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EFFECT OF OZONE IN EXPERIMENTS ON THE DEVELOPMENT OF FOOD IRRADIATION METHODS

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Abstract

Presented are the preliminary experimental results to evaluate the role of ozone in process of radiation sterilization comparing to ionizing irradiation. Computer modeling for the problem is provided.

INTRODUCTION

During sterilization by electron beam, ozone is formed in the air, which increases the efficiency of microorganism suppression. When studying the processes of radiation sterilization, it is necessary to estimate the contribution of the chemical factor of ozone formation. To make an accurate studies, one should evaluate the degree of influence of the ozone formation factor in air radiolysis.

The experiments on the irradiation of several cultures of microorganisms were performed, which make possible to find out the effect of ozone factor. Experiments were performed with different microorganisms.

To ease the calculation, the computer program "BEAM SCANNING" was used to model the experiments and to evaluate the factor of ozone creation.

MATERIALS AND METHODS

Irradiation center at IPCE RAS is based on radiation-technological installation with electron accelerator UELV-10-10-S-70 which is mounted in radiation-safe bunker and designed to perform irradiation by electron beam with electron energy up to 8 MeV, beam power up to 10 kW.

Figure 1: Radiation installation at IPCE RAS centre.

Radiation-technological installation consists of accelerator with beam scanning system attached to it and circular conveyer, which moves objects before the output window of accelerator, one meter far from output window. The conveyer with boxes and accelerator with beam scanning system of this installation are presented on Fig. 1.

Installation is used in different research, technological and commercial applications. Nominally, installation provides irradiation on conveyer at a dose rate near 3 kGy per second. This installation also makes possible to use a 5-6 MeV beam with low dose rate near 300 Gy/min. [1]. Installation is used for scientific research and applied studies of radiation-chemical transformations of materials and development of radiation technologies. One of the areas of research being held is the study of food irradiation.

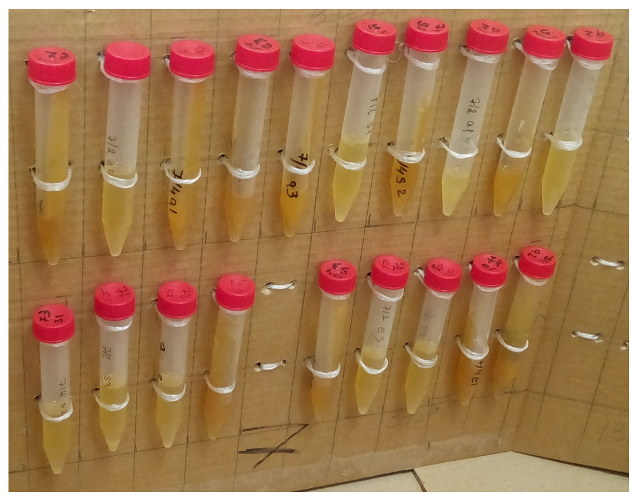

Figure 2: Test tubes with solutions.

In experiments carried out, irradiated closed test-tubes with model solutions of microorganisms, which have diameter of 15 mm and a height of 140 mm, as shown on Fig. 2. The study used Gram-negative E. coli bacterium with dimensions of 1.1-1.5 × 2.0-6.0 μm and gamma-positive coca Staphylococcus aureus, having spherical form with a diameter of 0.5-1.5 microns. The study used daily cultures of these microorganisms dissolved in meat-peptone broth. Single irradiation of microorganisms was carried out by electron beam with doses 3, 5, 7, 10 kGy in two positions of processed test-tubes: horizontal and vertical. Tubes were attached to the conveyor wall using copper wire thickness of 1 mm.

Three experiments were used in each case. Microbiological examination of irradiated and control samples were performed on the day after irradiation. Control ampoules were stored under the same conditions as irradiat-

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ed. Microbiological Studies were conducted in accordance with GOST 30726-2011 for E. coli and GOST 10444.2-94 for S. aureus according to which, the time of cultivation of microorganisms on dry nutrient agar should be 24 hours at 37 ° C. The studies were carried out by the method of determining the most probable number of microorganisms. The results were taken into account in each test sample for two repetitions.

