THE PRINCIPAL OF MICROWAVE OVEN AND MICROWAVE HEATING

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ABSTRACT

We report how the Microwaves transmit energy to water molecules in the food, how a microwave oven work and what is the magnetron. Finally, we study how can heat generated by microwave (i.e. power absorbed by the material) represent theoretically, in a view of microwave heating.

INTRODUCTION

When cook, we have to heat something to eat with fire. But today, we can cook easily by using a microwave oven. Instead of heating food products, we just push the button. Though everyone knows how to use it, it is hard to find someone who knows how it works. Because of its name we just know that it uses microwaves.

Originally, microwaves were principally used for communication. In 1950, the use of microwave energy to heat materials was discovered. Now microwave ovens have became common for heating food products in the home. The most prominent characteristic of microwave heating is volumetric heating, which is quite different from conventional heating where the heat must diffuse in from the surface of the material. Volumetric heating means that materials can absorb microwave energy directly and internally and convert it to heat. It is this characteristic that leads to advantages using microwaves to process materials. Now we present more detailed characteristics of microwave heating.

MICROWAVES

Microwaves are a form of electromagnetic energy, like light waves or radio waves, and occupy a part of the electromagnetic spectrum(Fig.1). Microwaves are used to relay long-distance telephone signals, television programs and computer information across the earth or to a satellite in space. They are used to detecting speeding cars. Yet, the microwave is perhaps most familiar as the energy source for cooking food.

All wave energy changes polarity from positive to negative with each cycle of the wave. In microwaves, these polarity changes happen millions of times every second. Food molecules - especially the molecules of water - have a positive and negative end, in the same way a bar magnet has a north and a south pole. When microwaves at the right frequency bombard food, they cause the polar molecules to rotate at the same frequency, millions of times a second. All this agitation on the molecular level creates friction, which heats up the food. Because microwaves don't interact with molecules of glass, plastic or paper, only the food is heated.

HOW A MICROWAVE OVEN WORKS

A microwave oven works as follows: (Fig. 2)

1. Electrical energy, in the form of low-voltage alternating current and high-voltage direct current, is transformed and converted into direct current.
2. A magnetron uses this direct current and generates microwaves with a frequency of 2450 megacyles per second or 2.45 GHz (gigahertz).
3. The microwaves are directed by an antenna at the top of the magnetron into a waveguide.
4. The waveguide channels microwaves to a fanlike device called a stirrer which disperses them inside the oven cavity.
5. The microwaves then reflect off the metal walls of the oven's interior and are absorbed by

molecules in the food.

6. Because each wave has a positive and negative component, the molecules in the food are jostled back and forth at twice the rate of the microwave frequency, namely 4.9 billion times a second.

HOW A MAGNETRON WORKS

The heart of a microwave oven is the magnetron. A magnetron converts electrical energy to microwave radiation. To do this, it uses low-voltage alternating current and high-voltage direct current. A transformer changes the incoming voltage to the required levels and a capacitor, in combination with a diode, filters out the high voltage and converts it to direct current.

Inside the manetron, electrons are emitted from a central terminal called a cathode. A positively charged anode surrounding the cathode attracts the electrons. Instead of traveling in a straight line, permanent magnets force the electrons to take a circular path. As they pass by resonating cavities, they generate a continuous pulsating magnetic field, or electromagnetic radiation. (Fig. 3)

MICORWAVE HEATING

The most prominent characteristic of microwave heating is volumetric heating, which is quite different from conventional heating where the heat must diffuse in from the surface of the material. Volumetric heating means that materials can absorb microwave energy directly and internally and convert it to heat. It is this characteristic that leads to advantages using microwaves to process materials.

Now, let's represent generated heat in a view of electromagnetic wave.

The relation between the power density absorbed by a material and the electric field has been given next equation.

$$p_{dis} = \omega\varepsilon''_{eff}\left|E\right|^2 = q_{abs}$$

From an electromagnetic (EM) point of view, p_{dis} is the power density dissipated in the materials. In the heat transfer equation, q_{abs} represents the heat generation term. It is this equation that connects the electromagnetic waves with heat transfer phenomenon. The variable ε'' plays an important role in microwave heating. For Maxwell's equations, ε'', combined with ε' (which is the real part of the complex permittivity of the material), represents the material.($\varepsilon = \varepsilon' - j\varepsilon''$)

