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Effect of Microwaves on the Hydronic Underfloor Heating System

Floors in residential buildings are often made of wood. To improve occupant comfort, underfloor heating systems with water circulation are commonly installed. However, wooden floors can be attacked by wood-boring pests. The use of microwave technology for pest elimination is becoming increasingly popular – no chemicals are required and occupants do not need to vacate the premises. The question arises whether microwave equipment can be used when an underfloor heating system is installed.

Underfloor heating with a top layer can be installed in many ways – solid or engineered wood boards, on a screed or on joists, glued to the substrate or laid as a floating floor. It is not possible to describe all variants, therefore this document focuses on one configuration, which is not representative of all possible solutions.

Power Density at the Wood Surface

Users of microwave equipment and their clients are most concerned that microwaves may damage the hydronic installation beneath the floor. To assess the associated risk, reference is made to well-established calculations of heating time for individual layers.

Materials absorb microwaves and heat up at different rates, characteristic to each material. Knowing the material type, it is possible to determine how quickly it will heat up to a given temperature and what fraction of energy will be absorbed.

Input Data

The calculations are based on the technical parameters of the MG-1500 generator. Distances, thicknesses, and diameters have been assumed arbitrarily. In practice, these values will differ from case to case. If any parameter changes by more than 20%, the calculations must be repeated.

$P = 1500$ W (generator power)
$A_{ap} = 0.25 \times 0.30$ m $= 0.075$ m^2 (antenna aperture − outlet)
$r = 0.03$ m (distance from antenna outlet to wood surface)
$f = 2.45$ GHz (generator operating frequency)
$\lambda = \frac{c}{f} \approx \frac{3 \cdot 10^8}{2.45 \cdot 10^9} \approx 0.122$ m (free − wavelength)

Far-Field Boundary

Far-field boundary (Fraunhofer distance) for an antenna with transverse dimension $D = 0.30$ m:

$$r_{far} = \frac{2D^2}{\lambda} = \frac{2 \cdot 0.09}{0.122} \approx 1.48 \text{ m}$$

The distance from the antenna to the wood and water pipes is significantly smaller than r_{far}. This means that these elements are located in the near field (Fresnel zone, or even the reactive near-field region).

Note:
In this case, the far-field formula $S = \frac{P \cdot G}{4\pi r^2}$ must not be used, as it would yield a grossly overestimated result. Near-field analysis also does not require other antenna parameters such as gain [G].

Near-Field Power Density – Aperture Method

In the near field, at distances smaller than the aperture dimensions, the beam does not diverge significantly. At an antenna-to-wood distance of 0.03 m, the power density at the wood surface is approximately equal to the power density at the antenna outlet:

$$S_{ap} = \frac{P}{A_{ap}} = \frac{1500}{0.075} = 20\,000 \text{ W/m}^2$$

At such a small distance, beam divergence is negligible. The power density at the wood surface can be taken as 20 kW/m^2, even when using the simplified expression P/A_{ap}.

Energy Absorption in Materials

Energy Absorption in Wood at f = 2.45 GHz

Since there is no single standard and no single wood species is universally used, it was necessary to assume one set of values arbitrarily in order to carry out the calculations and further analysis.

Averaged Parameters for Dry Wood

$\varepsilon_r' \approx 2.0 \qquad \text{(dielectric constant)}$
$\operatorname{tg}\delta \approx 0.06 \qquad \text{(loss tangent)}$

Penetration Depth

$$\delta = \frac{\lambda_0}{2\pi\sqrt{\varepsilon_r'}\cdot \operatorname{tg}\delta} = \frac{122.4}{2\pi\cdot\sqrt{2.0}\cdot 0.06} \approx 229.8\ \text{mm}$$

Attenuation (Absorption) in Wood

$$T_{20} = e^{-2d/\delta} = e^{-2\cdot 20/229.8} \approx 0.840$$

$$A_D = 1 - T_{20} = 1 - 0.840 = 0.160$$

$$A_D \approx 16\%$$

A 20 mm thick wood layer absorbs approx. 16% of microwave energy, while approx. 84% is transmitted further.

Energy Absorption in Cement Screed at f = 2.45 GHz

As with wood, the values used here have been assumed for the purpose of these calculations. The cement screed at any given location may have a different thickness or moisture content.

