Insect Control by Radio-Frequency High-Strength Electric Fields

Iryna Ponomaryova, Alejandro López Torrecillas, Nefi Alejandro Barron Herrera, Ana Dulce Ibarra Velázquez
Section of Postgraduate Studies and Investigation, Instituto Politécnico Nacional,
ESIME Culhuacán, Av. Santa Ana 1000, Col. San Francisco Culhuacán, CP 04430, México, D.F.
Tel/Fax: (52-55)56242000 ext. 73264. E-mail: iripon76@yahoo.com.mx .

Abstract — **Insect control with radio-frequency electric fields of high strength is reported here. The experiments were accomplished at frequencies 47.5, 900 and 2,450 MHz for both the pulse modulated and the continuous wave RF radiation. The coaxial type chamber experiments on Sitophilus granarius L. (granary weevil) at voltages U = 5.5-10.5 kV, frequency 47.5 MHz, electric fields 180-350 kV/m and exposures 5-60 s give 40-90% of mortality that mainly depends on voltage increase. The irradiation chamber with plane capacitor experiments are pulse modulated at the frequency 47.5 MHz and fields 350-2,000 kV/m. 100% of mortality is reached at the exposures 1-30 s and field 2,000 kV/m. The RF radiation of granary weevil in the coaxial irradiation chamber in stationary mode reaches 100% mortality at major exposure times and frequencies 900 and 2,450 MHz. Stationary mode permits 21-97% fungi control at voltage U = 10.5 kV, frequencies 900 and 2,450 MHz and exposures 120-180 s.**

Keywords — Frequency, permittivity, pulse

I. Introduction

Investigations of radio-frequency (RF) and microwave energy action on insects and microorganisms have been carried out for the last 50 years in different countries [1], [2], [4]. The action of electromagnetic RF-irradiation on biological organisms depends on the dielectric parameters of the biological structures, the electric field intensity and frequency, temperature and moisture content of the dielectric biological objects. Nelson [6] showed that the preferable wavelengths for insect treatment are of a few meters in the radio-frequency spectrum. Lethal outcome for insects, usually connected with heating of tissues or damage of their nervous system, depends considerably on the frequencies, field strength and their complex dielectric permittivity, with final temperature being the dominant factor [3], [5], [7].Sterilization of male insects was observed at relatively low RF-field levels [2], [4], [8]. This destroys the reproductivity of the population. Some investigations showed bactericidal effects of RF radiation. When the RF-field power is considerable, 0.8-4.5 kW, the process observed in microorganisms (*Paramecia*) exhibited a so-called "electric shock" when subjected to the action of microwaves while the medium is heated only one degree. The physical and biological investigations showed that one of the most important factors affecting the insects is the electric field strength [3], [5].

II. Methodology

The electromagnetic field within the coaxial line (Fig.1) can be described by the equations

$$H_\varphi = r_0 H_0 \exp(i(\omega t - \omega z / V_\varphi)) / r \,, \qquad (1)$$

$$E_r = r_0 H_0 \omega \exp(i(\omega t - \omega z / V_\varphi)) / \varepsilon r V_\varphi \,, \qquad (2)$$

where H_φ , A/m, is the magnetic field strength, E_r,V/m, is the electric field strength, H_0 , A/m, is the magnetic field strength amplitude, V_φ , m/s, is the phase velocity, ω, rad/s, is the angular frequency, ω/ V_φ , rad/m , is the phase constant and *z* is the wave propagation direction. From the equations (1) and (2) the nonuniform character of the RF fields can be noted. The flow of electromagnetic power *W* across the whole section of the coaxial line is

$$W = c \ln(R/r_0)(r_0 H_0)^2 / 4\sqrt{\varepsilon} \qquad (3)$$

where *c*, m/s, is the light speed in vacuum, *R*, m , is the internal radius of the outer conductor, r_0, m, is the radius of the center conductor and ε, F/m is the dielectric permittivity. Therefore the electric field strength is related with the generator power and is determined

