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Application of Electromagnetic Waves as a Solution to some Agricultural Problems

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ABSTRACT

A review of some applications of electromagnetic waves in agriculture is presented. There are many applications in the literature which are categorized in two sections of post-harvest indoor and pre-harvest outdoor applications. Taking a look at the applications suggested, there are still works to be done to industrialize the method. However, the proposed method is promising in special cases when the cost and hazards of other methods are high.

Key words: Electromagnetic waves, Application, Insect pests, Control, Heating.

INTRODUCTION

Currently, the major suffering problems which a farmer faces are the damages caused by harmful pests, in addition to the fruit freezing in unexpected cold weather. Although various new treatment methods have been introduced, some advantages of electromagnetic treatments are still without competitor. In the present paper, applications directly related to the main electromagnetic wave effects such as warming, as a physical (non-chemical) thermal method, were discussed (Aliakbarian *et al.*, 2004). The general idea is the same as heating food products to kill bacteria. It can be used to disinfect various foods and non-food materials including soil. The application of radio frequency to measure soil parameters and soil salinity has been reported as well.

Chemical fumigants are one of the conventional methods of pest control for farmers. Unlikely, many of these fumigants are composed of materials such as Methyl Bromide which has many disadvantages, i.e. reducing the thickness of Ozone layer (Tang *et al.*, 2003). The probable international ban of methyl bromide for post-harvest treatments has directed the attention to other safe methods. Some of these methods are ionizing radiation; cold treatments and conventional heating, those were introduced by (Wang and Tang, 2001).

It has been reported that use of electromagnetic waves in agriculture started in 1952 by Frings (1952), continued by Thomas (1952) in the same year and then by Nelson, (1966). Formerly, the electromagnetic waves method was advocated to post-harvest treatment, but recently, it has been suggested also for field applications.

The present paper includes the theory of

electromagnetic heating and its uses in pre- or post-harvest crops to control pests.

Theory of electromagnetic heating

There is a believe that the waves can only warm up the pests as they are mostly composed of water. Normally, the water percentage in their bodies is more than that in other materials present in the surrounding environment. On the other hand, there are some claims expressing that the electromagnetic waves not only heat the pests, but also they can interfere with their bodies' function without thermal effects. Consequently, non-thermal effects of electromagnetic waves on living tissue were confirmed by (Shapovalenko *et al.*, 2000).

Dielectric constant is known as loss factor. It can be used to heat up a material remotely using electromagnetic waves. The most efficient goal is to warm up a material while the surrounding medium is not affected. Hence, the difference between the imaginary parts of the dielectric constants of two different materials at a specified frequency can be used. The dielectric constant of each material is a frequency-dependent. It can be an appropriate frequency for which the electromagnetic energy is absorbed by the pest while the product or the plant does not absorb the energy at this frequency. Therefore, the accurate measurement of the dielectric constant is a crucial task to find the best frequency (Wang *et al.*, 2003).

Post harvest treatment

A. Walnuts treatment

Shell and air inside the walnut act as an insulator and protection from normal heating. Contrarily, electromagnetic waves select the victim inside the walnut to transfer the energy. The dielectric loss factors of walnuts' pests are much higher than those of the nuts (Wang and Tang, 2001). Therefore, the

Codling moth, the pest of walnuts, was killed within 3 minutes of treatment due to the difference in the absorption of energy between the pest and the walnut (Ikediala *et al.*, 2000). On the other hand, speed of temperature increased approximately 10 times that of the hot air method. The idea of combined methods can be an advantage. If the RF heating is combined with hot air, the temperature drop during the holding period, will be reduced and surface heating will be improved as well (Wang *et al.*, 2002). As oscillator circuit supplies, 6 kW RF power in 27 MHz, the gap between electrodes was adjusted to expose 0.8 kW to the samples under the treatment. From the other side of the device hot air was supplied using a drier tray.

