Evaluation and Designation of Making Agricultural Waste Risk-Free System by Microwaves

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Abstract: Nowadays, according to growing trend of agricultural production and consequently, increase of agricultural waste and their negative effects on environment, having a risk-free system gets a vital role in agriculture. Based on evaluations of WHO reports, approximately three million poisoning had occurred all over the world due to using overdose of pesticides in order to making risk-free waste. On the other hand, use of pesticides and chemical fertilizers in agricultural areas of Iran, have increased cancer growth in these areas. Because of importance of this issue, designation of waste risk-free systems with high efficiency became one of the main interests of researchers. In this study, true dimensions of waste risk-free systems were investigated. Besides, designation of micro-wave frequency producing systems with 2.45 frequencies and power of 1.3 KW were analyzed. Results of experiments on wastes after radiation showed the loss of 80% of germs and their reduction and reduction of waste volume in 20 minutes.

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1. Introduction:

Growth of agriculture industry and producing various agricultural products, have made increase the agricultural waste and have made millions tons of agricultural waste annually. As agricultural waste given the proper environment for growth and spread of viruses, bacteria, pests and diseases in human environments, it makes over use of pesticides in all over the world. Scientist researches shows that this kind of over use of pesticides for making risk-free waste, it would increase total cancer disease among humans. Importance of this issue is under focus of environmental and agricultural researchers. Many researches have been done for elimination of agricultural wastes until now which the newest one of them is autoclave systems. In this system, vapor pressure has been used to eliminate all pests and bacteria among wastes. Studies showed that many bacteria has wall over themselves which prevent from collisions hot steam pressure to viruses or closed chambers prevent vapor passing, so would lower the percentage of disinfection. But microwave waves could impress molecules due to their low size. Waves after collision to the molecules, would alter the polarity of molecules and after this incidence, a lot of energy would emitted because of changes in friction between them which make elimination all viruses and bacteria.

One of the methods commonly used today, also for treating municipal solid waste (EDANA, 2001), is incineration. Even if incineration eliminates the possible infectious micro organisms and substantially reduces the weight and the volume of the waste, it has many drawbacks, as gas emission, smoke and ash production, which modifies the soil texture at the disposal site (Tanakaet al., 2005), and last but not least—increasing public opposition (Salkin, 2003). Although incineration, as a waste treatment method, has the theoretical advantage of heat recovery, it is not the case of disposable diapers. It is well-known that waste processing, in order to produce energy, represents an option only if its latent heat of burning is greater than 11 MJ/kg. In the case of agricultural disposable diapers this latent heat value is about 7.5 MJ/kg (FIML, 2001), so the only alternative for this kind of waste is definitive neutralization (*i.e.* sanitation and destruction with no energy yielding). For waste neutralization, one positive, alternative treatment to incineration is microwaving (Diaz et al., 2005). This clean method is already used in waste management for two decades by now and its advantages, including costs, energy savings, ease of control, improved safety over incineration are evident (Jones et al., 2002; Lee et al., 2004; WPA, 2003). A proof of microwave heating effectiveness is given by its successful use for the paralysis of various materials and residues, with net superior results to those obtained with the conventional approach, *i.e.* an electrically heated furnace (El harfi et al., 2000; Ludlow-Palafox and Chase, 2001; Mendez et al., 2004; Miura et al., 2000).

