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The influence of low-temperature plasma on the electromagnetic spectrum structure of the selected liquid

***Abstract**. The aim of the research was to parameterise the degree of influence of low-temperature plasma on the structure of the electromagnetic spectrum in the visible light range of a selected fluid, which, after being parameterised, will constitute a benchmark marker of the analysed interaction. The scope of the research included the generation of plasma water in a plasma generator, the intensity of which was the differentiating element. The fluid so prepared was subjected to spectral analysis. Subsequently, water of varying interaction degree was used to prepare a medium for microorganisms, the growth of which was monitored by measuring the optical density of the solution. Differences were also observed in the kinetics of microbial growth, which developed in water subjected to cold plasma interaction and in water without this interaction. The measured optical density after a 6-fold exposure and 50-hour incubation was 3.72 McF and was 1.93 McF lower than that of the reference sample (without exposure).*

***Streszczenie.** Celem badań było sparametryzowanie stopnia wpływu plazmy niskotemperaturowej na strukturę widma elektromagnetycznego w zakresie światła widzialnego wybranej cieczy, która po sparametryzowaniu będzie stanowiła wyznacznik analizowanej interakcji. Zakres badań obejmował wytworzenie w generatorze plazmy wody, której intensywność była elementem różnicującym. Tak przygotowany płyn został poddany analizie spektralnej. Następnie woda o różnym stopniu interakcji została wykorzystana do przygotowania pożywki dla mikroorganizmów, których wzrost był monitorowany poprzez pomiar gęstości optycznej roztworu. Zaobserwowano również różnice w kinetyce wzrostu mikroorganizmów, które rozwijały się w wodzie poddanej interakcji z zimną plazmą oraz w wodzie bez tej interakcji. Zmierzona gęstość optyczna po 6-krotnym naświetlaniu i 50-godzinnej inkubacji wynosiła 3,72 McF i była o 1,93 McF niższa niż w przypadku próbki referencyjnej (bez naświetlania). (**Wpływ plazmy niskotemperaturowej na strukturę widma elektromagnetycznego wybranej cieczy**)*

Keywords: cold plasma, electromagnetic spectrum structure, microorganisms
Słowa kluczowe: zimna plazma, struktura widma elektromagnetycznego, mikroorganizmy

Introduction

The use of cold plasma in life sciences and medicine focuses on its antimicrobial properties. This research is carried out in two directions: sterilization effects, e.g. in the treatment of human infections, and the possibility of microbial decontamination of food and plant seeds and bulbs [1]. Cold plasma is assumed to occur in the energy range from 0.2 eV to 3 eV, which corresponds approximately to the temperature range from 2000 K to 30 000 K (l eV = 11600 K). Low-temperature plasma is usually a slightly ionized gas with a high or very high content of neutral particles. The importance of these particles, e.g.: in the collision process, is crucial for the behavior of plasmas of this type [2]. Characteristic for CAP, the low temperature of the process together with the generated properties: biomodulating, stimulating, disinfecting and sterilizing; enables its use in medicine [3, 4, 5], food technology [6, 7] and environmental protection. The fundamental use of cold plasma in life sciences and medicine focuses on its antimicrobial properties. This research is carried out in two directions: sterilization effects, e.g. in the treatment of human infections, and the possibility of microbial decontamination of food and plant seeds and bulbs [1].

There are several studies on the use of cold plasma technology for seed decontamination [8,9,10,11]. The action of cold plasma causes modification of the physico-chemical-mechanical plasma environment, which is especially true for liquids [12,13,14]. Elimination of microorganisms is also explained by changes in the pH of the environment. Liu et al [15] subjected water with a bacterial suspension of S. aureus to plasma exposure in a microJET system. Direct plasma treatment, during which the pH of the environment was changed, effectively inactivated S. aureus within 20 min. The best sterilization effect was obtained at pH 4.5. According to the authors, the killing of bacteria was due to the change in acidity of the fluid and the interaction of reactive compounds generated by the plasma, mainly hydroxyl radical (HOO-) with the cell. The use of cold plasma in microbial decontamination of food products simultaneously preserves the basic attributes of the product. The properties of the plasma are determined by four basic parameters: temperature, pressure, thermodynamic equilibrium and degree of ionization. For technological purposes, plasma is produced by means of electrical discharges. There are three basic electrode configurations in barrier discharges that lead to: 1) volume discharges (VD), 2) surface discharges (SD), and 3) coplanar discharges (co-planar discharges). There are also reactors built with all of the above mentioned discharges [16]. A very important parameter in the use of cold plasma technology is the method of determining the input and output parameters of the medium that is subjected to the above mentioned process. The determination of the method and the determination of the boundary conditions of the cold plasma interaction of the realization with the biological agent response will allow to model the process in a continuous way, which will be realized automatically.

