Biological Aspects of Clean-Room Ionization

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Abstract - Air ionization in clean rooms is expanding. Influence of air ions on biological objects, aerosol status, and charge neutralization should be considered. This paper discusses such biological effects of light ions as ion depletion, bacteria and virus's sterilization, and deodorization. Ion concentration, ion mobility, and chemical composition will be discussed as ways to characterize biological aspects of cleanroom ionization.

I. Introduction

Depending on industry requirements, certain tasks in room ionization can be prioritized, such as static neutralization, biological sterilization or the air purifying effect. To provide multiple effects of air ionization in a cleanroom environment, room systems should have closed loop control of positive and negative air ions generation and supply to the target.

Air ionization in a clean room environment became mandatory, in the disk drives industry and is likely to be the same in the semiconductor and flat panel industry in the near future. The utilization of cleanrooms is also expanding to new areas such as pharmaceutical, biological, genetic, and food industries. That is why it is necessary to take into account wider aspects of air ionization in a cleanroom environment.

Air ionization may provide a multisided effect on cleanroom personnel, as well as the technological process and environment:

1. Air becomes electrically conductive and provides neutralization of electrostatic charges accumulated by personnel, materials, and equipment in a cleanroom;
2. Air ions can have some biological effect on personnel, process and materials in a cleanroom;
3. Aerosol precipitation is a result of ion and aerosol interaction in cleanroom air.
4. Charge neutralization improves cleanroom environment quality by preventing the electrostatic capture of particles by charged cleanroom surfaces.

II. Ionized Air Characterization

To characterize charge neutralization effect we are usually confined with only three main parameters: positive, negative (discharge time), and offset voltage

[1] To discuss all above mentioned effects we should also define characterization parameters of air ionization that are relevant to life science and the physics of the atmosphere:

1 – Magnitude of ionization or ion concentration – N [ions/ cm^3]

2 – Air conductivity – [Mhos/cm]

3 – Ion mobility – M [$cm^2V^{-1}sec^{-1}$];

4 – Coefficient of unipolarity
K = (+)N/ (-)N;

5 – Ions age [sec];

6 - Ions dimension [micron or nm];

7 - Ions chemical composition.

Natural radioactivity, cosmic rays, and ultra-violet radiation are constant sources of molecular ions in atmospheric air. The ions produced under normal atmospheric pressure are rarely single species, but form clusters of water vapor, hydrogen, or oxygen molecules around a central ion.

Ion chemical composition depends on the method of their production (radioactivity, cosmic rays, UV light, corona discharge, water drops fractionating, or combustion process).

The negative air ions that have gained an electron are mostly oxygen atoms or molecules OH, NO_x core and attached water cluster molecules. The majority of positive air ions that lost an electron are usually composed of proton core H, carbon-oxide, and dioxide molecules and attached water molecular cluster [2].

Typical atmospheric ion concentration in room unpolluted air is about 400-500 ions per cm^3. In a clean rural environment air contents, usually about 2000 positive and 1500 negative ions per cm^3. The normal coefficient of unipolarity is about 1.2 –1.5 with positive ions predominating.

Air ions are usually classified on three main categories depending on dimensions and mobility [3]:

Small, light or “cluster ions” (dia. 0.36 – 1.6 nm, mobility 3.2 – 0.5 cm2/Vs)

Intermediate, or “aerosol ions” (dia. 2 –20 nm, mobility 0.4 – 0.035 cm2/Vs)

Large and heavy, or “Langeven ions” (dia. 30 –80 nm,
mobility 0.03 – 0.004 cm2/Vs).

Electrically and biologically the most active are the small light ions with average mobility about 1.5 cm2/Vs. However, these ions have a relatively brief life span, usually not more than 4 -5 min. in clean air, but in a polluted air generally less than 1-min. Large ions have a life span of about 15 -20 min. and about one hour in polluted air. That is why their concentration in polluted air is usually very high.

As the mass of the ion or aerosol particles increases, their behavior is more and more controlled by mechanical forces and less by electrical ones.