2. Background Information on Microwaves

Microwaves are electromagnetic waves with the wavelength between 1mm and 30 cm, in the electromagnetic spectrum being situated between the infrared radiation (having wavelengths smaller than 1 mm) and ultrahigh frequency waves used for television broadcasting (with wavelengths above 30 cm). Their corresponding frequencies are between 1 GHz (*i.e.* 109 cycles per second) and 300 GHz. These waves are produced by several types of microwave generators: magnetrons, klystrons and gyrotrons. Among them, the most common are magnetrons, the last two generators being used for generating ultrahigh frequency microwaves. In the commercial ovens the microwaves are produced by magnetrons and have the frequency of 2.45 GHz, the corresponding free space wavelength being 12.25 cm. The microwaves produced by the generator are guided trough a metallic channel (called "waveguide", which reflects the microwaves like a mirror does with light) towards the reactor cavity, where the processing sample is placed. Microwaves have the quality of penetrating the sample material and, in certain conditions, produce its heating. Before discussing the heating conditions, it must be stressed here that, unlike the conventional heating process, where the heat is transferred to the outer surface of the material and from there to its core, in the case of microwaves the heating process develops in the entire volume of the sample. Basically, the microwaves' action on materials is as follows: exposing the sample to their action, the dipolar molecules (or ions) from the sample structure start to vibrate. During their forth and back movement inside the sample, these molecules encounter frictional forces, which tend to slow them down. It is this friction phenomenon that produces heat. If the amount of heat produced as a consequence of microwaves' action surpasses certain values, then microwaves can safely disinfect a large variety of materials, by killing microorganisms, or even can burn the sample. If an ion (*e.g.* from a crystalline lattice of a metal or a frozen defect in a solid sample) cannot move from its equilibrium position, or if it is moving easily, then microwaves cannot produce heat. In the first case it is said that microwaves cannot penetrate the material, or, equivalently, that the material reflects microwaves. This is the case of metals. In the second case, of easily moving ions in the microwaves' field, it is said that microwaves have a very high penetration depth or that the material does not couple well with microwaves' field, or even that it is transparent to microwaves. To this class of materials belong the electrically insulating materials, like Teflon® (PTFE or polytetrafluoroethylene), quartz glass, pure alumina etc. In general, insulator–microwave coupling increases when the temperature gets higher. A good coupling with microwaves is encountered at semiconductors or at a large variety of materials containing water, because water molecules are dipolar and they "sense" very well the microwaves' field. This is the reason of heating food in microwave ovens or in using water or water steam in microwave devices used in waste management. In this research, designation and investigation of risk-free systems for agricultural wastes has been analyzed by microwave waves.

3. Materials and Methods:

a) Magnetron Lamp

In this research, in order to producing high power microwave waves nearly 1.5 KW and 2.45 GHz frequency, magnetron lamp which made by Philips company had been used (Figure 1-a). This lamp could convert electrical current by its internal accelerator to the 2.45 GHz frequency, if its input power reaches to 4.5 Kv. As it is obvious in figure 1, this lamp has power input and antenna output which spread produced waves in space through it. In order to supply input power to the lamp which is a great voltage, multiplier circuits were used. First, power of city which is 220 V converted to 220 V by using a transformer. Then this voltage was converted to 4.4 KW through doubling circuit (Figure 1-b). In order to continuous emission on the waves, a high voltage diode was used in the circuit to include all semi-range voltage.

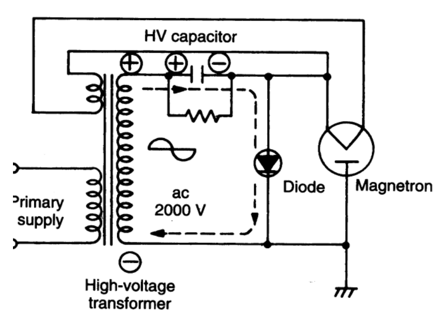

Figure 1: a) Magnetron Structure

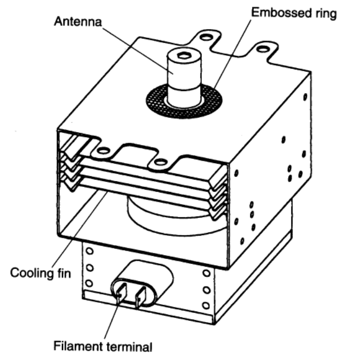

Fig. 1: b) High Voltage Circuit for Magnetron Setup

b) Metal Cavity

The experimental device is basically a microwave cavity reactor operating at atmospheric pressure. A photograph of the reactor in its present stage is presented in Figure 2. In order to exposing of wastes to all emissions and collision of waves to all point of them to increase their efficiency, a metal cavity system was constructed. Based on this reality that waves would not pass into metal objects, a body made of metal was constructed and also for better isolation of cavity, all joints and angles were covered with a foil sheet of aluminum. In order to prevent interference, internal body is covered by ceramic material. Perforated metal net was used in the compartment door in order to inside of chamber could be seen. According to the wavelength of the microwave which is 3 cm, holes' diameters should not be more than 3 cm, because in otherwise, waves would penetrate outside. In magnetron section, a filter was placed that only waves emitted into the chamber and prevent back waves to the lamp's antenna. The dimensions of the apparatus were constructed based on wavelength and 30 liter volume of wastes in 50×60×120 cm. in order to contact of all materials with waves in the floor of apparatus, a screen with rotary engine was placed in order to with its slow rotation, all parts of it became irradiated.


