Cleansing and Disinfecting with Plasma

Almost all matter in our Universe exists in the form of plasma. Although it's not easy to generate on Earth, it has a vast range of applications in medicine, biotechnology, farming and industry.

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Plasma is a conductive ionized state of matter consisting of unbound positive and negative particles (cations and electrons) with an overall charge of roughly zero. Over 99% of matter in the Universe exists as plasma, and under terrestrial conditions it is known as the fourth fundamental state of matter. We can admire its beauty during atmospheric discharges, while for research purposes plasma is generated by ionizing a gas through electrical discharges, in specially constructed reactors known as plasmatrons.

When the energies of the electrons in plasma are significantly higher than those of the other particles – cations and neutral particles – it is described as a non-thermal plasma. Depending on the components of the substrate gas that has been ionized to create a non-thermal plasma, we can obtain a range of different active factors which allow us to conduct biochemical reactions at relatively low temperatures (radicals, high-energy electrons, ions, metastable particles, neutral particles and radiation in various ranges of the spectrum). Generators of non-thermal plasma which can operate under atmospheric pressure are the preferred technology for this, due to their wide range of applications, simplicity of construction, and low investment costs.

Purifying ozone

Rapid technological development, leading to increasing levels of chemical and microbial pollution of air, water and soil, has brought a need to develop new, low-cost and effective technologies to combat pollution, especially given that standard chemical and biological methods are frequently insufficient.

Ozone (O_3), a powerful oxidizing agent and disinfectant, has long been used in environmental protection to remove contaminants from the air, water, sewage and soil. This is an example of a waste-free and environmentally-friendly technology. Ozone cannot be stored because it is highly reactive and has a short half-life, so it needs to be generated on-site. It's commonly obtained from a dry substrate gas (air or oxygen) in plasma reactors, usually using dielectric discharges, then transported to the site where it is required and distributed in a reactive chamber using a network of pipes and diffusers.

One increasingly popular technique, indeed even frequently a crucial step in the purification of certain polluted media, involves advanced oxidation processes (AOP). Here, various powerful biodegradable oxidizing agents which don't generate secondary contaminants are used as the main active factor. The AOP category includes simultaneous use of ozone, hydrogen peroxide, hydroxyl radicals, UV and gamma radiation and/or catalysts. In recent years, scientists have been searching for ways to minimize losses resulting from the need to transmit oxidizing agents, and to simplify the construction of purification systems. In many polluted media (including wet gases and liquids), using specially-constructed hybrid reactors makes it possible to eliminate contaminants and generate oxidizing agents at the same time. The processes can take place in the same reaction space, for example by using electrical discharges occurring directly in the medium being purified, such as liquids, foams, wet gases or moist surfaces (e.g. human skin). Studying interactions in liquid-gas systems and the phenomena occurring in them during electrical discharges is an important field of research in electrical and biochemical engineering.

During a 12-year tenure in Japan, the present author was involved in experiments with electrical discharges in moist environments that helped open up new avenues of research into plasma applications. In 2010, I received a Marie Curie Reintegration Grant for a research project in sterilization using low-temperature atmospheric plasma, and so returned to Poland. This initiated research into direct decontamination of materials using cold plasma at the Faculty of Electrical Engineering and Computer Science at the Lublin University of Technology, and resulted in participation in the COST Action MP1101: Biomedical Applications of Atmospheric Pressure Plasma Technology and COST Action TD1208: Electrical Discharges with Liquids for Future Applications programs, and also in the BalticNet PlasmaTec network. At the moment the LUT team is working with partners from Slovakia, Japan, Korea, Turkey, Slovenia, and Germany.

Fig. 1:
Dielectric barrier discharge plasma jet

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Fig. 2:
LUT team with developed plasma jet and its creators (from left: Michał Kwiatkowski, Joanna Pawłat, Piotr Terebun)

Plasma in medicine

We are especially interested in potential applications of plasma in healthcare. Many medical wards, biotech labs, and food processing plants face major problems with persistent bacterial contamination caused by the presence of biofilms on various surfaces. Surfaces which require additional disinfection include water distributors, catheters, drains, masks, dentistry equipment and ventilation elements, bedding, fabrics, dressings, living tissues (bed sores, chronic wounds), prosthetics, implants, stents, containers used to store