Material and methods

The aim of the research was to parameterize the degree of influence of low-temperature plasma on the structure of the electromagnetic spectrum in the visible light range of a selected fluid, which, after parameterization, will serve as a benchmark marker of the analyzed interaction. The scope of the study included the generation of plasma water in a plasma generator, the intensity of which was the differentiating element. The fluid prepared in this way was subjected to spectral analysis, which was carried out with an Exemplar spectrometer, in the wavelength range from 350 to 1050 nm, and on a bench equipped with a multi-channel spectrophotometer C5964 from Hammatsu, which allows the analysis of the spectral structure in the visible range [12]. In addition, water with varying degrees of interaction was used to prepare a medium for microorganisms whose growth was monitored by measuring the optical density of the solution.

In this study, a cold plasma generator was used, which is constructed with two half bridges in H configuration on MOSFET transistors feeds a resonant circuit with a high voltage transformer (Fig.1). The secondary winding supplies the ionizing electrode with 7.5kV. The sinusoidal waveform of the generator is modulated with adjustable frequency in the range of 0 - 350Hz and adjustable pulse filling of 0-100%. The tests were carried out with a frequency of 175Hz and a pulse filling ratio of 50%. The degree of influence of cold plasma on the fluid was controlled by the multiplicity of its influence. In the experiment, the number of times the fluid passed through the cold plasma generator was determined to be 1 to 6, the zero test was the fluid without cold plasma interaction. The fluid flow rate through the generator was 0.9 l/min.

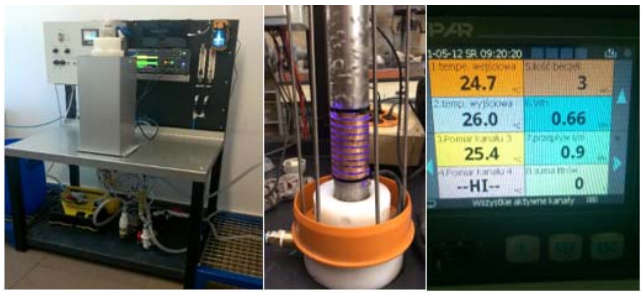

Fig. 1. View of laboratory station for cold plasma interaction

The fluid used for the study was spring water whose turbidity was 0.13 NTU, hydrogen ion concentration (pH) 8.0, electrical conductivity 603 μS/cm, total hardness 282 mg/l CaCO3, nitrates 33.6 mg/l, chlorides 69 mg/l, coliforms 0, these values were determined by a laboratory accredited by PCA with accreditation number AB521.

Water of varying intensity of cold plasma exposure was the medium composition for microorganisms, where then their life cycle was analyzed as a function of time. Enterococcus faecalis strain ATCC 29212 (Figure 2) from the strain collection of the Experimental Research Techniques Laboratory of Raw Materials and Biological Products was used in this study. In order to restore vital functions, a reductive culture was performed on TSA solid medium (BioMaxima, Poland) in Petri dishes. The plates were incubated for 24 h at 37 °C.

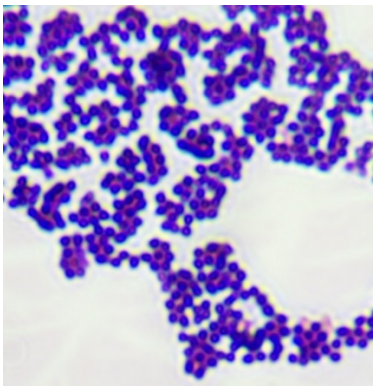
Fig. 2. View of the microorganisms used in the experiment

Nutrient Broth liquid medium (BioMaxima, Poland) was prepared from plasma water. The liquid medium was inoculated with Enterococcus faecalis ATCC 29212 obtaining an initial optical density of 0.35 McF. The culture was carried out at 37 C for 7 days. Optical density was measured every 24 hours using a DEN-1B densitometer as in [19,20].

Results

There was a variation in the spectral characteristics between water without and with cold plasma exposure. Figure 3 shows the characteristics of the water before cold plasma exposure where the highest value of 7757.25 mV is recorded at 806 nm with an average value of 5533.13 mV and a standard deviation of 1286 mV.

