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Sterilization of Biotic Pests by Microwave Radiation

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Abstract

Some of the issues connected to timber structures are caused by wood-destroying insects. The sterilization of timber elements affected by wood-destroying insects with the help of microwaves removes the deficiencies of other available methodologies. Hence the given paper deals with the experimental sterilization of wood-destroying insect by the application of microwave radiation. It explains the principles behind heating with microwaves and also describes the biological effects of microwave radiation in a simplified manner. The following chapter introduces the equipment required for microwave sterilization to take place and the actual experimental sterilization process. In the final part of the paper are the results of the experimental activity. Throughout the experiments it was found out that microwave radiation seems to be an effective methodology to sterilize wood-destroying beetles. Within the conclusion the intensity of microwave radiation needed for a successful and effective sterilization process is recommended together with the time along which the timber element must have a constant temperature achieved by heating in the primary phase.

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Keywords: Sterilization, microwave radiation, wood (timber), biotic pests, wood-destroying beetle (insect).

1. Introduction

A common issue of timber building elements is that they may be attacked by biotic pests. In the first place it handles about mold, then fungi and wood-destroying insects. All of these agents do lead to an irreversible degradation of the invaded structural element. Nevertheless if the affected structure is without any harm in a structural viewpoint and the infection is only partial, then there is a possibility to have it remedied. To ensure a reliability of the rehabilitation process it is necessary to destroy the biotic pests causing a degradation, in the beginning.

The paper is focused on the possibilities of wood-destroying insects sterilization using microwave radiation and it also presents some of devices used by the given process. Furthermore it describes the experimental principle behind the sterilization and the intensity of radiation required for the disposal of various pests. Nonetheless it also recommends the time necessary for the radiation to be effective with respect to the efficiency of microwave source.

2. Microwave radiation

Microwaves are electromagnetic waves which lie between infrared radiation and radio waves in the electromagnetic spectrum. Their frequency ranges from 300 MHz to 300 GHz which corresponds to the wave length 1–1000 mm [1].

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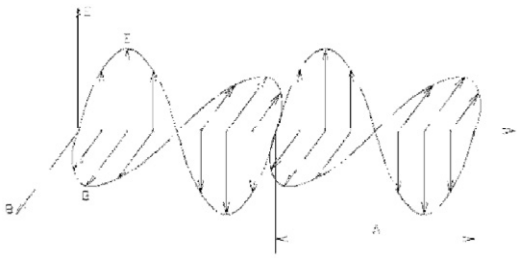

Fig. 1. Electromagnetic wave with wavelength λ – electric (E) and magnetic component (B) of the wave [1]

$$\lambda = \frac{c_\lambda}{f}, \qquad (1)$$

where λ … wavelength [m],

c_λ … speed of propagation [$\mathrm{m.s^{-1}}$],

f … microwave radiation frequency [Hz] (2450 MHz).

Microwave radiation is generated by the transformation of the electricity to microwave energy within a generator, which consists of high-voltage tubes. According to the frequency of we are talking about either of magnetrons or klystrons. The resulting microwave waveguides are redirected into the space of the antennas. The design and the shapes of the antennas are dependent on their usage. The microwaves within the antennas are reflected on the metallic surfaces and form a local but also time-variable spatial field. After inserting and affixing the given material depending on the characteristics and volume distorts the MW field. MW radiation is partially absorbed, reflected and part is permeated. The absorbed microwave radiation is then converted into to heat [1].

The microwaves usage to destroy pests and remove moisture from the masonry is used at the industrial frequency of 2450 MHz, which was chosen deliberately in order to avoid interference with telecommunications frequencies (electromagnetic interference – EMI is a process in which the energy produced by a source of interference is transmitted through the electromagnetic links to the interfered systems). Furthermore it has been proved that this frequency is suitable for heating water, and therefore the removal of moisture from the structure. It is also usable for the disposal of biological organisms. The frequency of 2450 MHz corresponds to a wavelength of 122 mm.

Microwave radiation acts on living organisms by principle in two ways. These are the non-thermal effects – or reversible, and the thermal – so called non-refundable. The interface between these two factors is called the threshold of the MW radiation, or power density. Thermal effects arise on the basis of dielectric loss in the body. Due to the movement of the molecules mutual friction and collisions arises due to which local overheating of the organism can occur. This may lead to the weakening and killing of the organism (the removal of biological organisms is based on this principle).

