A MICROWAVE DEVICE FOR WOODWORM DISINFESTATION

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INTRODUCTION

In a recent paper [1] the Authors demonstrated that microwave heating can be effectively used to rid wooden articles of woodworm. The main task of the study described in the present paper is to realize a portable and harmless system for treating painted boards, picture frames and other valuable objects of artistic interest. Reliable control of the maximum temperature reached by the wood and, in particular, by its surface, during treatment is an essential requirement for such applications.

Painted boards and other valuable wooden objects are usually infested by woodworms of the *Anobidae* family, such as *Oligomerus ptilinoides* Wollaston. The dependence on temperature for the mortality of this insect was investigated.

In a typical treatment, the infested object is exposed to microwave radiation to increase the woodworm temperature over 53-54 °C (which we have proven to be lethal for such insects), while maintaining the temperature of the wood at safe levels, usually no higher than 50 °C. In order to have sufficient control over the heating conditions, the electrical characteristics (permittivity and conductivity) of the wood should be known. For this reason, the electrical properties of several wood types of interest to us were measured in the 2.4 ÷ 3 GHz frequency range and at standard humidity. The results obtained for *silvester pine* are presented.

DEPENDENCE OF WOODWORM MORTALITY ON TEMPERATURE

The temperature lethal to *Oligomerus ptilinoides* Wollaston (Op) were determined with the experimental procedure described in [1], used for *Hylotrupes bajulus* L. (Hb). Woodworms were heated in a thermostatic bath for a time sufficient to maintain them at a prescribed temperature for at least one minute. The mortality curve of Op (Fig.1, solid line: regression logistic; filled rectangles: experimental data) is quite steep, and shows that all the woodworms died above 53.5 °C. The similarity between this curve and the curve relative to Hb (Fig.1, dashed lines) suggests a temperature response that is practically identical for both families of insects.

DEVICE DESCRIPTION AND TREATMENT SETUP

A prototypal device suitable for the treatment of small-size and delicate wood objects was set up. The equipment consisted of a 2.45 GHz microwave generator, a radiative applicator, and some ancillary control electronics. The generator made use of a commercial magnetron whose radiofrequency (RF) power could be manually adjusted up to 250 watt.

The applicator was made up of a section of rectangular waveguide suitable for operating at 2.45 GHz, fed by a specially-designed coaxial-waveguide adapter. The waveguide cross section was 7.7 x 3.7 cm^2. An RF trap, consisting of two $\lambda/4$ grooves all around the mouth of the applicator [2], was added to block RF leakage (Fig. 2). The applicator was provided with a system for blowing air through its aperture to allow the cooling of the treated surface. The treated surface was approximately twice the waveguide aperture area. Attention was paid to the electrical matching between the applicator and the wood surface, in order to maximize the power delivered to the treated object and to minimize the fraction leaked in the environment. The distance between the applicator and the wood surface could be adjusted (18 to 30 mm) by means of four dielectric rods to optimize the power delivering. SWR measured in operative conditions was usually of the order of 1.2 (1% reflected power).

Fig. 3 shows the treatment setup. The object to be treated lay on a wooden table in such a way that its more delicate surface (e.g. the painted one) was facing downward, with the RF power impinging on the opposite side. The temperature of that surface was controlled by means of a non-contact infrared thermometer through a window opened in the treatment desk. The thermometric probe could be moved away from the treatment region by means of a compass-like tool. Microwave absorbers were placed on the floor below the table to avoid the reflection of RF fields from the earth and to reduce power dispersion in the surroundings.

TREATMENT OF WOODEN BOARDS

Tests on woodworm-infested boards were carried out. The woodworms (Op) were inserted in small horizontal cavities carved in three-centimeter-thick boards, placed at depths ranging between one and two centimeters, and positioned parallel or normal to the wood grain, at varying distances (1-3 cm) from the axis of the applicator aperture. The wooden boards were exposed to microwave radiation (200 W delivered power), using different heating cycles (e.g. 2 min ON, 1 min OFF, 2 min ON) so that a temperature in the 40-50 °C range was reached on the controlled surface.

A total of seven assays were carried out, regarding all three metamorphic stages of interest: egg (Hb species), larva and pupa (Op species). Larva weights ranged between 1 and 8 mg. The conditions of the larvae were observed five minutes after the end of the microwave treatment, and were subsequently controlled one day later. Pupae and eggs were followed up for ten days. All the specimens were destroyed independently of their position in the wood: larvae died, eggs did not hatch and pupae did not develop into insects.

The effects of the microwave treatment on the painting were also investigated. Three square boards divided into four sectors and painted according to ancient recipes were treated positioning the applicator on their corners. One of the four sectors of each board was not treated, to take care of possible confounding effects (colour deterioration not due to temperature, measurement errors). A spectroscopic analysis in the visible region of the surface was made before and after treatment, using a fiber-optic reflectance spectroscope [3]. The difference between those two analyses is below the original variability of the pigment spreading, indicating the absence of damages due to the microwave treatment.

RF LEAKAGE AND SAFETY

Measurements of RF power radiated in the environment during a disinfestation treatment were conducted by means of a RAHAM 4 field monitor. The power density was below 2 mW/cm^2 in any area that could be accessed by the operator, a situation that can be considered safe according to the most accepted standards (IRPA Guidelines, 1988 and CENELEC ENV 50166-2, 1995: 5.0 mW/cm^2 for occupational exposure; IEEE C95.1, 1991: 8.2 mW/cm^2 for controlled environments). A power density of between 1 and 2 mW/cm^2 was measured close to the applicator handle. These low stray fields were due to the RF trap and to the microwave absorbers, as described in a previous section; significantly higher power densities would be present without them.