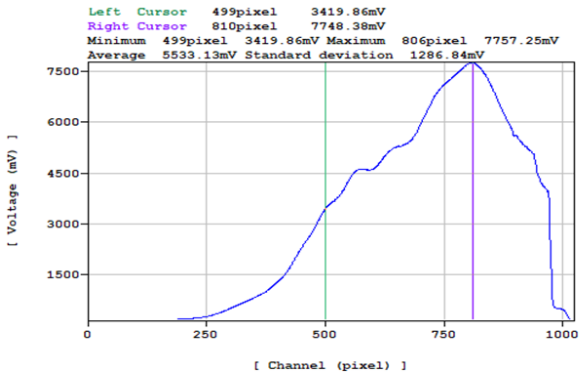

Fig. 3. Spectral characteristics of water before cold plasma exposure

Analyzing the values obtained after six times of cold plasma exposure, it was noted that the maximum value was characterized by the same wavelength (806 nm), but the value of radiation intensity was higher than that of water before cold plasma exposure by 14.9% and was 9120.79 mV (Figure 4). Also in the mean value there was a variation, which described by relative value was more than 17%, it should also be noted that the water after cold plasma interaction was characterized by greater variation, which expressed by standard deviation was 1463.19 mV. Therefore, despite the apparent similarity of the two spectral characteristics, it is possible on their basis to identify the water that has been exposed to cold plasma.

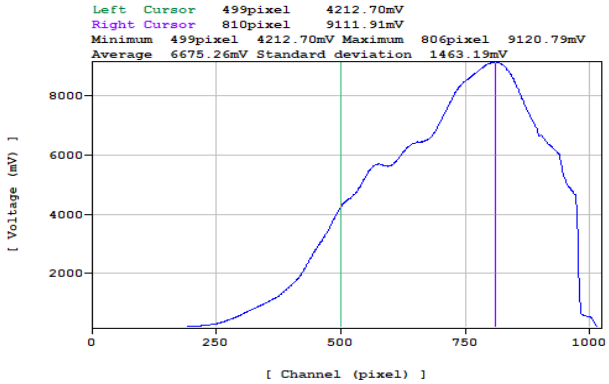

Fig. 4. Spectral characteristics of water after six times cold plasma exposure

Next, the prepared water was used to prepare media for Enterococcus faecalis ATCC 29212 microorganisms, the number of combinations of the experiment remained unchanged. Analyzing the kinetics of microbial growth on media where water with different degree of plasma treatment was used and water where this interaction was absent. A very clear variation was found between 40 and 80 hours of microbial incubation. In this interval, the highest number of microorganisms was recorded for the zero sample (water without plasma treatment) and the lowest for the sample in which water after six times of plasma treatment was used (Figure 5).

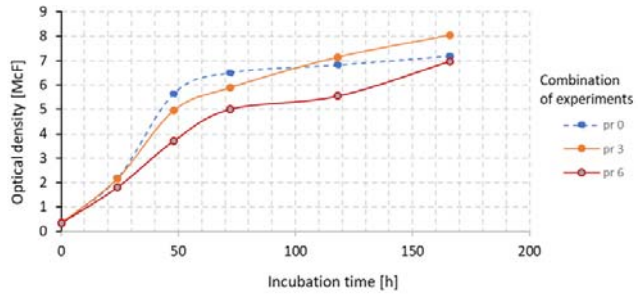

Fig. 5. . View of the microorganisms used in the experiment

It should also be noted that a lower multiplicity of exposure (threefold exposure) of cold plasma to the water that was used to make the media had a stimulating effect beyond 120 hours of incubation of microorganisms compared to the control sample. Figures 6 and 7 show the spectral analysis of the suspension with microorganisms that diluted in water without plasma interaction (6) and in water that was exposed six times to the cold plasma generator (7). It should be noted that the measurement was made after a 50 hour incubation, where the optical density of the suspension in the case of the zero sample (without cold plasma interaction) was about 5.5 McF, while the optical density of the suspension after cold plasma interaction (six times interaction) was about 4.0 McF.

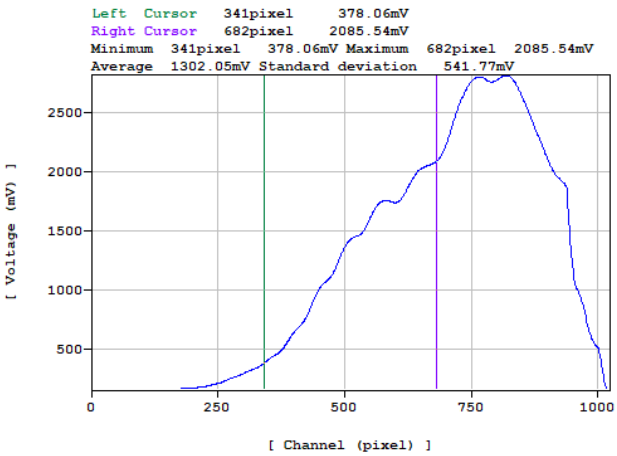

Fig. 6. Spectral characteristics of the suspension of microorganisms for which water was used before cold plasma interaction

