: Applied Physics, 39(16), 3520.
12. Tremblay, J.F., (2007) Plasma skin regeneration (PSR) in the treatment of acne scars. Journal of the American Academy of Dermatology, 56(2, Supplement 2), AB1
13. Bogle, M.A., K.A. Arndt, and J.S. Dover, (2007) Evaluation of plasma skin regeneration technology in low-energy full-facial rejuvenation. Archives of Dermatology, 143(2), 168-174.
14. Kronemyer, B., (2006) Portait PSR3 Technology Provides True Skin Regeneration, in European Aesthetic Buyers Guide. Spring.
15. Doubla A. (2002) Oxydo-reducing properties of non thermal plasmas of humid air: application to the cleanup of waters and to the corrosion metallic (in French). Diploma of authorization to direct Research, The University of Rouen, Rouen, France.
16. Rodier J. (2009) The analysis of water (in French). 9th Edition, Dunod, Paris.
17. Coulombe, S., et al., (2006) Miniature atmospheric pressure glow discharge torch (APGD-t) for local biomedical applications. Pure and Applied Chemistry, 78(6), 1147 1156.
18. Kieft, I.E., M. Kurdi, and E. Stoffels, (2006) Reattachment and apoptosis after plasma needle treatment of cultured cells. Plasma Science, IEEE Transactions on, 34(4), 1331-1336.
19. Stoffels, E., (2006) Gas plasmas in biology and medicine. Journal of Physics D: Applied Physics, 39(16).
20. Fridman, G., et al., (2006) Blood coagulation and living tissue sterilization by floating electrode dielectric barrier discharge in air. Plasma Chemistry and Plasma Processing, 26(4), 425-442.
21. Shekhter, A.B., et al., (2005) Beneficial effect of gaseous nitric oxide on the healing of skin wounds. Nitric Oxide, 12(4), 210-219.
22. Fridman, A., A. Chirokov, and A. Gutsol, (2005) Non-thermal atmospheric pressure discharges. Journal of Physics D: Applied Physics, 38(2), R1-R24.
23. Fridman G, Shereshevsky A, Fridman A, et al. (2007) Floating electrode dielectric barrier discharge plasma in air promoting apoptotic behavior in melanoma skin cancer cell lines. Plasma Chemistry and Plasma Processing, 27(2), 163-176.
24. Hanna HA, Raad II, Hackett B, et al. (2003) Antibiotic impregnated catheters associated with significant decrease in nosocomial and multidrug-resistant bacteremias in critically ill patients. Chest, 124(3), 1030-1038.