

Design and Evaluation of Air Ionizer with Plasam System and its Applications

Mehrdad Fojlaley¹ Reza Nasrollahi Narges Abad², Raman Piran², Mohammad Amin Mohammadi Banadaki³

1-Department of biosystem mechanic engineering, Urmia university, urmia, Iran

2-Department of microbiology, Urmia branch, Islamic Azad university, urmia, Iran

3-Department of computer engineering, Tabriz branch, Islamic Azad university, Tabriz, Iran

CORRESPONDING AUTHOR: Dr. Mehrdad Fojlaley

Abstract: Recent developments in the application of con-trollable air ionization processes that apply dielectric-barrier discharge devices to generate nonthermal plasmas have led to applications for chemical and biological decontamination in indoor air environments. These include significant reductions in airborne microbials, neutralization of odors, and reductions of specific volatile organic compounds (VOCs). Removal of very fine particulates (PM) is also enhanced by air ionization. The process of air ionization involves the electronically induced formation of small air ions, including reactive oxygen species, such as superoxide O₂⁻, the diatomic oxygen radical anion, which react rapidly with airborne VOC and PM. The physics and chemistry of air ionization, and its utility for contributing to significant improvements in indoor air quality are discussed. Index Terms—Air ionization, dielectric-barrier discharge, indoor air quality (IAQ), nonthermal plasmas, particulate matter, superoxide, volatile organic compounds (VOCs).

Keywords: Aire ionizers, cold plasma, dielectric discharge

INTRODUCTION

Where We Are Coming From. air thus loaded with putrid effluvia is exceedingly noxious”—J. Priestley, “On the Noxious Quality of the Effluvia of Putrid Marshes” (Phil. Trans., vol. 64, pp. 90–95, 1774). “I have sometimes found the noxious effluvia so very strong, that I have hastened out to breathe a purer air.”—John Read, “Experiments and Observations Made with the Doublor of Electricity, with a View to Determine Its Real Utility, in the Investigation of the Electricity of Atmospheric Air, in Different Degrees of Purity” (Phil. Trans. Royal Soc. London, vol. 84, pp. 266–274, 1794). Electrical phenomena occurring in ionized gases involve physicochemico-biologically reactive ions, radicals, and molecular species. These phenomena are encountered and overlap among diverse fields of chemistry, physics, engineering, meteorology, climatology, medicine, microbiology, physiology, and industrial hygiene. Each scientific discipline has coined its own “terms of art” for the phenomena: air

ionization, corona discharge, nonthermal plasma, dielectric-barrier discharge (DBD), etc. Reports describing gaseous ionization in outdoor ambient (in ambio) and indoor (in camera) air environments are scattered throughout the literature, both in diverse fields of endeavor and across centuries of time, making evaluations and comparisons challenging. The scientific literature reads across three centuries. The historical quotations cited in this paper are intended to offer appropriate perspectives on this “old-yet-new” technology. The physical and chemical aspects of small air ions and radicals have been under investigation almost from the discovery of electricity. Plasma chemistry and discharge physics are inexorably intertwined. The health implications of air ionization have been reviewed elsewhere [1]–[7]. Improved diagnostics and mechanistic understandings of electrical discharges in gases [8]–[12] have led to the development of engineered devices with highly controllable processes for the generation of non-thermal plasmas in the treatment of

chemical [13]–[19] and biological contaminants [20]–[24]. Coupled with the increased interest in controlling the potpourri of airborne contaminants, there has been an awakening kindled in applying this technology for improving the air quality of enclosed indoor environments [25]–[29]. This paper first provides a background of the physics and chemistry of bipolar air ions. Specific applications of air ionization technology for air cleaning and treatment of indoor air environments is then presented.

II. PHYSICS OF AIR IONS

Air Ionization: What is the Physics? “It has been ascertained, that the air of most countries, and probably of the whole world, as well as the clouds, fogs, rains, &c. are almost always electrified; but we are ignorant of the office (role) which this electricity can have in the great laboratory of nature; for surely so general and so active a power can hardly be intended by nature, merely to intimidate mankind now and then with thunder and lightning.”—Tiberius Cavallo, “Of the Methods of Manifesting the Presence, and Ascertaining the Quality, of Small Quantities of Natural or Artificial Electricity” (Phil. Trans. Royal Soc. London, vol. 78, pp. 1–22, 1788).

“In this striking series of phenomena are to be found the essential occurrences of electric arcs, sparks, lightning, aurora borealis and all other phenomena of electric discharge through gases.”—Karl T. Compton, “Adventures with Electricity in a Partial Vacuum” (Scientific Monthly, vol. 32(1), pp. 69–72, Jan. 1931). Most matter in the universe is “ionized.” In the high vacuum of space, atoms and molecules are present in excited energized states and possess electrical charges. An ionized gas is called a “plasma” [30]. By contrast, most matter on earth (and in the earth’s atmosphere) is not ionized. A source of sufficiently high energy is required to induce ionization and separation of charge. Energy can be supplied by natural or artificial (anthropogenic sources, as derived from nuclear, thermal, electrical, or chemical processes. These sources include: cosmic radiation; ionizing (nuclear) radiation from earth sources, UV light, frictional charging by wind, water-droplet breakup (waterfalls, showers) electrical

discharge (lightning), combustion (fire, burning gas jets, engines), and strong electrical fields (corona). Human contributions of air ions include the following:

- combustion processes: simultaneous generation of both ions and particles, the latter also tend to scavenge ions e.g., smoking, candles;
- indoor environments: synthetic décor and artificial ventilation deplete space charge;
- others: transmission lines produce ion plumes; video displays deplete local charges;
- specific devices: produce air ions for air cleaning or charge neutralization.

