

NONCONVENTIONAL APPLICATIONS OF MICROWAVES

URSU Mircea-Petru, GROZA Mihai-Dan, BUIDOȘ Traian
 University of Oradea, Managerial and Technological Engineering Faculty
mpursu@gmail.com , grozamd@uoradea.ro , tbuidos@yahoo.com

Keywords: microwaves, vulcanization, ceramics, pest removal, decontamination

Abstract: this paper presents basic notions about microwaves and studies of the authors about some nonconventional uses for microwaves in several domains; also, an electronic experimental device is shown, which allows microwave treatments with settable parameters, according with the required processing.

1. BASIC NOTIONS ABOUT MICROWAVES

Microwaves are electromagnetic waves with frequencies in the 300 MHz ÷ 300 GHz range (fig.1). In order to avoid the interferences with the communication systems (which is one of the many uses of microwaves), the 2450 MHz (12.25 cm) and 915 MHz (33.3 cm) ranges were allocated for industrial, scientific and medical applications (ISM).

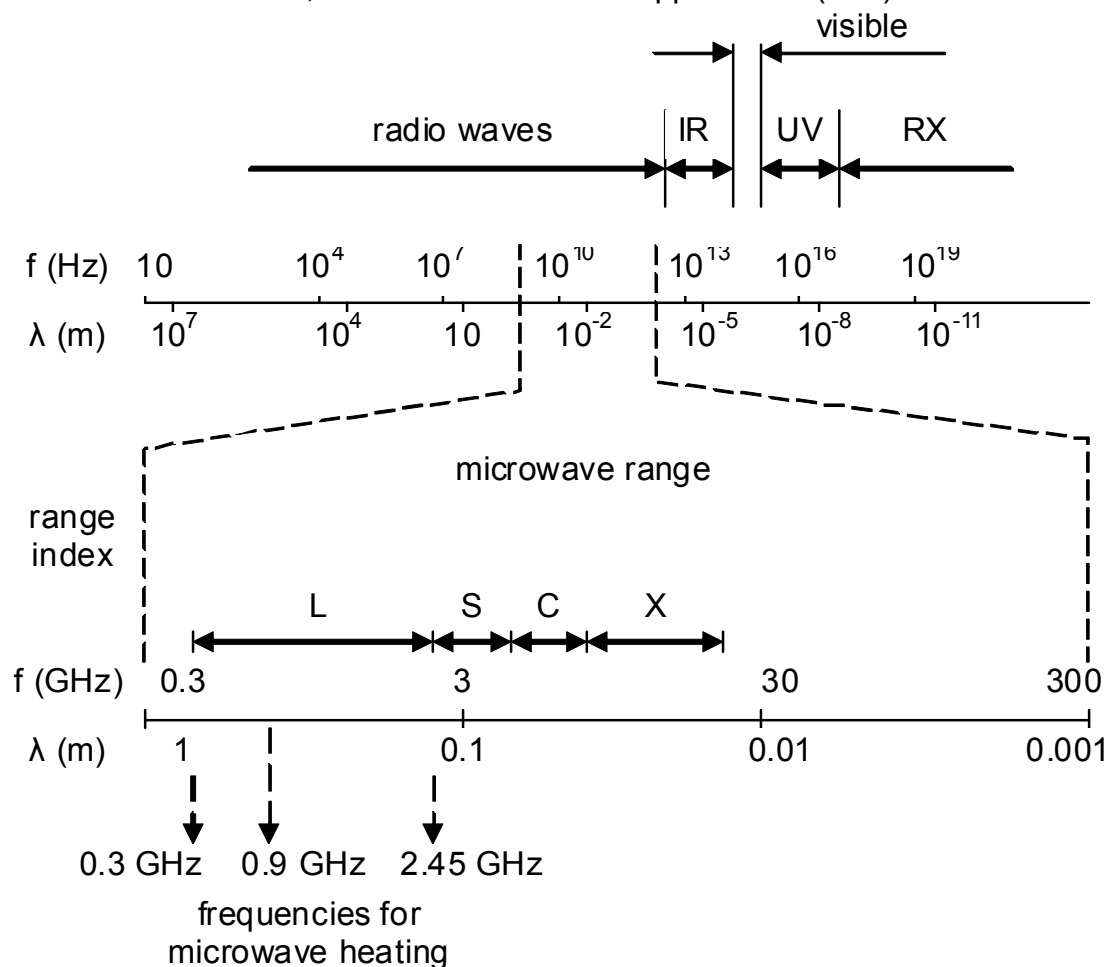


Fig.1. Microwaves, in the electromagnetic waves spectrum.

