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Quantum Microwave – Compost Interaction Model

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Abstract

The well-known analogy between quantum mechanics and optics is used to study the interaction between electromagnetic field and compost in order to control the compost sterilization with microwave. Here we establish an experimental model for compost in relation to microwaves and present the conclusions of this study. The measurements of the compost imaginary permittivity, responsible for electromagnetic energy absorption are presented.

Keywords: *compost, water, microwave, quantum potential, sterilization*

Introduction

Compost is a natural product resulted from plant decomposition in presence of oxygen. More specifically, the decomposition is caused by aerobic germs, bacteria and fungi, which results in the transformation of plant scraps in soil nutritious.

Compost is used as a germination support of various plants. For this purpose it may be mixed in different proportions, depending on the type of plants to be grown, with soil, sand, gravel, and minerals. The compost can be considered a binary mixture of minced vegetable scraps in various stages of decomposition and water. Water concentration in compost can vary within very large limits. This influences the evaluation of refractive index of mixture and consequently it is one of the parameters that must be considered in the analysis below.

Due to special nutritional qualities, the compost is a soil particularly favorable development of weeds, unwanted by the growers, due to increasing costs of production. Also this soil may present a high fitototoxicity [1, 5]. To prevent these is very important that before the compost is used it should be sterilized, and so secondary vegetation that could develop around the useful plants is strongly reduced.

The sterilization method studied in this paper, consists in heating the water – compos mixture with microwave, (mainly through water heating) to boiling point. The boiling temperature can be increased by closing the mixture in a sealed enclosure in which the internal pressure of the air-water vapor mixture can be controlled.

Quantum Model - Theory and Experiment

Theoretical Model

Let us consider a section where water is mixed with vegetables with refractive index n_{veg} different than that of water n_{apa}

$$n_{veg} \neq n_{apa}. \quad (1)$$

To simplify the analysis we consider three regions of composting (Figure 1), corresponding to a sequence of alternative water, vegetable material, and again water.

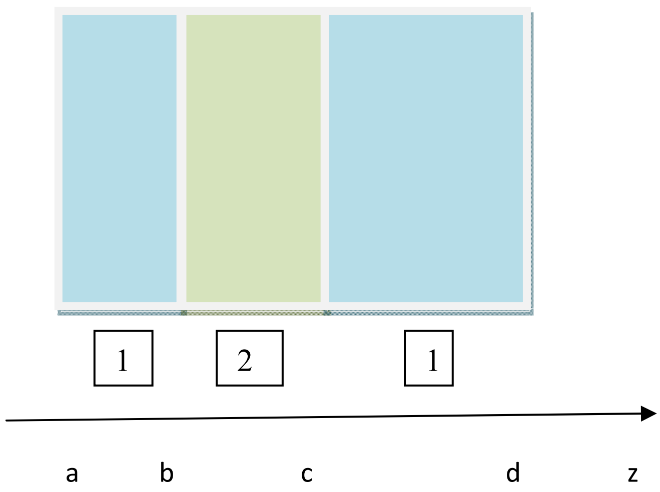

Fig. 1. A sequence of alternate layers of water (1) and vegetable products (2). The direction of propagation of microwave signal is Oz

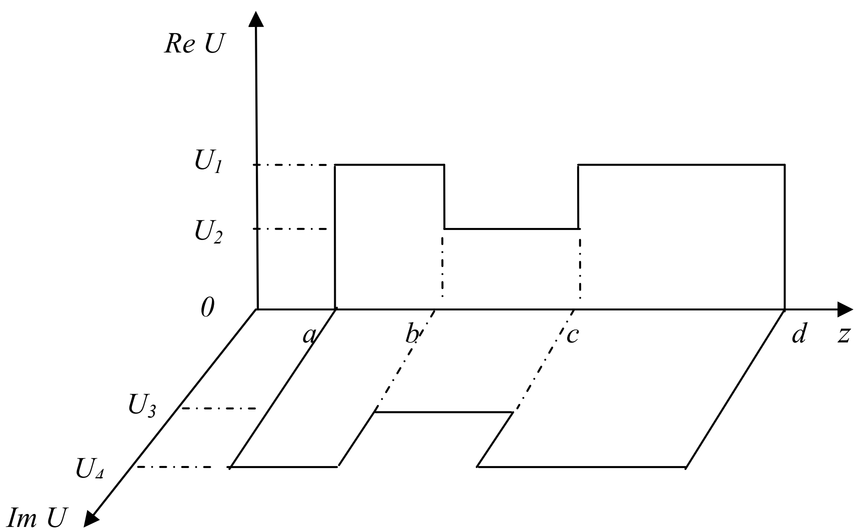

Fig. 2. The quantum potential corresponding to the sequence of water/plant dielectrics from Fig.1