Averaged Parameters for Cement Screed

$d = 60\ \text{mm} \qquad \text{(screed thickness)}$
$\delta = 160\ \text{mm} \qquad \text{(penetration depth)}$

Attenuation (Absorption) in the Screed

For exponential power attenuation:

$$T_{60} = e^{-2d/\delta}$$

$$\frac{2d}{\delta} = \frac{2 \cdot 60}{160} = 0.75$$

$$T_{60} = e^{-0.75} \approx 0.472$$

$$T_{60} \approx 47.2\%$$

Absorption

$$A_B = 1 - T_{60} = 1 - 0.472 = 0.528$$

$$A_B \approx 53\%$$

A 60 mm thick cement screed absorbs approx. 53% of microwave energy, while approx. 47% is transmitted further.

Examples of Material Heating

The examples below should not be treated as fixed or definitive parameters. They are intended solely to illustrate how quickly materials can heat up when exposed to microwaves and how significant the differences can be under varying conditions.

The microwave equipment parameters are the same as those stated in the section "Input Data".

For a wooden floor made of oak boards, 20 mm thick, with a moisture content of 9% and an initial temperature of 20°C, the average heating time to reach a given temperature is shown in the table below. Heating times for wood with the parameters assumed in the calculations are also provided. It should be noted that heating times for different wood species and moisture levels may differ by as much as a factor of two.

Temperature T [°C]	**Time [min]** standard wood	**Time [min]** oak
60	≈ 5.1	≈ 2.5
80	≈ 7.6	≈ 3.7
100	≈ 10.2	≈ 4.9

Screeds are made from various materials – cement, anhydrite, or even concrete. Their moisture content may also vary, which affects microwave absorption and consequently the rate of heating. The comparison table below shows indicative temperatures reached by the screed after a given heating time.

Time [min]	**Cement screed T [°C]**	**Anhydrite screed T [°C]**
1	24.2	23.0
2	28.3	25.9
3	32.5	28.9
5	40.8	34.8
8	53.3	43.6
10	61.6	49.5

This section illustrates the thermal risk to the hydronic underfloor heating system arising from screed heating. Wooden flooring heats up quickly – within 3–4 minutes it reaches the temperature required for effective pest elimination (approx. 80°C). During the same period, the screed temperature does not exceed 35–40°C, which poses no risk to the hydronic installation. The operator should not attempt to heat the wood beyond the effective treatment temperature – this serves no purpose and unnecessarily increases risk. Provided that a minimum water flow is maintained in the system, the risk of pipe damage is negligible.

Analysis of Pipes Without Aluminium Layer

Preliminary note:
PEX/Al/PEX pipes contain an aluminium layer that effectively shields against microwaves – in this case $P_{abs} \approx 0$ W (microwaves do not reach the water). However, a different issue may arise – arcing at the edges and sharp ends of metal components. This is outside the scope of this document.
The following calculations apply to PE-RT/EVOH/PE-RT pipes (without aluminium), in which microwaves penetrate through the pipe wall. Absorption by the pipe wall has been neglected – the pipe is treated as transparent to microwaves.

Input Data

$d_{ext} = 16$ mm (pipe outer diameter)
$d_{int} = 12$ mm (pipe inner diameter)
$L = 0.25$ m (length of pipe section exposed to microwaves)

Microwave Power Density at Pipe Level

$$S_{pipe} = S_{ap} \cdot (1 - A_D) \cdot (1 - A_B) \approx 8000 \text{ W/m}^2$$

The value rounded up to 8000 W/m^2 represents a conservative approach, increasing the estimated potential risk.

