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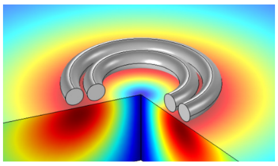

Electoheat - laboratory

Title of exercise:

Microwave heating measurements

Date:	Date of assessment::	Rate:

1. Introduction

Microwave heating - the generation of heat in the charge, primarily due to displacement current flow (polarity), and optionally - the conduction current for a solid or liquid materials, subjected to microwave radiation at a frequency of several hundred MHz to several hundred GHz.

Electromagnetic energy is transferred from the magnetron (where it is produced) by the waveguide to the applicator (e.g. the cooking compartment of a microwave oven) in which there is a load (charge). Sometimes the load is placed at the open end of the waveguide. The electromagnetic field penetrates into the load and causes the occurrence of polarization phenomena that leads to the flow of the bias current.

At the same time the phenomenon of strong attenuation of the electromagnetic field occurs, which causes an uneven distribution of thermal power and heating. If a flat electromagnetic wave with the surface power density p (W/m^2) falls into the dielectric, a part of this power (p_r) will be reflected, and the remaining power (p_s), penetrates into the dielectric.

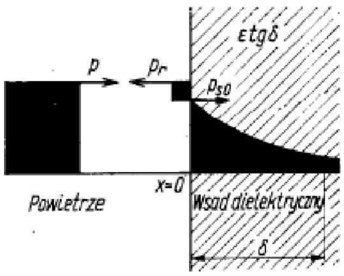

Fig.1. Distribution of power density in case of a plane wave penetrating into the dielectric

The field strength inside the dielectric decreases exponentially. This is determined by the formula:

$$E_x = E_0 e^{-\frac{x}{\delta}} \tag{1}$$

where E_0 is the field intensity at the surface, and E_x is the field intensity at depth x.

The quantity δ (measured in meters) is called: "***penetration depth***", defined as the depth at which field E decreases e-fold compared to E_0.

$$\delta = \frac{1}{\pi\sqrt{\mu_0\varepsilon_0\varepsilon_r f \cdot tg\delta}} \approx 0.95 \cdot 10^8 \frac{1}{f \cdot tg\delta \cdot \sqrt{\varepsilon_r}} \tag{2}$$

where μ_0 is magnetic permeability of vacuum, ε_0 is dielectric permeativity of vacuum, f – field frequency and tgδ is dielectric loss factor.

The power produced in the charge unit volume p_v depends upon::

- parameters of the field (intensity E and frequency f),
- parameters of the charge (relative dielectric permeativity ε_r, dielectric loss factor tgδ),
- distance x from the surface

and the formula for p_v versus x is the following:

$$p_{vx} = 55.64 \cdot 10^{-12} \varepsilon_r \cdot tg\delta \cdot f \cdot E_0^2 \cdot e^{-\frac{2x}{\delta}} \quad (3)$$

A **microwave oven** is a kitchen appliance used to fast defrosting and heating of food and, more rarely, to its cooking and baking. The food is exposed to strong microwave radiation of frequency 2.45 GHz.

The microwaves in a **microwave oven** are produced by a magnetron, built of a heated cathode (a solid metal rod) surrounded by a ring shaped anode and of two magnets (Fig. 2). Additionally, the anode contains resonant cavities. High voltage is applied between the anode and the cathode producing an electric field between them. The magnets produce a magnetic field. The cathode emits electrons, which (due to the influence of the electric and magnetic fields) turn around the cathode. As the electrons past the cavities, the cavities resonate and emit microwave radiation. This radiation is collected up and channeled by a kind of tunnel called a waveguide into the cooking compartment (applicator) of a microwave oven.

Under the influence of the high frequency microwave radiation the dipolar molecules of the charge, such as water, oscillate back and forth. As a result, heat is produced in the charge raising its temperature. The charge contains usually a lot of water. Therefore the frequency of the microwave radiation is so selected (2.45 GHz) that its impact on water particles is maximum.

The electromagnetic waves reflect from the walls of the cooking compartment of a microwave oven. The result of this can be so called „standing waves". This means that the rate of heating the charge would depend upon its position in the heating compartment. To increase heating uniformity turntables are usually used to rotate the food.

