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Wood-Boring Insect Control in Constructions by High Temperature and Microwaves

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/66094>

Abstract

The chapter focusses on the control wood boring insects in constructions. The influence of temperature in the range of 50–65°C was studied for the larvae of *Hylotrupes bajulus* L. Attempt is made to clarify the influence of high temperature on the larvae in the context of the different results in the former German publications. The paper presents too the conditions in which the insects, which are technical pest to timber, can be combated by the use of high air temperature and microwaves 12,2cm length (2,45GHz) and which are emitted in the form of scattered field. In the experiments two prototype microwave devices were used, their power being 600W and 1400–2400W, as well as one microwave chamber whose power was 1000 W. Laboratory results of author were presented against the designer results obtained with other insect species and the results in the recent publications by other authors. The aim of this work is to present the results of the author's microwaves research and some problems in practice. Additional experiments were conducted on polychrome and gilded timber as well as the timber into which two-inch steel nails had been driven. The study included the possibility of melting wood resin.

Keywords: insect control, old house borer, physical methods, microwaves, hot air method

1. Introduction

Because of some problems involved in the use of chemicals for insect extermination in wood, physical methods of wood-boring insect control have been applied for a long time. The insecticidal factors used in those methods include, for example, high temperature. Insects, as all living organisms, can exist only in appropriate thermic conditions. They are poikilothermic

animals; however, they have a limited ability of thermic regulation by changing the intensity of breathing and evaporating. In general, however, the temperature of their bodies is preconditioned by ambient temperature.

Research on wood-boring insect control in wooden constructions was first started in Denmark [1–3]. Also in Denmark, in the 1930s, the method of exterminating the old house borer by heating wooden constructions using hot air was developed. The method was soon introduced in Germany as well. To produce masses of hot air, DEUBA heaters were applied. Hot air at the temperature of 100–120°C was inflated into attics of wooden buildings. Next, the temperature in the attics was maintained at the level of 80–100°C for several hours. Such thermic regime caused heating of the internal layers of constructional wood up to the temperature of at least 50°C. Several companies performing the old house borer extermination advertised their services in industry periodicals in the 1930s, for example, by the name of DEUBA (Hanover) and DEOB (Leipzig). After the Second World War, the method was continually applied on a wide scale. Specialist literature of that period is full of descriptions of the old house borer control in wooden roof constructions and the positive effects of the method [3–10].

Fundamental knowledge on thermic conditions of the old house borer extermination was acquired thanks to the research of Wichmand [1], Jensen [2], Schmidt and Schneider [11] and Becker and Loebe [12]. The results obtained in those examinations, however, were very diverse. The research was continued by Krajewski [13]. As for heating wood with solid-state objects and with infrared radiation, both methods have proven to be unpromising [13].

The phenomenon of a very limited resettlement in the wood by the old house borer after applying the heating method of insect control was also widely discussed in German periodicals at the end of the 1950s and in the early 1960s. This matter, however, of great interest and examined by the author, is outside the scope of the present chapter.

The effect of heating whole volume of wood can be also obtained using electromagnetic field of high frequencies, that is, high-frequency and ultra-high-frequency radiation, and especially microwaves. In the research, homogeneous or scattered field was applied. The term “microwaves” is usually attributed to the spectrum of electromagnetic radiation of frequencies ranging from 0.3 to 300 GHz, that is, of wavelengths ranging from 1000 to 1 mm, respectively. As far as high-frequency radio waves can be emitted in the form of both homogeneous and scattered field, in the case of microwaves, due to technical possibilities, only scattered field is available for practical purposes. According to Thomas and White [14], the first experiments on exterminating the *Lyctus brunneus* Steph. with the use of some indefinite radio waves of high frequencies were performed by J. Green in London. The research was conducted simultaneously with the experiments of MacDonald [15], concerning fighting the fungi *Serpula lacrymans* and *Coniophora puteana* with the use of microwaves of 9.1 cm wavelength. Osmolovsky [16] tested the possibilities of wood disinfestation with the use of short radio waves (frequencies ranging from 58 to 70 MHz, wavelengths ranging from 5.17 to 4.28 m). Some indefinite short radio waves were also applied by Jacquot [17], and Wälchli and Tscholl [18] used 23-m short radio waves (13 MHz). Most research on ridding wood-boring insects from constructional wood, however, was performed using waves of frequencies ranging from 2.365 to 2.45 GHz [19–23] which correspond to wavelengths ranging from 12.7 to 12.2 cm, respec-

tively, thus falling in the range of microwaves. After the first period of interest in applying radio waves to wood-boring insect control in the 1950s and 1960s, the subject of the use of 2.45-GHz microwaves for disinfestation was not further examined until the mid-1980s and 1990s [24–26] and the beginning of the twenty-first century [13, 27–29], with an exception for the paper by Wälchli et Tscholl [18].

Currently, a renewed interest in microwaves as a wood-boring insect control factor can be observed. Microwave heating has been recently approved by the Food and Agriculture Organization (FAO) as a significantly effective phytosanitary treatment for wood packaging materials. According to International Standards for Phytosanitary Measures (ISPM) 15 [30], target organisms are eradicated if a temperature higher than 60°C is maintained for 60 s across the entire profile of the board. The study, using pallet boards, was carried out in order to set up a treatment program that would meet ISPM 15 [30] requirements in terms of wood temperature and mortality of the insects. A 4-m long industrial tunnel oven (maximum power of 28.8 kW) was used to perform the experiments. The temperature was measured using a VarioCAM infrared camera [28, 29, 31]. The results obtained in the experiments were satisfactory. Some research in the recent years focussed only on the temperature of the wood treated with microwaves [32–34] and on the physical effects involved in such microwave processing.