Engineered devices for intentional air ionization are more controllable than incidental sources. Recent developments in design and operation of large ion generators have led to commercial availability of energy-efficient units. These units produce controlled outputs of specific ions on demand. The formations of undesirable byproducts, such as ozone, are minimized and in some applications reduced. Ion generators have been used in a number of applications to control surface static charges. Air ionizers (ion generators) are being used more extensively to clean air in indoor environments. Ionization is the process, or result of a process, whereby an electrically neutral atom or molecule acquires either a positive or a negative electrical charge. Ionization occurs when energy in excess of the ionization energy is absorbed by an atom yielding a free electron and a positive ion. A free electron can also combine with another atom to form a negative ion. Atmospheric ions have been of scientific interest for more than a century [31]. Observations of chemical actions in electrical discharges in gases go back equally far [32]. The term “air ions” refers broadly to all airborne “particles” that possess electrical charges whose movements are influenced by electric fields [33].

ions) to protonated hydrates, H_3O^+ , while the free electrons quickly attach to oxygen to form

the superoxide radical anion O_2^- , which also can form hydrates. These inter-mediate species are collectively called “cluster ions” [35]. Cluster ions react further with trace volatile and particulate constituents. A single cluster ion may collide with as many as molecules in air at ground level during its brief (1 min) lifetime [35]. Subsequent molecular dissociations and reactions in the gas phase and on particulate surfaces complicate reaction schemes in real-world atmospheres. Ion chemistry continually changes through reactions, molecular rearrangements, and growth of molecular ion “clusters” and ionically charged particulates. Protonated hydrates are about one nm (0.001 m) in diameter with electrical mobilities of 1–2 cm²/V-s. Ion clusters are about 0.01–0.1 μm, with mobilities of ~1 cm²/V-s. The later are larger in size, but orders of magnitude less electronically mobile. Fog droplets or dust particles range up to 10 μm. Ions and electrons together define overall space charge, i.e., the total free unbalanced charge existing in the atmosphere. Unipolar positive or negative space charge densities can be measured. Fair weather values for air ions at sea level are ~10³ ions/cm³ of both polarities. Small ions increase significantly during rainfall and thunderstorms due to natural activation: negative ions may increase to 14 000 ions/cm³, while positive ions may increase to 7 000 ions/cm³. The ratio of positive to negative air ions at ground level normally is about 1.1–1.3, decreasing to about 0.9 following certain weather events. Smoking one cigarette can reduce air ions in a room to ~10² ions/cm³. Small ions and ion clusters have numerous opportunities for collision and reaction with any air impurity. As reactive oxygen species (ROS), they are removed through reaction with other volatile constituents; as reactive charged species (RCS) they are removed through attachment to larger particles by diffusional and field charging. The lifetimes of air ions are strongly dependent on both humidity and temperature, and on the relative concentrations of trace volatile and particulate species. Lifetimes of ions are longer, the lower their concentrations, i.e., less chance of hitting something. Typical lifetime of a

naturally generated small air ion in clean air is ~1 s

. III. CHEMISTRY OF AIR IONS

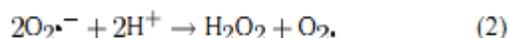
Air Ionization: What is the Chemistry? “The influence of physical forces, of modes of aggregation

and of mass, not only on the result, but on the manner of the transformation of one kind of matter into another kind—in brief, the conditions of chemical change—present a problem to the chemist which only of late years has been submitted to experimental investigation. The difficulties besetting this line of inquiry are many, but the greatest of them is the difficulty of finding a reaction that is simple in kind, that takes place between bodies which can be prepared in great purity, and that yields products which can be exactly measured.”—H.B. Dixon, “On Conditions of Chemical Change in Gases” (Phil. Trans. Royal Soc., vol. 175, p. 617, 1884). Oxygen is required by most lifeforms. There is a dynamic balance, however, between generation of any oxygen species. The chemical evolution of air ions, whether created naturally outdoors or artificially indoors depends on the composition of each environment and especially on the types and concentrations of trace species [34]. Specific reactions depend upon the physical properties of individual atoms and molecules, e.g., ionization energy, electron affinity, proton affinity, dipole moment, polarizability, and chemical reactivity. The primary positive ions N^+ , O^+ , N_2^+ , and O_2^+ are very rapidly converted (microsec-necessary for life on one hand and protection against its toxic effects on the other [36]–[39].

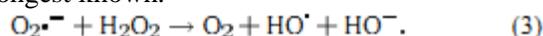
Ordinary oxygen does not react well with most molecules, but it can be “activated” by the addition of energy (naturally or artificially derived; electrical, thermal, photochemical, or nuclear), and transformed into ROS. Transformation of neutral oxygen into a reactive state by addition (attachment) of a single electron is called reduction (1). The donor molecule that gave up the electron is oxidized. The result of this monovalent reduction of triplet oxygen is superoxide, O_2^- . It is considered both a radical (·, dot sign) and an anion (charge of -1)



The superoxide radical anion is quantitatively the most important radical formed in humans: a 70-kg adult synthesizes at least 10 kg per year [40]. Approximately 98% of the oxygen consumed by respiring mitochondria is converted to water the remaining 2% forms superoxide through side reactions in the respiratory chain [41]. Human cells constantly produce superoxide (and the reactive molecules



Superoxide is the dissociated form of a weak acid, the hydroperoxyl radical, HO^\bullet . In aqueous systems, the relative proportions of these two species depend upon pH, and the appropriate equilibrium constant. Superoxide also is formed in air as negative ion [42]. The generation of low concentrations of hydrogen peroxide in wet air subjected to negative air ionization also has been confirmed [38], [43], [44]. In the absence of metallic impurities, a solution of superoxide in strong alkali can be kept in the refrigerator overnight. By contrast, superoxide ion clusters formed in air react rapidly with airborne particulates and volatile organic species. While hydrogen peroxide is an oxidizing agent, the combination of hydrogen peroxide and superoxide (3) yields a much more reactive species, the hydroxyl radical, HO^\bullet , one of the strongest known.



Identification of individual chemical species that might become involved in chemical reactions in air environments is not trivial. Modeling of the reaction scheme may involve dozens of homogeneous and heterogeneous reactions among the aforementioned species. The formation of transient intermediates adds complexity.