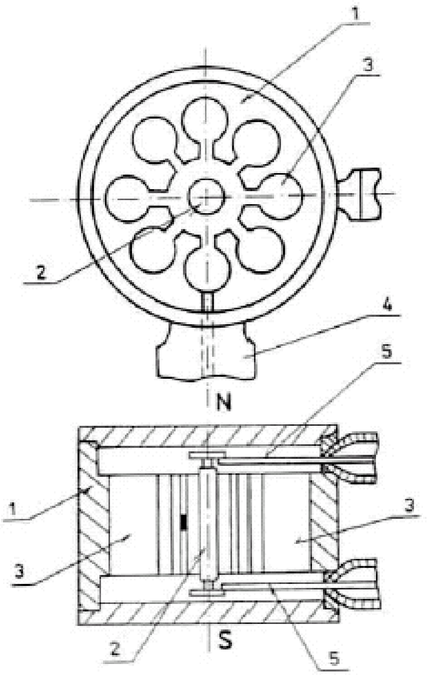

Fig.2. Structure of a magnetron [1]
1-anode; 2-termocathode (heated cathode); 3-resonant cavities; 4-microwaves output; 5-cathode filament voltage application; ***N,S***- magnet poles

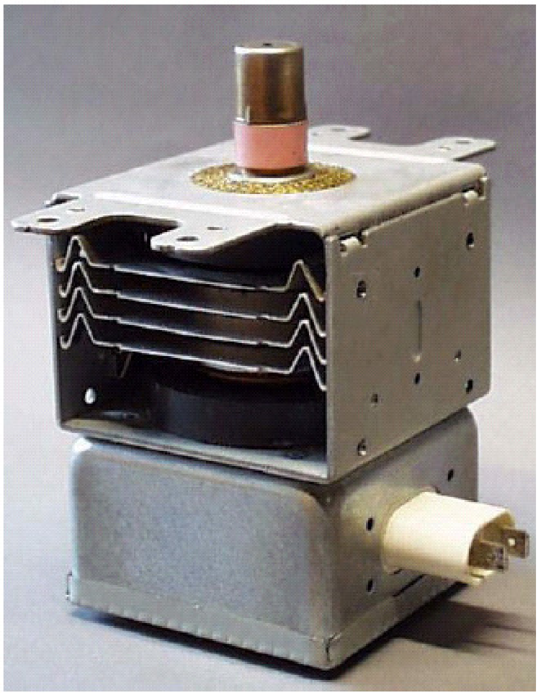

Fig.3. A magnetron [2]

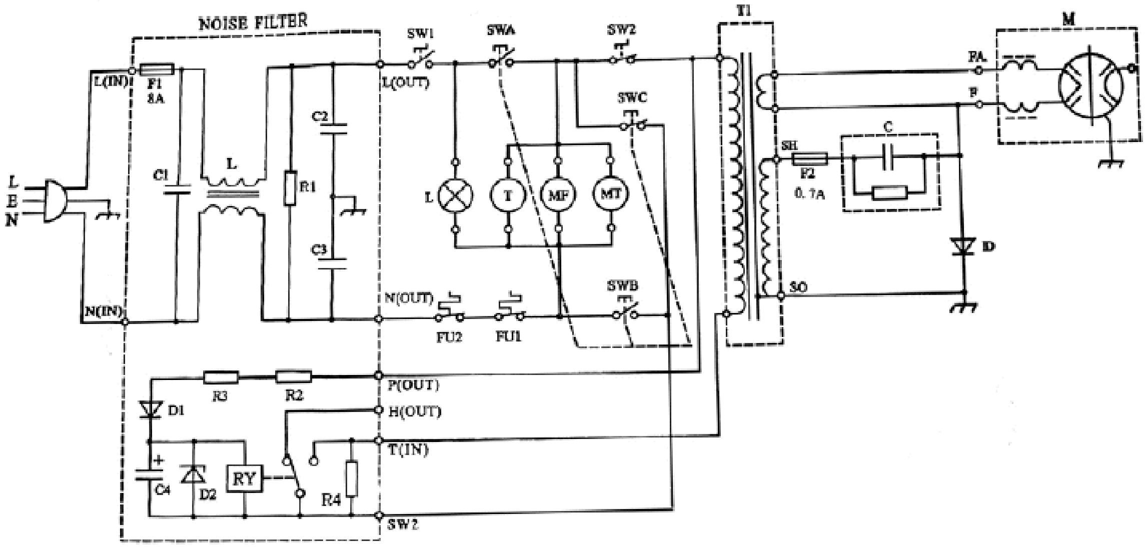

Fig. 4. An electrical circuit diagram of a microwave oven

SW1: time setting contactor; SW2: power supply switch; SWA: first contactor of closed door; SWB: second contactor of closed door; SWC: third contactor of closed door; L: heating chamber lamp; T: timer motor; MF: fan motor; MT: turntable motor (not used in our model)

2. Program of the exercise

2.1 View the inside of the microwave oven; get aquainted with the electrical circuit diagram - name the particular parts.

Note the data from the rating plate.