In spite of a relatively large number of publications and a long-time practice in using hot air and microwaves for the aims of wood-boring insect control, the discrepancies in results obtained by researchers working independently in the field of susceptibility of well-grown old house borer larvae to heating the wood with hot air have not been explained so far. Several conditionings connected with applying microwaves to wood-boring insect control also require further explanation. It is the author's intention to provide grounds for such explanations in the present chapter, being a summary of the author's 15-year-long research on those two issues. The author's research has covered several species of wood-boring insects. However, it mainly focussed on the old house borer larvae (*Hylotrupes bajulus* L.). For this reason, the information presented here on methodology and the results of research on this particular species are more detailed. In the case of other species, the obtained results are indicated with short references only.

2. Material and methods

2.1. Experiments on the impact of high temperature on the old house borer larvae

The experiments on lethal effect of high temperature were constructed based on the results obtained by Becker and Loebe [12]. Variants of temperature and duration of action were chosen. For all experiments, well-grown individuals of the old house borer larvae (*H. bajulus* L.) were used, taken from individuals living in the wild in central and eastern Poland. The impact of high temperature was tested in the range from 50 to 65°C with 5° interspace and the following durations: temperature 50°C—duration 180, 240, 300 and 360 min; temperature 55°C—duration 20, 30, 40, 50 and 60 min; temperature 60°C—duration 5, 10 and 15 min; temperature 65°C—duration 5 and 10 min. A dryer with over doors was used. In order to prevent the possibility of temperature deviations from the temperature given in the variant of the experi-

ment, pairs of blocks of Scots pine sapwood (*Pinus sylvestris* L.) were used, sized $15 \times 25 \times 50$ mm³ (see **Figure 1**). One block in each pair was carved on the surface 2-mm deep. The blocks were heated for at least 2 h to the previewed temperature. The temperature of the air was measured using mercury thermometers with the accuracy of 0.5°C.

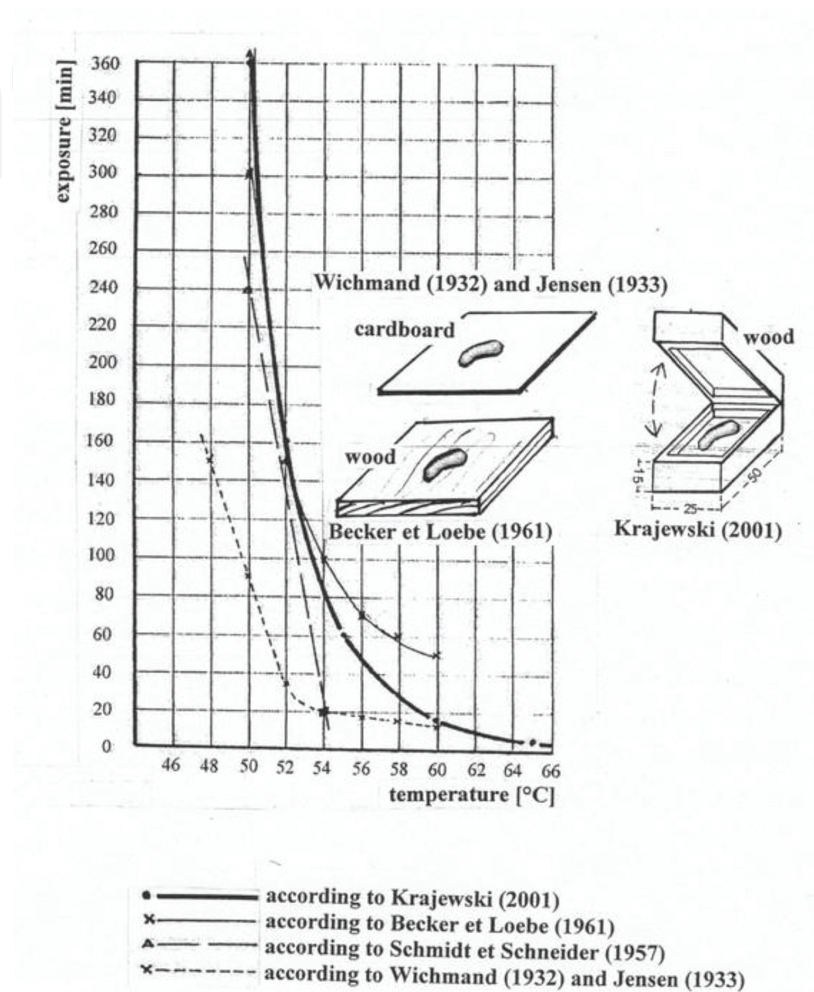


Figure 1. Effective time of exposure to high temperature in the old house borer larvae control procedures and methods of exposing larvae to hot air in different experiments (according to Krajewski [13]).

The only significant difference in relation to the experience of Becker and Loebe [12] was the way to put the larvae in the dryer. Becker and Loebe [12] installed the larvae in dryer on wooden plate (see **Figure 1**). Temperature of wood at the start was as temperature of air in the laboratory (probably about 20°C). The type of incubators in the experience of Becker and Loebe [12] was not given in the publication.