Radiated power density (S) was also measured along the axis of the applicator in operative conditions, i.e. in the previously-described setup (Fig. 2). An inverse square fit of S versus the distance from the applicator aperture: $S=S_0/(r-r_0)^2$, gave S_0=67958 mW/cm^2 and r_0=-3.1 cm, with 98% explained variance proportion. With an input power of 200 W, a power density higher than 5 mW/cm^2 was present at distances up to 115 cm when a 3-cm-thick board was treated. Attention should be paid to this when treating vertical objects, to avoid dangerous exposure.

The applicator was provided with a switch that turned the power OFF when the said applicator was lifted from the surface of the object under treatment, to avoid the risk of unintentional irradiation to the operator. The power switch was driven by one of the dielectric rods used for impedance matching.

DIELECTRIC CHARACTERISTICS OF WOOD

The dielectric properties of Silvester Pine (the type of wood mainly used in the trials here described) were measured by using an open-coaxial probe system (HP 85070A) suitable for permittivity measurements in the 200 MHz - 20 GHz frequency range. The typical accuracy of the measurement is ±5% on the dielectric constant and ±0.05 on the loss tangent, as declared by the manufacturer. The precision and the repeatability determined by several measurements on a teflon block in the frequency range of interest (2.4 - 3 GHz) were significantly better, the result being ε' = 2.1 ± 0.01 standard deviation.

Table I summarizes the results obtained at ambient temperature on several wood samples conditioned at standard humidity (10%). The variations in both real and imaginary parts of permittivity reflect the region from which the samples were cut, with the lowest values pertaining to *duramen* and the highest to *alburnum*. The measured permittivity must be understood to be an "average" between the longitudinal (electric field parallel to the wood grain) and transverse (electric field normal to the grain) values, due to the structure of the dielectric probe.

Table I: Measured permittivity of Silvester Pine

frequency (GHz)	ε'	ε"	σ (S/m)
2.40	2.22 - 3.92	0.18 - 0.72	0.025 - 0.097
2.45	2.23 - 3.92	0.24 - 0.78	0.032 - 0.106
2.50	2.23 - 3.92	0.20 - 0.77	0.028 - 0.107
2.60	2.23 - 3.88	0.21 - 0.79	0.030 - 0.114
2.70	2.22 - 3.86	0.26 - 0.82	0.039 - 0.123
2.80	2.19 - 3.85	0.27 - 0.84	0.042 - 0.131
2.90	2.17 - 3.83	0.27 - 0.85	0.044 - 0.137
3.00	2.18 - 3.84	0.27 - 0.88	0.045 - 0.147

CONCLUSIONS

A portable microwave disinfestation device was designed and realized. The system was tested on a suitable setup to determine its effectiveness in treating wood objects infested by woodworms. The microwave treatment resulted effective against all methamorphic stages of woodworms, while keeping the wood temperature below 50 °C where damages to wood or to the painting on its surface were never observed.

The device has proven to be safe according to the most accepted safety recommendations and standards concerning RF fields radiated in the environment.

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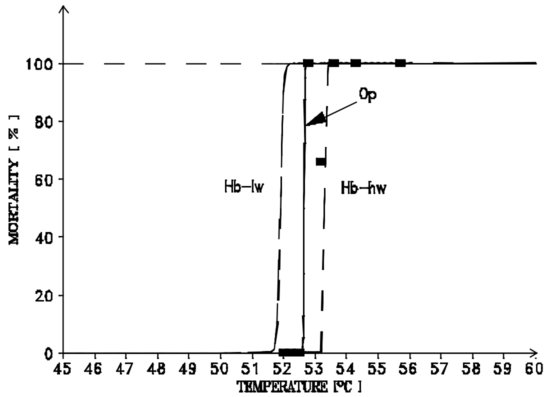

Fig. 1 Percentage of mortality vs. temperature of two woodworm species: *Oligomerus ptilinoides* (Op) and *Hylotrupes bajulus* (Hb-lw: weight < 0.1 g; Hb-hw, weight > 0.1g).

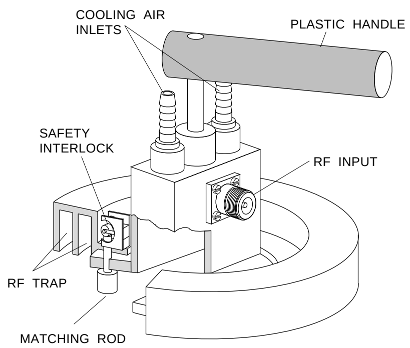

Fig. 2 Radiative applicator with corrugated flange to reduce EM field leakage.

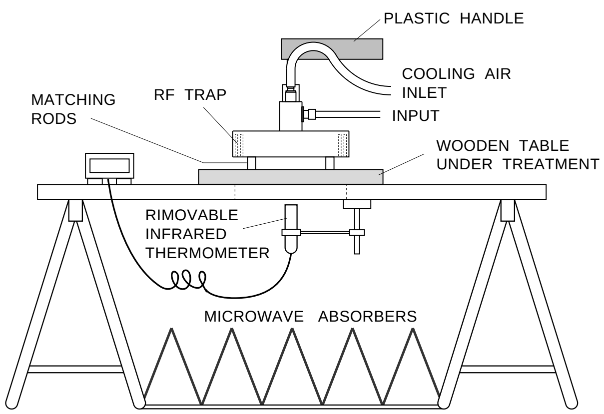

Fig. 3 Laboratory setup for microwave treating painted boards.