The safety conditions should also be mentioned while staying in the locality of higher intensity of electromagnetic radiation. The allowed values for a single exposure to microwave radiation are determined by the Ministry of Health of Czech Republic and are given in digest 408/1990. This value is 800 μW.cm–2 with compliance to the maximum density of microwave field with a value of 2650 μW.cm–2.

By microwave drying the evaporation of water from the structure occur, which may precipitate on the surface of the structure and other surrounding areas. It is therefore necessary to effectively ventilate the rooms in which the dehydration process is going on or to catch the humidity by absorption dehumidifiers.

The water molecules are electrically neutral, while having a bipolar character. The electric field is oriented according to the polarity (positive to negative pole or negative to the positive pole). The polarity of the electromagnetic field changes approximately 109 times per second depending on the frequency F [1].

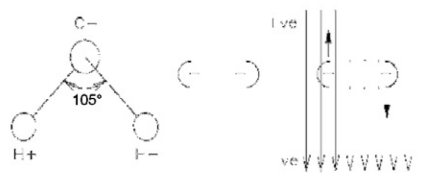

Fig. 2. Water molecules and their orientation in the electric field

The high frequency radiation, i.e., high speed changes of the polarity (the so-called oscillating vibration) and subsequent changes in orientation of the loosely bound water molecules creates frictional heat energy. This phenomenon is called as the polar rotation or friction. Generally it's a phenomenon described as follows, after the entry of the microwave radiation into the structure very rapid changes in the polarity of molecules loosely bound water, which causes the rapid movement of the material occur. By this movement as the particles themselves face each other heat energy is created. As an effect of this the intense transformation of water from liquid state to gaseous state and then the evaporation of water from the structure occur. The drying period of construction is dependant on several parameters, including the type and thickness of walls and on the moisture content.

3. Microwave heating

When the microwave radiation enters the dry material from a free space the oscillation speed and the wave length of wave changes according to the characteristics of the material. The effect of the microwave interaction with the material that is exposed to the microwave radiation is decided on the composition and structure of the material, its physical state as well as on the power and frequency of microwaves. Among the materials that are permeable to microwaves (transparent) are included: wood, ceramics, glass, etc. On the other hand reflective materials include mostly metals. In the meantime, the only effect of showing the impact of microwaves on biological materials is the thermal one.

Microwave heating is characterized as quick and economical and it is based on electromagnetic induction. Heating takes place directly in the structure of the material and not from the surface. The mechanism of changing microwave energy to heat is expressed by this formula:

$$P = 2.\pi.f.\varepsilon'.\varepsilon''.E^2 \tag{2}$$

where P … energy absorbed in a volume unit [$W.m^{-1}$],

f … frequency of the microwave field [2450 MHz],

ε′… permittivity [$F.m^{-1}$],

ε′′…dielectric material loss factor,

E … intensity of an electric field inside the material [$V.m^{-1}$] [2].

Microwave radiation causes a non-polar oscillation of water molecules, which occurs due to the rapid heating and consequent reduction of free water in the volume. The principle of this method forwardly designated the possibility of its use for the ideal removal of biological agents causing the corrosion of building materials. Very often the attention is focused only on the material damage, and less to health aspects such contaminated objects. One of the biological agents that mostly occur in residential premises are the microscopic fungi or mold which not only cause aesthetic defects and destruction of material, but may lead to various diseases of persons who inhabit the affected areas. Usually causes irritation to the conjunctiva, respiratory tract due to which the various allergic diseases arise. Molds are especially dangerous for individuals with lowered immunity after transplantation and for patients treated in oncology. Therefore it is necessary to dispose the fungi by various available methods [1].

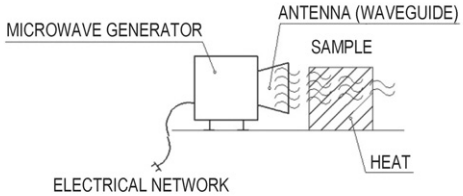

Fig. 3. Scheme of drying microwave device *(author)*

The MW system consists of a power and a microwave generator, waveguide and a magnetron with the antenna head. The antenna can be either of the straight funnel or rod plug type. The device can be furthermore powered by electricity of 220/380 V, 50 Hz for 1–6 kW power output and a microwave frequency 2450 MHz.