Ten old house borer larvae were used in each variant of the experiment (i.e. for each given temperature and duration), exactly as in the experiment of Becker and Loebe [12]. The masses of the old house borer larvae used in the test ranged from 20 to 230 mg (usually 70–150 mg). Each testing group of insects was compared to a control group of 10 larvae which were not

exposed to high temperature. Both the testing larvae and the control group larvae were then put into wooden blocks with a glass allowing observation of behaviour of the larvae and their boring into the wood (**Figure 2**).

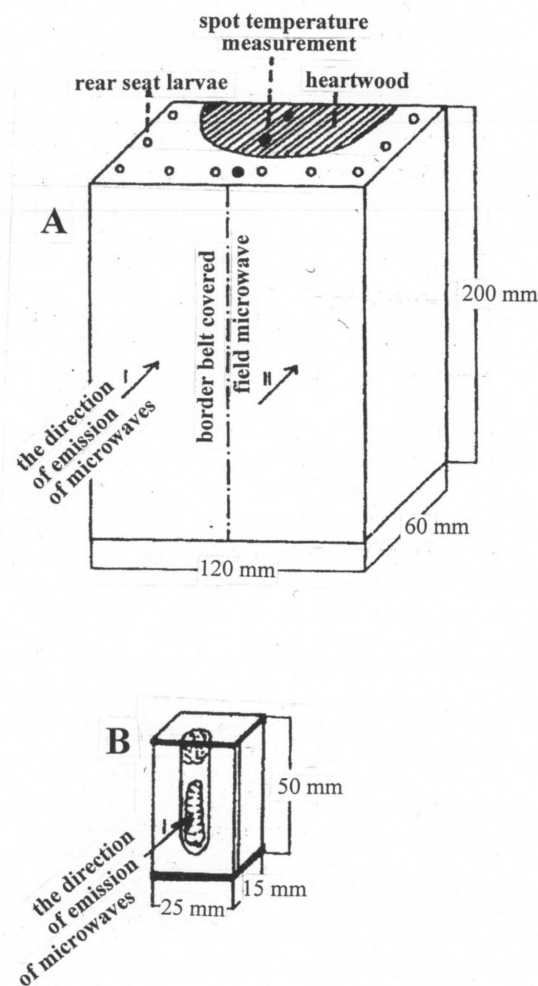


Figure 2. Samples of wood used by the author in experiments on using microwaves for the old house borer larvae control (according to Krajewski [25]). (A) Blocks used in experiments on the old house borer larvae control heartwood place of larvae introduction into the wood direction of microwave radiation. (B) Blocks used in additional observation of the larvae after microwave exposure points of temperature measurements.

2.2. Experiments on the old house borer larvae control using microwaves

Apparatus radiating microwaves of the frequency of 2.45 GHz (wavelength of 12.2 cm) in the form of scattered field was used in the experiments. Two prototypical mobile devices of 0.6 and 2.4 kW and a microwave chamber of 1 kW were produced at Wroclaw University of Science and Technology for PP PKZ Wroclaw Branch.

In the experiments, blocks sized $60 \times 120 \times 200 \text{ mm}^3$ were used (see **Figure 2**), made from:

Scots pine wood (*P. sylvestris* L.) of density ranging from 0.43 to 0.47 g/m³ (with the average value of 0.45 g/m³),

spruce wood of density ranging from 0.41 to 0.45 g/m³ (with the average value of 0.43 g/m³)

and fir wood of density ranging from 0.41 to 0.45 g/m³ (with the average value of 0.43 g/m³).

The radius of the heartwood semi-cylinder ranged from 30 to 40 mm. Different series of blocks were used for testing biocidal qualities of microwaves in each variant of the experiment, and for estimating the temperature corresponding to each variant.

The old house borer larvae were used in the experiments. The larvae were put into groups of 10 in each block, inside the holes drilled as shown in **Figure 2**. The length of each drilled path ranged from about 1.5 to 2 times the length of larvae body length. The diameter of each hole was a little bigger than the width of larvae. After introducing the larvae, the holes were plugged with a cotton wool cork. The blocks with larvae inside were first kept in an incubator in the temperature of 28°C, with air humidity of about 90%. After the larvae had bit into the wood, they were kept in the temperature of 20°C and air humidity of 70–75% for 12 weeks. For each variant of the experiment (i.e. power of device/time of exposure/0 mm distance between antenna and the surface of wood), three blocks were used (1 pine wood, 1 spruce wood and 1 fir wood). As a rule, microwaves were radiated by the apparatus of 0.6 kW individually onto each block, in two parallel straps of 60-mm width, onto the biggest surface opposite heartwood, with 0 mm distance between the radiating antenna and the surface of the wood. Most of the obtained results of larvae mortality and temperature measurements were handled using linear regression analysis.

Additionally, for each time of exposure, sapwood blocks sized 50 × 25 × 15 mm³ with larvae placed individually into the carved path behind the glass (**Figure 2**) were also exposed to microwave processing. For each time variant of the experiment, 10 blocks were used (i.e. 10 larvae).

Only in a few variants of the experiment two other devices of different powers were used, as well as the 0.6 kW apparatus, with the distance between antenna and wood surface set to 100 and 200 mm. In the case of a 100- and 200-mm distance, microwaves were radiated in a single strap of 120-mm width. In those variants of experiment, single wood blocks were used.