A classification of the microwave frequency ranges is shown in tab.1, which includes the meter (1 m ÷ 10 m), decimeter (0.1 m ÷ 1 m), centimeter (0.01 m ÷ 0.1 m) and millimeter waves (0.001 m ÷ 0.01 m). The S (1.55 ÷ 5.20 GHz) range is used in the microwave heating technique.

Tab.1. Classification of microwave frequency ranges.

Indicative	Frequency range [GHz]	Wavelength [cm]
P	0.225 ÷ 0.39	133.3 ÷ 76.9
L	0.30 ÷ 1.55	76.9 ÷ 19.3
S	1.55 ÷ 5.20	19.3 ÷ 5.77
X	5.20 ÷ 10.90	5.77 ÷ 2.75
K	10.90 ÷ 36.00	2.75 ÷ 0.834
Q	36.00 ÷ 46.00	0.834 ÷ 0.652
V	46.00 ÷ 56.00	0.652 ÷ 0.536
W	56.00 ÷ 100.00	0.536 ÷ 0.300

Compared to the classical thermal energy, the microwave energy features important advantages: it is non-pollutant and flexible, it acts instantaneously upon the treated object without any transmission medium, it gives important energy savings, it reacts immediately to adjustments and it ensures highly hygienic operating conditions.

Shortly, the electric polarization phenomenon is responsible for the behaviour of the dielectric material in the microwave field. Considering the polarization \mathbf{P} , the electric induction \mathbf{D} and the electrical field \mathbf{E} as complex quantities, one can notice that \mathbf{P} and \mathbf{D} are retarded from \mathbf{E} , which we call *electric viscosity*, and can distinguish the complex relative permittivity $\varepsilon_r = \varepsilon'_r - j \cdot \varepsilon''_r$ and the dielectric hysteresis loss factor:

$$\operatorname{tg} \delta_h = \frac{\varepsilon''_r}{\varepsilon'_r} \quad (1)$$

The heating of the dielectric materials in high-frequency electromagnetic field is due to the variable electric component, which produces hysteresis dielectric losses, to which the electric conduction losses are added. They all together give the total dielectric losses, characterized by the tangent of the total loss angle:

$$\operatorname{tg} \delta > \operatorname{tg} \delta_h \quad (2)$$

The conversion specific volume power P_v is the heat developed over the time unit in the volume unit of the dielectric material between the plates of a capacitor:

$$P_v = \omega \cdot \varepsilon_0 \cdot \varepsilon_r \cdot E^2 \cdot \operatorname{tg} \delta \quad (3)$$

This is an important quantity, which determines the capacitive heating rate. According to the above equation, for a given dielectric material and in identical thermal conditions, where the relative permittivity ε_r and the total loss angle δ can be considered as approximately constant, the enhancement of the heating rate is possible by increasing the frequency $\omega = 2\pi\nu$ and the applied electric field \mathbf{E} . However, the electric field cannot be increased too much because of the breakdown risks, so the frequency increase proves itself to be very useful, thus the use of microwaves is a very good option.

The electromagnetic field features a great penetration depth in the dielectric material, so the heat is rapidly and evenly produced in all its volume. The small thermal conductivity values of the transmission medium or of the treated material itself cannot impede on the heating rate, as in the case of classical conduction and convection heaters. Nowadays, the possibilities of the microwave heating of dielectric materials in vacuum are not yet fully used, and may provide new efficient techniques in electrothermia.

2. DIAGRAM OF A MICROWAVE SYSTEM

Fig.2 shows a complete system which generates, transmits and uses the microwave energy. Its components will be shortly presented as follows.

The *microwaves* are produced by the *magnetron* and are emitted in a *waveguide* segment. Because arcing may occur in the waveguide in case of mismatch or other faults, the system has got an *arc detector*, which immediately halts the system at the occurrence of

this unwanted phenomenon. Also, the magnetron itself is protected against overheating by means of a temperature sensor (thermal cut-out).