In Figure 2 we assumed that the real potential U_2 as the imaginary U_3 of vegetables are smaller than those of water respectively U_1 and U_4 [6].

$$U_2 = Re\left\{i\hbar\omega\sqrt{n_{veg}^2 - 1}\right\} \text{ and } U_3 = Im\left\{i\hbar\omega\sqrt{n_{veg}^2 - 1}\right\} \quad (2)$$

$$U_1 = Re\left\{i\hbar\omega\sqrt{n_{apa}^2 - 1}\right\} \text{ and } U_4 = Im\left\{i\hbar\omega\sqrt{n_{veg}^2 - 1}\right\} \quad (3)$$

An idealized model for the water-plant mixture is represented in Figure 3. An incident electromagnetic signal on such an environment will degrade into a reflected signal and a transmitted one. In case of compost sterilization we want that the reflected signal to be minimal. Transmitted signal must undergo a maximum attenuation, meaning a maximum transfer of energy from microwave to water-vegetable mixture.

The reaction to a microwave signal of such a environment depends largely on microwave frequency and, importantly, it is independent of the behavior of water to the electromagnetic signal. Thus for the two frequency domains used in our measurements, 3-10 GHz and 50-115 GHz the interactions are completely different. In the first case, the wavelength of the electromagnetic signal is ranged between 3 - 10 cm, and in the second between 2.6 - 6 mm.

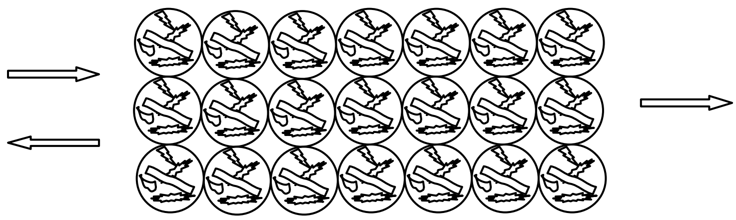

Fig. 3. An idealized periodic array of spherical aggregates

In the first case, the wavelength of the signal is larger than the size of an individual obstacle in the mixture, and so the mixture is "seen" as a body with homogeneous structure. We can say that we are in the area of large wavelengths relative to the medium. In the second case, the wavelength is comparable or smaller than the size of vegetables mixed with water and thus, in case of a homogenous mixture of compost, we can consider that it is perceived by the microwave signal as a periodic structure. We can say that we are in the small wavelengths area relative to the body structure.

The Case of Large Wavelengths

Incident microwave signal amplitude *I* is decomposed in both a reflected signal of amplitude *R* and a transmitted one of amplitude *T*. Since we always report the incident signal, we consider his magnitude equal to unity. *A* and *B* are the wave amplitudes inside the compost.

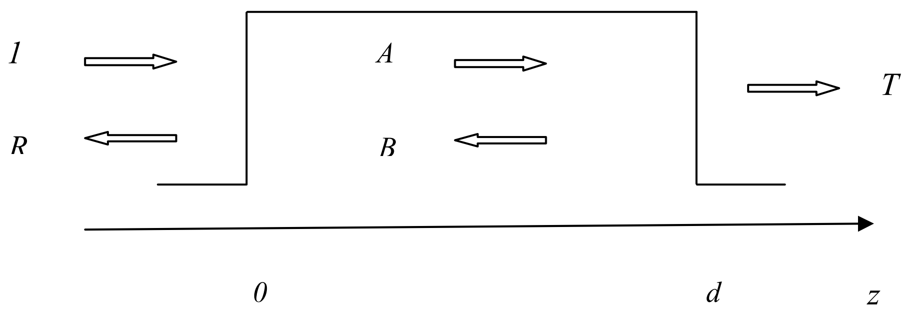

Fig. 4. The case of large wavelengths
Potential and waves in a block of compost, considered as an homogeneous dielectric

The wave numbers for the three areas (see Figure 4) are:

$$z < 0 \qquad k_1 = \frac{E}{\hbar c}$$
$$0 < z < d \qquad k_2 = \frac{1}{\hbar c}\sqrt{E^2 - U^2} \tag{4}$$
$$z > d \qquad k_3 = k_1 = \frac{E}{\hbar c}$$

where E is the energy of microwave photons, and potential U the average potential from equations (2) and (3). As we can see they have the real and the imaginary parts. This makes the average potential U to have a real and an imaginary component, as well. Finally, so does the wave number. Imaginary component of k_2 will generate a real exponential in the wave function, responsible for the signal absorption and for microwave compost heating.

$$k_2 = k + i\mu. \tag{5}$$

Wave functions describing these signals [6] are listed below:

$$\begin{array}{ll} z < 0 & \psi_1 = e^{ik_1 z} + Re^{-ik_1 z} \\ 0 < z < d & \psi_2 = Ae^{ikz}e^{-\mu z} + Be^{-ikz}e^{\mu z} \\ z > d & \psi_3 = Te^{ik_1 z} \end{array} \quad . \tag{6}$$