For measuring the temperature of the wood, a platinum resistance sensor of electric current and a digital electric meter V 543 were used. Electric resistance of the sensor was measured directly after radiation inside holes drilled in the front of each block and half the length of the block, in the distance of 10, 30 and 50 mm from the surface exposed to microwave radiation. The resistance of the sensor was then converted into wood temperature. Temperature measurements were performed for the variants of the experiment with 0 mm distance between the radiating antenna and the surface of the wood (for all devices of different powers) as well as for the wood exposed to radiation from the 0.6 kW device with 100-mm distance between the antenna and the surface of the wood.

Additionally, three systems imitating chocks of constructional wood of 300 mm thickness were tested. For this purpose, three models were made from blocks of pine wood sized 60 × 120 × 200 mm³, tightly attached by the 120 × 200 mm² surfaces. The 0.6 kW apparatus was used. Each model

was radiated with microwaves in two straps of 60 mm width, with 0 mm distance between the antenna and the surface of the wood. Time of exposure for each model was 5, 10 and 15 min.

3. Results

3.1. Mortality of the old house borer larvae after being exposed to high temperature in the experiment with hot air

The results of the experiment on the impact of high temperature, obtained with the use of hot air, on the old house borer larvae are shown in **Table 1** and **Figure 1**. In **Figure 1** only those variants of the experiment are shown where all the larvae were killed. Results obtained in earlier experiments by other researchers are also shown in **Figure 1**.

Exposure time (min)	The average time of onset of mobility larvae after exposure (days) – in parentheses are extreme cases	The average time after exposure, when the larvae have taken a wood boring (days) – in parentheses are extreme cases	The average completion time entry larvae in the wood (days) – in parentheses are extreme cases	The level of mortality of larvae (%)
Temperature 50°C				
180	2.0	5.0 (3–6)	8.3 (6–12)	0
240	2.6 (2–4)	10.3 (7–14)	13.2 (9–17)	0
300	2.8 (2–6)	7.6 (4–12)	13.2 (10–20)	0
360	4.8 (4–6)	14.0 (12–16)	22.0 (20–24)	20
Temperature 55°C				
20	2.6 (2–4)	4.6 (4–6)	6.2 (6–7)	0
30	3.5 (3–4)	5.5 (5–6)	9.0 (8–10)	60
40	8.7 (4–16)	13.0 (6–20)	17.3 (15–23)	20
50	3.0 (2–4)	6.0 (4–8)	12.0 (10–14)	80
60	0	0	0	100
Temperature 60°C				
5	4.0 (3–5)	6.0 (7–8)	9.0 (8–10)	60
10	5.5 (4–7)	15.0 (14–16)	20.0 (19–21)	60
15	0	0	0	100
Temperature 65°C				
5	0	0	0	100
10	0	0	0	100

Table 1. The results of experiments on the effects of high temperature on old house borer larvae (hot air).

3.2. Temperature of wood heated with the use of microwaves and mortality of the old house borer larvae

Average temperatures of wood measured 10, 30 and 50 mm below the surface after heating the wood with microwaves radiated by the 0.6 kW device are shown in **Figure 3**. The process

of cooling of the wood is also illustrated. The distance between the microwave radiating antenna and the surface of the wood was 0 mm in this case. In **Figure 4**, mortality rate of the old house borer larvae in pine wood, fir wood and spruce wood, determined in the experiment,

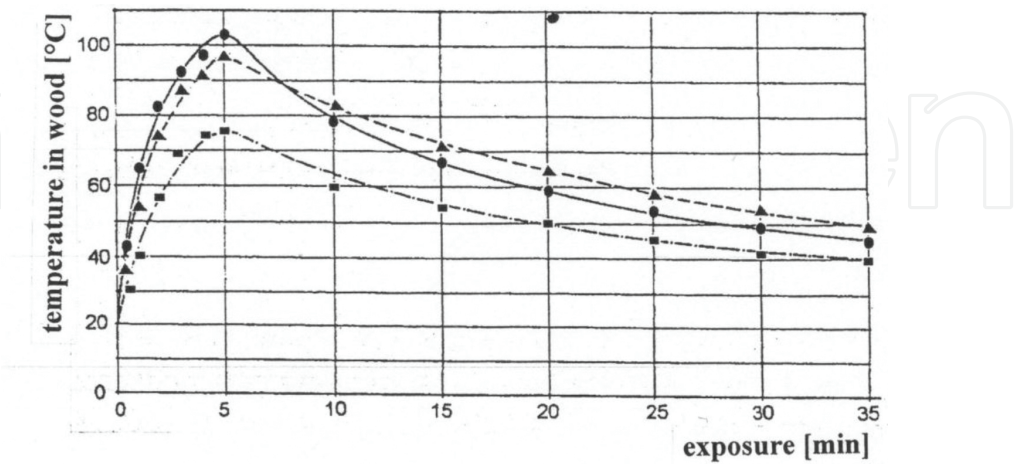


Figure 3. The process of heating in the case of wood of 60-mm thickness with microwaves (0–5 min) using the 0.6 kW device with 0 mm distance between the radiating antenna and the surface of the wood and the process of cooling of wood (5–35 min) measured 10 mm (● —), 30 mm (▲ - - -), and 50 mm (■ - · - ·) below the surface (according to Krajewski [25]).

