Theoretical and practical comparison of energy conversion of microwave frequencies 2,45 GHz and 5,8 GHz

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The theory of microwave heating shows that the power absorbed by a material can be calculated by the following formula:

$$P = 2 \cdot \pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon'' \cdot E^2 \cdot V$$

P= power absorbed by material; f= microwave frequency;
ε_0= electric field constant; ε“= imaginary part of complex dielectric constant;
E= electric field strength; V= material volume

Considering the variable parameters only, the absorbed power depends on the frequency, dielectric constant and electric field strength. Comparing both frequencies 2,45 GHz and 5,8 GHz, it can be deduced that the absorbed power increases with frequency at constant microwave power and therefore constant electric field strength. As a result , in theory, a material absorbs approximately twice the energy at 5,8 GHz than at 2,45 GHz at the same incident microwave power.

Additionaly, the dielectrical constant is, in most cases, not really a constant for many materials. It depends both on temperature and microwave frequency. In most materials, the dielectric constant increases with frequency. An example of frequence dependency of the dielectric constants for water is shown in a Cole-Cole equation in diagram 1.

The maximum of imaginary part of complex dielectric constant for water at 25°C is at about 18 GHz. The two discussed frequencies are shown in the diagram with a higher value at 5,8 GHz than at 2,45 GHz. Therefore, in theory, water can absorb up to four times the microwave power at 5,8 GHz in comparison with 2,45 GHz, theoretically.

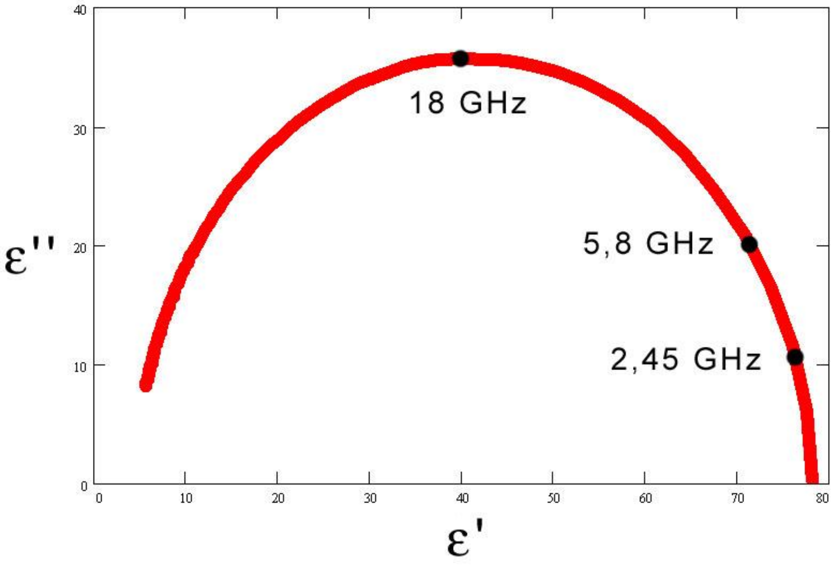

Diagram 1: Cole-Cole equation for water at 25 °C.

Under real-life conditions it has to be taken into consideration that the law of energy conservation cannot be flouted. An effective microwave process operates with an effectiveness of 70 to 90 %, it is simply is not possible to double the energy absorption. But for microwave processes that have a low effectiveness due to small material volumes or inappropriate material properties, the 5.8 GHz frequency can result in a significantly a improved energy absorption.

Some examples of this effect are :

Water: A test was performed to heat water with microwaves. An increase in water temperature of 25 K was achieved after 10 minutes with a microwave power of 800 W at 2,45 GHz. With 500 W at 5.8 GHz a temperature increase of 37 K was observed in the same time. Taking into consideration the different microwave powers, the microwave heating at 5.8 GHz was 2.5 times as effective as at 2.45 GHz.

Quartzsand: An amount of 150g of high-purity quartz-sand was heated in a microwave test unit for 25 min. with 800W at 2.45 GHz. In this time the temperature increase was 122 K. The same experiment was done with 500W at 5.8 GHz and a temperature increase of 288 K was measured. The effectivity at 5.8 GHz was therefore 3.8 times higher than at 2.45 GHz.

Paper/ Cardboard: Because of the low thickness of paper and cardboard, heating by 2,45 GHz is not effective (please refer to power absorption formula). With microwaves of 5.8 GHz at least twice the power can be absorbed by the material. Applications are for example drying of print color or removal of solvents.

Filter paper impregnated with resin: Samples of these materials are difficult to cure with the standard frequency of 2.45 GHz. For example, a sample with dimensions of 50 x 10 x 4 mm was heated to a temperature of 73°C in 25 min. by 2,45 GHz with appr. 3,2 kW. The same increase of temperature can be obtained in 1.5 min with a frequency of 5,8 GHz and a power of 1,5 kW. The curing temperature of 180°C was reached after 6.5 min.

Isopropanol-Quartz slurry: At 2.45 GHz, after the evaoration of the isopropanol, a temperature of appr. 83°C was achieved. This temperature is not sufficient to completely remove the solvent from the remaining cake. At 5.8 GHz and the same microwave power of 1.6 kW, a temperature of appr. 100°C was reached, enough to completely remove the solvent.

Figure 1: MKE Dual-Frequency – experimental unit for testing material and process development
(2 x 800 W 2.45 GHz / 2 x 500 W 5.8 GHz)

Figure 2: Dual-Frequency Laboratory Furnace
(800 W 2.45 GHz / 500 W 5.8 GHz)