RAD Conference Proceedings, vol. 2, pp. 11–14, 2017
www.rad-proceedings.org

SURFACE IRRADIATION OF CHICKEN EGGS BY NANOSECOND ELECTRON BEAM

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Abstract. *The irradiation exposure experiments were carried out by means of the pulsed repetitive nanosecond accelerator URT-0.5 (electron energy of up to 500 keV, a pulse width of 50 ns, pulse repetition rate of up to 200pps). The determination of the distribution of the absorbed dose (AD) in the depth in the polyethylene was conducted by a gray wedge. The measurement of the electron beam AD on the surface of the shell (removed from the eggs) and under the shell, as well as beneath the absorber layer (polyethylene 80 microns thick) was also performed by the film dosimeter. Thermoluminescent dosimeters, TLD-500, were used to determine the distribution of the bremsstrahlung AD inside chicken eggs. These results lead to the conclusion that the irradiation of an electron beam with the AD level of 5 kGy is sufficient for complete disinfection on the surface of an egg. The AD inside of it will not exceed 8 cGy because of bremsstrahlung.*

Key words**:** *Disinfection, electrons, bremsstrahlung, dosimetry, radiation treatment, Salmonella, chicken egg*

DOI: 10.21175/RadProc.2017.03

1. INTRODUCTION

Foods must be safe for the consumer. One of the hazards is microbiological contamination. The requirements for microbial contamination include monitoring of both the overall microbiological contamination and the presence / absence of the certain types of especially dangerous pathogens. The permissible level of microbial contamination is achieved by a complex of sanitary and hygienic conditions at the production and packaging of food products.

At present, virtually the only way to reduce the microbial contamination of foods is the heat treatment. However, thermal sterilization leads to irreversible changes in the properties of raw materials, which is not always acceptable. Applied chemical methods, such as salting, sugaring, etc. lead to the same result, and use a lot of preservatives. Therefore, the heat pasteurization is widely used to increase the shelf life of foods, followed by cooling to temperatures at which the multiplication of microorganisms is difficult.

It is known that one of the indicators of the quality of the eggs is the purity of the shell. However, the presence of dirt (i.e., microorganisms), not only makes the appearance of the eggs unattractive, but also facilitates the penetration of microorganisms through pores in the shell egg into its content, which leads to rapid deterioration of eggs, and makes them hazardous to Salmonella infection, as well.

Wash improves the appearance of the eggs, but sharply reduces their storage stability, so it is usually used before breaking up the eggs in the food industry [1]. Such a washing results in the opening of pores in the shell, through which the microorganisms can penetrate the egg. It also requires a hot water flow (~ 800C) and chemically disinfecting substances (3.2 % hydrogen peroxide), which greatly increases contamination of nature by toxic waste [2].

An alternative is radiation sterilization, due to the universality of the harmful effects of ionizing radiation on any biological objects. In this way, the absorbed dose (AD) of radiation sterilization (regardless of the type of radiation) does not exceed 25 kGy [3].

However, the irradiation of the foods may be accompanied by a variety of chemical reactions which may transform the organoleptic properties of the products. Thus, it is necessary to set the limits of AD for irradiation of various products.

For example, for fresh eggs, a level of AD ≤ 3 kGy is recommended, which is close to the AD level for inactivation of the bacteria of the Salmonella group [4]. Irradiated foods are marked with a special sign “radura”, so that the buyer could choose whether to use irradiated products or nor. Unfortunately, the radiation phobia is of great importance for the consumer choice.

To solve the problems of microbiological contamination of eggs and the consumer sentiment, in our view, the following approaches look promising.

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Firstly, by proper electron energy selection, to choose such an AD distribution profile within the product, that will destroy, upon irradiation, all kinds of microbes, including the pathogenic ones both on the shell surface and in its pores as well as in the air chamber up to the under-shell membranes. In that way, there will be practically no exposure of the protein itself to the accelerated electrons.

Secondly, the ozone will be produced under the irradiation, which will also contribute to the disinfection of the surface, especially by irradiation of the eggs sealed in plastic containers. It is possible, to sterilize the eggs after packaging by the radiation itself as well as by the creation of ozone at a concentration levels lethal to microorganisms in the packaging – radiation-chemical sterilization [5]. At the same time, it is possible to select the AD distribution profile within the egg in such a way that, its protein is not irradiated by electrons, at all. It is important that the presence of sealed plastic containers allows us to solve the problem of re-semination of eggs during storage.