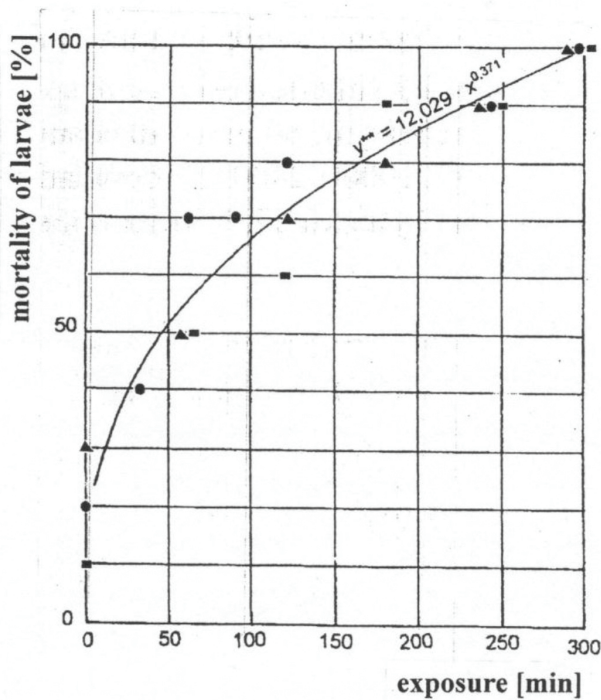


Figure 4. The relationship between mortality of the old house borer larvae and the time of exposure to microwaves radiated by the 0.6 kW device with 0 mm distance between the radiating antenna and the surface of the wood in the cases of pine wood (●), fir wood (■), and spruce wood (▲) of 60 mm thickness (according to Krajewski [25]).

is shown. In this case, the thickness of the wood was 60 mm and it was heated using microwaves produced by the 0.6 kW device with 0 mm distance between the radiating antenna and the surface of the wood.

Average temperatures of pine wood of 60 mm thickness, heated with the radiating antenna located 100 mm from the surface of the wood, are shown in **Figure 5**. Mortality rate of the old house borer larvae obtained in the experiment with 100 and 200 mm distance between the radiating antenna and the surface of the wood is shown in **Figure 6**.

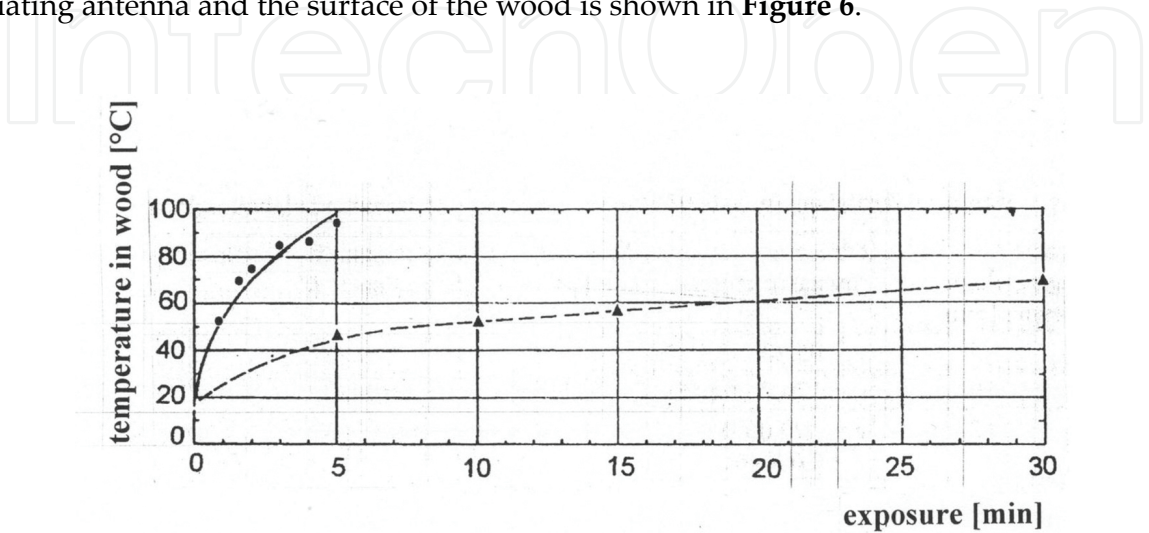


Figure 5. Average temperature of pine wood heated with microwaves radiated by the 0.6 kW device with 0 mm (● —) and 100 mm (▲ - - -) distance between the radiating antenna and the surface of the wood (according to Krajewski [25]).