RF heating can be combined with chemical fumigation (Wang and Tang, 2001). Right after fumigation, in-shell walnuts were washed and dried that cause cracks in walnuts' shells, due to several drops into the bins. Damages, treatment time and required space were effectively reduced using RF drying. There are many other practical problems such as; different moisture content in walnuts which change the dielectric constant. One of the reasons of various moisture contents is different bleaching operations based on the customer (Wang *et al.*, 2006). 3% hypochlorite for Spain while 6% hydrogen peroxide for Germany, which are absorbed differently by the walnuts' tissues. Moreover, the absorption depends on the condition of the walnuts such as; to be opened, closed, or cracked. Wang *et al.*, (2006) designed and implemented a practical system in 27 MHz. The schematic of the system is shown in Fig. (1).

B. Wheat's indoor pest control

Heating the pests selectively, using electromagnetic waves decrease the undesirable effects of waves on the products, especially when they are sensitive to temperature increment. Significant difference between dielectric loss factor of insect's body and stored wheat helps to select the insect for heating. Another problem is to find out the best frequency of treatment. The difference in biological and physiological substances, shape and size of the bodies of different insects make it difficult to reach the proper single frequency. This is why a band of frequencies is more reasonable.

Between ISM candidates for indoor treatment, (Nelson and Teson, 1974) stated that treatment of the affected products, with lower frequency bands around 11-90 MHz, was much better and more efficient than the microwave counterpart in 2450 MHz and higher using lower temperature and power. Their measurements also, confirmed that the

frequency band between 5 to 100 MHz was the best region for differential heating. Comparison of mortality of 39 and 2450 MHz, for 1 day and 8 day periods, validated their idea. The results showed that the complete mortality for 39 MHz frequency was achieved by less temperature around 50 °C degrees, compared to more than 80 °C for 2450 MHz. The used RF power was not mentioned; therefore the result showed that the complete mortality was delayed to be achieved in higher frequencies although the required time was not mentioned.

In some cases, during the treatment, when the temperature increases, the frequency of maximum absorption (relaxation frequency) shifts to higher frequencies. This is due to a change in the biological tissue of the insects. In another words, the dielectric loss factor depends on the temperature. Consequently, it may be more efficient to change the frequency of exposure during the treatment. This can be done using a sweeper starting from lower up to upper frequency bound.

As another example, the prototype system described here had used a bigger microwave oven to control insects of stored wheat (Mofidian *et al.*, 2007). A 2.44 GHz magnetron source had been used to affect two kinds of harmful insects, *Sitophilus granarius* and *Tribolium sp.*. Andreuccetti *et al.*, (1994) tried this frequency band before, as a commercial high power and low-price technology exists. Most of stored-product pests were killed within few minutes having temperature of 50 °C or more.

On the other hand, there are possible methods such as; cutting down insects' activities using a lower temperature increment, which requires a lower power as well. Mortality, as a general rule, depends on the duration that insects are exposed. However, during heat treatment, temperature can be differed within a structural profile of a storing facility. Hence, the essential time, at which insects are exposed to the lethal temperature, can differ, depending on their locations within the facility. This is one of the main problems of the electromagnetic exposure systems.

A practical scaled system was designed similar to a real wheat-storing silo. The system was modeled in CST Microwave Studio 5 shown in Fig. (2), with more than 1 meter diameter and 70 centimeters height. The exposed wheat is located at the bottom of the silo and the insects are inserted in middle areas of wheat-filled section.

Simulation of the structure was done using 2.44 GHz normalized microwave source. Results shown