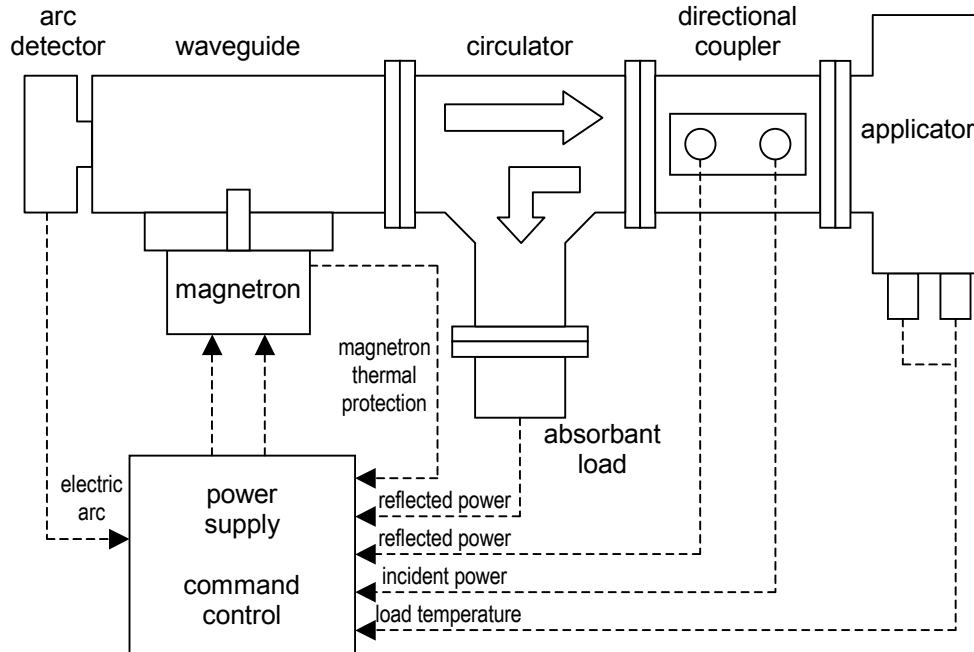


Fig.2. System for microwave supply, transmission and use.

The electromagnetic energy is sent to the applicator (resonant cavity), where the treated material is placed. Because the perfect matching between the load, applicator, waveguide and magnetron is almost impossible to attain, there always will be reflections towards the magnetron. This is why a *circulator* is inserted, which allow the microwaves to pass only form the magnetron to the load (incident power) and from the applicator to an *absorbent load* (reflected power). In order to monitor the incident and reflected power levels, a *directional coupler* with output sensors is also inserted, which separates the incident power from the reflected power and measures them both.

Inside the applicator takes place the proper microwave irradiation of the treated material. The applicators come in different dimensions and shapes, in order to provide an optimal matching of the load, an uniform or concentrated electric field, continuous or discontinuous loading etc. The applicator is fitted with temperature sensors, as thermocouples (which are used only when the magnetron is stopped or in places with minimum electric field), infrared radiation or laser pyrometers (usable during emission) etc.

The entire system is fed by means of a *power supply*, which provides the adequate voltages and currents for the magnetron and for the *command and control devices*, which allow the operator to input the parameters of the heating process and, according to the received signals, they supervise the maintaining of the functional parameters in the safety range and, in case of overheating, overloads or other faults, sets of the alarm and immediately stop the system.

This is an ideal situation, where all these elements do exist. In reality, many microwave systems are simplified, and do not contain the circulator and the directional coupler and its sensors. In this case, the mismatching and backward reflections are accepted, which implies that the power measurement errors may get quite large, so the only adequate way of measurement is the direct one, by calorimetric methods.

3. MICROWAVE APPLICATIONS

The best-known effect of microwaves is the heating of the irradiated dielectric materials. So microwaves are used more and more frequently for applications that require uniform and controlled heating of non-metallic materials. However, as seen before, the dissipated power is limited by the maximum intensity of the electrical field; if exceeded, unwanted phenomena may occur, as electric breakdown, which destroy the treated object.

The heat is generated directly inside the treated material by the applied electrical field. Also, the heat is more intense as the loss factor is larger; this is why it is necessary to know the dielectric properties of the treated materials at microwave frequencies, as well as their variations with temperature, which is also very important.

Microwaves are used in applications of food industry (drying, thawing, heating, dry honey processing, pest removal and/or sterilization of seeds etc), medicine, pharmaceutical industry etc.

