

INVESTIGATION OF PRINCIPAL FACTORS OF THE STERILIZATION BY PLASMA DC GLOW DISCHARGE

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Abstract

This report presents the results of investigation the factors of the sterilization of medical devices directly in the plasma of DC glow discharge. The researches have provided convincing evidence that main sterilization factor is presented by ultraviolet radiation of the plasma in wavelength range of $160\text{ nm} < \lambda < 240\text{ nm}$ for opened surface and active electroneutral particles for the instruments with complex shape or long narrow tubes. It is shown that effective sterilization is possible using either air or other gases (argon, nitrogen, oxygen, carbon dioxide, hydrogen) with comparatively low power density ($W_d = 0,003 \div 0,03\text{ W/cc}$).

1. Introduction

A new technique for sterilization of medical articles and instruments by gas discharge plasma is now developed intensively. This technique possesses a number of advantages compared to known dry heat, steam autoclave and gas (EtO) techniques. Principal advantages are low heating of articles, short time of the sterilization and ecological purity. The essential aspect of determining the optimal conditions for the plasma sterilization consists in establishing relative contributions of main sterilizing factors: a) chemically active electrically neutral plasma particles (radicals, excited atoms and molecules); b) ions and electrons of the plasma; c) ultraviolet radiation of the plasma.

The information about detailed and systematic investigation of main factors of the plasma sterilization is practically absent in publications. Just certain aspects of this complex phenomenon were studied [1-3]. In our previous report [4], it was established that the charged particles of the plasma don't play sufficient role in plasma sterilization and that principal sterilizing agents of the gas discharge plasma are ultraviolet radiation and active electrically neutral species.

This proceeding is devoted to studying the relative contribution to plasma sterilization these main factors.

2. Experimental technique

Investigations have been performed at the plasma sterilizer setup with chamber volume of 25 liters, which was evacuated by a forepump down to residual pressure of 1 Pa. Air, oxygen, argon, nitrogen, carbon dioxide, hydrogen and their mixtures were used as working gases. Pressure of the gas was established by means of feeding values in a range $10 \div 30$ Pa. Power density introduced into the discharge was varied in a range $0,003 - 0,03$ W/cc. Thermo-pair was used for direct measurements of the temperature of sterilized articles. Temperature did not exceed 60°C during a time of complete sterilization.

Metallic and glass Petri dishes internal surface of $\sim 10\text{cm}^2$ were used as test objects. The majority of studies has been performed using spores *Bac.subtilies* as the strain, which is most resistant to sterilizing action of the plasma.

3. Results and discussion

For determining of relative contribution of ultraviolet radiation in sterilizing features of the plasma, the experiments have been performed in which one group of test objects was sterilized in plasma in opened mode, and another group – under the filters of lithium fluorine (LiF) or quartz glass KU-1 of 3 mm thickness. Sterilization of the first group of test objects was performed with action of all factors of the plasma, whereas the second group was affected only by UV radiation with wavelength $\lambda \geq 120$ nm in case of LiF filter and $\lambda \geq 160$ nm in case of quartz filter.

Fig. 1 shows the dependencies of a number of survived microorganisms on a time of plasma action, obtained by colony count technique with the use of air and oxygen as operating gas. (Each point in graph represents average results of counting for 12 test samples). One can see that survival curves for the spores both placed immediately in the plasma, and separated by the filter of KU-1 are practically identical. That is, one can state that in this case, the sterilization of opened surfaces is determined mainly by ultraviolet radiation of the plasma.

Additional experiments performed in wide range of pressure and specific power introduced into the discharge have proven major significance of ultraviolet radiation for the sterilization process in all used gaseous media.

It should be noted that, besides the value of UV radiation power, essential role in the sterilization process is performed by spectrum of the radiation. Particularly, it follows from the comparison of radiation power required for the sterilization in case of the plasma and that of mercury UV lamp, which is used in medical practice. The measurements have shown that major portion of UV radiation of air plasma is generated in wavelength range $160 \div 240$ nm and at $W_d = 0,006$ W/cc power density of UV radiation comprises $80 \div 120$ $\mu\text{W}/\text{cm}^2$. In case of mercury gas discharge lamp which possesses maximum of radiation power in wavelength range of $253 \div 254$ nm, as it follows from fig.2, essentially stronger radiation power is required for achieving of the same sterilizing effect.

As it follows unambiguously from given data, UV radiation of the plasma determines the sterilization of opened surfaces. However, since the plasma cannot penetrate far inside small holes, the sterilization time for articles with complex shape will be determined by less essential factor – electrically neutral active particles of the plasma. For determining the relative contribution of this factor in overall sterilizing features of the plasma, a technique has been developed which enabled extraction of role of electrically neutral particles from the background provided by more efficient action of UV radiation. The idea of the technique consisted in the use of small mesh size grid for reflection of the plasma as a composition of charged particles, and the use of a shield opaque for UV radiation, which was installed behind the grid for reflection and absorption of ultraviolet radiation. Thus, test objects placed behind the grid and the shield could be reached only by non-charged active plasma particles. Density of active particles inside the test object (Petri dish) was determined by the balance between

their income via the grid of square S_0 and their death on internal surface of test object (square S) and reverse flow from the test object into the discharge volume

$$n_0 S_0 \approx n_1 S k + n_1 S_0 \quad (S \gg S_0, k \ll 1)$$

where n_0, n_1 are densities of active particles in the plasma and inside test object, respectively, and k is coefficient of active particles death.

Thus with the growth of S_0 , the density of active particles inside the test object increases at first, and then at $S_0 \gg S k$ reaches the density of active particles in the plasma. At that the sterilization time should reach its minimum value.