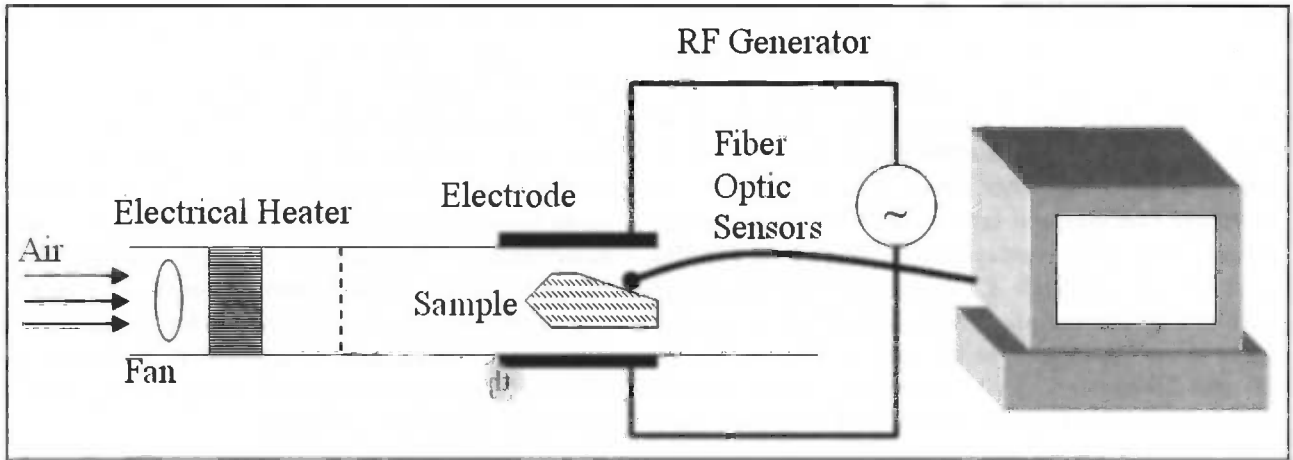


Figure (1): Schematic of the setup used by Nelson

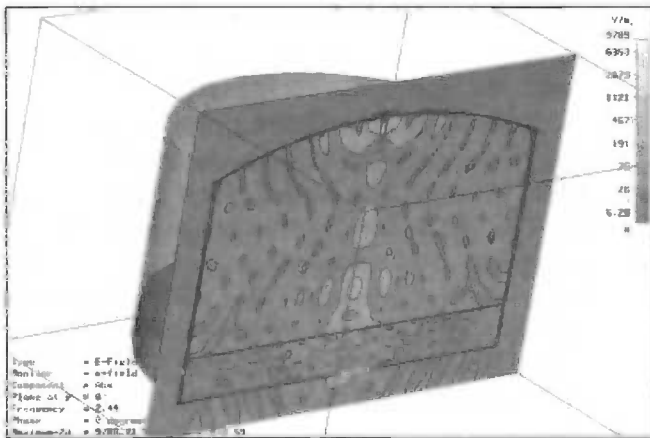


Figure (2): 2.44 GHz setup and its CST simulation.