The device described below was used to eliminate wood-destroying insects in the samples with MW radiation: z

- MW (microwave) radiator with continuous power control 0–1200W,
- funnel antenna,
- different radiation intensity (influences the temperature of the material),
- different time intervals.

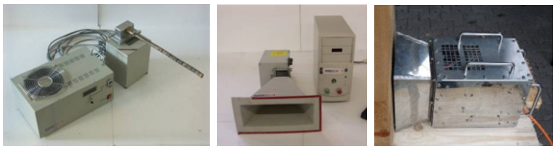

Fig. 4. Photos of drying microwave device *(author)*

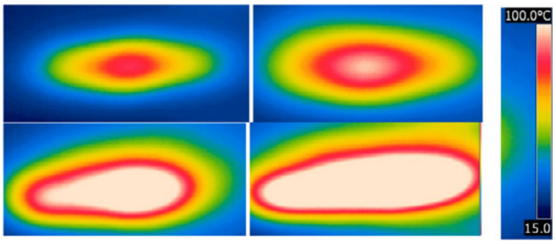

Fig. 5. Scope of the temperature field in the irradiated sample using EMW elimination *(author)*

In the previous picture you can see the temperature distribution at microwave sterilization of moulds on the masonry attacked. It is evident that the sterilized area increases during EMW sterilization.

For thermal imaging of constructions is used FLIR B425 camera. Which is powerfull for its performance in thermal sensitivity [3], [4].

4. Experimental sterilization of wood-destroying insects

Perhaps the most serious damage to wood built in structures in Central Europe is caused by Hylotrupes bajulus L. However, woodworms belong to the most common ones, which also cause significant damage to the wood. Experimental wood-destroying beetles' sterilization was performed on the following species:

- Hylotrupes bajulus,
- Anobium Pertinax,
- Anobium striatum.

The common feature of these selected representatives consists in their development. This is a perfect transformation, namely:

- egg, larva, pupa, adult imago.

5. The course of experimental elimination of wood-destroying insects

At temperatures above 50 °C, irreversible changes in insect tissues and subsequent death occur in all developmental stages. How fast the situation is achieved depends on the temperature reached; the higher temperature, the faster exitus.

Fig. 6. Presentation of experimental sterilization of wood-destroying insects *(author)*

For the experimental sterilization, prisms with a cross section 120×160 mm were used. These prisms were drilled from the front surface. These holes were 6mm in diameter, depth 120 mm, distance from the outside 25 mm.

One type of wood-destroying insects, woodworms, larvae of longhorn beetles, etc. were always inserted in each hole. The ends of the hole were always blocked. Thus prepared samples were then subjected to microwave radiation.

Table 1. The course of experimental sterilization of wood-destroying insects in the test prism (woodworm larvae)

	First part	Second part
Initial surface temperature	19.8°C	19.9°C
Initial surface moisture temperature	18.8%	18.8%
Irradiation time	15 minutes	30 minutes
The temperature at the front	82.8°C	104.2°C
The temperature at the back	34.3°C	51.4°C
The temperature at a depth of about 30 mm	51.8°C	68.8°C
Moisture on the front after irradiation	15.6%	14.3%
Moisture on the front side after cooling 120 min.	16.4%	15.2%

In this experiment, the woodworm larvae were successfully destroyed after the second drying cycle, when the temperature exceeded 50 °C.

Further, an experimental sterilization "in situ" was made; woodworm and its larvae were eliminated.

Fig. 7. Presentation of experimental sterilization of wood-destroying insects "in situ" *(author)*

In comparison with laboratory experiments, it was found that similar temperatures are achieved within the same time. This suggests that experimental laboratory work offers the right information value and thus it corresponds to real conditions [5], [6].

6. Conclusions to sterilization of wood-destroying insects

Based on experiments, the project found out that in terms of elimination of wood-destroying insects, it is required to achieve heating temperatures above 60 °C for several minutes.