Conversely, electrical forces are governing path of small ions almost completely. Small ions have a tendency to attach (cluster) to larger particles (large neutrals and large ions). As the number of larger particle s increases, smaller ions attach to them causing the small ion concentration to decrease.
To monitor air ion concentration, air conductivity, and ion mobility a group of special instruments named ion counters were developed [4]. The most advanced ion characterization device is an ion mobility spectrometer (IMS). This kind of device has become more and more popular as a means of air quality monitoring.

III. Effect of Air Ions on Human Health and Well Being

The effect of air ions on human health is one of the most controversial topics in the discussion of biological effects of air ionization. There are two basic opinions: one that considers there is a biological significance of air ionization and a second one that points out in spite of many years of extensive studies there is little agreement between researchers regarding the mechanism of these effects.
Opponents of air ion health effects often point out that the ratio of ionized groups to neutral air gas molecules is of the order 1 to 20 trillion [5]. So, human beings should have a very high sensitivity to air ions, which is may be true in some cases.

III.a. Small Ion Depletion or Ion Insufficiency

In confined spaces like cleanrooms characterized by intense mechanical and chemical filtration, and air conditioning, ion content may drop more than 10 – 20 times to 100 positive and 50 -10 negative ions per cm^3 or less. Under these conditions personnel often complain of such syndromes as headaches, fatigue, dizziness, respiratory distress, and skin rashes.. It has been acknowledged that people have different air ions depletion sensitivities. It was found statistically that about 25% of the population is quite strongly affected by levels of ions in the air, 50 % are affected considerably, although 25% do not appear sensitive at all [6, 7, 8].
Researchers in Russia, Germany, Israel, USA, Norway, Hungary and England successfully linked the existence of air ion depletion to determined biological and behavioral effects in humans. As a result B.L. Rosenberg from Federal Aviation Administration (FAA) recommended that concentration of negative ions should not be allowed to drop below 500 ions per cm^3. More detailed standards regarding minimum and maximum biological threshold levels of ion concentration have been enacted in Russia. In Australia air ionizers with variable frequency of ion generation are officially listed as therapeutic devices.
To avoid ion depletion cleanrooms should be equipped with an appropriate means of additional air ionization. The room ionizers should include ion production as well as ion concentration monitoring means and possibly, closed loop automatic systems.

III.b. Bacterial Sterilization Effect of Air Ionization

Significantly better agreement of test results exists regarding effects of air ions on microorganisms [6, 7, 8, 9]. Both positive and negative ions may suppress the growth of bacteria and fungi on solid media, exert lethal effect on vegetative form of bacteria suspended in small droplets of water, and reduce the viable amount of bacteria aerosols. However, the most specialists consider negative ions as more powerful mean providing sterilization. The mechanism of negative ions action relates with chemically active forms of O and OH light ions and molecules.
Viruses and germs flourish in rooms with ion depletion conditions. Additionally, filters and ducts of air supply systems are prone to accumulation of viruses and germs. Experiments with artificial air ionization on colony forming units (CFU) showed that microbial levels were reduced 32-52% or more.
Similar results were obtained with bacteria aerosols and specifically with such infectious agents as s*taphylococcus aureous*. Artificial air ionization kills over 90 – 98 % of all tested germs both round and rod shaped. Obviously, the bacteria l sterilization effect depends on both air ion concentration and exposure time. There are compelling evidences that concentration 5000 – 50,000 ions/cm3 of light ions provides fresh clean air, practically free of bacteria and germs.

In many medical experiments radioactive ion generators were used. With corona ion generators, a possible additional sterilization effect is provided by the generation of small amounts of ozone and nitric oxide accompanying the corona discharge. Smell threshold of ozone concentration is very low, about 0.01-0.02 ppm, but the limit allowed for any medical equipment by OSHA and American Food and Drug Administration (FDA) is significantly higher 0.05 ppm. [10].

There is also a known experience and practice of using "Ionic showers" for odor destruction and sterilization of clothes and cleanroom garments. Ozone, being highly chemically reactive, has the capacity to combine with some gases and neutralize them. That is why a small amount of ozone has powerful antibacterial action and can also kill molds, mildew, and spores.

Interesting information was announced by Japan electronics giant Sharp Corporation [11]. The company has developed and started production of a new family of ionizing devices named "Plasma Cluster". The plasma device generates large quantities of both positive and negative light ions to deodorize indoor odors and decompose nitric oxide, as well as surround viruses, germs, and molds. The respective ions cluster around micro-particles such as bacteria and odor causing molecules and react chemically with them. The active substances formed at that time exhibit strong air purification affects.