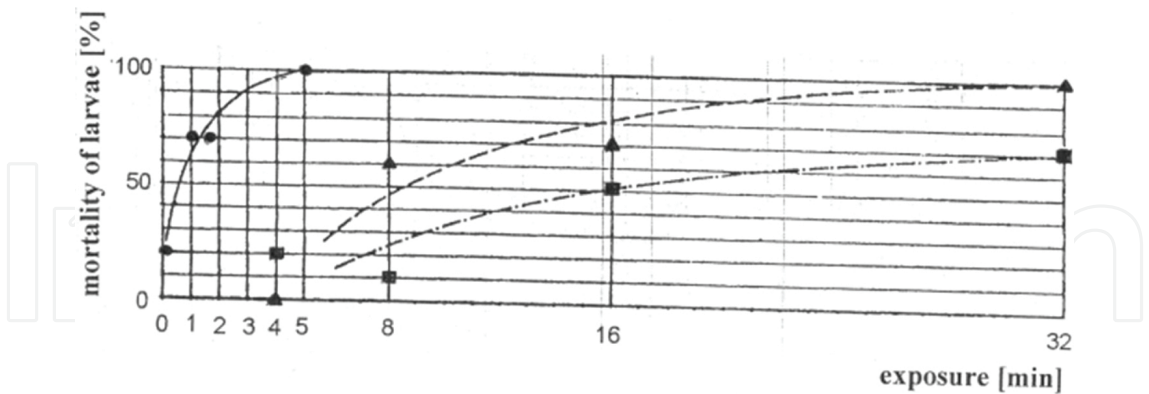


Figure 6. Mortality of the old house borer larvae after exposure to microwaves radiated by the 0.6 kW device with (● —), 100 mm (▲ - - -), and 200 mm (■ - · - ·) distance between the radiating antenna and the surface of the wood (according to Krajewski [25]).

The results of heating wood of larger section (thickness of 300 mm, i.e. 5 blocks 60-mm thick, tightly attached) are shown in **Figure 7**. The graphically suggested process of thermal degradation of the wood is related to phenomena between pyrolysis and ignition 5 to 30 mm below the surface of the wood.

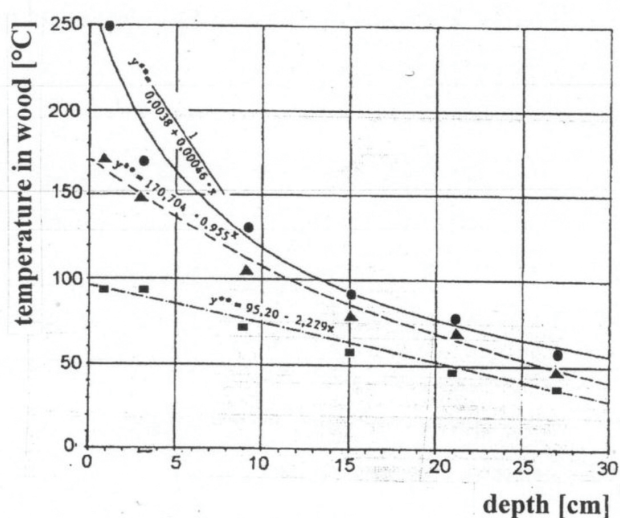


Figure 7. The temperature of different layers of wood of 300 mm thickness heated with microwaves radiated by the 0.6 kW device with 0 mm distance between the radiating antenna and the surface of the wood after 5 min (● —), 10 min (▲ ----), and 15 min (■ - · - ·) of exposure (according to Krajewski [25]).

The effect of faster heating of the wood radiated with microwaves produced by devices of higher output power is shown in **Figure 8**. In the case of 0.6 and 2.4 kW devices, the distance between the radiating antenna and the surface of the wood was 0 mm. The 1.0 kW device was a microwave chamber, refocussing the scattered microwave field.

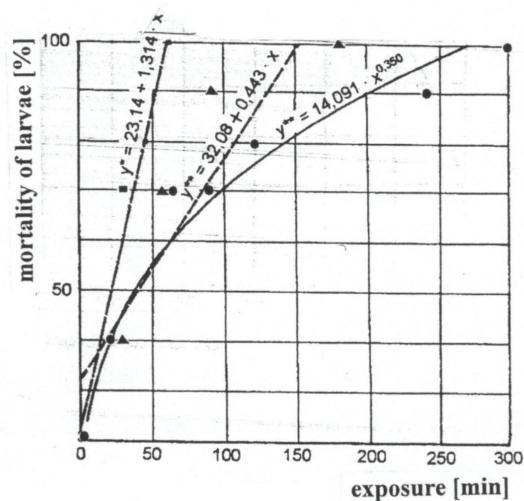


Figure 8. Mortality of the old house borer larvae after exposure to microwaves radiated by the 0.6 kW (● —), 1.0 kW (▲ ----), and 2.4 kW (■ - · - ·) devices (according to Krajewski [25]).

Unwanted effects of heating of pine wood radiated with microwaves in laboratory test conditions and in practice are shown in **Figures 9** and **10**, respectively. In **Figure 9**, pine wood blocks are shown which are used to examine the effectiveness of the old house borer larvae control.



Figure 9. Monitoring the temperature of the wood by thermal imaging can cause distortions to the view of the situation: the areas of high temperature, visible on the screen, can cover layers of much lower temperature, harmless to the larvae (photo by CARSEKT).



Figure 10. Resin melting in pine wood after exposure to microwaves radiated in practice by the 0.6 kW SAURUS device made in Italy (photo by CARSEKT).

4. Discussion

4.1. The old house borer larvae control with the use of hot air

All larvae surviving from high temperature exposure fell into thermic numbness because the duration of the procedure had not been long enough to cause mortal effects. The numbness lasted for a period of time depending on variant of the experiment (see **Table 1**). Larvae from the control group remained active for all the time, continuously carving the wood. In the experiments of Becker and Loebe [12], the phenomenon of thermic numbness of larvae was also observed if the duration of exposure to high temperature had been too short to cause death of the exposed individuals. Larvae surviving from microwave exposure also fell into numbness.