V. REACTIVE OXYGEN SPECIES/REACTIVE CHARGED SPECIES

Air Ionization: A Chemical Perspective. "In the case of gases, it has been known, since the time of Priestley and Cavendish, that the spark

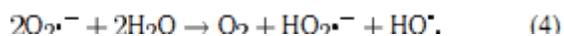
derived from it) as an "antibiotic" against invading micro-organisms. The biology of small air ions [1]–[3] and oxygen radicals [36]–[39] has been reviewed. Superoxide, along with nitric monoxide radical, NO^\bullet acts as signaling molecules to regulate many cellular processes. Under biological conditions, as described in a vast literature it reacts with itself to produce hydrogen peroxide and oxygen through a reaction (2) known as "dismutation", which can be spontaneous, or catalyzed by superoxide dismutase ("SOD").

discharge has the apparently antagonistic properties of causing decomposition in some cases and combination in others."—Thomas Andrews and Peter G. Tait, "On the Volumetric Relations of Ozone, and the Action of the Electrical Discharge on Oxygen and Other Gases" (Phil. Trans. Roy. Soc. London, vol. 150, pp. 113–131, 1860). "From a chemical perspective, the indoor environment is a reaction vessel with chemicals continually entering and exiting. Some of these chemicals can react with one another (or themselves) creating reaction products that might otherwise be absent from the indoor setting."—C. J. Weschler and H. C. Shields, "Potential Reactions Among Indoor Pollutants" (Atm. Environ., vol. 31(21), pp. 3487–3495, 1997).

Oxygen, superoxide, peroxide, and hydroxyl species are all ROS that participate in a potpourri of oxidation-reduction reactions in solid, liquid, and gaseous phases [28], [45], [46]. Concerns for limiting excessive levels of ROS in vivo to reduce adverse health effects are tempered by other concerns for increasing their levels in the environment to reduce adverse environmental effects. ROS are significant in the atmospheric destruction of organics, but they also participate in the ground-level formation of "smog" and the tropospheric destruction of ozone (O_3). The hydroxyl radical is key to the tropospheric destruction of volatile organic compounds through a series of complex chemical reactions involving oxidation (abstracting electrons from

organic compounds), which in turn can react with other organic molecules in a chain reaction. The chemistries of ROS in the form of ions are encountered from “inner” to “outer” space. Solid-state sensors of the SnO type, commonly used to “sense” trace gases, are affected by chemisorption of oxygen and water vapor. At sufficiently high operating temperature, O from air is adsorbed onto crystalline surfaces having negative charges. Donor electrons in the crystals are then transferred to the adsorbed O₂ forming superoxide radicals that react with CO, hydrocarbons, and other trace gases or vapors. The resulting liberation of electrons decreases the surface charge and produces an increase in conductance that is then “sensed.” Similar chemistries are encountered in photo-catalytic oxidation processes [47], [48], solid-oxide fuel cells, and various nonthermal plasma processes. Chemical ionization, nuclear ionization, photoionization, and electroionization techniques are used in analytical chemistry to separate and to identify chemical spectra. Chemical-ionization mass spectroscopy (CIMS) is an important tool of analytical chemistry in which “reagent” ions are electronically generated to react at very low levels with “target” molecules in very specific reactions [49]. Matrix-assisted laser desorption ionization (MALDI) is another analytical technique that

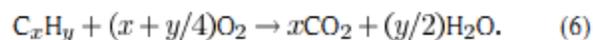
involves a laser ablation technique to fragment biological molecules.



Superoxide may also react directly with ozone to form hydroxyl anion and hydroxyl radical (5). This is postulated as a route for O removal:



A reaction scheme (6) might be postulated in which superoxide, and other ROS generated by air ionization, depicted simply as O₂^{·-}, initiate the oxidation of volatile organic compounds, and also semivolatile organic compounds associated with airborne particulates



This simplistic representation is patterned after the calculation of the theoretical oxygen demand (ThOD) for wastewater treatment and the calculation of the oxygen required for thermal combustion. A more generalized “reaction” of volatile organic compounds (VOCs) with ROS and particulate matter (PM) with RCS might be invoked to yield terminal oxidation products from the organics and a larger size distribution of the particulates that are more easily removed or tolerated.

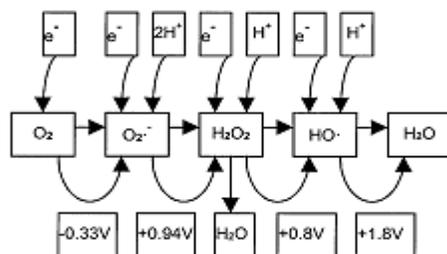


Fig. 1. Sequential reduction of the oxygen molecule.

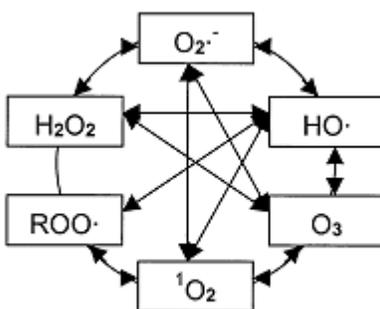


Fig. 2. Interconversion of oxygen species.

Many reaction schemes have been suggested, depending on whether focus was placed upon detection of stable reaction products or the more difficult detection of transient intermediates [54]–[56]. These generally involve excitation, dissociation, ionization, and electron-capture reactions. For any given ROS, there exists some confirmed or postulated reaction scheme for interconversion to any of the other species. This may take the form of a series of sequential reductions (electron transfers) beginning with the dioxygen molecule and ending with the water molecule [39] (Fig. 1). Alternatively, the interconversion of ROS can be depicted in a cyclic pattern [39] (Fig. 2). Similar transformations occur in the natural environment. The key to effective air ionization is twofold: i) maximize the formation of those ROS that beneficially react to form desirable end products like carbon dioxide and water and ii) minimize the formation of other ROS that adversely react to form undesirable intermediate products. Speciation of VOCs during air ionization, i.e., the disappearance of parent species and the formation of byproducts, other than carbon dioxide and water, has been speculated upon and modeled [57]–[60]. The impact of electron-driven chemistry was the subject of a recent workshop [61]. It was stated to be “well-known” that nonthermal, gas-phase plasmas that are electronically generated at ambient temperature and atmospheric pressure can destroy low initial concentrations of VOCs.