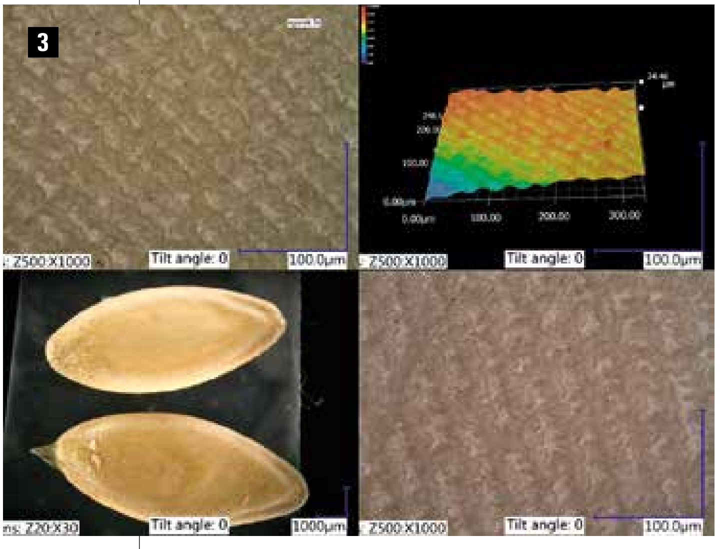

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Fig. 3:
Cucumber seeds tested before and after a 5-second plasma treatment (upper left), which enhances germination

food and medicine, and also food itself. Biofilms are complex, three-dimensional colonies of microorganisms (bacteria, fungi, protozoa) suspended in a matrix of highly adhesive polymers which they secrete. Biofilms have been implicated by numerous medical and healthcare agencies in the course of most known infections, and bacteria that are present together with other microorganisms in the form of biofilms tend to be significantly more resistant to drugs and disinfectants than those that exist alone.

Research into plasma-based sterilization using vacuum reactors dates back to the 1960s. Although plasma generated under atmospheric pressure has much promising potential for use in bactericidal, virucidal, and fungicidal applications at low temperatures and with limited thermal degradation of samples, development of an applicable, efficient system still poses a major challenge.

Biological and medical applications of low-temperature plasma take advantage of specific properties of electrical discharges. The main role is performed by chemical compounds such as ozone, nitrogen oxides, hydrogen peroxide and their highly reactive derivatives, formed during the discharges. Other significant factors are electromagnetic radiation (heat, light and electrical fields all have an effect on the permeability of cellular membranes) and the shear stress caused by gas flow. The active factors penetrate only to a small depth, so plasma can be described as having mostly a surface effect, but recent research reports have revealed some kind of complex systemic response, too. Research is being conducted into using plasma reactors at temperatures approaching that of the human body, thereby avoiding the degeneration of proteins in living cells, for example in decontamination and coagulation of superficial wounds and treatment of diabetic foot ulcers and cancers of the skin and mucosa. Plasma also has applications in tissue engineering and in the modification of surface properties of materials in order to improve biocompatibility of implants, stents, lenses and prosthetics.

Promising results have been obtained for non-thermal plasma and active particles generated within it in the agricultural and food industry, for example in protecting against pathogens and extending shelf life. Our own results and those reported by other laboratories indicate that low-temperature plasma has a positive effect on reducing the germination time of selected plant species and increasing their rate of growth (for example in tomatoes and spinach). Nitrogen oxides generated in low-temperature plasma also have a positive effect on the growth and ripening of plants and soil parameters, which reduces the need for artificial fertilizers.

Our inventions

The Plasma Technology and Renewable Energy Lab specializes in designing non-thermal plasma reactors and studying their potential applications. We are aiming to optimize a working gas chemical composition, pressure and discharge geometry which would make it possible to initiate certain chemical reactions

Many medical wards, biotech labs, and food processing plants face major problems with persistent bacterial contamination. **Here, plasma treatment may be useful.**

by high-energy electrons, while still preserving a safe temperature in the sample. We have designed glide-arc reactors and plasma jets of different constructions working with high-frequency power systems.

My Lublin University of Technology team, comprising Michał Kwiatkowski, Piotr Terebun and Jarosław Diatczyk, has constructed a small, simple, safe, low-cost mobile reactor which makes plasma technologies available to a wide range of users. The team's plasma jet was hailed as one of the best new inventions in Poland during the 6th "Student-Inventor" competition, with doctoral students Michał Kwiatkowski and Piotr Terebun being awarded a trip to the 44th International Exhibition of Inventions in Geneva, where our invention received a silver medal.

Joanna Pawłat

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