3.1. Rubber Vulcanization

Shortly, the vulcanization transforms the rubber from a plastic material into an elastic one, with enhanced properties: increased elasticity over a larger temperature range, better resistance to chemical and mechanical agents, impermeability to gases, good electrical insulating qualities. The vulcanization process requires large amounts of heat, and the microwaves proved themselves to be very useful to this purpose. Thus, the profitability can be dramatically improved by enhancing the extrusion lines, by means of the adequate combination of microwave, hot air and infrared heating. These specialized devices must be fitted with accurate and automated electronic control, which can result in greatly increased productivity, improved product quality and reduced waste. Nowadays, the use of microwave heating is a well-established technique in rubber vulcanization, and each such system is adapted to the production requirements and to the the implied physical and chemical processes. Fig.3 shows a microwave rubber vulcanization unit, and fig.4 shows a microwave tunnel RC-MW 12/6.



Fig.3. Microwave rubber vulcanization system.



Fig.4. Microwave tunnel RC-MW 12/6.

3.2. Ceramics Drying

The actual classic drying processes are based on the transfer of heat into the material by means of convection and conduction. Most of the conventional dryers are convection-type and they use air as thermal agent. The conventional drying process is slow, and the temperature gradient between the material outer surface and the interior limits the water transfer rate. Furthermore, if this gradient becomes too large, very dry zones may appear which prevent the heat transfer and may cause the destruction of the treated material.

The microwave techniques are successfully used in the ceramics industry. The microwave energy is efficient for the drying and burning of bricks, tiles, porcelain, refractory bricks, sanitary objects etc. The conventional drying consumes 22% of the total energy required for the finite product, and the conventional burning consumes 64%. According to the experiments carried out so far, it is estimated that the use of microwaves will reduce the energy consumption by 50% compared to classical drying, and to 90% compared to conventional burning, as shown in tab.2, the data being provided by the Energy Ministry of Ontario, Canada.

Tab.2. Energy consumption for ceramics processing ($\times 10^6$ kWh/year).

Material	Classic drying	Microwave drying	Classic burning	Microwave burning
Bricks, tiles	56.10	28.05	198.90	19.90
Porcelain	4.53	1.76	12.48	1.25
Glazed ceramics	16.63	8.30	58.97	5.89
Tiles	1.96	0.98	6.94	0.69
Refractory bricks	10.87	5.40	38.53	3.85
Ceramics for sanitary objects	1.30	0.65	4.60	0.46

According to the preliminary results, we can express the following conclusions:

- the drying rate increases with the emitted microwave power; thus, when injecting the microwave energy into the applicator, stabilization occurs to an equilibrium point, which depends upon the initial humidity content; in this stage the humidity is eliminated, and the crack occurrence risk is avoided by carefully choosing the heating rate;
- when the final humidity content is reached, the microwave power absorption in the treated object decreases, no matter of the injected power in the applicator;
- the energy balances show a 35 – 40% reduction of the total energy consumption, compared to the classic drying processes;
- the radiant-type elements connected as applicators have provided an uniform heating of the material, a regime which eliminates the crack occurrence risk caused by pressure and temperature gradients inside the treated material;
- the calculations and execution of the radiant-type element has proven correct, and it will be used in the future microwave drying installations.

3.3. Microwave and hot air combined drying of pasta

The worldwide attempts to use microwaves to cook and dry the bakery and pastry products are known since the seventies. First, the bread baking was studied, and the experiments showed that microwaves alone can not adequately bake the bread, but only in combination with hot air which creates a crisp crust on the baked bread surface. Next, the microwave drying was applied also to other bakery and pastry products.

A combined microwave and hot air drying technology for pasta has been developed in Romania. Fig.5 shows a comparison between the actual classic technological flow for noodle drying (a) and the combined microwave and hot air technological flow (b).

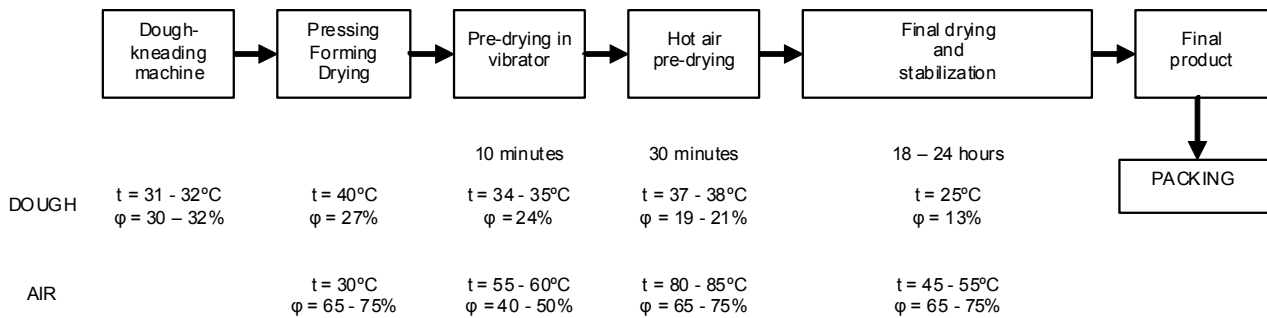


Fig.5.a. Technological flow for pasta classic drying.