Ionization was particularly applicable to treating air containing relatively low initial concentrations of ten common VOCs using a packed-bed, pulse-corona reactor [62]. Destruction efficiencies were estimated by comparing ionization energies.

The ionization energy (IE) is the amount of energy, expressed in units of electron volts (eV), required to effect the removal of an electron from a molecule or atom leading to the formation of an ion. IE values are available for a number of chemicals [63] reported by a number of private and governmental researchers in the open literature to be chemically altered or destroyed by air ionization or allied processes (Table I). As a first estimation, those chemicals with lowest IE are most amenable to treatment by air ionization. Those with oxygen are most difficult. Because ionization energies and bond dissociation energies may be of comparable magnitudes (eV), kinetics govern which reactions predominate. Specific energy consumption (eV/mol-ecule) (or its reciprocal, the η -value) can be used to determine relative ion efficiency [64]. Treatment efficiencies vary with temperature, relative humidity, and oxygen content, but are surprising independent of concentration, power, and airflow. Air ionization involves reactions of electrically charged species: 1) recombination with other air ions; 2) reaction with gaseous molecules; 3) attachment to larger particles; and 4) contact with surfaces. The former two processes generally involve

ROS in the removal of volatile organic compounds; the latter two processes generally involve RCS in the removal of particulate matter. The former includes bipolar ions, free radicals, and radical ions; the latter includes

cluster ions, hydrated ions, and charged particles.

TABLE I - CHEMICAL COMPOUNDS AMENABLE TO TREATMENT BY AIR IONIZATION

| | Chemical | Formula | IE, eV |
|-----|------------------------------|---|--------|
| 1. | Phenanthrene | C ₁₄ H ₁₀ | 7.89 |
| 2. | Pinene, α- | C ₁₀ H ₁₆ | 8.07 |
| 3. | Naphthalene | C ₁₀ H ₈ | 8.14 |
| 4. | Trimethylbenzene, 1,2,4- | C ₉ H ₁₂ | 8.27 |
| 5. | Limonene (1-Pentene) | C ₁₀ H ₁₆ | 8.3 |
| 6. | Xylene, p- | C ₈ H ₁₀ | 8.44 |
| 7. | Styrene | C ₈ H ₈ | 8.46 |
| 8. | Xylene, o-, m- | C ₈ H ₁₀ | 8.55 |
| 9. | Ethyl Benzene | C ₈ H ₁₀ | 8.77 |
| 10. | Toluene | C ₇ H ₈ | 8.83 |
| 11. | Cyclohexene | C ₆ H ₁₀ | 8.95 |
| 12. | Chlorobenzene | C ₆ H ₅ Cl | 9.07 |
| 13. | Benzene | C ₆ H ₆ | 9.24 |
| 14. | Nitric Oxide | NO | 9.26 |
| 15. | Tetrachloroethylene | C ₂ Cl ₄ | 9.33 |
| 16. | Trichloroethylene | C ₂ HCl ₃ | 9.46 |
| 17. | Methyl Ethyl Ketone | C ₅ H ₈ O | 9.52 |
| 18. | Nitrogen Dioxide | NO ₂ | 9.59 |
| 19. | Dichloroethylene, trans-1,2- | C ₂ H ₂ Cl ₂ | 9.64 |
| 20. | Octane | C ₈ H ₁₈ | 9.80 |
| 21. | Cyclohexane | C ₆ H ₁₂ | 9.88 |
| 22. | Butyl Acetate, n- | C ₈ H ₁₆ O ₂ | 9.92 |
| 23. | Heptane, n- | C ₇ H ₁₆ | 9.93 |
| 24. | Ammonia | NH ₃ | 10.07 |
| 25. | Hexane, n- | C ₆ H ₁₄ | 10.13 |
| 26. | Acetaldehyde | CH ₃ CHO | 10.23 |
| 27. | Methyl Acetate | C ₃ H ₆ O ₂ | 10.25 |
| 28. | Pentane, n- | C ₅ H ₁₂ | 10.28 |
| 29. | Hydrogen Sulfide | H ₂ S | 10.46 |
| 30. | Ethyl Alcohol | C ₂ H ₅ OH | 10.48 |
| 31. | Ethylene | C ₂ H ₄ | 10.51 |
| 32. | Butane | C ₄ H ₁₀ | 10.53 |
| 33. | Methyl Alcohol | CH ₃ O | 10.84 |
| 34. | Formaldehyde | CH ₂ O | 10.88 |
| 35. | Trichloroethane, 1,1,1- | C ₂ H ₃ Cl ₃ | 11.0 |
| 36. | Trichloroethane, 1,1,2- | C ₂ H ₃ Cl ₃ | 11.0 |
| 37. | Carbonyl Sulfide | COS | 11.18 |
| 38. | Phosgene | COCl ₂ | 11.2 |
| 39. | Halon FC 12-B | CClBrF ₂ | 11.21 |
| 40. | Methyl Chloride | CH ₃ Cl | 11.26 |
| 41. | Methylene Chloride | CH ₂ Cl ₂ | 11.33 |
| 42. | Tetrachloromethane | CCl ₄ | 11.47 |
| 43. | Ethane | C ₂ H ₆ | 11.52 |
| 44. | Nitric Acid | HNO ₃ | 11.95 |
| 45. | CFC-113 | C ₂ Cl ₃ F ₃ | 11.99 |
| 46. | CFC-12 | CCl ₂ F ₂ | 12.0 |
| 47. | Oxygen | O ₂ | 12.07 |
| 48. | Methyl Cyanide | C ₂ H ₃ N | 12.20 |
| 49. | Sulfur Dioxide | O ₂ S | 12.35 |
| 50. | Sulfuric Acid | H ₂ O ₄ S | 12.40 |
| 51. | Ozone | O ₃ | 12.53 |
| 52. | Methane | CH ₄ | 12.61 |
| 53. | Water | H ₂ O | 12.62 |
| 54. | Hydrogen Chloride | HCl | 12.74 |
| 55. | Nitrous Oxide | N ₂ O | 12.89 |
| 56. | Hexafluoroethane | C ₂ F ₆ | 13.6 |
| 57. | Hydrogen Cyanide | HCN | 13.60 |
| 58. | Carbon Dioxide | CO ₂ | 13.78 |
| 59. | Carbon Monoxide | CO | 14.01 |
| 60. | Nitrogen | N ₂ | 15.58 |