Table 2. Success in elimination of wood-destroying insects, depending on the temperature

	Elimination of biotic factors (%)		
	Wood-destroying insects		
(°C)	Hylotrupes bajulus	Anobium Pertinax	Anobium striatum
20°	3%	5%	10%
40°	15%	25%	35%
60°	100%	100%	100%
80°	100%	100%	100%
100°	100%	100%	100%

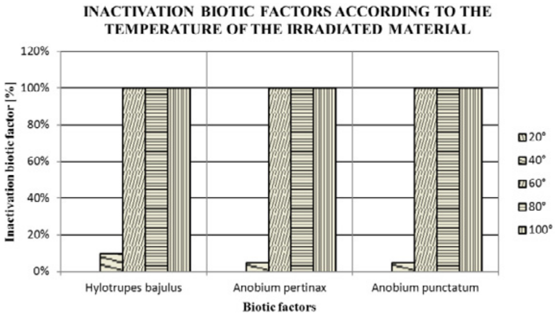

Fig. 8. Efficiency of sterilization of wood-destroying insects using microwave radiation, depending on the temperature of heating *(author)*

These organisms in all developmental stages contain significantly higher percentage of water compared to wood attacked as well as the environment. A prerequisite consisted in the fact that these organisms should theoretically be heated more than the surrounding material. This has been experimentally confirmed, as evidenced by the following table and graph.

The Table 2. with a Fig. 8 clearly illustrate inactivation of wood-destroying agents which occur in wooden structures most frequently. It can be said that using microwave radiation for sterilization of wood-destroying insects is unambiguously very appropriate [7], [8].

7. Conclusions

For the elimination of wood-destroying insects using microwave radiation, we can say that this method is 100% effective. You can easily eradicate wood-destroying insects in all their stages, namely egg, larva, pupa, adult imago. Elimination of wood-destroying insects using microwave radiation is also advantageous because it is possible to get to less accessible places. Insects can be eradicated within the structure if the attacked wooden component. The method is very fast and efficient.

Experimentally it was found that temperature about 60 °C is sufficient for successful elimination of wood-destroying insects. Furthermore, it was found that at this temperature irreversible changes in insect tissues and subsequent death occur in all developmental stages. To achieve these temperatures, the microwave power generator in the range of 400 to 700 W is sufficient. This temperature has to be maintained for approx. 10 minutes.

Acknowledgements

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References

[1] Šuhajda, K., 2006. Rehabilitation of moist masonry structures - Use of rod antenna during microwave pre-drying of injection holes. Thesis. Brno.
[2] Škramlik, J., Novotný, M., Šuhajda, K., 2011. "Modeling of diffusion in porous medium", International Conference on Numerical Analysis and Applied Mathematics: Numerical Analysis and Applied Mathematics, ICNAAM 2011; Halkidiki. ISSN 0094-243X, ISBN 9780735409569, American Institute of Physics, Greece, 2011.
[3] Baroň I., Bečkovský, D., Míča L., 2012. Application of infrared thermography for mapping open fractures in deep-seated rockslides and unstable cliffs. Landslides, Springer Verlag. DOI 10.1007/s10346-012-0367-z
[4] Charvat, P., Mauder, T., Ostry, M., 2012. Simulation of latent heat thermal storage integrated with room structures. Materiali in tehnologije, Vol. 46, nNo. 3, pp. 239-242. ISSN 1580- 2949
[5] Ostrý, M., Bečkovský, D., 2009. "Influence of Panels with Phase Change Materials on the Thermal Stability of Attic Spaces". In Proceedings of the 8th IIR Conference on Phase Change Materials and Slurries for Refrigeration and Air Conditioning, June 3-5, 2009, Karlsruhe: International Institute of Refrigeration, pp. 163-169. ISBN 978-2-913149-69-4
[6] Klimes, L., Charvat, P., Ostry, M., 2012. Challenges in Computer Modeling of Phase Change Materials. Materiali in tehnologije, Vol. 46, no. 4, pp. 335-338. ISSN:1580- 2949
[7] Ginevicius, R., 2011. A new determining method for the criteria weights in multicriteria evaluation. International Journal of information technology & decision making. Vol. 10, Issue 6, pp. 1067-1095. ISSN 0219-6220. Published: NOV.
[8] Zavadskas, E. K., Turskis, Z., Antucheviciene, J., *et al*., 2012. Optimization of Weighted Aggregated Sum Product Assessment, Elektronika ir Elektrotechnika, Issue 6, pp. 3-6. ISSN 1392-1215. Published.