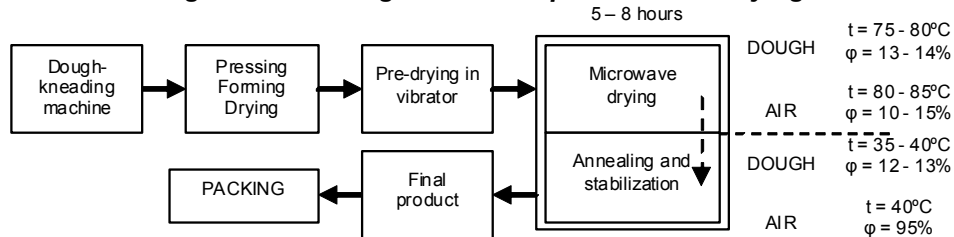


Fig.5.b. Technological flow for pasta microwave and hot air drying.

The combined microwave and hot air features three main components:

- ❖ conventional hot air pre-dryer, at the upper part;
- ❖ microwave and hot air dryer, at middle level;
- ❖ final annealer.

As shown in fig.5, the mixed microwave and hot air technological flow has the following steps:

- ✓ the product (pasta) enters the pre-dryer with an initial 30% humidity content; in less than 5 minutes the humidity decreases to 23%;
- ✓ the pasta drying continues at decreasing rate for 35 minutes, until humidity content reaches 18%;
- ✓ the product is transferred to the microwave and hot air phase, where the humidity decreases to 13% in 12 minutes; the installed power of the microwave generator represents 10% of the total energy required by the entire noodle fabrication process; the microwave power must be carefully correlated to the noodle quantity, because a level too elevated will cause bubbles, expansion and other flaws; the hot air used with microwaves has 83°C temperature, 10 ÷ 15% relative humidity and 304.8 cm³/min flow;
- ✓ the final annealing phase, without any microwave or hot air input; a 70 – 80% relative humidity is maintained to stop drying and to allow the equalization of temperature gradients and product cooling; the pasta come out from the microwave drying phase with 74°C temperature, so it is necessary to lower their output temperature, in order to avoid any thermal shocks that can cause cracks in the product; the annealing takes about one hour, and the product loses about 0.5 ÷ 1% humidity.

The use of combined microwave and hot air drying procedure for pasta, which replaces the conventional one, has the following advantages:

- *reduced space*: the microwave & hot air dryer is about 1 ÷ 2 m long and about 4 ÷ 5 m, wide, which is average compared to classic dryers;
- *reduced time*: the microwave & hot air drying time is about 3.5 times shorter then classic drying;
- *better product quality*: the microwave & hot air dried pasta feature better quality, longer validity period due to elimination if infestation danger etc.
- *lower operation costs*: the specific electric energy consumption is reduced by 25%, and the operation costs, including utilities, maintenance, hygiene etc., are reduced by 35%.

3.4. Microwave Seed Treatment

The thermal microwave treatment of seeds gives the possibility of completely destroying the pathogen fungi, both on the surface and in the interior of the seeds without affecting their germinative capacity. Unlike the conventional thermal systems, the microwave treatments feature shorter operation times, which makes them interesting. Tests have been carried out to eliminate the *Fusarium ssp.* fungus from the wheat seeds, with good results.

Currently, the seeds are protected against pathogen agents diseases by means of chemical treatments. However, the organic farms are not allowed to use such substances, so the only way they can act is by means of physical treatments. Furthermore, the reduction of soil pollution is discussed worldwide, and measures have been taken in this matter, by limiting the pollutant levels and banning of the chemical seed treatment substances. So it was necessary that science would give alternatives, and it was found that the seed thermal treatment destroys the pathogen fungi both on the surface and inside the seed. The classical convection systems are rarely used because of their weak results and many technological and economical disadvantages.