Both ways have their merits. Moreover, in the real technological process, both ways can be combined in different proportions.

The disadvantage of irradiation sterilization is its high cost and heightened risk for the working staff. This risk can be significantly reduced by optimizing the radiation source.

At present, nanosecond electron accelerators for the technologies [6] which significantly reduce the costs of the radiation source itself, as well as the costs of the personnel radiation protection have been developed and produced.

Furthermore, a stronger bactericidal effect of the nanosecond electron beam (NEB) is known [7]. That will allow to reduce the AD magnitude of the electron beam 2-3 times, which will increase the efficiency of the method while leaving the energy consumption and material costs the same.

A feature of the NEB spectrum is the presence of a much greater body of the low-energy electrons, which occur at the acceleration at the pulse fronts of the accelerating voltage. For our purposes, this is a positive feature, because it allows us to obtain the desired AD distribution profile within the product (Figure 1).

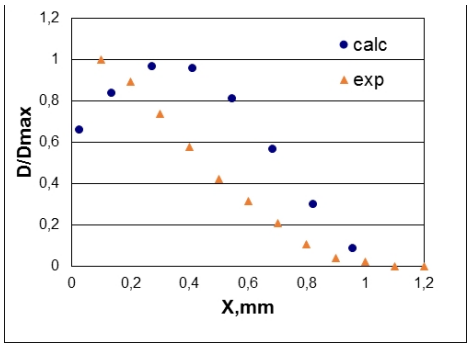

Figure 1. Measured experimentally and calculated distribution of absorbed dose in the depth in the polyethylene

Unfortunately, it is impossible to completely avoid irradiation of the egg protein since bremsstrahlung is induced by absorption of the electrodes which makes a major contribution to the AD, created inside the egg.

Thus, the aim of this study was to investigate the profile of AD distribution on the surface and inside the egg from the electron beam and bremsstrahlung.

2. The methodology and experiment results

The exposure experiments were carried out by the pulsed repetitive nanosecond accelerator URT-0.5 [8] (electron energy up to 500 keV, pulse width about 50 ns, pulse repetition rate up to 200 pps). At the first phase the measurement of the absorbed dose distribution in depth in polyethylene (analogue of biological tissue) was carried out by a gray wedge. AD was tested by a film dosimeter CO AD (F) R-5/50 [9], covered with polythene layers of varying thickness (up to 600 microns). AD measurements on the film dosimeters were conducted by determining the density of darkening of the spectrophotometer PE 5400VI, followed by recalculation of calibration lines. During the experiments, the accelerator was operating at the regimes of a charging voltage of 25 and 30 kV. Electron beam dosimetry results are shown in Figure 2.

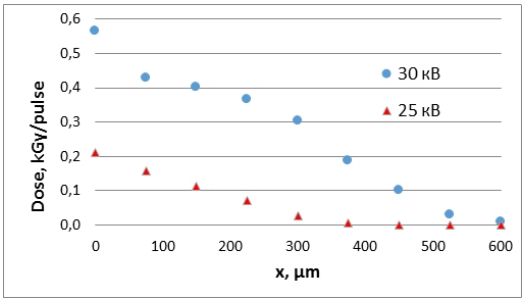

Figure 2. Distribution of the electron beam AD in the depth in the polyethylene at a different charging voltage on the accelerator URT-0.5

Besides that, using the film dosimeter, a measurement of the electron beam AD on shell surface (removed from the egg) and under the shell as well as beneath the absorber layer (polyethylene of 80 microns thick) was performed (Figure 3). The sample was placed in a plastic container to save the geometry used for the irradiation of eggs. The results of dosimetry at a different charging voltage are shown in Table 1.

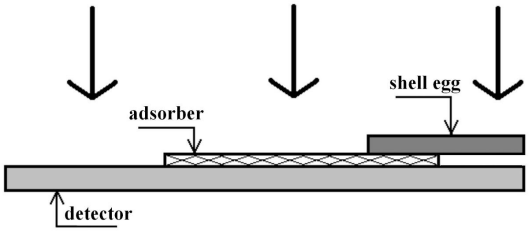

Figure 3. The geometry of the irradiation under the electron beam dosimetry

To determine the distribution of AD bremsstrahlung inside chicken egg thermoluminescent

dosimeters (TLD) TLD-500 (diameter of 5 mm and a thickness of 1 mm) based on aluminum oxide doped with carbon were used [10]. The dosimeters were placed in sections of boiled eggs (or cut lengthwise, or crosswise), in such a way that it was possible to determine the AD distribution in various points of the biological object (Figure 4).