Supply voltage [V]	
Frequency of supply voltage *f* [Hz]	
Maximum power drawn from the mains P_1 [W]	
Maximum useful power P_2 [W]	
Range of microwave frequency *f* [MHz]	

2.2 Investigation of the microwave oven power control method

Put 3 glasses with water into the chamber. For 3 consecutive operation cycles (one cycle consists of magnetron on- anf off-time) measure magnetron on-time $\boldsymbol{t_z}$, magnetron off-time $\boldsymbol{t_w}$ and power $\boldsymbol{P_x}$ consumed by the microwave oven. Repeat the measurements for the other power settings of the oven. Calculate mean power $\boldsymbol{P_{av}}$ for each setting.

Power setting	Magnetron on		Magnetron off		Operation cycle time	Mean power
	Time t_z [s]	Power P_z [W]	Time t_w [s]	Power P_w [W]	T[s]	P_{av} [W]

2.3 Investigation of the volume power distribution in the chamber

The investigations should carried out sequentially for small load (¾ glass of water) and big load (4 glasses filled with water).

2.3.1 Small load

Measure the mass of a glass and water. Place the glass with the water (charge) in position 11 of the heating chamber. After having measured the temperature of the water (we assume that the glass has the same temperature) heat the charge with pull power for 30 s measuring the input power (power from the mains). After the heating has been completed measure the charge temperature again.

Repeat the measurements for subsequent positions of the charge in the heating chamber (see the table below) using the same glass with the same amount of water. Put the results into the table. Calculate the increases of the water and the glass temperatures as well as the powers generated in the particular positions of the chamber.

Position of the charge (1 glass with water)	Temperature		Heat amount		Power in the charge in the given position P[W]
	initial t_P[°C]	final t_k[°C]	for glass Q_1[J]	for water Q_2[J]	
11					
12					
13					
21					
22					
23					
31					
32					
33					
Mass of glass [g]		Mass of water [g]		Total mass of charge	

2.3.2 Big load

Prepare 4 glasses full of water. Measure the mass of each glass, mass of water in each glass and the initial temperature of water in each glass. Next put all the glasses with the water into the chamber. Heat the charge with full power for 120 s measuring the power drawn from the mains. Next, measure the temperature of water in each glass. Calculate the temperature increases and the powers generated in the charges situated in particular positions of the chamber.

Position of the charge:	Mass of glass [g]	Mass of water [g]	Mass of the charge [g]	Temperature		Amount of heat		Power in the charge in a given position **P** [W]
				initial t_p [°C]	final t_k [°C]	Glass Q_1 [J]	water Q_2 [J]	
11								
12								
13								
21								
22								
23								
31								
32								
33								
Power of the equipment [W]			Czas pracy [s]		Total power of the charge [W]			

2.4 Investigation of the microwave oven efficiency in function of the amount of the charge

For maximum heating power and heating time of 60 s make the measurements of heating:

A. ½ glass of water,
B. 1 glass of water,
C. 3 glasses of water,
D. 6 glasses of water,
E. 9 glasses of water

successively.

Before heating measure the mass of the glasses used, the total mass of water and the average temperature of the charge. During heating measure the input power of the oven and after the heating has been completed – measure the average temperature of the warm charge. Calculate the temperature increases and the power generated in the charge. Plot the efficiency as a function of the mass of the charge in the chamber.

Charge	Mass		Temperature		Heat		Power	Efficiency
	Glass	Water	initial	final	Glass	Water		
	m_1 [g]	m_2 [g]	t_p [°C]	t_k [°C]	Q_1 [J]	Q_2 [J]	**P** [W]	η [%]
A								
B								
C								
D								
E								

2.5 Investigation of heating various materials

For maximum heating power and heating time of 90 s put successively into the oven one glass with water, groats and dry sand. Measure the mass of the charges, their initial and final temperatures and power drawn from the mains during heating. Calculate the temperature increases and the power generated in the charge. Determine the efficiencies.

Charge	Mass		Temperature		Heat		Power	Efficiency
	Szkła	Wody	initial	final	Grass	Water		
	m_1 [g]	m_2 [g]	t_P [°C]	t_k [°C]	Q_1 [J]	Q_2 [J]	P [W]	η [%]
Water								
Groats								
Sand								

3. Constants, designations and formulae

Specific heat:

	Material			
	Water	Glass	Groats	Sand
specific heat kJ/(kg·deg)	4,19	0,67	1,85	0,7

Designations:

m - mass

c_w – specific heat

t_k – final temperature

t_p – initial temperature

Formulae:

Amount of heat $Q = m\, c_w\, (t_k - t_p)$

Power in the charge $P_w = \frac{(Q_1 + Q_2)}{t}$

Efficiency $\eta = \frac{P_w}{P_{urz}} \cdot 100[\%]$

4. Literature

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