Differences in results of the relationship between larvae mortality and the temperature and duration of exposure, obtained by different researchers, result from methodological differences of their experiments. As stated in Becker and Loebe's publication [12], they placed the larvae onto a wooden plate in room temperature (about 20°C) and only after that the substrates with larvae were put inside the heating chamber. For this reason, they did not obtain the assumed homogeneous ambient temperature. Larvae were thus exposed to hot air operating from the top, while the wood in the bottom was heated only after a long period of exposure. For this reason, the results obtained by Becker and Loebe [12] are close to the author's results in the temperatures ranging from 50 to 55°C and to the results of Schmidt and Schneider [11]. Different course of the curve of relationship between mortal exposures and temperatures in the range from 54/55 and 60°C, obtained by Becker and Loebe results [12] from using wood which did not reach the temperature of the heating chamber. It seems improbable even at first glance that mortal impact of the temperature of 60°C on the old house borer larvae occurs only after as long as 50 min, unless a factor comes into play which significantly changes the assumed conditions of the experiment. In Becker and Loebe's experiment [12], only about 1/3–1/2 of the larvae body surfaces was exposed to the assumed temperature for the whole time of a given variant of the experiment. The size of the protected surface of the body depends on whether the wood was smooth or carved, a matter which is not covered by Becker and Loebe's publication [12].

A completely different location of the curve, related to the experiments of Wichmand [1] and Jensen [2], results from putting the larvae on a cardboard (again, no notice whether it was plain or corrugated) before placing them into the heating chamber. It can be assumed that the thin layer of cardboard heated much faster than wood in Becker and Loebe's experiment [12]. However, the influence of a much poorer resistance of Danish larvae (the area of Atlantic climate) as compared to the resistance of larvae from the surroundings of Berlin (much bigger impact of continental climate), suspected by Becker and Loebe [12], cannot be definitely ruled out. Larvae in Schmidt and Schneider's experiment [11] were placed inside holes drilled in previously heated wood. However, a small number of individuals (2–3) in each variant of their experiment make their results unreliable.

As for the results of the author's research [13] on resistance of various species of *Anobiidae* (*Anobium punctatum* De Ger, *Ptilinus pectinicornis* L., *S. paniceum* L., *E. mollis* L.) to high temperature, which are not presented here, they show that those species are much less resistant to the temperature factor than the old house borer larvae. Similar conclusions were reached by Becker and Loebe [12], who performed tests on larvae of *A. punctatum* and *L. brunneus*.

The temperature in a given place in a piece of wood can be calculated using an appropriate formula. Instead of performing time-consuming calculations, the parameters of the procedure of the old house borer control can be established in practice with the help of a suitable diagram. In order to estimate quickly the time of heating the inside of the cross section of a wooden constructional element up to the temperature of 55°C, deadly for the old house borer larvae, Schmidt et Schneider [11] presented applicable charts. The time required to heat wood to the temperature of 55°C ranges from 1 h (cross section is 100 × 140 mm²; temperature at start time is 50°C; and temperature of inflated air is 90°C) to 14 h (cross section is 200 × 240 mm²; temperature at start time is 0°C; and temperature of inflated air is 60°C). For example, a wooden constructional element of 180 × 180 mm² cross section in temperature of around 20°C at start time must be heated for 8 h if the temperature of inflated air is kept at about 60°C. According to the theory, time value taken from **Figure 1** must be added to the value of time taken from the chart. However, because of slowness of the process of heating the wood to the assumed temperature and slow returning of the heat by the wood, temperature above 40°C also acts destructively to larvae by gradual dehydration.

4.2. The old house borer larvae control using microwave radiation

The energy absorbed by a dielectric solid (Q_a), placed in a homogeneous electric field of a given intensity (E) and frequency (f), can be calculated according to the formula:

$$Q_a = 2 \cdot f \cdot \epsilon_r \cdot \epsilon_0 \cdot E^2 \cdot V \cdot t \cdot \operatorname{tg} \delta \quad (1)$$

where

f – frequency of the wave,

ϵ_r – relative permittivity of the material,

ϵ_0 – permittivity of free space,

E – electric intensity,

V – volume of the solid,

t – time of exposure

δ – dielectric loss angle.

Particles of water are dipoles. Placed in an electromagnetic field, for example, microwave field, they are oriented towards the rapid field changes, causing molecular friction. Apart from the qualities of the material, electric intensity and frequency of the wave are decisive. The formula

given above illustrates some relationships well, yet has little practical usefulness, as modern devices, based on cavity magnetrons, produce heterogeneous (scattered) electromagnetic microwave field. Electric intensity of the field is thus varied in different points in the volume of a wooden block.

Even if the reports from research [14, 16–18] using high-frequency and ultra-high-frequency radio waves, not being microwaves, are left apart, it is still difficult to compare the results obtained by the author with the results from publications by Van den Bruel et al. [19], Bollaerts et al. [20], Berwig and Schühly [21], Watson and Moss [22], Bletchly [23], Henin et al. [28]. All those experiments, however, achieved an effective method of the old house borer larvae control, resulting from heating wood in microwave field. It is presently emphasised that for the effectiveness of the method, a temperature of 60°C must be maintained in whole interior of the wood for at least 60 s [28, 29, 31]. Wood heated with microwaves, being a good thermal insulator, allows to maintain the temperature at the level of 55–60°C for a relatively long time even after cessation of microwave radiation (see **Figure 3**). The temperature can also be maintained after cessation of electromagnetic field action. However, the temperature obtained in this way in different areas of the wood is varied. Most publications omit the effect of gas pressure, resulting from microwave radiation of the wood. It was closely noted only by Berwig and Schühly [21]. Pressure of gases, especially vapour, is so big that it causes detaching of bark from the surface of conifer wood. The effect can also act to a degree destructively to insects.