AD measurement was carried out by a hardware system to highlight TLD dosimeters. Thermoluminescence lines were recorded by a special automated apparatus at a heating rate of 2 K/s [11]. The signal was detected by a photomultiplier FEU-142 with reduced sensitivity to thermal radiation of the heater, the maximum temperature of which could be 1200 K.

Table 1. Measurement results of the electron beam AD

№	Place of detector arrangement	AD, Gy/pulse at a different charging voltage		
		30 kV	25 kV	20 kV
1	On the lid of a plastic container outside	583	505	173
2	On the surface of the shell	195	170	8
3	Under the shell	8.43	-*	-
4	Under the shell and absorber layer	0.61	-	-

*AD value is below the threshold of detector sensitivity

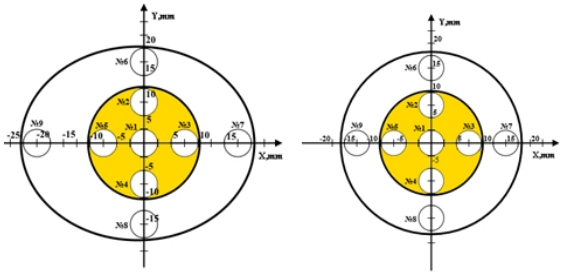

Figure 4. Location of TLD dosimeters (5 mm in diameter) at vertical (right) and the horizontal section of the chicken egg

Table 2. Measurement results of bremsstrahlung AD inside the egg

Dosimeter № (Figure 4)	AD, cGy/pulse	
	horizontal section	vertical section
1	0.13	0.16
2	0.25	0.15
3	0.18	0.17
4	0.17	0.13
5	0.15	0.14
6	0.18	0.18
7	0.31	0.21
8	0.15	0.15
9	0.17	0.26

3. Discussion of the measurement results

As one can see from Figure 2, by varying the charging voltage of the accelerator, it is possible to choose the depth of the electrons' penetration, in order to limit the exposure of the shell (0.3-0.4 mm) and the under-shell protein membranes (~ 70 μm) [1].

It should be noted that the shell consists of calcium carbonate with a density (2.74-2.83 g/cm^3) and an atomic number close to those of aluminum. However, the shell is a porous structure and the passage of electrons through it will be a complicated process.

The data of Table 1 shows that at the charging voltage of 30 kV, it is possible to obtain the desired profile of the absorbed dose distribution in the depth at which the electron irradiation does not penetrate below the absorber layer, simulating the under-shell egg membranes (Figure 3).

The measurement results showed that the bremsstrahlung AD inside the egg does not exceed 0.31 cGy / pulse and at the yolk not more than 0.2 cGy / pulse (Table 2).

At the same time the electron beam AD on the surface of eggs was 0.2 kGy / pulse (see Table 1). Consequently, at AD = 5 kGy, which can be acquired by 25 pulses and is sufficient to disinfect the surface of eggs from Salmonella, bremsstrahlung AD in protein will not exceed 8 cGy and in yolk 5 cGy.

This AD value should not lead to the biological transformations of the biological tissue, but rather to be within the AD range that has a stimulating effect on the living organisms (radiation hormesis) [10].

Bremsstrahlung yield calculations under irradiation surface of the egg (4.5 cm in diameter) by electron beam from an accelerator URT-0.5 (the electron current density per pulse ~ 3 A/cm^2), were made according to the Foster's formula [12] and in accordance with the biological protection calculation method for electron accelerators [13]. The results show that the AD is in the range of 0.11-0.15 cGy / pulse. Additional irradiation of the eggs is created by the electron beam bremsstrahlung, being absorbed by the radiation-absorbing accelerator output structures, as well as by the scattered radiation.

4. Conclusion

The results obtained lead to the conclusion that the irradiation by an electron beam with AD level of 5 kGy is sufficient for the complete disinfection on the surface of an egg. At the same time the AD inside of the egg will not exceed 8 cGy because of bremsstrahlung. This AD value should not lead to biological transformations of the protein and the yolk.

Acknowledgement: *This work was supported by the Russian Science Foundation, project No 16-16-04038.*

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