V. AIR-CLEANING TECHNOLOGIES

Air Ionization: Let us Clear the Air! “Although the electrical discharge in gases has been investigated in its various phases ever since the study of electricity itself began, it is only in the last five or six years that our knowledge of the subject has begun to take systematic and satisfactory form.”—Earnest Merritt, On reviewing the new book by J. J. Thomson (Lord Kelvin), “The Discharge of Electricity Through Gases” (Charles Scribner’s Sons, New York: 1899; Science, vol. 9, pp. 289–291, 1899). Air-cleaning technologies have been cataloged [25], [65]–[67] by functionality and specificity for removal and/or destruction of PM and/or VOCs. They include: 1) physical;

2) physicochemical; and 3) electronic processes, and various combinations. Air-cleaning processes fall into one or more of six overlapping classifications (Table II). Solid media filtration of PM involves physical or mechanical collection of particles on porous granular or fibrous media. Mechanisms of removal are impaction, settling, and diffusion. Gas-phase “filtration” involves sorption of

VOCs onto surfaces, and into pores of solid media, with or without chemical reactions. Catalytic oxidation includes solid media with imbedded catalysts or photochemically active materials. Electronic air-cleaning systems are cataloged by types of ionization and modes of operation [68], [69]. They include: bipolar air ionization, ozone generation, and electrostatic precipitation. Air ionization forms “nonthermal” plasmas, i.e., the electron and ion clusters are highly but uniformly energized (heated). The bulk of the surrounding neutral gases, however, remains at ambient temperature. Thermally speaking, the mixture is in “nonequilibrium.” Air ionizers produce local clusters of bipolar ions. Clustered ions then electrically charge PM thereby facilitating their removal by filtration. Cluster ions also chemically react and destroy VOCs. This process, although similar to many familiar oxidation processes, is more subtle and complex. It is effected at ambient temperature without the need for solid catalysts. Microbials are inactivated, destroyed, and/or agglomerated by bipolar ions.

TABLE II
COMPARISON OF AIR-CLEANING SYSTEMS

| Technology | Bipolar Air Ionization | Ozone Generation | Electrostatic Precipitation | Gas-Phase Filtration | Solid Media Filtration | Catalytic Oxidation |
|-----------------|--|--|--|-------------------------------------|----------------------------------|-------------------------------------|
| Function | Electronic | Electronic | Electronic | Physicochemical | Physical | Physicochemical |
| Principle | DBD (Dielectric Barrier Discharge). | Sparking Discharge. | High-voltage wire and plate. | Sorption and reaction. | Flat, pleated, or HEPA media. | Solid catalysts with or without UV. |
| Process | (+) & (-) ion generation. | Ozone generation. | Charging of particulate matter. | Sorption and reaction. | Collection on porous media. | Catalytic oxidation. |
| Active Species | Reactive Oxygen & Charged Species. | Ozone (O ₃). | Charged particles. | Sorption and reaction sites. | High surface area. | Reactive oxygen species. |
| Products | CO ₂ , H ₂ O, larger PM _x | CO ₂ , H ₂ O, O ₃ | Larger PM _x | Less VOCs | Less PM _x | Less VOCs |
| Byproducts | Min. byproducts, O ₃ is controlled. | Significant O ₃ , atm. reactants. | O ₃ , if not cleaned regularly. | Spent media with contaminants. | Spent filters; contaminants. | Exhausted or fouled catalysts |
| Health Concerns | O ₃ , limited by control. | High ozone exposure. | Exposure to high voltages and O ₃ . | Breakthrough, spent media disposal. | Contaminated filter disposal. | Catalyst disposal or recovery. |
| VOCs | Chemical oxidation | Chemical oxidation | Sorption of VOCs on PM _x | Ad/absorption | NA | Chemical oxidation |
| PM _x | Agglomeration. | Not applicable | Collection on plates. | Collection in media. | Impact, settling, and diffusion. | NA |
| Microbials | Inactivation, destruction, agglomeration. | Inactivation. | Particle removal. | NA | Particle removal. | Inactivation |
| Control | Ions on demand. | Continuous generation. | Process design. | Process design. | Process design. | Process design |

VI. OPERATION OF AIR IONIZERS

Air Ionization: How is It Done? “It will be readily allowed, that an apparatus capable of rendering perceptible, or, as it were, of magnifying the smallest, an otherwise unobservable, degrees of natural as well as artificial electricity, is of great advantage to the science of electricity in general, and especially for the investigation of atmospheric electricity.”—Alexander Volta, “Of the Method of Rendering Very Sensible the Weakest Natural or Artificial Electricity” (Phi Trans. Royal Soc. London, vol. 72, p. 237, 1782). “The great importance of a machine for the purpose of detecting very minute quantities of electricity has occurred to many of the cultivators of this science; as by such an assistance not only many chemical combinations or solutions, but also many yet unexplained atmospheric phenomena, may become intelligible.”—Abraham Bennet, “An Account of a Double of Electricity” (Phil. Trans. Royal Soc. London, vol. 77, pp 288–296, 1787).