Survival curves for spores *Bac.subtilies* obtained at the sterilization with electrically neutral particles generated at the discharge glowing in oxygen are presented in Fig. 3 for various S_0 . One can see from the figure that the sterilization time indeed decreases with the growth of opening square S_0 , reaching its minimum value at $S_0 \geq 0,2 \text{ cm}^2$. This time does correspond to that of sterilization of opened surfaces in oxygen plasma due to active electrically neutral particles. One can see from the comparison of Figs. 1 and 3 that in the case of oxygen, the sterilization time due to active particles is just 2 times longer than that due to ultraviolet radiation. In case of air these times differ more essentially (by a factor of 5-6).

It should be noted that these relations are valid only when the density of active particles is close to that in the plasma. As we have seen earlier (see Fig. 3), the density of active particles inside the cavities depends essentially on the square of the hole which these particles are coming from. That's why at the sterilization of real instruments, the sterilization time can be essentially longer than that resulting from given data. For illustration of this statement, Fig. 4 exhibits survival curves obtained at "pure" sterilization by active particles (that is when the density of active particles near the surface of Petri dishes is close to their density immediately in the plasma) and at the sterilization under medical packaging paper TPP-0034 (DuPont company), when access of active particles onto the surface is limited by gas conductivity of the paper. One can see from the figure that the sterilization time for packed articles is significantly longer than that for unpacked ones, and reaches several hours. However, even such sterilization time is suitable for medical practice, since respective chemical techniques with the use of toxic gases also require several hours.

4. Conclusions

1. Principal role in the sterilization process for opened surfaces in case of gaseous plasma generating media is performed by ultraviolet radiation of the plasma.
2. Efficiency of the sterilization by UV radiation of gaseous plasma is essentially higher than that provided by standard UV sources used in medicine.
3. The most efficient plasma generating gas with respect to the sterilization is oxygen, subsequently followed by air, carbon dioxide, hydrogen, argon, nitrogen.
4. The most efficient radiation with respect to the sterilization is that of the gas plasma in wavelength range of 160÷240 nm.
5. Sterilization time for the instruments with complex shape is determined by chemically active neutral plasma particles.

6. Sterilization time for opened surfaces in the plasma due to active particles is $\sim 2\div 6$ times longer than that due to ultraviolet radiation for the most efficient plasma generating gases.

Acknowledgments

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References

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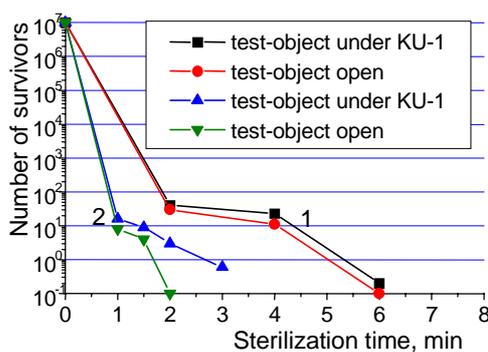


Fig. 1. Kill curves for spores *Bac.subtilies* obtained by plate count for the plasma sterilization. Initial population 10^7 spores. $P=26$ Pa, $W_d=0,003$ W/cc, working gas: 1 – air, 2 – oxygen.

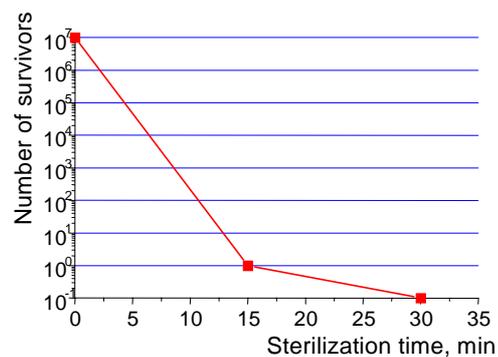


Fig. 2. Kill curves for spores *Bac.subtilies* obtained by plate count for the sterilization by UV radiation of mercury lamp. Initial population 10^7 spores. Power density of UV radiation $1,5$ mW/cm².

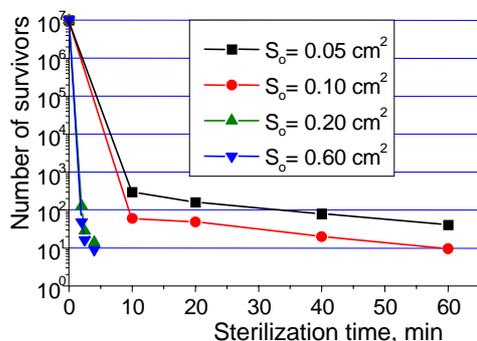


Fig. 3. Kill curves for spores *Bac.subtilies* obtained by plate count for sterilization by electroneutral active particles of the plasma. Initial population 10^7 spores. $P=26$ Pa, $W_d=0,0035$ W/cc, working gas – oxygen.

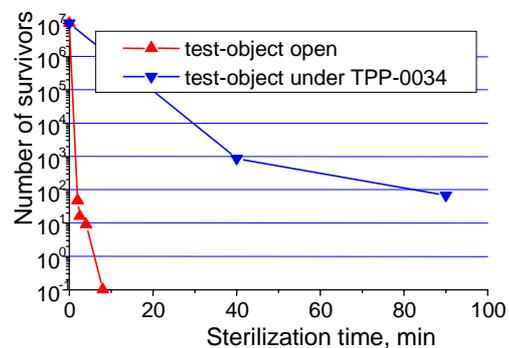


Fig. 4. Kill curves for spores *Bac.subtilies* obtained by plate count for sterilization by electroneutral plasma particles of opened packed test objects. Initial population 10^7 sp. $P=26$ Pa, $W_d=3,5$ mW/cc, oxygen.