The fields can be expressed as

$$\vec{E} = E_0 e^{-\gamma z}\hat{x} \qquad , \qquad \vec{H} = \frac{E_0}{\sqrt{\mu/\varepsilon}} e^{-\gamma z}\hat{y}$$

where $\varepsilon = \varepsilon' - j\varepsilon''$ and μ is the permeability of the material. Throughout this dissertation, $\mu = \mu_0$, the free space permeability. In the above equations, γ, the propagation constant, is the most important parameter to describe a EM wave. The definition of γ is

$$\gamma = \alpha + j\beta = \sqrt{j\omega\mu j\omega\varepsilon} = \omega\sqrt{\varepsilon_0\mu_0}\sqrt{-\varepsilon'_r + j\varepsilon''_r}$$
$$= \frac{\pi(2\varepsilon'_r)^{1/2}}{\lambda_0}\left(\sqrt{(1+\left(\frac{\varepsilon''_r}{\varepsilon'_r}\right)^2)^{1/2} - 1} + j\sqrt{(1+\left(\frac{\varepsilon''_r}{\varepsilon'_r}\right)^2)^{1/2} + 1}\right)$$

where ε'_r and ε''_r are relative dielectric constant and relative loss factor, which are defined as

$$\varepsilon'_r = \varepsilon'/\varepsilon_0 \qquad , \qquad \varepsilon''_r = \varepsilon''/\varepsilon_0$$

where ε_0 is the permittivity of the free space and λ_0 is the wavelength in free space defined as

$$\lambda_0 = \frac{2\pi}{\omega\sqrt{\mu_0\varepsilon_0}}$$

If the frequency of the microwave source is 2450 MHz, λ_0 is equal to 12.24 cm.
Now the fields are written as

$$\vec{E} = E_0 e^{-\alpha z} e^{-j\beta z}\hat{x} \quad , \qquad \vec{H} = \frac{E_0}{\sqrt{\mu/\varepsilon}} e^{-\alpha z} e^{-j\beta z}\hat{y}$$

The Poynting vector $\vec{S}$, which defines the power flux associated with a propagating EM wave, is given by

$$\vec{S} = \vec{E}\times\vec{H}^* = \frac{(\sqrt{\varepsilon})^*}{\sqrt{\mu}}|E_0|^2 e^{-2\alpha Z} \qquad ----- \quad \text{(a)}$$

From an energy balance, the power density dissipated in the material is

$$p_{dis} = -\mathrm{Re}(\nabla\cdot\vec{S}) = \frac{2\alpha\,\mathrm{Re}\left(\left(\sqrt{\varepsilon}\right)^*\right)}{\sqrt{\mu}}|E_0|^2 e^{-2\alpha Z} = \frac{2\alpha\,\mathrm{Re}\left(\left(\sqrt{\varepsilon}\right)^*\right)}{\sqrt{\mu}}|E|^2 \qquad ----- \quad \text{(b)}$$

The power density dissipated in the lossy materials can be expressed as

$$p_{dis} = \frac{2\alpha\,\mathrm{Re}\left(\left(\sqrt{\varepsilon}\right)^*\right)}{\sqrt{\mu}}|E_0|^2 e^{-2\alpha Z} = \omega\varepsilon''|E_0|^2 e^{-2\alpha Z} = q_{abs}$$

The variable E_0 is the amplitude of the electric wave at z = 0, from where the wave originates. E0 is related to the microwave power source through the reflection coefficient Γ and transmission coefficient T. In microwave heating, at least two media exist in the system. Microwaves travel from medium 1 into medium 2 and heat medium 2. Since the materials have different properties, only part of the energy from the power source can be transmitted into the heated material, while the remainder will be reflected. The reflection and transmission are described by Γ and T. Normally, and T of a specified mode2 are functions of the media. For a uniform plane wave traveling in half infinite space, the formulas to calculate Γ and T can be found in any EM waves book.

From Eq. (b), part of the energy carried by waves changes into heat as EM waves travel in the lossy material. As a result, the amplitude of the wave and the carrying power attenuate exponentially. A useful parameter describing the attenuation effect is the penetration depth, which is defined as

$$D_p = \frac{1}{2\alpha}$$

The physical meaning of penetration depth is the distance that the EM wave must travel in a lossy medium to reduce its power to e−1 = 0.368 of the original value, as seen from Eq. (a). This value is one half of the skin depth used in electromagnetics.