These functions must be continuous at points of discontinuity of potential associated with dielectric (Figure 4). The discontinuities are at the air/dielectric interface $z = 0$ and signal emerge point at interface dielectric/air $z = d$. In these points the following continuity conditions must be satisfied:

$$z = d \qquad \psi_2|_{z=d} = \psi_3|_{z=d} \;\; si \;\; \psi_2'|_{z=d} = \psi_3'|_{z=d}, \tag{7}$$
$$z = 0 \qquad \psi_1|_{z=0} = \psi_2|_{z=0} \;\; si \;\; \psi_1'|_{z=0} = \psi_2'|_{z=0} \, . \tag{8}$$

These conditions are actually a system of equations whose solutions are amplitudes R and T and absorption coefficient μ, which can be assessed when the potential, namely the refractive indices of water and compost, are known.

The Small Wavelengths Case

As stated above, in this case microwave signal meets a structure that can be considered as periodic. In such a case allowed and prohibited energy bands occur, or allowed and prohibited microwave frequencies (Figure 5).

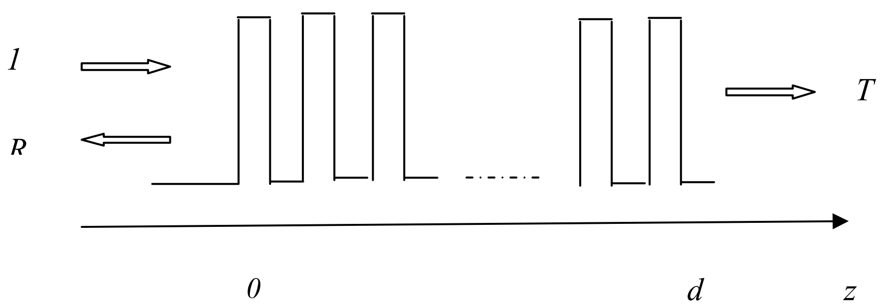

Fig. 5. The case of smallar wavelengths.
Potential and waves in a block of compost, considered as a periodic structure

Analysis of such interactions is already something very complicated [3] even the number of periods is small, which is not our case. We believe therefore that an experimental analysis of microwave signal behavior relative to compost is preferred to a theoretical one.

The Analyzing Method

Mainly two parameters affect the microwave absorption in compost:

a) The change in water concentration, during the sterilization process, and the concurrent change of the real and imaginary component of the electrical average permittivity of mixture as described in [2];
b) The temperature of compost and water embedded in it, which also change during sterilization process.

There are many methods by which the dielectric constant of a medium can be determined using microwaves. A complete analysis of a dielectric implies the evaluation of the loss tangent, i.e. to establish the real and the imaginary component of permittivity, the second one being responsible for the dielectric loss and dielectric heating.

The technique used was to measure the so-called S parameters of the dielectric sample. “S” symbol comes from the term "scattering" introduced for the first time in 1965 [4]. The studied dielectric, water in our case, was introduced into a microwave resonator. The resonance frequency of the resonator was modified by the presence of the water [7]. S parameter measurements were performed successively with emptied, cleaned resonator and then refilled with water. Difference between the two situations allowed assessment of the dielectric parameters with minimum error.

The Equipment

The measurements were made with a vector network analyzer "VectorStar Broadband NPV - ME7828A" whose working frequency covers both analyzed frequency domain, the first 3-10 GHz and the second 50 - 115 GHz.

Calibration was done with the calibration device provided by the manufacturer "36585 Series Precision AutoCal”. We also used for mechanical calibration the kits model 3655E-1 and 3655V-1, provided by manufacturer as well.

It was estimated that the measurement error made in this way has not exceeded 3% on all areas of analyzed frequencies.

Experimental Results

Next there are presented the imaginary part ε_2 of average compost electric permittivity, responsible for microwave absorption, as defined in [2] and measured on a sample of compost with water concentration of 27% (Figure 6). Microwave absorption was studied at various frequencies and temperatures. We mention that during the measurements the concentration of water was constantly checked and brought to the initial values each time a correction was necessary.

The water used in the experiment came from the city water network.