Air ionizers create charged air molecules upon the application of an energy source. By energetically either adding or removing an electron, air molecules are given a negative or positive charge (usually oxygen or nitrogen

species, respectively). Three modes of ionization have been employed: photon ionization, nuclear ionization, and electronic ionization. Photon ionization uses a low-energy X-ray energy source to displace electrons from the gas molecules. Nuclear ionizers use polonium-210 radiation sources that emit alpha particles which then collide with the gas molecules and displace electrons. Molecules that lose electrons become positive ions. Neutral gas molecules rapidly capture these free electrons and become negative ions. These types of ion generators do not have electrodes, so deposits are not a concern. X-ray and nuclear sources must be carefully installed and controlled to avoid creating safety hazards. Electronic ionizers, or corona-discharge ionizers, are devices that historically contained electrodes configured either as sharp emitter points or as flat wires. Strong electric fields interacting with electrons of adjacent gas molecules produce ions of the same polarity as the applied voltage [8]. Electrode configuration is especially important in defining the character of the corona and the propensity to produce or not produce ozone [82]. Ionizers are classified according to the type of electrical current that is applied to the emitter electrodes: pulsed or steady-state dc or ac. AC devices are “bipolar” ionizers in that they alternately produce clouds of both negative and positive ions within each current cycle.

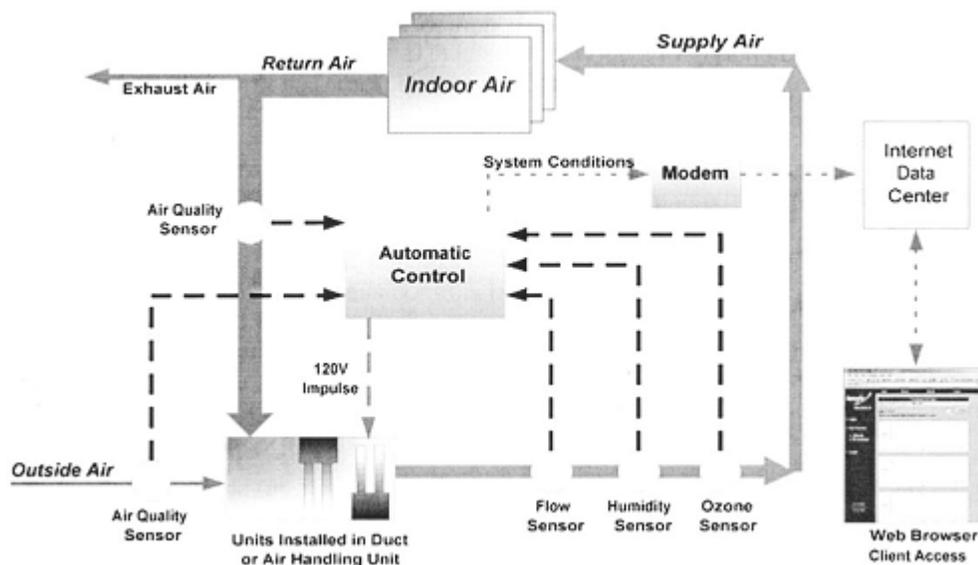


Fig. 3. Air ionization: process schematic.

In addition to electrode configuration and type of current, formations of clustered ions and other transient chemical species are affected by the relative concentrations of positive and negative ions, reactive target species (either volatile of particulate), and relative humidity. AC ionizers have inherent voltage swings as the electric fields being produced move from positive to negative maxima. Such swings may cause more intense corona discharges that in turn can produce undesired byproducts unless controlled. DBD devices which produce multiple “microdischarges” (i.e., a multitude of current filaments of short duration) have been developed that allow for improved process control and reduced formation of undesirable species such as ozone.

Locations of air ionization units are tailored to particular residential, commercial, industrial, or public facilities depending upon sources and strengths of VOCs and PM. Air ionization modules are fitted directly into the central AHU to treat the entire airflow. Alternatively, the modules can be fitted into the existing ductwork

downstream of the central HVAC system. Free-standing devices can also be located in individual room spaces to meet immediate demands. Proper operation of an air ionization system to improve in-door air quality requires optimization of up to eight process variables describing both the physical air handling system and the demand. A process control unit is centrally located. Inputs are set manually, based on fixed situation design parameters, and automatically, based on monitored demand parameters. Three manual inputs include: desired ion intensity level, power capacity, and airflow area. Five electronic inputs include: airflow, humidity, outside air quality, return air quality, and ozone detection. A flow sensor measures volumetric airflow (cfm), and a humidity sensor measures airborne water vapor. Air quality sensor(s) determine the relative demand for air ionization. Air quality sensors can be placed both in the return air duct and in the outside air intake. Metal oxide sensors (MOSs) can be used to measure total volatile organic compounds (TVOCs).

TABLE III
CASE HISTORIES FOR AIR IONIZATION

| Case History | Location | Application Objectives | | | | |
|-----------------------|-----------------------|------------------------|-----------------|-------|-------|----------|
| | | VOCs | PM _x | Odors | Smoke | Microbes |
| Engineering Center | Major city | X | | | | |
| Travel Center | International airport | X | X | | | |
| Vintage Hotel | City center | | | X | | |
| Modern Hotel | International airport | X | X | | | |
| Shopping Center | Metropolitan center | X | | | | |
| Parliament Building | Capital city | X | | X | | X |
| Restaurant Complex | Central plaza | | | X | | |
| Individual Restaurant | City center | | | X | X | |
| Meat Processing | Odor from waste | | | | | X |
| Meat/Food Storage | Supermarket | | | X | | X |
| Anatomy Laboratory | Medical school | X | | | | |
| Pathology Laboratory | Hospital | | | | | X |
| Soccer Stadium | Major city | | | X | | |
| Furniture Plant | Manufacturing site | | | | X | |
| Printing Plant | Small city | X | | | | |
| Hairdresser | Nail polishing | X | | | | |
| Research Laboratory | Animal Handling | | | X | | X |
| Gaming/Smoke Shop | Indian Reservation | | | | | |

any ozone present in the outside air or incidentally formed at low levels, is below recommended the ASHRAE limit (50 ppb). A third type of air quality sensor can be used to measure relative levels of certain size fractions of particulate matter (PM). Signals from the sensors can be logged by a personal computer or transmitted by modem to an internet data center. Performance of the system can be visually displayed on a series of real-time plots and stored for archival retrieval or real-time viewing using a standard web browser.