Figure 2: Metal Cavity of Apparatus

In the cavity, a sensor for evaluation of temperature of wastes was used in order to their temperature analyzed in the experiments.

c) Wastes:

30 liter of vegetable and fruits wastes and also more than 30 liters of other waste materials which had remained for long time in the regular environment in Urmia County had been analyzed. All waste material were remained in open areas in order to their microbial properties do not change. In order to investigation, abovementioned apparatus were analyzed in 3 various powers and different times (30, 60 and 120) and their data were analyzed.

4. Results and Discussion:

a) Thermal Properties of the Cavity Wall Materials

Prior to the device construction, the thermal properties of some materials selected as potential candidates for building the walls of the experimental reactor were studied by microwave heating. Thus, the heat insulator material and two different types of ceramics were heated in a commercial microwave oven, operated at 600W injected power. The results (Fig. 3) show that the tested materials have two different heating domains, reflecting the modification of their specific heat. These two domains are delimited in Fig. 3.

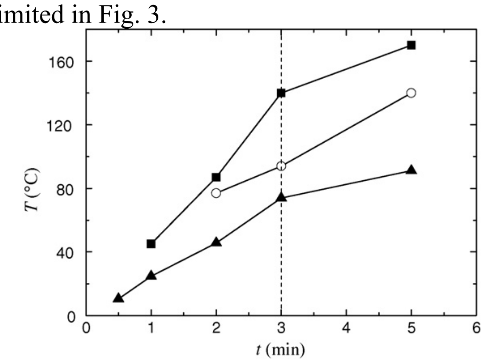

Figure 3: Heat Characteristics (temperature T *vs.* heating time t) for Two Different Ceramics ("ceramics 1"; "ceramics 2") and a Heat Insulator Material obtained for a Microwave Injected Power of 0.6 KW in a Commercial Microwaves Oven.

By a vertical dashed line located at the same time moment, t = 3 min, for all the tested materials. Specifically, the relationship between the absorbed power P and the temperature increase rate dT/dt is given by the well known equation from thermodynamics:

$P = mc\, \mathrm{d}T\, \mathrm{d}t$

Where c is the specific heat of the heated material and m is its mass. Admitting that the absorbed power is the same for all the tested materials, knowing that all of them have the same mass, and taking into account the experimental data from Fig. 3, it follows that the slope of the represented graphs (*i.e.* d*T*/d*t*) is inversely proportional to the specific heat *c*. So, up to a threshold temperature, approached, as said above, in all cases after 3 min of microwave heating, the specific heat of the analyzed materials proved to be the same with that at room temperature. Above this threshold, their thermal properties change abruptly, as a result of a structural phase transition (*i.e.* the specific heat changes its value). In the case of the heat insulator [main components: SiO_2 (50%) and Al2O3 (28%)], the specific heat increases 3.5 times, in that of the "ceramics 1" [main components: SiC (30%), black mud (40%), Petalite (15%) and Gayrome clay (15%)] the specific heat increase is just 1.5 times, while in the case of "ceramics 2" [main components: SiC (89.8%) and SiO_2 (8.9%)] the specific heat decreases. Among all tested materials, as heat insulator was chosen the one having the smallest temperature increase rate (*i.e.* the highest specific heat). Because "ceramics 2" was the best thermal conductor, its specific heat decreasing above the threshold, it was eliminated in the end and "ceramics 1" was used for building the experimental device.

b) The Microwave Field inside the Reactor

The relatively big characteristic dimension of the processing chamber can induce the idea that the cavity is operating in a non-resonant, multimode regime (*i.e.* the microwave power is "spread" quasi-uniformly throughout the cavity volume, allowing in this way a more uniform heating of the waste material). On the other hand, because the characteristic dimension *L* of the cavity is an integer multiple of the free space wavelength λ of the microwave radiation (L/λ = 8), it means that the reactor should operate in the resonant regime, leading to the formation of modal patterns in the electromagnetic field of the microwaves (*i.e.* a spatial pattern of the microwave power density field with alternating maxima and minima). In order to decide the operation regime of the device, a fluorescent lamp (denoted by "4" in Fig. 4), with a metallic inlet tube, mounted on the aperture of a ceramics plate (labeled by "3" in Fig. 4), was used. The brightness checking was performed along the horizontal axis of the lateral waveguides, the measurements being made when just the left microwave generator was working. The experiment was carried out at room temperature, with the door opened and a plane metallic mesh grid (with square holes of 3 mm ×3 mm) closing the cavity. This kind of mesh is shielding the microwave field, not allowing the electromagnetic radiation to propagate outside the cavity. The specific procedure consisted in the gradual increase of the injected power until the lamp lighted.