In experiments the irradiation on conveyer was performed. To find out the role of ozone, the dependence of the degree of microbial suppression on the method of installing a test tube with a nutrient medium under a beam of an accelerator was investigated. Irradiation was carried out with horizontal and vertical installation of test tubes with cultures. With the horizontal, the size of the area of contact between the medium and the ozonized air inside the tube is higher than in the vertical tube.

The irradiation process was monitored by film dosimeters located near and inside the test tubes with a substrate analog.

To ease the calculation for evaluation the ozone influence, simulation of the experimental conditions carried out by using the computer code "BEAM SCANNING" [2-5]. "BEAM SCANNING" program can be used in different applications of irradiating beam of industrial sterilization installations. Simulation allows to determine the beam current and dose distribution in the irradiated objects and to propose the optimal method of irradiation. Calculations were performed to determine a total beam current in the tube air to define a final ozone concentration after irradiation.

RESULTS

In experiments found, that the effect of irradiation with a horizontal position of the tube is higher than with the vertical arrangement. In Fig. 3 and Fig. 4 on a logarithmic scale there are graphs of inactivation of microorganisms of E. coli and S. Aureus are presented, depending on the value of the absorbed radiation dose. The graphs show, that it is possible to distinguish two "phases" of inactivation: a "fast" direct radiation exposure to microorganisms and "slow", determined by the post-radiation impact associated with accumulation of products of radiation-chemical reactions (ozone, etc.), possessing bactericidal effect. To confirm this assumptions, irradiating tubes with a suspension of microorganisms were carried out in two positions: horizontal and vertical. From the graphs it can be seen that in the horizontal position the number of survived microorganisms are about an order of magnitude smaller than in vertical position of the test tubes. This can be explained by the fact that with horizontal position of the contact area of the suspension with the steam-air medium (ozone) more than with the vertical position.

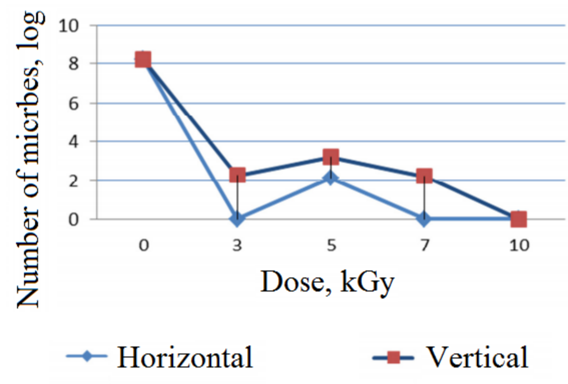

Figure 3: Results for E.Coli.

The results of the study are shown in Fig. 3 for E. coli and Fig. 4 for S. Aureus both for vertical and horizontal positions of tubes. The figures are presented in logarithmic scale content of surviving microorganisms from the absorbed dose. It was found that E. coli and S. aureus cultures exposed to radiation irradiation die at 80-100%.

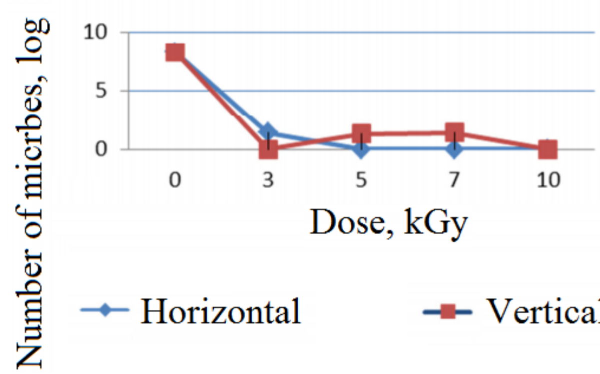

Figure 4: Results for S.Aureus.

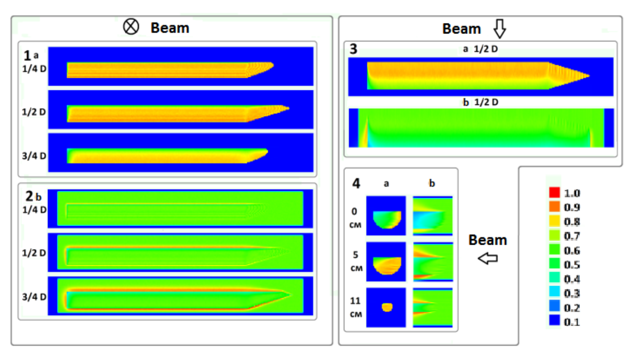

Figure 5: Calculation results for horizontal tubes. Beam direction is shown on figure by arrows and signs. Presented distributions in different cross-sections, relative to diameter of a test tube, which is written near each figure. 1a, 3a and 4a represents the energy density, while 2b, 3b, 4b represents dose distribution in tube and surrounding air.