VII. APPLICATIONS

Air Ionization: Zapping the Stuff in Air. “The molecular changes produced by the electric current, or discharge, in certain compound bodies through which it is transmitted, furnish some of the most interesting examples of the action of a decomposing force that have been discovered in late times.”—Thomas Andrews and Peter G. Tait, “On the Volu metric Relations of Ozone, and the Action of the Electrical Di charge on Oxygen and Other Gases” (Phil. Trans. Roy. So London, vol. 150, pp. 113–131, 1860). Air ionization has a long history in varied

applications. A ionization is applied for air cleaning where increasingly mor stringent controls are demanded. volatile organic compound (VOCs), e.g., odors, are oxidized by ROS. PM, e.g., environ mental tobacco smoke (ETS), pollen, and dust, are agglomerated by RCS). Microbials are inactivated, destroyed, and/or agglomerated. Less energy is required since less outside makeu air is used. Typical air ionization systems have been installed I domestic and office locations, as well as in institutional, com mercial, and industrial locations (Table III).

CONCLUSION

Air Ionization: Where We’re Going To “Chagrined a little that we have been hitherto able to pro- duce nothing in this way of use to mankind; and the hot weather coming on, when electrical experiments are not so agreeable, it is proposed to put an end to them for this season.”—Benj. Franklin, Esq., Letter IV, to Peter Collinson, F.R.S., “Farther Ex- periments and Observations in Electricity” (1751; reprinted

in Science, vol. 123(3185), pp. 47–50, 13 Jan., 1956). “No matter how sophisticated we believe we have become, there is much we do not know and considerably more we do not understand.”—Dr. Stephen M. Kinne, “A Public Health Approach to Evaluating The Significance of Air Ions.

Air Ionization: Recollections of the Past. “We now know that every drop of rain falling on the ground or in the sea, and every drop of fresh water spray of a breaking wave, falling on a fresh water lake, sends negative electricity from the water surface to the air.”—Lord Kelvin, “On the Electrification of Air” (Science, vol. 1(22), pp. 589–596, May 31 1895). “That slow chemical action accompanies various types of electrical discharge in many gases has been long known.”—S.C Lind, “The Theory of Chemical Action in Electrical Discharge (Science, vol. 67(1745), pp. 565–569, June 8, 1928).

Authors :

Dr.M.foj llaley :



PhD in biosystem mechanic engineering, urmia university, urmia.iran
Honorary phd in electrical engineering ,california university ,usa

Reza nasrollahi nargesabad: microbiology researcher



Raman piran :microbiology researcher



REFERENCES

- [1] S. M. Kinne, “A public health approach to evaluating the significance of air ions,” Health Science Center at Houston, School of Public Health, Univ. Texas., Houston, TX, May 1997.
- [2] M. N. Kondrashova, E. V. Grigigorreko, A. N. Tikhonov, T. V. Sirota, A. V. Temnov, I. G. Stavrovskaya, N. I. Kosyakova, N. V. Lange, and V. P. Tikonov, “The primary physico-chemical mechanism for the beneficial biological/medical effects of negative air ions,” IEEE Trans. Plasma Sci., vol. 28, pp. 230–237, Feb. 2000.
- [3] A. P. Krueger and E. J. Reed, “Biological impact of small ions,” Science, vol. 193, no. 4259, pp. 1209–1213, Sept. 24, 1976.
- [4] F. Soyka and A. Edmonds, The Ion Effect—How Air Electricity Rules Your Life and Health. New York: E. P. Dutton, 1977, pp. 1–181.
- [5] A. L. Tchijevsky, “Aeroionization: Its role in the national economy (Russia),” U.S. Office of Naval Intelligence, Washington, DC, 1960.
- [6] A. Varga, “Fundamentals of electrobioclimatology, with special consideration of environmental health,” in Bioclimatic Significance of Air Ions. Heidelberg, Germany: Springer-Verlag, 1981, ch. 5, pp. 307–398, 416.
- [7] A. P. Wehner, “Air ions: Physical and biological aspects,” in History of Air Ion Research, J. M. Charry and R. I. Kavet, Eds. Boca Raton, FL: CRC, 1987, ch. 9, pp. 1–538.
- [8] J. R. Roth, “Industrial plasma engineering,” in Principles. Philadelphia, PA: IOP, 1995, vol. 1, pp. 1–538.
- [9] A. Schutze, J. Y. Jeong, S. E. Babayan, J. Park, G. S. Selwyn, and R. F. Hicks, “The atmospheric-pressure plasma jet: A review and comparison to other plasma sources,” IEEE Trans. Plasma Sci. , vol. 26, pp. 1685–1694, Dec. 1998.
- [10] H. Conrads and M. Schmidt, “Plasma generation and plasma sources,” Plasma Sources Sci. Technol., vol. 9, pp. 441–454, 2000.
- [11] E. M. Van Veldhuizen, Ed., “Electrical discharges for environmental purposes: Fundamentals and applications,” in Nova Science New York, 2000, pp. 1–432.