Unfortunately, scattered microwaves lose much of their effectiveness in the old house borer larvae control procedures (see **Figures 5 and 6**) which is related to the decrease of electric intensity with growing distance between the radiating antenna and the surface of the wood. The effect can be counteracted, for example, by using industrial tunnel oven, as did Henin et al. [28, 29]. A relatively big power of the applied industrial tunnel oven allows fast wood heating. The procedures of phytosanitary treatment of European pallets by microwave radiation provided for 22-mm wooden planks facilitate the task. It is also assumed that heating wood with microwave radiation concerns only wood of thickness up to 200 mm [31]. Negative effects of heterogeneous heating of wood blocks of big thickness using microwaves in the form of scattered field are shown in **Figure 7**. For this reason, application of microwave radiation to the old house borer larvae control in building constructions is a significantly more difficult task. Some unexpected thermic effects can also occur in frozen wood, as was shown by Henin et al. [31]. Also, it must be noted that monitoring the wood by thermal imaging (**Figure 9**) can cause distortions to the view of the situation. Areas illustrated with high temperatures can cover layers of wood of much lower temperatures than the temperature required to eliminate larvae. This issue concerns in particular building constructions, where there is not always the possibility to measure the temperature from two directions: from the side of microwave radiation and from the opposite side. The most heated areas of the wood are shown very bright but they can cover much colder layers. Such cases were observed in practice during the old house borer larvae extermination in wooden constructions.

Some unwanted effects of heating the wood for the aims of the old house borer larvae control include resin melting in the case of some wood species, for example, Scots pine wood. It was

observed in research and was later confirmed in practical application of microwave heating in building constructions (**Figure 10**).

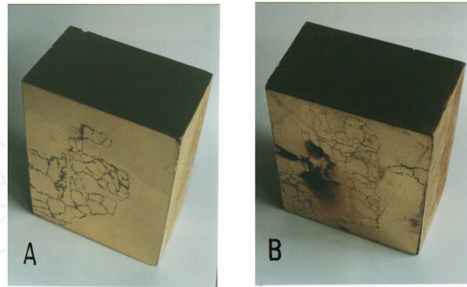


Figure 11. Condition of pine wood covered with gilding after exposure to microwaves radiated by the 0.6 kW device (photo by Krajewski): (A) 2 min and (B) 4 min.

The application of microwave heating for the aims of wood destroying insects control is limited by the presence of accompanying materials used in the construction. The author carried out ample observation, yet its results cannot be discussed in detail due to the limitations of the publication. Wood contraction, caused by desorption as a result of drying the whole volume of the wood, may result in very small cracks in both monochrome and polychrome made with some kinds of paint, for example, tempera. In the case of oil paint, binder may melt or blisters may occur on the surface of the wood. Particular threats are caused by the presence of thin electrical conductors, for example, gilding (**Figure 11**). According to Maxwell's law, electric current flows in a conductor placed in electromagnetic field. Current flow is accompanied by electrical resistance, and resistance results in heating which can even lead to ignition of the wood. The presence of 2-inch nails in the wood, exposed to microwave radiation, which guarantees effectiveness of the old house borer larvae control with a 0.6 kW device, is not dangerous. However, an attempt to destroy *Anthrenus* sp. larvae in entomological collections with entomological pins resulted in a fire.

5. Conclusions

The possibility of effective wood-boring insect control using hot air and microwave radiation was proven many years ago. However, the author's research and practical observation allow to formulate several proposals, giving a new view on some issues:

1. The differences in estimations of the old house borer larvae susceptibility to high temperatures contained in different publications result mainly from methodological differences of the performed experiments. The author's result point to purposefulness of taking up unexplained issues from past publications, even very old ones.
2. Because of high thermic insulation of wood, practical application of wood-boring insect control both using hot air and microwaves shapes favourably in regard to theoretical indications basing on research. The biocidal effects of the suggested temperatures of 55°C

(in older publications) and 60°C (in newer publications) do not occur suddenly. Temperatures just below the theoretical limits may be hot enough to cause the effect of dehydration of larvae. In the case of microwaves, heating process is indeed very quick, but it involves releasing vapour from the wood and thus growth of pressure. Using hot air in order to heat the wood requires more time, but in this case also, besides protein denaturation, dryer effect occurs. In both methods, temperatures causing not only wood drying but also larvae dehydration are maintained for a long time.

3. It seems that microwave radiation method has better possibilities of application using industrial tunnel oven for phytosanitary treatment of wood packaging material than for wood-boring insect control in the wood of building constructions. Covering a larger space with microwave field refocalised in industrial tunnel oven and smaller thickness of wood packaging material create the possibility to obtain a more homogeneous temperature distribution in the element subjected to insects control. On the other hand, devices used to wood-boring insect control in wood of building constructions operate on the basis of “microwave brush”, covering small areas of the wood. Even a small distance between the microwave radiating antenna and the surface of the wood causes huge decrease in effectiveness of the procedure.
4. Microwaves always cause some problems concerning accompanying materials in wooden constructions. Special attention must be paid to metals, including metal connectors (nails, screws etc.), also in the case of wood packaging materials. Rapid wood contraction resulting from wood drying definitely excludes applying microwaves to treatment of coated wood, even if the coating is relatively resistant to high temperatures.

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