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Effect of oscillating magnetic field pulses on the survival of selected microorganisms**

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A b s t r a c t. The aim of this paper was to study the influence of oscillating magnetic field pulses on the survival of certain selected pathogenic microorganisms of potatoes. The less resistant of the tested microorganisms proved to be the *Ervinia carotovora* and *Streptomyces scabies* bacteria. The tested fungus *Alternaria solani* proved to be the most resistant. When treating bacteria, it was found that their number was reduced by over 3 orders of magnitude, and when treating fungi their number was reduced by not even 2 orders of magnitude. The application of oscillating magnetic field pulses might be used in disinfecting agricultural products and food.

K e y w o r d s: oscillating magnetic field, antimicrobial effects

INTRODUCTION

Among the various methods of food preservation from spoiling, destruction or decomposition, the non-thermal methods should be focused on, especially the pulses of magnetic field and electric field as well as microwave radiation. The traditional methods of food preservation guarantee its safety, though, at the same time, these methods cause a loss of temperature sensitive nutrients, denaturation of proteins, change of structure, change of colour and change of taste. They also cause the formation of new undesirable substances. That is why there can be observed a growing interest in the non-thermal methods of food preservation. These methods preserve the nutritious value of food and at the same time they might diminish the microbiological threat. The antimicrobial effect of oscillating magnetic field pulses is not due to the temperature effect, but rather to the ability to cause damage in cells. Studies published in the literature show contradicting results on the inhibition of microorganisms when placed in oscillating magnetic fields. Some studies indicate that variable magnetic fields have an inhibitory effect on microbial population, while others note no effect or in some cases even a stimulating effect. In one study, food with high electrical resistance was placed within a magnetic coil in an apparatus and treated with one or more pulses of oscillating magnetic field with an intensity of 2 to about 50 T, with time of exposure from 25 s to a few ms. It was observed that a single pulse of magnetic field generally decreased the microbial population by at least 2 orders of magnitude (Pothakamary *et al*., 1993; Ray, 2001; Gerencser *et al*., 1962; Moore, 1979; Tsuchiya *et al*., 1996; Van Nostran *et al*., 1967). The lethal effect of the pulsed magnetic field against microorganisms has given rise to interest in its use for non-thermal treatment of food.

The aim of the research was to analyze the antimicrobial effect of oscillating magnetic field pulses at the 20 T amplitude, 250 s period and a full time of duration below 1 ms. The research was made possible thanks to the original apparatus designed and constructed at the Department of Physics, Agricultural University of Cracow.

MATERIALS AND METHODS

An oscillating pulsing magnetic field that has an induction up to several score T and growing time of orders of magnitude ms can result from discharging a high voltage condenser through a suitable solenoid. The parameters of

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the condenser (capacity, induction, charge, and voltage) and the solenoid (induction, geometry of winding), as well as the way the power connection has been constructed, decide about the amplitude, the time of growth and the duration of the obtained pulse. Even though it seems to be a simple idea, the construction of a system with the required parameters was a very difficult constructional and technological task. This is due not only to the work of the system at the level of several score kV and currents of kA but, first of all, to the mechanical stresses appearing in the tested winding and its supply lines, reaching up to several hundred MPa (Knoepfel, 1970).

At the Department of Physics, Agricultural University of Cracow, a measurement stand made it possible to conduct research on various aspects of the oscillating magnetic field pulses effects on biological material.

The concept of the system is presented in Fig. 1. A battery of high-voltage condensers (C) with a total capacity of 1.5 mF is charged up to the required voltage through a high voltage supply, with a maximum working voltage of 5 kV and a working current up to 100 mA. The solenoids (L) producing magnetic field are single-layer coils which have been wound with a copper wire of 20-40 mm^2 surface and a rectangular section. Epoxy-glass composite material has served as the internal and external coil isolation. The *ca*. 17 mm internal diameter of the solenoids has been chosen to enable placing standard test-tubes with analyzed material inside. The coils were placed inside a special holder which provides the appropriate mechanical resistance. Although different options were put into practice in the experiment itself, it was rarely possible to use the same coil more than 10 times at the highest applied voltage. The discharge of the condenser batteries went through the spark gap which has an electrode gap precisely regulated by a step engine. In that system, there is another alternative discharging system built on the basis of high-tension thyristors, which allows getting single unidirectional magnetic field pulse. Directing the process of charging and pulse discharging is controlled remotely from the control panel placed, for the safety reasons, in a different room.