Consider the assessment of the effect of ozone on sterilization in the presented experiments. The calculations of

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the amount of ozone produced in the experiments were performed, and simulation of the irradiation process was carried out using computer code “BEAM SCANNING”.

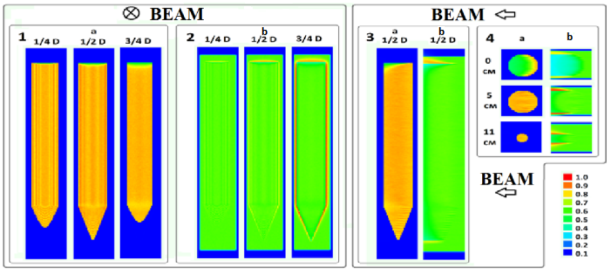

Figure 6: Calculation results for vertical tubes. Beam direction is shown on figure by arrows and signs. Presented distributions in different cross-sections, relative to diameter of a test tube, which is written near each figure. 1a, 3a and 4a represents the energy density, while 2b, 3b, 4b represents dose distribution in tube and surrounding air.

Figure 5 shows the dose and energy distribution, found in calculations on vertical tubes, while Fig. 6 presents the results for horizontal tubes.

Consider the task for irradiating the cylindrical test-tube with length of 12 cm and diameter – 1.5 cm. In the air above the solution, ozone is formed. Simulation concerns vertical and horizontal tube, to find process characteristics, needed to evaluate the ozone concentration in experiments. The contact area for a tubes can be easily calculated: in half-filled horizontal tube the spot area is 18 cm^2, while in vertical it is only 1.77 cm^2.

In process of simulation we consider the moving of the tube into the beam and it’s removing from it. So the process of irradiation is not going with constant power. But as in formulas for defining the ozone concentration the dose rate parameter is used, which is the constant for accelerator, we assume that the difference in irradiation processes manifests itself only in irradiation time.

In modeling process we calculate the passing current through process for each dose, using air as the trap for electrons. From this data we can define the passing current. The surface of tube, opposite to the beam is 9 cm^2. So we can find the data, needed to use in formula [6].

$$C_{O3} = 4.27 \cdot 10^7 \frac{J}{S(\lambda_{rad} + K)}(1 - e^{-(\lambda_{rad}+K)t}),$$

which gives the ozone concentration in milligrams per meter cube, where J is the current in air in Amperes, S is the surface, crossed by the beam in meter square, t is the time of irradiation in hours, K is the coefficient of air change, which is equal to Zero for the closed tube.

$$\lambda_{rad} = 1.6 \cdot 10^{-2} \cdot P^{0.6},$$

where P is the dose rate which is $1.08 \cdot 10^9$ cGy/h for all experiments, λ_{rad} = $4.209 \cdot 10^3$. Using this formula we can find data for ozone concentration depended on dose, presented on Fig. 7

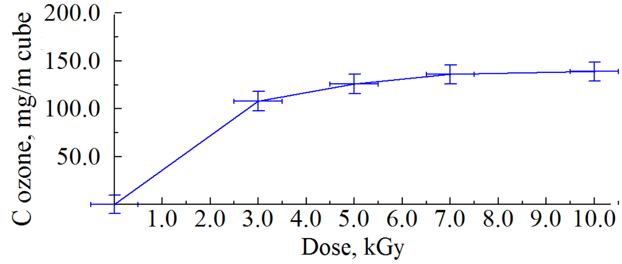

Figure 7: Dose dependence of ozone concentration

CONCLUSION

From the results of this study we conclude that ozone formation has a significant effect on the suppression of microorganisms during irradiation. It has essential effect at doses from 3 to 7 kGy, while at doses more than 10 kGy effect is created mostly by irradiation.

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