Efficient air ionization technology may be deployed in a wide range of products that use conditioned air, such as refrigerators, laundry drying dehumidifiers, space heaters, humidifiers, air cleaners, and conditioners.

IV. Aerosol Electrostatic Precipitation and Ion – Aerosol Interaction in Atmospheric Air of Clean Room

Small airborne particles in the size range from 0.01 to 10 μm present a particular health hazard, since they can be readily inhaled and retained. They are also notoriously difficult to capture. Smoke particles and pollens are two examples of airborne particles in this size range. HEPA and ULPA filters have serious efficiency limitations in aerosol size range 0.3 μm and smaller. At the same time, the semiconductor industry is witnessing the scaling to 0.13 μm design rules and advanced control of particles in this size range is crucial. Typically "killer particles" are 1/3 to 1/10 the design rule size.

Electrostatic precipitation is known as the first commercially successful processes based on air ionization. Electrical forces in air cleaning are very effective for small particles and act directly on charged aerosol rather than on air medium [9, 12].

In general, the process of electrostatic aerosol precipitation could be divided into 3 main stages:

Particle charging by ion – aerosol interaction.

Charged aerosol transportation.

Charged aerosol collection.

Charging process depends on many factors, such as ion density and mobility, electrical field intensity, and air velocity. But, the main factor is particle dimensions. Relatively large particles acquire charges by electric field charging. For small particles (diameter > 2μm) the dominant process is diffusion charging. Industrial electrostatic precipitators mainly using monopolar air charging may cause some electrostatic problems in a clean room. Bipolar aerosol charging is more complicated, but has certain advantages as a combined aerosol precipitation and static neutralizing effect.

Aerosol transportation and collection are significantly slower processes compared to charging. There are three main governing forces here – electrical attraction (or repulsion), air flow, and gravitation sedimentation.

Aerosol collection is also dependent upon airflow, but main factors are the clean room wall, window, floor materials, and design.

"Ion showers" and corona ionizers have proven to be very effective means in aerosol precipitation [3]. Corona ionizers are able to reduce particle concentration by up to two orders of magnitude. They are most effective with aerosol particle size from 0.05 – 2.5 μm.

Experiments showed that the scavenging of aerosol particle (0.05 – 10 μm) by charged ions or charged fine water spray (10 – 50 μm) are several order of magnitude greater than by fine uncharged water droplets.

Many type of local ionizers – air cleaners are on the market now. Typically they comprise intake filter, fan, and unipolar ionizing cell with dust

collecting electrodes. Some of them are using the "ionic wind" effect and operate without air driving fan. Recently, interesting experiments were run to compare air cleaning efficiency of local ionizers and complete room ionization system [9]. The results show that a room ionization system is ten times more efficient than local ionizers are.
Bipolar room ionization also provides particle coagulation effect and accelerates aerosol collection. Aerosol particles often are carriers of germs, fungus, and bacteria. That is why air precipitation not only prevents particle deposition on technologically crucial surfaces, but has sterilization effects needed in food processing, medicine, biological, and pharmaceutical industries.
Static charge neutralization is necessary in clean room powder handling and processing. As soon as ratio charge to object mass became significant, electrostatic forces playing more and more destructive role. Well-known example is the weighing inaccuracies due to electrostatic powder adhesion in pharmaceutical measurements.

V. Conclusions

The semiconductor, disk drive, and other high tech industries have significant experience in the development and implementation of cleanroom ionization systems. Now it is a possible to use this knowledge and expertise by implementing Cleanroom Ionization systems in industries like pharmaceutical, biological, and food processing. Expanded list of parameters should be used to characterize biological aspects of cleanroom ionization.
Depending on industry requirements, certain tasks can be prioritized, such as static neutralization, biological sterilization, or the air purifying effect. Cleanroom ionization systems can provide the required timing of the air ionization levels that result in the needed polarity and concentration of ions.
To provide multiple effects of air ionization in a cleanroom environment, room systems should have closed loop control of positive and negative air ions generation to supply the appropriate ion concentration levels to the target.

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