Microwave seed treatment proved itself possible and a good alternative to chemical treatment. As a physical process, the microwave heating is also adequate to treat seeds in organic production systems. The pathogen agents from seeds surface and interior will be totally destroyed without any chemical substances. The seed microwave heating can be used in continuous feeding systems; thicker seed layers can be treated by means of capacitive heating in bulk or continuous systems.

Nevertheless, before effectively building the microwave installation, it is still necessary to carry on with the research and experiments on several kinds of seeds, with different microwave treatment devices.

3.5. Book Treatment and Pest Removal

Many documentary and patrimony materials, mainly those on paper support, are damaged by biologic agents, as fungi or other microorganisms, and their destructive effects are boosted by the high humidity and acid pH. So, in order to preserve these unique precious objects, it is required to perform complex operations for restoration, conservation, decontamination, protection etc. The specialists in this field proposed several ways of action against these degradations, and the conservation and restoration laboratories of the great museums are working hard for this purpose. Practically, the restoration and reconditioning action is not aimed to attain a new cultural article, but to bring this particular object into a state that would best express its original function.

Nowadays, special chemical substances are used to eliminate pests, pH rebalancing, stopping of the destructive chemical reactions etc. These substances are specific to every particular case, and their advantages are often accompanied by disadvantages, such as toxicity for environment or human operators, difficulty of treatment, long-term secondary effects on the treated object etc.

The action of the above-mentioned chemical substances can be enhanced by the presence of microwaves, as their thermal effect produces the heating of the treated object in its whole volume.

As requested by Mr. Vasile Deac, from the Bihor County Library, we carried out an experiment in order to study the acidity neutralization treatments of paper-supported collections, by means of specialized chemical substances (magnesia, Borax solution and calcium hydroxide) combined with exposure to microwaves. Fig.6 shows an old book with pages affected by high acidity, which leads to flexibility loss, hardening and crumbling of

paper, and fig.7 the document during treatment by means of the experimental microwave device at the University of Oradea.

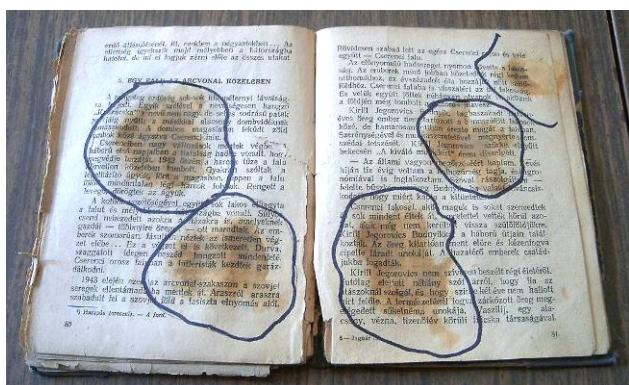


Fig.6. Old book, affected by elevated acidity.

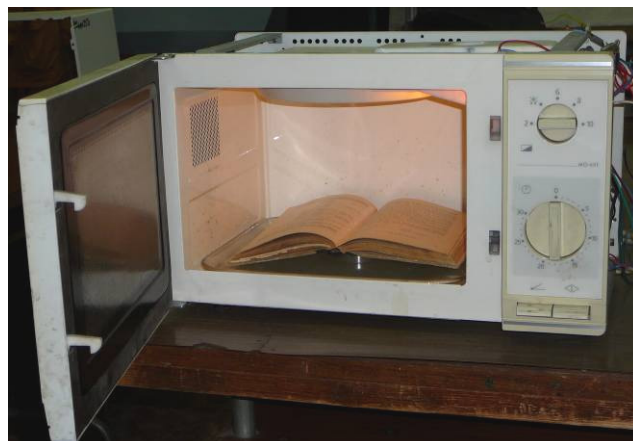


Fig.7. Old document, ready for treatment with magnesia and microwaves in the experimental microwave research installation at the University of Oradea.

In order to evaluate the influence of microwaves on the chemical treatment, we carried out the experiments and measurements as follows: document untreated and unexposed, document untreated and exposed for 60s to maximum microwave power, document treated and unexposed, document treated and exposed to maximum microwave power (350W) for 60s, 120s and 180s, The results are shown in tab.3.

Tab.3. Temperatures and pH values for an old document.

