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Atmospheric Pressure Plasma Jet for Sterilization of Heat Sensitive Surfaces

Streszczenie. *W artykule omówiono możliwości zapewniane przez nowoczesne metody sterylizacji dla potrzeb medycyny oraz przemysłu spożywczego i biotechnologicznego ze szczególnym uwzględnieniem innowacyjnej, nietermicznej dyszy plazmowej do dekontaminacji materiałów nieodpornych na działanie wysokiej temperatury.*

Abstract*. The paper presents review of possibilities offered by currently applied decontamination methods for medicine, biotechnology and food industry, emphasising the application of non-thermal atmospheric pressure plasma jet for heat non-resistant materials* ***(Dysza plazmowa działająca pod ciśnieniem atmosferycznym do sterylizacji powierzchni nieodpornych na działanie wysokiej temperatury).***

Słowa kluczowe: dysza plazmowa, sterylizacja, dekontaminacja.
Keywords: atmospheric pressure plasma jet, sterilization, decontamination.

Introduction

With increasing of pathogens' drug resistance it is necessary to develop sterilization and decontamination methods based on alternative approach: cost-effective sterilization tool, which combines physical and chemical treatment and, which could be safely and flexibly applied to various surfaces and materials.

According to M. Favero, 1998, 2001 any item, device, or solution is considered to be sterile when it is completely free of all living microorganisms and viruses, including bacterial endospores [1, 2]. From the practical point of view sterility assurance level defined as probability of a microorganism surviving on an item subjected to treatment of less than one in one million (10 - 6) was introduced. There is number of factors, which influence sterilization process including type of pathogen, type and condition of surface undergoing sterilization, environmental conditions (e.g. temperature, pressure), amount of other contaminants, etc., [3-5]. Pathogens can be present in variety of forms deposited on inert and living surfaces like walls of equipment, wound dressing, living tissues, medical prosthetics, food containers and food itself. National Institute of Health have reported that 80% of all known infections are caused by complex communities of microorganisms (bacterias, fungi, protozoa, etc.) embedded in self-secreted matrix of strongly adhesive hydrated polymers called biofilms [6]. Some studies have shown that bacteria in biofilms can be 1000-fold more resistant to antimicrobials than are planktonic cells [7].

Methods of decontamination

The idea of plasma sterilization was already proposed in 60-ties [8] as a good, low toxicity method for patients and operating staff. In spite of fact that the number of research papers and devices related to this topic is constantly increasing, most of the solutions were not fully implemented, mainly because of the lack of system optimization, lack of comparability between the proposed reactors and methods, lack of matching between plasma properties and sterilized material, and because of the incomplete sterilization in the case of multi-microorganisms biofilms. Therefore, industrial plasma-based decontamination is still a great challenge.

For medical sterilization several techniques have been implemented so far:

- the most popular thermal sterilization: dry and moist heat. Temperature in the autoclave is about 121°C, which cannot be applied to the heat-sensitive materials.
- membrane filters for liquid heat-sensitive components (problem with filter recycling)
- commercially used ethylene oxide sterilizers (EtO), method with many questions concerning the carcinogenic properties of the EtO residues adsorbed on the materials after processing [9] and worries about the safety of operators when opening the sterilizer before the end of the very long vent time. Because of high toxicity one cycle of EtO operating ranges from 12 to 48 h (sterilization itself- about 60 min).
- liquid formaldehyde and glutaraldehyde, not applicable to the tissues, not environmental-friendly
- costly gamma irradiation process, with many questions about the location of the operation site and damaging of the disinfected materials' surface [10]. Method is sometimes used for sterilizing selected kinds of foods.

Pulsed electric field processing (15-50 kV cm^{-1}, pulse frequency of 200-400 Hz) and high pressure method for food sterilization (300-700 MPa) [11] are currently gaining attention. However, the last one alone seems to be ineffective towards endospores. Sterilizing efficiency of ultrasonic devices is very low.

All above methods cannot be applied to the living tissues and in the most of cases, they require closed systems. Except the thermal one, the traditional medical sterilizers involve harmful compounds. Thus, application of plasmas seems to be reasonable solution for biological decontamination. Plasma can inactivate most of pathogens: gram negative and positive bacteria, microbial spores, molds and fungi, viruses and maybe even prions.