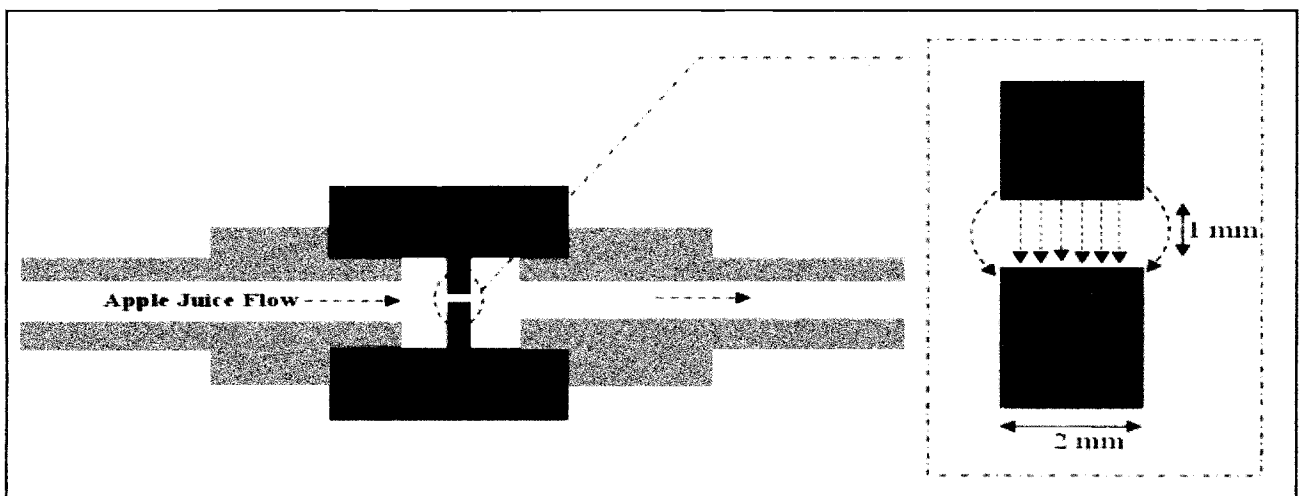


Figure (3): Schematic of Geveke's none-thermal setup for apple juice.

in fig. (2), illustrate that the power density was concentrated in the center part of the system, approximately ten times higher than near the wall. Therefore, the wheat's located in the center of the bulk was expected to absorb much more power in comparison to the other areas. The comparison of mortality rate between larvae and adults showed that larvae were more susceptible to high temperatures than adults. Although *S. granarius* was quite more sensitive to the radiation than *Tribolium*, it showed quite same loss factor in the low mortality rate for 10 and 20-minutes' tests, caused by none-uniform distribution of the field. In the high intensity part, the pests were burnt, while they were still alive in the low intensity ones. To improve the performance, the system antenna could be restructured using an array antenna. Obviously, a complete mortality of insects can be reached by increasing the exposure time or the power magnitude as well.

C. Millimeter wave protection from insects

A practical device for stored-grains was designed by (Halverson *et al.*, 1998). They tried to assess the effectiveness and financial side of controlling stored-grain insects with microwave energy in millimeter wave and microwave band using the free-water relaxation frequency. It is worth pointing out that the crucial bottleneck of using these bands, which were the development of high-power microwave oscillators with tolerable price, had already been solved.

Another problem in using these bands was the poor penetration depth compared to low RF. The skin depth in a dense medium is inversely proportional to the frequency and the conductivity. Conductivity (σ) is also directly related to loss factor (ϵ''). Thus, a good compromise should be done between volume percentage of the gain in a mixture of air and grain, when mass product rolls in. This calculation can help to estimate the efficiency of maximum penetration of the energy into the flowing products. Several one-way path attenuation measurements was done on controlled air-grain mixtures of flowing soft white wheat, hard red wheat, and rice over a range of 18 to 50 GHz. The measurement results of maximum and minimum penetration depths for the three products, soft white wheat, hard red wheat, and rice illustrated that the highest penetration depth occurred in the range of 18 to 26.5 GHz compared to that of the 26.5-40 GHz and 33-50 GHz frequency bands. Halverson and Biglow, (2001) patented their designed system in 2001.

D. Non-thermal effect on fruit Juice

The use of electromagnetic waves to make safer fruit juices is a special application due to its useful

none-thermal effect and its use in food processing applications although it has not been commercialized yet. Conventional pasteurization has been done using different heating techniques, but they can affect the nutrient composition and flavor of the fruit and vegetable juices. The new idea of using radio frequency electric fields eliminated these disadvantages. The electric field inactivates bacteria in apple juices without heating them. The method was used since half century ago for pasteurization purposes (Andreuccetti *et al.*, 1994), but now it is claimed that they successfully inactivate bacteria of fruit juice using this technique.

Again, using the combined method of moderate heat in addition to the none-thermal method has much greater effects than those of the either processes has alone. A special designed device exposes the high-intensity radio frequency electric fields to apple juice. The schematic of the device, in fig. (3) illustrates the juice flow passing the RF part in the center. The narrow line in the center confines the juice flow to reduce the required RF power.

Electrical field strengths up to 20 kilovolts per centimeter and frequencies in the range of 15 to 70 KHz for 0.17 ms period were used. Frequency increase, field strength and temperature increment enhanced the inactivation effect. However, increasing the electric field above 16 Kilovolts intensity did not improve the inactivation performance. Also, if the frequency was increased to more than 20 KHz, it was no longer useful for the deactivation.