The above discussion can be applied only in an infinite half space. In reality, all materials have finite dimensions. Multiple reflections will occur on the interfaces; thus, the form of the waves existing in materials is the superposition of traveling waves and standing waves. It is the interferences among the waves that make the problem more interesting. We will use a simple example to illustrate such phenomena.

CONCLUSION

In this work, we discussed the principle of microwave heating. We have come to know how to make the microwave in the microwave oven, and how much thermal energy can be absorbed. We explained the process of microwave oven's making foods with maxwell's equation. Now, we can come to calculate the delivered energy by using the equations in this work. And get more apprehension of electromagnetic waves, too.

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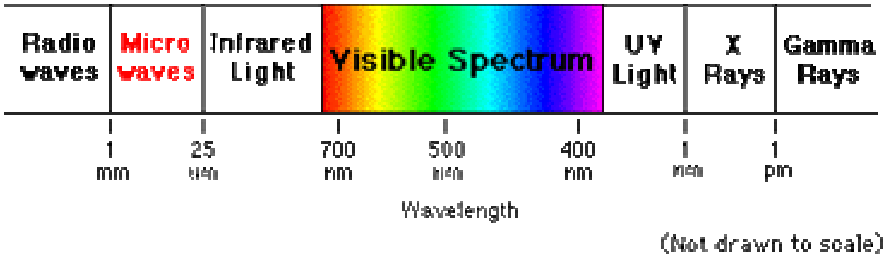

Figure 1 Electromagnetic spectrum

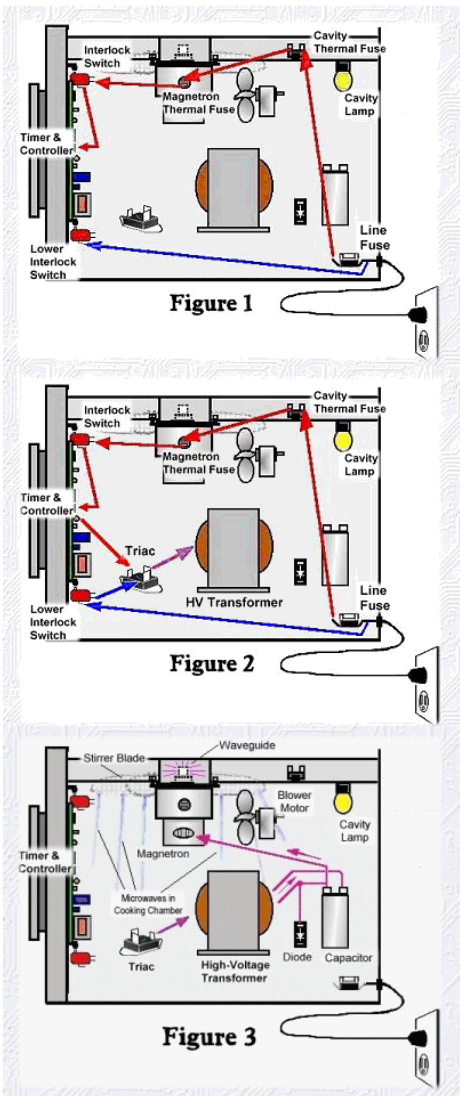

Figure 2 Microwave oven

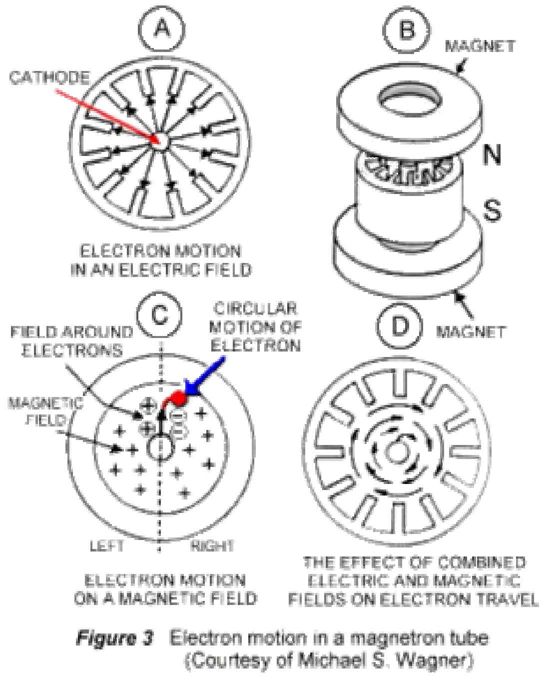

Figure 3 Magnetron tube