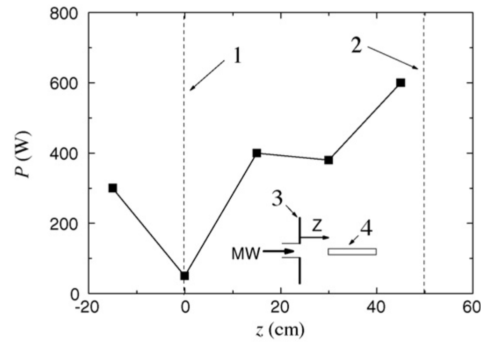

Figure 4: Microwave Field inside the Reactor (expressed by the representation of the microwave power *P* as a function of distance *z* measured from the left wall of the cavity) with one working microwave generator (the left one).
(1) Outlet of the microwave waveguide (the entrance in the cavity);
(2) Center of the cavity;
(3) Ceramics plate bordering the metallic channel used for brightness measurements; (4) fluorescent lamp. The horizontal arrow denoted by *z* indicates the sense of *z* increasing.

If the cavity was operating in a non-resonant mode, for example, the lamp would light at the same microwave injected power, excepting the inherent fluctuations, in all the checked points inside the cavity. The experimental results, presented in Fig. 4, show that the needed microwave injected power *P* at which the lamp is lighting increases over 10 times, going from the left wall (z = 0 cm, where P = 50W) towards the center of the cavity (z = 50 cm, where P = 600 W). These measurements prove that the cavity does not allow for a uniform heating of the waste material and that the waste will be best neutralized if it is not placed in the middle of the cavity (*i.e.* at z = 50 cm). With other words, the device does not work in the non-resonant mode, the modal concentration of microwave power density producing a non-uniform heating of the cavity. However, excepting the short treatment times, the waste and its gaseous environment will reach the thermal equilibrium with the inner walls of the device, so that the cavity can be uniformly loaded.

c) Thermal Properties of the Microwave Reactor Working without Load

Operating the reactor with all the microwave generators working at 1.5 KW (*i.e.* 6 kW total injected powers) without using any load, the thermal properties of the ceramic wall, as well as the time evolution of the temperature in the center of the cavity were monitored. The results are presented in Fig. 5. They prove that after 80 min the air inside the cavity reaches the thermal equilibrium with the ceramics wall surface. The other face of the ceramics wall (denoted as "backside" in Fig. 5), in thermal contact with the heat insulator layer, displays lower temperature rates, as expected.

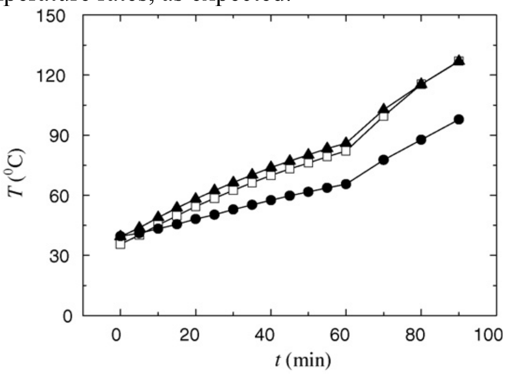

Figure 5: Heat Characteristics (temperature *T vs.* heating time *t*), without waste, at the surface of the ceramics plate; backside of the ceramics plate; in the center of the reactor. The total microwave power is 6 KW.

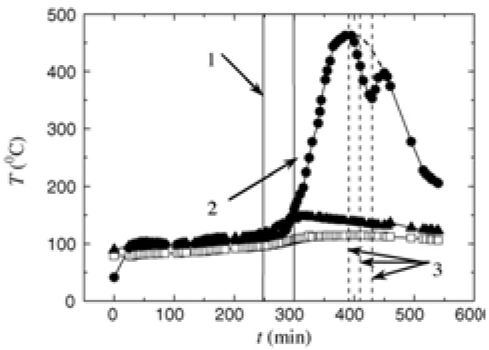

Figure 6: Heat Characteristics (temperature *T vs.* heating time *t*) at the surface of the ceramics plate; backside of the ceramics plate; inside the disposable waste. The total microwave power is 6 kW. (1) Moment of smoke exhaustion; (2) moment of switching off the microwaves generators; (3) moments of smoke evacuation.