- [12] A. Bogaerts, E. N. Neyts, R. Gijbels, and J. van der Mullen, "Gas discharge plasmas and their applications," *Spectrochim. Acta Part B*, vol. 57, no. 4, pp. 609–658, April.
- [13] B. Eliasson and U. Kogelschatz, "Nonequilibrium volume plasma chemical processing," *IEEE Trans. Plasma Sci.*, vol. 19, pp. 1063–1077, Dec 1991.
- [14] U. Kogelschatz, B. Eliasson, and W. Egli, "From ozone generators to flat television screens: History and future potential of dielectric-barrier discharges," *Pure Appl. Chem.*, vol. 71, no. 10, pp. 1819–1828, 1999.
- [15] B. M. Penetrante and S. E. Schulthesis, Eds., "Non-thermal plasma techniques for pollution control: Part A. Overview, fundamentals, and supporting technologies, part B," in *Electron Beam and Electrical Discharge Processing*. Berlin, Germany: Springer, 1993.
- [16] L. A. Rosocha, "Processing of hazardous chemicals using silent-discharge plasmas," in *Plasma Science and the Environment*, W. Manheimer, Ed. Woodbury, NY: American Institute of Physics, 1997.
- [17] E. H. W. M. Smulders, B. E. J. M. van Heesch, and S. S. V. B. van Paasen, "Pulsed power corona discharges for air pollution control," *IEEE Trans. Plasma Sci.*, vol. 26, pp. 1476–1484, Oct. 1998.
- [18] K. Takaki, "Multipoint barrier discharge process for removal of NO from diesel engine exhaust," *IEEE Trans. Plasma Sci.*, vol. 29, pp., 518–523, June 2001.
- [19] T. Yamamoto, "Optimization of nonthermal plasma for the treatment of gas streams," *J. Haz. Met. B*, vol. B67, pp. 165–181, 1999.
- [20] M. Laroussi, "Biological decontamination by nonthermal plasmas," *IEEE Trans. Plasma Sci.*, vol. 28, pp. 184–188, Feb. 2000.
- [21] M. Okubo, T. Kuroki, H. Kametaka, and T. Yamamoto, "Odor control using the AC barrier type plasma reactors," in *Proc. Industrial Applications Conf.*, vol. 2, 2000, pp. 868–875.
- [22] K. H. Seo, B. W. Mitchell, P. S. Holt, and R. K. Gast, "Bactericidal effects of negative air ions on airborne and surface salmonella menteritidis from an artificially generated aerosol," *J. Food Protection*, vol. 64, no. 1, pp. 113–116, 2001, [Online] Available: <http://www.sepri.ars.usda.gov/bmitchell/status.htm>.
- [23] R. Zhang, T. Yamamoto, and D. S. Bundy, "Control of ammonia and odors in animal houses by a ferroelectric plasma reactor," *IEEE Trans. Ind. Appl.*, vol. 32, pp. 113–117, Feb. 1996.
- [24] H. W. Herrman, I. Henins, J. Park, and G. S. Selwyn, "Decontamination of chemical and biological warfare (CBW) agents using an atmospheric pressure plasma jet (APPJ)," *Phys. Plasmas*, vol. 6, pp. 2284–2289, May 1999.
- [25] S. L. Daniels, "Engineered solutions for mitigation of IAQ problems," in *Proc. 2nd NSF Int. Conf. Indoor Air Health*, Miami Beach, FL, Jan. 29–31, 2001, pp. 243–249.
- [26] , "Control of VOCs and PM in indoor environments by air ionization, poster presentation, electromed 2001," in *Proc. 2nd Int. Symp. Non-thermal Medical/Biological Treatments Using Electromagnetic Fields and Ionized Gases*, Portsmouth, VA, May 20–23, 2001.
- [27] , "Applications of air ionization for control of VOCs and PM ,paper #918," in *Proc. 94th Annu. Conf. Exhibition Air and Waste Management Assoc.*, Orlando, FL, June 24–28, 2001.
- [28] S. L. Daniels and M. T. Fox, "Engineering design for indoor air environments: Perception vs. reality, *Indoor Air Health: Impacts, Issues, and Solutions*, Denver, CO, May 3, 1999, pp. 65–74.
- [29] S. L. Daniels and C. Frost, "Applications of negative air ionization for removal of volatile organic compounds (VOCs) and particulate matter (PM)," in *Proc. 2nd NSF Int. Conf. Indoor Air Health*, Miami Beach, FL, Jan. 29–31, 2001, pp. 346–52.
- [30] A. M. Tyndall and G. C. Grindley, "The mobility of ions in air. Part I. Negative ions in moist air," *Proc. R. Soc. A*, vol. 110, no. 754, pp. 341–358, Feb. 1, 1926.

[31] J. A. Pollack, "The ions of the atmosphere," *Science*, vol. 29, no. 754, pp. 919–928, June 11, 1909.

[32] S. C. Lind, "The theory of chemical action in electrical discharge," *Science*, vol. 67, no. 1745, pp. 565–569, 1928.

[33] H. Tammet, *CRC Handbook of Chemistry and Physics*. Boca Raton, FL: CRC, 1997, pp. 14-30–14-32.

[34] P. B. Comita and J. I. Brauman, "Gas-phase ion chemistry," *Science*, vol. 227, pp. 863–869, Feb. 22, 1985.

[35] T. D. Bracken, "Small air ion properties," in *Air Ions: Physical and Biological Aspects*, J. M. Charry and R. I. Kavet, Eds. Boca Raton, FL: CRC, 1987, ch. 1, pp. 1–12, 205.

[36] I. Friedovich, "The biology of oxygen radicals," *Science*, vol. 201, pp. 875–880, 1978.

[37] F. Irwin, "Superoxide Anion Radical (O⁻), Superoxide Dismutases, and Related Matters," *J. Biol. Chem.*, vol. 272(30), no. 18, pp. 515–518, 1997.

[38] M. N. Kondrashova, "Negative air ions and reactive oxygen species," *Biokhimiya*, vol. 64, pp. 361–363, 1999.

[39] I. Kruk, *The Handbook of Environmental Chemistry*, O. Hutzinger, Ed. New York: Springer, 1998, pt I, vol. 2, pp. 1–261.

[40] K. U. Ingold et al., "Oxidative Stress," *Activities Rep., Steacie Inst. Molecular Sci., NRC-CNRC*, Ottawa, Canada, 1999, [Online] Available: <http://www.sims/nrc.ca/report99.pdf>.

[41] V. P. Skulachev, "Biochemical Mechanisms of Evolution and the Role of Oxygen," [Online] Available: <http://pro-tein.bio.msu/su/biokhimiya/contents/v63/full/63111570.htm>.