Power Absorbed by Water

Projected area of the pipe:

$$A_{proj} = d_{int} \cdot L = 0.003 \text{ m}^2$$

Power absorbed by water:

$$P_{abs} = S_{pipe} \cdot A_{proj} = 24 \text{ W}$$

Mass of Water Exposed to Microwaves

Internal cross-sectional area:

$$A_{int} = \pi \cdot \left(\frac{d_{int}}{2}\right)^2 = \pi \cdot (0.006)^2 \approx 1.131 \cdot 10^{-4}\ \mathrm{m}^2$$

Volume:

$$V = A_{int} \cdot L = 1.131 \cdot 10^{-4} \cdot 0.25 = 2.827 \cdot 10^{-5}\ \mathrm{m}^3$$

Mass of water:

$$m = \rho \cdot V = 1000\ \mathrm{kg/m}^3 \cdot 2.827 \cdot 10^{-5}\ \mathrm{m}^3 \approx 0.0283\ \mathrm{kg}$$

Heating of Standing Water (No Flow)

Initial water temperature (outside heating season): $T_0 = 20\ ^\circ\mathrm{C}$
Specific heat of water: $c_p = 4200\ \mathrm{J/(kg \cdot K)}$

Temperature rise after time t minutes:

$$\Delta T = \frac{P_{abs} \cdot t}{m \cdot c_p} = \frac{24 \cdot t}{0.02827 \cdot 4200} \approx 12.13 \cdot t \left[\frac{\mathrm{K}}{\mathrm{min}}\right]$$

Heating of Water at 2 l/min Flow Rate

Volumetric flow rate:

$$Q = 2\ \mathrm{l/min} = \frac{2}{60}\ \mathrm{l/s} = 3.333 \cdot 10^{-5}\ \mathrm{m^3/s}$$

Mass flow rate:

$$\dot{m} = \rho \cdot Q = 1000 \cdot 3.333 \cdot 10^{-5} = 0.03333\ \mathrm{kg/s}$$

Steady-state temperature rise (continuous flow):

$$\Delta T_{ss} = \frac{P_{abs}}{\dot{m} \cdot c_p} = \frac{24}{140} \approx 0.17\ \mathrm{K}$$

Water exchange time in the pipe section exposed to microwaves:

$$t_{ex} = \frac{m}{\dot{m}} = \frac{0.02827}{0.03333} \approx 0.85\ \mathrm{s}$$

The first portion of water passing through the pipe section exposed to microwaves will be heated by 0.17 K within approx. 3 seconds. After this time the temperature rise stabilises. As long as the flow rate remains unchanged and flow is not interrupted, each subsequent portion of water will be heated by 0.17 K only.

If water flow is not initiated or is interrupted, a drastic temperature rise will occur. Within 2 minutes, the water temperature in the pipe section exposed to microwaves will increase by more than 24°C.
Critical condition for PE-RT pipe (maximum continuous operating temperature approx. 60 °C, short-term approx. 70 °C).
With no flow, pipe failure will occur after approx. **3 minutes**. After approx. 6 minutes the water will reach 100 °C and begin to boil.
Representative data consistent with the calculations are shown in the table below.

Time [min]	**Standing water T [°C]**	**Flow 2 l/min T [°C]**
0	20.0	20.0
1	32.1	20.2
2	44.3	20.2
3	56.4	20.2
5	80.6	20.2
6	92.8	20.2
6.6	≈ 100	20.2

Operator Guidelines

1. **Check the pipe type before starting work.** Pipes with an aluminium layer (e.g. PE-X/Al/PE-X) are shielded – the risk of damage to the hydronic installation is minimal. Pipes without an aluminium layer (PE-X, PP, PB, multilayer without Al) require compliance with the following rules.

2. **Ensure that water is circulating in the system.** Before starting work, check the flow meters (rotameters) on the manifold. At a flow rate of 2 l/min, the water temperature increases by only approx. 0.17 K – the installation is safe.

3. **Limit exposure time at any one location to 2 minutes.** With no water flow, the critical pipe condition occurs after approx. 3 minutes. The 2-minute limit provides a safety margin accounting for calculation uncertainty and variability of material parameters.

4. **If in doubt – do not start work.** If there is any uncertainty regarding pipe type, flow status, or screed thickness, the installation must be verified before work begins.

5. **Monitor water flow continuously during work.** A rotameter is a mechanical device and may fail. This does not relieve the operator of responsibility for conducting work correctly. The choice of monitoring method and supervision procedure is the operator's responsibility.

6. **This document does not guarantee safety.** The calculations were carried out for one arbitrarily defined configuration – specific thicknesses, dimensions, and material parameters. In practice, every case is different. If any parameter changes by more than 20%, the calculations must be repeated.
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