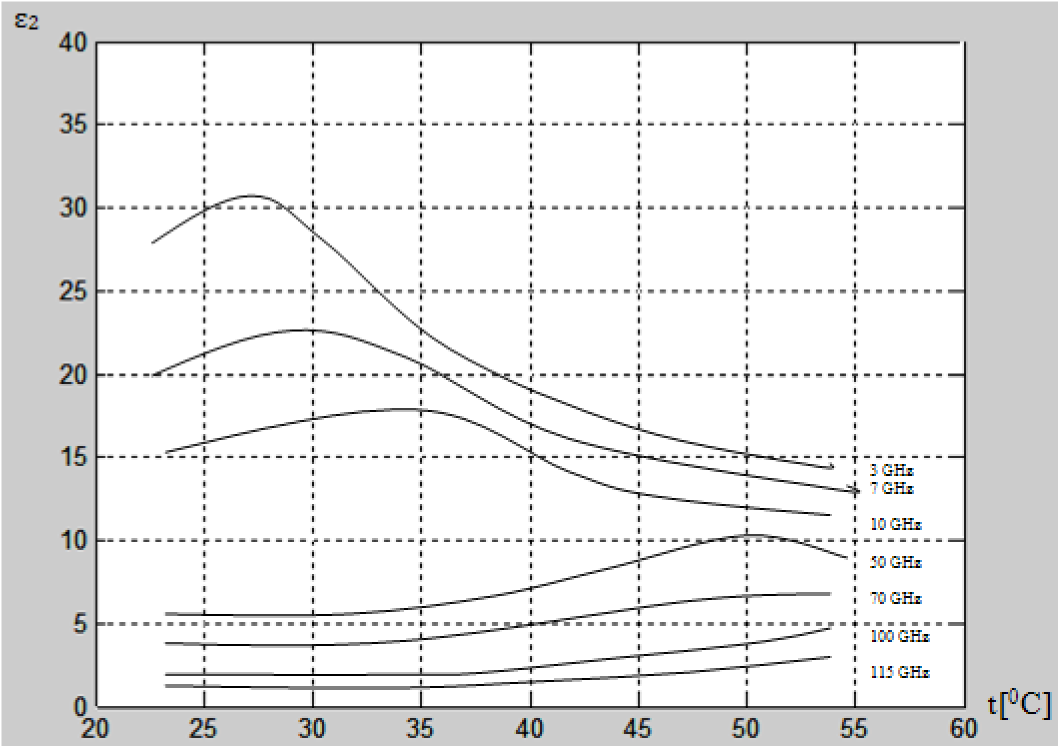

Fig. 6. Imaginary part of average electric permittivity ε_2 of compost depending on temperature. Determinations made for temperatures between 23 – 54^{0}C

Conclusions

Note that the maximum of absorption is more pronounced at lower frequencies and also that a movement towards higher temperatures with increasing frequency of microwave signal can be observed. Also one can see diminishing the value of parameter ε_2 with frequency. This shows the correctness of using different models for our dielectric and high-frequency low frequencies.

Thus, with the increasing of frequency appear frequency allowed strips in dielectric, i.e. it becomes transparent to the microwave signal and the energy absorbed - so the losses in the dielectric - will diminish.

In fact, other authors show that low frequencies in the microwave sterilization processes are used. Thus, the authors have used frequency of 2.45 GHz and found that is enough to annihilate, in 11 min of exposure, 1.3 billion Bacillus subtilis in 5 ml of distilled water [8].

In the process of sterilization, the water concentration in the mixture will decrease, which may require a preliminary supplementation of water to the mixture, so that the final water concentration corresponds to the desired one.

To this purpose it is necessary to follow a number of essential steps in order to obtain a sterile product with an optimal concentration of water.

Thus, initial concentration of water must be determined from the compost that is to be sterilized. This parameter will be compared with the final concentration of water requested by the user. Results of the analysis may be fixed during microwave exposure of compost. However, this duration cannot be less than the time required to a safe sterilizing the mixture. Otherwise it will proceed before sterilization to a deliberate increase of the amount of water in the mixture.

The steps outlined above lead us to the conclusion that we need to know with sufficient accuracy the parameters of interaction between microwave field and compost – water mix.

The main parameters involved in the process of sterilization are: microwave power, microwave frequency, the initial and final concentration of water in the mixture, the temperature at which the sterilization should took place, the time of mixture exposure to microwave field, and how the coefficient of microwave absorption varies with decreasing water concentration during the sterilization.

The mere enumeration of these parameters tells us the complexity of the problem that will be studied in the next paper. It becomes self-evident that the study of interaction between microwaves and water–compost mix is the key to the successfull solving of the problem of microwave compost sterilization.

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Model cuantic de interacţie dintre microunde şi compost

Rezumat

Binecunoscuta analogie dintre mecanica cuantică şi optică este utilizată pentru descrierea interacţiei dintre câmpul electromagnetic şi compost în scopul de a putea controla sterilizarea acestuia cu microunde. Se stabileşte un model experimental pentru compost relativ la interacţia acestuia cu microundele. Se prezintă rezultatele măsuratorilor componentei imaginare a permitivităţii electrice a compostului, responsabilă cu absorbţia energiei electromagnetice.