Presently, low-pressure plasma sterilizers are commercially offered in the market [12]. However, low-pressure plasma besides the costly vacuum system shares some of the disadvantages of traditional sterilizers- it requires closed reactor and cannot be applied to the living tissues.

Many research groups concentrate on the efforts of designing plasma sterilizing device working in the ambient conditions [13-20] using variety of methods such as barrier discharge, pulsed corona reactors, or plasma jets.

To maintain the uniform discharge under atmospheric pressure mainly quite expensive gases as helium and argon are used in high concentrations. Plasma disinfection time given in the literature varies from several minutes to even hours. Recently, many investigations concerning atmospheric-pressure plasma jet (APPJ) as the compact, portable, low-temperature gas discharge plasma device for cold sterilization of various heat-sensitive surfaces and materials have been performed.

Gas flowrate, [m^3/h] / Temperature, [^{o}C]				
0,2 / 170	0,4 / 120	0,6 / 90	0,8 / 60	1 / 35

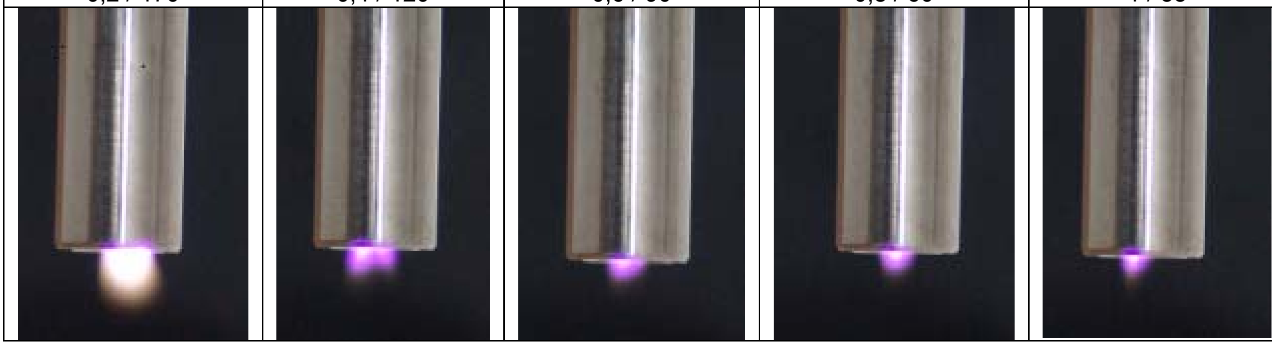

Fig 2. Photographs of the plasma jet generated in RF powered device with different flow of air. P=80 W, f=12,98 MHz

The pathogens are going to be inactivated due to:
- direct destruction, volatization and etching of the cells, decreasing of the biofilm adhesivity by the decomposition of polymer matrix
- oxidative stress (due to the fact of formation various active agents (ozone, OH and O radicals, hydrogen peroxide, etc. during the electrical discharge),
- nitrogen stress (recent research results suggest cells' damage from reactive nitrogen intermediates as nitric oxide, peroxynitrite, nitrous acid, nitrogen trioxide, etc.[21]).

Atmospheric pressure plasma jet

APPJ for decontamination purposes developed in LUT consisted of:
- gas and liquid dosing sub-system,
- electrical discharge generating sub-system
- chemical and biological analyzing sub-system

The main part of the device was powered changeable needle electrode encapsulated in a tubular metal case. Surface of the needle electrode was turtle-shell shaped to assure the uniformity of the discharge. Discharge gap between the electrodes was 2 mm. Device was powered by a regulated RF supply through an impedance matching network. For the best operation on heat non-resistant materials the temperature of plasma should not exceed 70°C. For treatment of living surfaces (wounds, skin) temperature of APPJ outlet post glow gas below 40°C is recommended. Presented system assured safe operation with temperature of 35°C measured with the thermocouple at the outlet of the nozzle (Fig. 1).

Implementing APPJ can ensure the sterile conditions for production, handling and preservation of variety of materials. APPJ device could be applied on the different stages of medical and biochemical procedures, in food factories and restaurants, for a broad range of curvatures and surfaces.

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