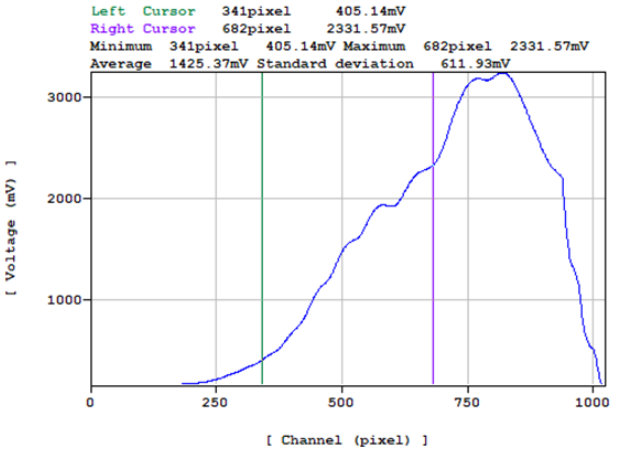

Fig. 7. Spectral characteristics of the suspension of microorganisms for which water was used after six times cold plasma exposure

Analyzing the optical characteristics shown in Figures 6,7, it was found that higher intensity values were recorded for the suspension without cold plasma treatment compared to the values recorded for the suspension that was treated with cold plasma six times. However, it should be noted that the differences recorded are much smaller than for water alone.

The relative difference in maximum values was about 10%, while in minimum values it was only 6%. As in the case of water, the suspension also reached its maximum intensity at the same wavelength, which in this case was 682 nm, lower than that of pure water.

Figure 8 identifies the intensity of the light penetration signal in relation to the intensity of the cold plasma generator interaction with the liquid. The description 0.1 means that reference was made to trial zero (without the interaction of the cold plasma generator), variant one and each subsequent number, is the next variant of the experiment. It is noted that up to a wavelength of 350nm, the radiation intensity is the same for each variant and is below 250 mV.

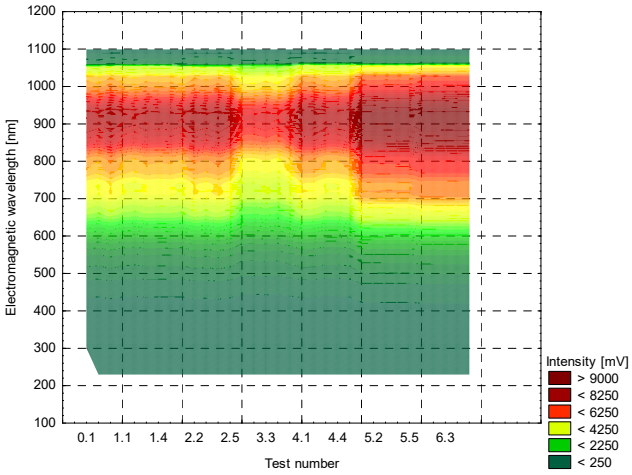

Fig. 8. Electromagnetic wavelengths identified after passing through a fluid with different plasma levels

A clear differentiation was read from a wavelength of 600nm. For samples zero, one, two and four, the intensity gradually increases as the wavelength changes to a longer wavelength. After the radiation intensity reached a maximum at a wavelength of about 900nm, the intensity began to decrease similarly for each sample. The lowest intensity over the entire experiment was read for sample three. Less than 4250 mV was obtained at 800nm. Nor was a maximum intensity above 9000 mV obtained as for the other trials. The highest intensity values were read for trial five and six. The maximum intensity value of the signal radiation was read when the wavelength exceeded 800nm and was above 9000 mV. The intensity was unchanged up to a wavelength of 1000nm. It then began to slowly decrease, but was still higher than the other samples. It was noted that the liquid that was exposed to the cold plasma generator five and six times showed the highest signal radiation intensity and it persisted the longest in relation to the wavelength change.

Conclusion

Preliminary studies showed an indirect effect of cold plasma exposure on the growth of microorganisms that developed on the medium after cold plasma exposure. The optical density after 6-fold exposure and 50-hour incubation was 3.72 McF and was 1.93 McF lower than the reference sample (without exposure). Thus, there is an opportunity to use cold plasma technology to model the kinetics of microbial growth and selective growth of different microbial

strains at different stages of incubation. Parameterization of this phenomenon will require further studies necessary to model the interaction of microbial incubation kinetics - the spectral characteristics of the suspension with microorganisms and the intensity of cold plasma interaction.

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