Pre-harvest treatment

A. Disinfection of soil

Lagunas-Solar *et al.*, (2006), used lower bands of the RF spectrum (few kHz to < 10 MHz) to disinfest the soil from pests at UC-Davis, USA. New RF systems was designed and engineered based upon solid-state electronics. Its test was relatively efficient for the control of fungi, nematodes and can compete with the other methods specially fumigation such as methyl bromide. The principle of the work based on the relatively high electrical conductivity and heat capacity of the agricultural soils. Therefore, the RF oscillator of the system can transfer the energy to the soil, make it warm efficiently and then retain the energy for a while. One of the biggest challenges for efficient implementation of the system was the large volume (and mass) of soils and consequently required energy. To save the energy inside the soil, some kind of covers on top could be used. Using lower frequencies, the RF waves can easily penetrate the soil without affect it. Then, the absorbed energy in pests, mites, and micro-organisms annihilate them. Lagunas-Solar *et al.*, (2006) stated that using

microwave frequencies may also cause permanent changes in the soil in contrary to the RF lower frequency waves 'effects which are always reversible.

B. Pre-emptive attack on Sunn Pest

Sunn pest, *Eurygaster integriceps*, is the most destroying sap-sucking bug of wheat in the Middle East, Central and East Europe and North Africa in about twenty countries. The most damage to wheat production in these regions is due to this pest. The proposed idea is to use electromagnetic exposure to control Sunn pest in winter before its migration and attack to wheat farms. The method is based on interfering the biological organization of Sunn pests in its life period. The lifetime of the Sunn pest is only one year. By the end of March, groups of Sunn pest start to migrate to wheat farms and cause the widest harm to flourishing wheat in 15 to 30 days. Also, it starts reproducing and then moves to the mountains until next year. Furthermore, it has a winter diapause, when it is in the mountains and uses its stored energy until the next year. Sunn pest can fly about 30 kilometers to the farms and so all of its winter shelters are known. Traditional method of spraying pesticides to kill it in the winter is unsuccessful because it takes crucibles as shelters during this period. Sunn pest, like many other insects, is sensitive to temperature variations in the period of diapause. The variation of climate temperature in this period usually causes an immense damage on it. Therefore, if we can heat it up to about 12 to 15 degrees, it will develop and its diapause will be broken. Consequently, it can fly, reproduce, and move but does not eat because it will not find its host. These activities may result in shedding its energy with impunity and probably it cannot live until spring and cannot fly due to lack of energy. If this heating up was exposed more, its live will be threatened seriously. The goal then is to find the proper frequency, which is more focused on RF ISM band.

C. Pistachio freezing

Sudden freeze of a product in a cold day of spring is one of the most damaging agricultural events. In many desert areas, temperature reduction in a few days may cause great economic injuries. These detriments will be more painful when occur for costly productions like pistachio. By the end of winter, at the beginning of spring, plants are about to flourish. Because of the fact that the weather is not stable, the temperature may fall all of a sudden. Therefore, the biological tissues of the budded pistachio or other products may be damaged. It was found that if the temperature of the production increased about two or three degrees, it can be saved from being greatly damaged.

The previous techniques of anti-freezing were limited to physical, biophysical and genetic treatments. For instance, in some areas, farmers place a fan and a diesel heater under each tree. These methods are more expensive and hard to exploit than the solution, suggested here. Moreover, they have some potential hazards for consumers. Additionally, they need much time than they can be exploited on demand when the weather gets colder. There is no need to forecast weather conditions before necessity to the use of electromagnetic waves. Regarding these advantages, it seems that this method could find a suitable place among the other methods in anti-freezing applications. The proposed idea is to warm up the pistachio remotely and selectively using electromagnetic exposure, while the other materials of the environment are not warmed up. The most significant work is to find out the optimum frequency in which the difference in the absorption rate of energy in pistachio and sensitive objects is the most. This frequency also depends on the electromagnetic characteristics of the objects and can be measured practically.

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