The parameters of the oscillating magnetic field were accurately measured by a induction probe placed for that very purpose inside the solenoid and connected with the digital oscilloscope Voltcraft DSO 2100. The magnetic field generated in the solenoids had features of strongly suppressed oscillation vibrations with the growing magnetic induction of over 100 kT s^{-1} of speed. The oscillation periods were from 250 to 350 s depending on the coils used. The results of the research were obtained while using a 250 s oscillation period coil. A full pulse would last below 4 periods which means that its duration is *ca*. 1 ms. Figure 2 shows an example (for a coil producing pulse of 250 s period and 20 T amplitude) of oscillating magnetic field pulse route with a marked period, amplitude and the total duration read out from the digital oscilloscope Voltcraft DSO 2100.

The three selected species of microorganisms: *Ervinia carotovora*, *Streptomyces scabies* and *Alternaria solani*, had been taken from paralysed potatoes and used in the biological part of the research. The microorganisms were grown on a special and selected medium and afterwards multiplied in liquid nutrient medium. As a result, we received the initial material ready for detailed testing. From every breed, 1 cm^3 inoculum was taken and placed in test-tubes. Then the test tubes were treated with the magnetic field pulses (oscillating magnetic fields were used at the following amplitudes: 5, 10, 15, and 20 T). Non-treated

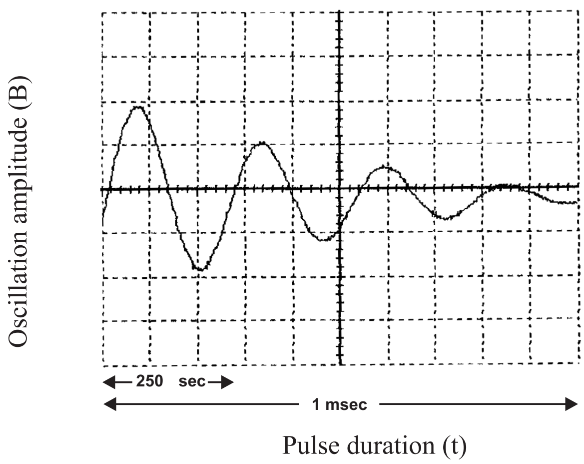

Fig. 2. The oscillating magnetic field pulse route. B – oscillation amplitude, t – pulse duration.

microorganisms were taken as a control material. After the treatment, the microorganisms were sown on Petri dishes containing selected medium and incubated under conditions appropriate for every species. All the microbiological experiments were made in three parallel replications. After the incubation period, the colonies (c. f. u.) were counted and scaled into 1 cm^3.

The Kruscal-Wallis and LSD test were used for statistical analysis of differences in reaction of the tested microorganisms treated with pulses of oscillating magnetic field.

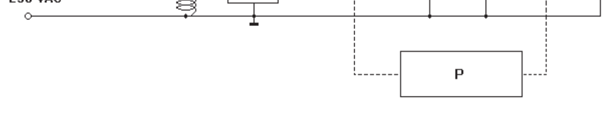

Fig. 1. Measurement system chart: C – condenser batteries, L – coil, P – control panel, R – resistance.

RESULTS

Further to the results of the research in which the oscillating magnetic field pulses effected selected microorganisms, it can be said that the tested microbiological material had different reactions when treated with the magnetic field. The results obtained for the tested microorganisms are shown in Table 1, and in Fig. 3 they are shown with relation to: the number of cells in 1 cm^3 of the test tube effected by the oscillating magnetic field, and the B pulse amplitude. The tested bacteria *Ervinia carotovora* and *Streptomyces scabies* were more sensitive to the oscillating magnetic field pulses effects. The tested *Alternaria solani* fungus turned out to be the least sensitive to the analyzed magnetic field effects.

A double reduction of the surviving colonies can be observed for *Streptomyces scabies* already at 5T pulse amplitude, at 10T pulse amplitude in the case of *Ervinia carotovora,* but only at 15T pulse amplitude in the case of *Alternaria solani*. Treatment with pulses at the maximum amplitude of 20T caused the reduction of the surviving bacteria to *ca*. 4000 times in the case of *Ervinia carotovora*, *ca*. 1000 times in the case *Streptomyces scabies,* and only 30 times for the fungus *Alternaria solani*. For all the tested microorganisms treated with pulses at the 20 T amplitude, the differences between the number of surviving microorganisms and the control values were statistically significant ($p<0.05$).

