An overview of post-discharge systems used for plasma sterilization

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In the last decade the use of polymer based heat sensitive tools in the medical praxis or pharmaceutical industry have brought the need of new low temperature sterilization and decontamination methods, which ensure complete inactivation or removal of all possible infectious microorganism: e.g. bacterial spores, viruses, or other potentially harmful biological residuals: e.g. endotoxins, proteins, present on the used instruments. For the heat sensitive medical devices the most common sterilization methods in use are based on chemical treatment, which imply toxic active agents, or exposure to ionizing radiation, which may alter the bulk properties of polymers being sterilized.

A new method, which overcomes these drawbacks, implies the use of low-temperature plasmas. Low-temperature plasmas can be created either at atmospheric or low ($p \leq 10$ Torr) pressures. Numerous experimental studies have been carried out in different discharge configurations in a wide pressure range: i.e. atmospheric e.g. [1,2], mTorr [3,4] and Torr regions [5,6] in various gas mixtures: e.g. N_2 [3], O_2 [3], N_2-O_2 [2,7], Ar [8], Ar-O_2 [9], Ar-H_2 [4], O_2-CF_4 [10], in order to test the sterilizing ability of these plasmas. Either the active discharge regions have been used [3,4,10], or the afterglow region of discharges [2,9]. The afterglow is believed [5] to have advantage over the discharge region since it provides at relatively low temperatures high concentration of chemically active radicals, such as excited species and UV photons, capable to inactivate microorganisms, while is free of charged species, which may be damage the material to be sterilized. The post-discharges of N_2-O_2 and Ar-O_2 microwave discharges, shown to be efficient sterilizers, have been extensively investigated [5,6,9]. Although the reaction kinetics in the afterglow is more simple than in the active discharge region, it is difficult to isolate the action of different species as has been done in [11], when the role of H atoms, Ar^+ ions and O atoms in the etching of bacteria spores has been investigated. The numerical model of such a post-discharge system provides the spatial distribution of absolute densities of active species in the sterilization reactor as a function of discharge parameters, and thus contributes to the identification of the species relevant for sterilization under given conditions and to the understanding of the processes occurring in the system. Further, the numerical results can help in the optimization of the experimental systems.

A post-discharge system can be described with two different models valid for the discharge and early afterglow region, and for the late afterglow present in the large reactor, respectively. The species densities in the discharge region are calculated with a 1-D kinetic model, which solves the homogeneous electron Boltzmann equation coupled together with the rate balance equations describing the creation and destruction of different species. The concentrations obtained for the steady-state discharge are used as initial values to the early afterglow taking place in the tube connecting the discharge to the main reactor, where the same system of rate balance equations for species is solved in time under zero electric field. The evolution of the species densities in the post-discharge reactor are followed with a 3-D hydrodynamic model composed of: (*i*) the total mass conservation equation (*ii*) the momentum conservation equation, (*iii*) the energy conservation equation and (*iv*) the species continuity equations [12]. In the post-discharge model only the neutral active species are taken into account, since due to recombination the density of ions and electrons become negligible at the end of the early afterglow region.

With the aim to understand the processes occurring in the sterilization system and to contribute to their optimization, an N_2-O_2 microwave discharge and its afterglow have been studied by investigating the effect on the species densities distribution in the reactor of several parameters: (*i*) distance between the discharge and post-discharge reactor,(*ii*) discharge characteristics: tube radius, microwave field frequency, input power, (*iii*) gas pressure, (*iv*) initial gas mixture composition and (*v*) gas flow rate. The model is validated by comparing the measured emission intensities with the calculated densities of emitting species.

In the presentation a full characterization of this system will be given, both the advantages and disadvantages of the system will be discussed, as well as the contribution of the modeling results to the understanding of sterilization processes.

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