It also emphasizes on two different conduction regimes, the threshold being reached after 60 min of microwave heating.

d) Thermal Properties of the Microwave Reactor Working without Load

The operation of the device in the presence of load (*i.e.* disposable diapers), in the same conditions as above (*i.e.* the same microwave injected power), drastically changes the thermal properties illustrated in Fig. 5. The results are displayed in Fig. 6, the data being obtained for a total mass of diapers of 1.98 kg. To make possible the microwave heating and to get closer to the real conditions of the disposed diapers, they were wetted with water, the total mass of water added for humidification being 6.2 kg. The nonlinearity of the curves in Fig. 6 starts to manifest from the moment when the load begins to burn. Under the experimental conditions, that specific moment was encountered after 250 min of heating, when some smoke exhaust was registered. This is marked by the first vertical line (denoted by “1” in Fig. 6).

After that moment, the thermal equilibrium inside the cavity is no longer possible, the temperature inside the load steeply increasing (with 360 ◦C in 60 min), while the increase of the ceramics wall temperature, in the same time interval of 60 min, is rather modest (40 ◦C). After 300 min from the beginning of the heating process, the microwave generators are switched off to allow the heat to “diffuse” naturally through the load volume, from the hot spots to the colder ones. This moment is marked in Fig. 6 by the vertical line “2”. After switching off the microwave power-supplies, the temperature of the ceramics wall surface, facing the cavity, starts to decrease slowly, in order to reach the thermal equilibrium with its side in thermal contact with the heat insulator layer. Regarding the load temperature evolution after the moment of switching off the microwave generators, it can be easily seen that it abruptly grows due to the burning ignition. After the global maximum of the temperature attained at t = 390 min, a local minimum (at t = 410 min), followed by a local maximum (at t = 430 min) can be clearly seen in Fig. 6. Their explanation is as follows: at t = 390, 410 and 430 min, respectively, an evacuation channel is opened for a short time; in order to exhaust the smoke resulted after load burning.

All these moments are marked in Fig. 6 by vertical dashed lines, all denoted by “3”. In this way the temperature decrease rate is externally forced to increase. After the last closing operation of the evacuation channel at t = 430 min, the load temperature increases, in order to reach the thermal equilibrium with the atmosphere inside the cavity. If the evacuation channel was closed all the moments enumerated above, the load temperature would follow the dashed curve sketched in Fig. 6. The temperature decrease, after t = 390 min from the beginning of the experiment, marks the end of the burning process due to the lack of oxygen in the cavity. The results of the preliminary tests showed that, besides the mass reduction of the processed diapers with more than 50%, the result was a dry and sanitized waste. Because the waste temperature during the process surpassed 460 ◦C (at the global maximum in Fig. 6), according to the results obtained in a previous work of Atwater et al. (1997), our device is also working as an ultrahigh temperature sterilization chamber.

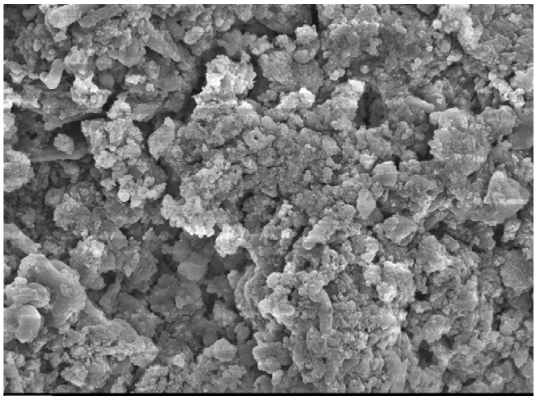

Figure (7): a) Imaging by Electron Microscopy after Radiation

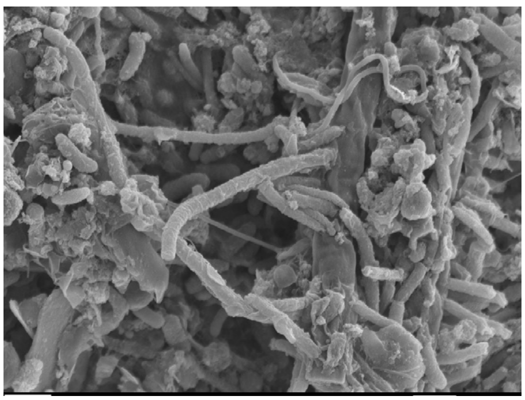

Figure (7): b) before Radiation.

All wastes were imaging before and after of radiation in Urmia university by electron microscopy (Figure 7). As it is obvious in the above pictures, not only cellular structure were damaged, but also it's became denser and no real traces of bacteria is observed.

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