DISCUSSION

The growing interest in what is commonly known as healthy and safe food, that is food with a high nutritive value, can be observed world-wide. The changing conditions of various food products production, transport, storage and treatment cause that they are exposed to various environmental factors which could cause their damage. One of these threats is microorganisms, due to their metabolic activity. That is why new safe methods which could help reduce the number of microorganisms, which are always present in the raw material and food products, are being looked for. One of the non-thermal methods of microorganism reduction is the oscillating magnetic field effect. In fact, there are only a few works on that very subject (Pothakamary *et al*., 1993; Ray, 2001; Gerencser *et al*., 1962; Moore, 1979; Tsuchiya *et al.*, 1996; Van Nostran, 1967; Singh, 2001). The oscillating quantity applied in our research proved to be effective in reducing the population of bacteria by even over 3 orders. Still, the tests on the selected fungus *Alternaria solani* are less satisfactory. One of the probable explanations of the oscillating magnetic field pulses effect on the microbiological material might be the rotating electric field formed by the variable magnetic field. If we take for granted that the obtained differences in the results in the level of the oscillating magnetic field pulses effect on bacteria and fungus are correct, we should look for the cause, taking into account differing conditions when exciting different induction currents in cells. It is possible that the used quantities of the field were too low, though, for the time being, it is impossible to use magnetic fields of a higher induction for technical reasons. The research is being carried on.

T a b l e 1. Average and SD number of cells in 1 cm^3 treated with the oscillating magnetic field

Treatment / Species	Control	5T	10T	15T	20T
Ervinia carotovora	$(10.3\pm2.05)10^8$	$(81.3\pm3.4)10^7$	$(48.0\pm2.20)10^7$	$(11.0\pm2.1)10^7$	$(24.7\pm2.6)10^4$
Streptomyces scabies	$(9.7\pm2.35)10^6$	$(46.3\pm3.4)10^5$	$(18.0\pm2.45)10^5$	$(35.0\pm2.2)10^4$	$(9.66\pm1.7)10^3$
Alternaria solani	$(9.7\pm1.7)10^6$	$(9.3\pm1.25)10^6$	$(8.7\pm1.25)10^6$	$(4.8\pm0.7)10^6$	$(3.14\pm0.45)10^5$

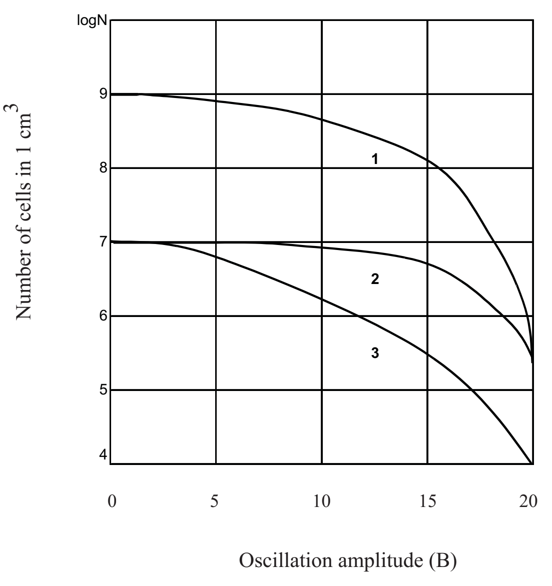

Fig. 3. Relation between number of cells in 1 cm^3 (LogN) of test tube treated with the oscillating magnetic field and amplitude of the used magnetic field oscillations (B) (see Fig. 2); 1. *Ervinia carotovora*, 2. *Alternaria solani*, 3. *Streptomyces scabies*.

CONCLUSIONS

1. An apparatus that allows obtaining magnetic field pulses at the speed growth of over 10^6 T s^{-1} has been designed and constructed.

2. The microorganisms used in the study are good as indicators in testing the lethal activity of oscillating magnetic field.

3. A varied oscillating magnetic field pulses effect has been shown on the tested microorganisms. The treatment with the oscillating magnetic field pulses reduces the number of tested bacteria in liquid nutrient medium 4 000 times and the number of tested fungus 30 times.

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