

Abstract

According to the world health organization, air pollution is one of the top 5 risks causing chronic diseases, and airborne transmitted pathogen infection is a huge challenge. In the modern era, indoor air pollution has become a complex issue involving various contaminants that harm human health. Furthermore, the rise of multidrug-resistant pathogens (ESKAPE bacteria) within the clinical environment presents a mounting problem in hospitals worldwide. The available indoor air purification methods do not effectively address long-living pathogens and small-size aerosols. In this context, a few dielectric barrier discharge (DBD) based portable cold-plasma devices have been designed and developed. The optimized source has been studied for its disinfection efficiency in the indoor environment of sizes up to $\sim 28.3 \text{ m}^3$. The developed source comprises a coaxial DBD configuration with a specially designed wire mesh structure acting as a ground electrode. The need for feed gas, pellets and/or differential pressure has been eliminated from the plasma sources. The device is able to produce active air ions predominantly dominated by hydroxyl radicals ($\bullet\text{OH}$) in the indoor environment similar to Mother Nature, which disrupts bacterial cell structures and metabolic processes. The existence of active air ions for more than 25 seconds on average is the key advantage, which can also deactivate long-living pathogens and small-size aerosols.

One of the electrodes of the plasma source has been coated with TiO_2 nanoparticles for the efficient production of active air ions and $\bullet\text{OH}$. The operating parameters such as applied voltage and frequency has been optimized on the basis of active air ions, $\bullet\text{OH}$, and ozone (O_3) generation. The deactivation efficiency of total bacterial counts (TBCs) and total fungal counts (TFCs) has shown more than 99% in 90 minutes of continuous operation of the device at the optimized parameters. The complete inactivation of MS2 phage and *E. coli* bacteria with more than 5 log reductions (99.999%) has been achieved within 30 minutes and 90 minutes of device operation in an enclosed environment. In just 60 minutes of device operation, more than 99.9% ESKAPE bacterial inactivation has also been achieved. The mechanism underlying bacterial inactivation by active air ions and $\bullet\text{OH}$ has been discussed.

A similar source for high efficiency volatile organic compounds (VOCs) degradation has been tested for the decomposition of toluene and benzene in an enclosed environment of $\sim 0.34 \text{ m}^3$. For about 60 minutes of continuous source operation, a decomposition efficiency of 99.7% (toluene) and 74.8% (benzene) has been achieved. Furthermore, the on-site generation of $\bullet\text{OH}$ has been confirmed by the chemical actinometrical method and is basically due to the highly energetic electrons (3 – 5 eV) and active air ions from the DBD plasma source.

To comprehend the analysis, another study examining the impact of varying relative humidity (RH) using a surface dielectric barrier discharge (SDBD) plasma source has been carried out. The effect of RH on the discharge parameters is discussed in detail. The results show that, even with the same peak-to-peak applied voltage, the peak-to-peak current and discharge power decrease with increasing RH. Instead of UV radiation, the plasma-produced highly energetic electrons activate the TiO_2 nanoparticles for electron-hole pair generation, and the same has been confirmed using X-ray photoelectron spectroscopy. From the developed DBD plasma source, the airborne microorganism's disinfection efficiency of $\sim 95.8\%$ and $\sim 98.7\%$ has been achieved in the TBCs and TFCs at an RH range of 70% – 90% in just 20 minutes of continuous operation. However, in the RH range of 20% – 40%, the inactivation efficiency dropped to $\sim 78.8\%$ and $\sim 87.5\%$ for the TBCs and TFCs, respectively. The outcome indicates that higher humidity levels are better for indoor air purification using the developed source and that plasma with a circulation system can effectively disinfect indoor environments.

Development and demonstration of efficient cold plasma sources in this thesis for indoor air purification at the lab scale is a significant achievement with promising future scope. More efforts are needed to implement cold plasma sources in the actual conditions, to inactivate several airborne viruses, including SARS-CoV-2 and the MS2 phage, in order to establish this as useful technology for the general public.

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