Document	Ti (°C)	Tf (°C)	ΔT (°C)	pH
untreated, unexposed	28.2	28.2	-	5.5
untreated, exposed 60s at maximum power	29.5	40.1	10.6	5.7
treated 1% magnesia solution, unexposed	29.3	29.3	-	7.4
treated 1% magnesia solution, exposed 60s at maximum power	29.4	45.1	15.7	7.8
treated 1% magnesia solution, exposed 120s at maximum power	29.7	58.2	28.5	7.9
treated 1% magnesia solution, exposed 180s at maximum power	31.2	61.5	30.3	8.0

4. EXPERIMENTAL DEVICE

Because the objects must be treated with utmost care, the microwave exposure must be carried out very attentively and only after performing tests. Also, it is recommended that the modification of the microwave power level should be made by means of time division with higher clock frequency, for uniform heating in time of the treated object. For this purpose, we used the experimental installation, designed and realized within the doctoral thesis research of Mr.Ursu. This device features accurate minute and second setting of the treatment time, power level setting in 10 steps of 10% each, as well as setting of clock frequency which drives the time division of the emitted microwave power. The block-diagram of the electronic digital settable timer is shown in fig.8, and fig.9 shows the assembled electronic command device.

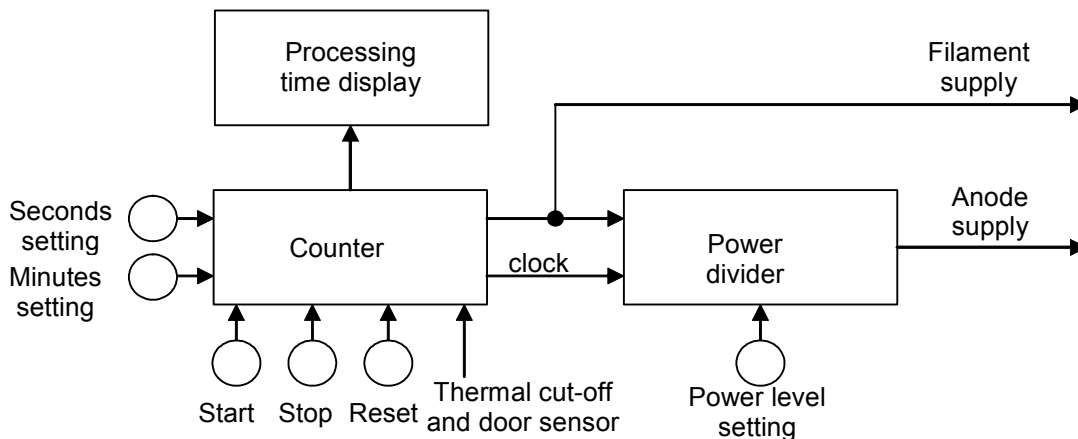


Fig.8. Block-diagram of the electronic digital timer, designed and realized.

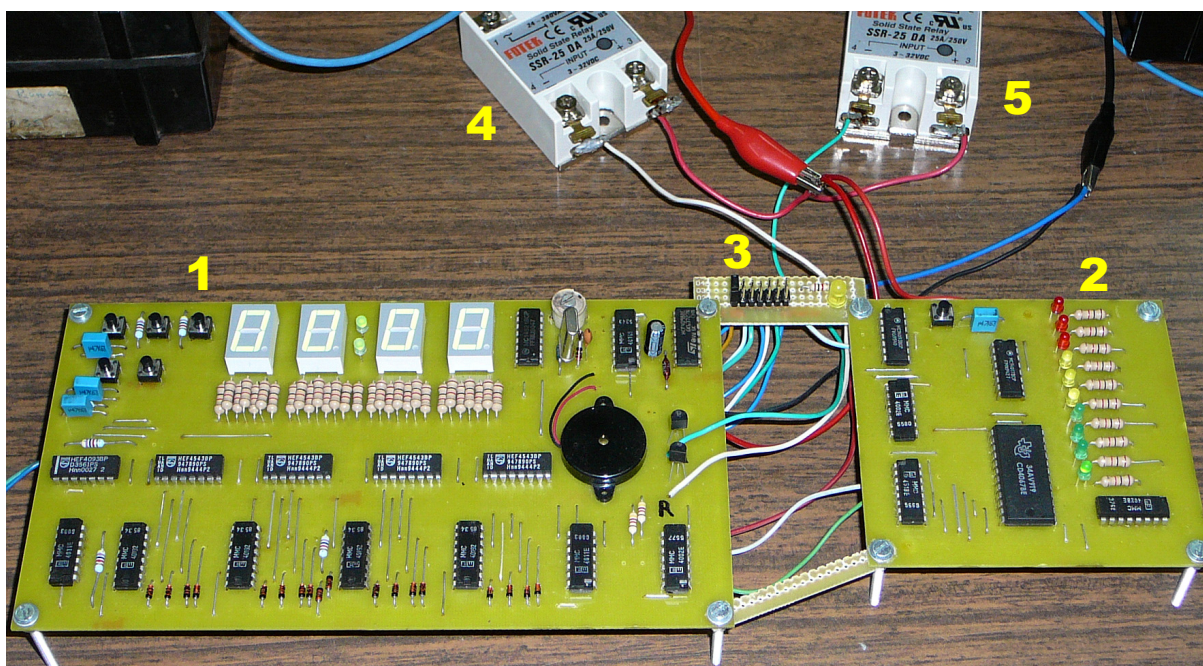


Fig.9. Electronic digital timer, designed and realized; 1 – timer and time display, 2 – time divider, 3 – clock frequency selector, 4 – static relay for filament command, 5 – static relay for anode command.

By means of the designed and realized device, the microwave installation can be accurately driven according to the parameters of the required operation. The electronic device sets the treatment time between 1 second minimum and 99 minutes and 59 seconds maximum. The power level (division factor) can be set between 10% minimum and 100% maximum, in steps of 10% each. The novelty of this device consists in the choice of the clock frequency for time division.

5. CONCLUSIONS

Microwaves are an advantageous alternative to the conventional heating systems. Due to its high efficiency, the microwave usage makes possible the rational use of primary energy sources and the short-term investment recovery, but the limited generator lifetime, the particular safety measures and the requirements of high-qualified personnel point out that microwave energy should be used with much caution. Special attention must be paid to the general and particular safety standards.

When starting up the microwave installation, as well as during use, it is required that measurements are carried out in order to detect any microwave leakage that may occur because of access systems inadequate tightness and of the improper operating conditions (overload, no-load, overheat etc).

REFERENCES

- [1] Deac A.V., Conservarea colecțiilor infodocumentare din biblioteci, muzee și arhive; simptomatologia complexului de degradare multifactorial, Biblioteca Județeană "Gheorghe Șincai", Laboratorul de Conservare, editat CPPC, Bihor, Oradea, 2008;
- [2] Roman Șt., **Ursu M.P.**, *Adjustable power level microwave generator (10 ÷ 600 W / 2.45 GHz), equipped with low-cost magnetrons, for diathermical purposes*, A 5-a Conferință Internațională de Inginerie a Sistemelor Moderne în Electrotehnică EMES 1999, ISSN-1223-2016, 1999;
- [3] Roman Șt., **Ursu M.P.**, *Reglarea puterii medii și temporizarea unui magnetron cu componente indigene*, Sesiunea de comunicări a Universității din Oradea 1996;
- [4] Rulea G., Tehnica microundelor, Editura Didactică și Pedagogică București, 1981;
- [5] **Ursu M.P.**, *Cercetări privind creșterea randamentului energetic în cuptoarele cu microunde cu puteri variind între 100 – 1000W; contribuții personale la realizarea instalației-pilot*, teză de doctorat, Universitatea din Oradea, 2009;
- [6] **Ursu M.P.**, *Adjusting The Microwave Power Of A Given Magnetron*, International Scientific Conference TMCR-2005, Iași-Chișinău, pp.417÷420, ISBN 9975-9875-7-5, 2005;
- [7] **Ursu M.P.**, Budoș T., Maghiar T., *Microwave Power And Leakage Measurement*, Sesiunea anuală de comunicări IMT2007, Oradea, 2007;
- [8] Zheng-Wei Cui, Li-Juan Sun, Wei Chen and Da-Wen Sun, *Preparation of dry honey by microwave–vacuum drying*, Journal of Food Processing, volume 84, issue 4, february 2008, pages 582-590 (www.sciencedirect.com);
- [9] Research project Tehnologii cu microunde utilizate pentru îmbunătățirea calității semințelor agricole depozitate, PNCDI 2007-2010 – PN-II PARTENERIATE Nr.51-082/24.09.2007;
- [10] http://www.alibaba.com/product/in103443602-103566827-0/Microwave_Rubber_Vulcanization.html ;
- [11] http://www.rubicon-halle.de/eng/vulcanization_lines/microwave_vulcanization_line.htm
- [12] https://www.pueschner.com/downloads/publications/article_mw-vacuum-drying_hk2007-short_pap.pdf