$$E_r = 0.5 E_0 \exp(i(\omega t - \omega z / V_\varphi)) \qquad (4)$$

For the coaxial line used at the frequency 47.5 MHz, $r_0 = 0.035m$ and $R = 0.080m$. Thus the field nonuniformity along the radius is large: $[E(R)/E(r_0)] = 0.44$. To reduce this nonuniformity, the use of the additional dielectric tube is needed. One can assume that the volume with grain and insects surrounds the central conductor from $r = r_0 = 0.035m$ to $r_1 = 0.060m$. Then $E(r_1)/E(r) = 0.6$ or $E^2(r_1)/E^2(r_0) = 1/3$ and this means that the heat generated within insects near the outer channel radius will be three times less than that generated at the internal conductor. The following values will be obtained as a function of the electromagnetic power radiated by the HF generator:

$$W_1 = 1\times10^6 \text{ w} \,\ldots.. \, E_0 = 6\times10^5 \text{ V/m}\ldots..$$

$$E = 4.2\times10^5 \text{ V/m}$$

$$W_2 = 1.6\times10^6 \text{ w}\ldots E_0 = 7.5\times10^5 \text{ V/m}\ldots..$$

$$E = 5.15\times10^5 \text{ V/m} \qquad (4)$$

IEEE Catalog Number:CFP09827
ISBN: 978-1-4244-4689-6
Library of Congress: 2009904789

$$W_3 = 2\times10^6 \text{ w}\ldots E_0 = 8.4\times10^5 \text{ V/m}\ldots..$$

$$E = 5.15\times10^5 \text{ V/m}$$

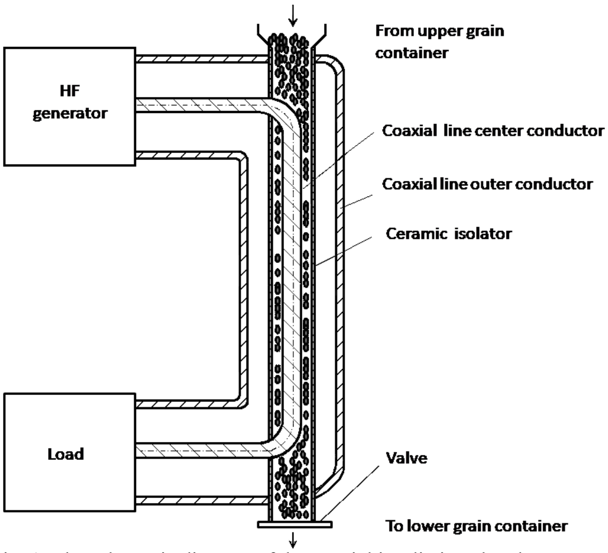

Fig. 1. The schematic diagram of the coaxial irradiation chamber.

The values E_0 and E are the electric field values near the inner conductor at the radius 0.035 m (from the coaxial line to the point, where the electric field is measured) and near the outer conductor at the radius 0.06 m respectively, both are in the coaxial configuration. W_1, W_2, W_3 , w are the values of electromagnetic power radiated by the HF generator.

1) *The coaxial type irradiation chamber:* This chamber (Fig. 1) was made from standard copper coaxial 0.160m/0.070m feeder line 1m in length with a ceramic tube mounted coaxially between the center and outer conductors.

The infested grain flowed from the upper grain container through the ceramic isolator tube around the inner conductor (Fig.1). The ceramic isolator (dielectric permittivity $\varepsilon \approx 1$) helped to limit the variation in the radial electric field intensity between the coaxial line center conductor and outer conductor. At one end, the coaxial-line feeder was connected to the RF-generator output, and the other end was connected to the active generator load. Here, an electric field of 6.2×10^5 V/m was achieved close to the surface of the inner conductor (radius = 0.035m) and decreased to 4.5×10^5 V/m at the inner surface of the ceramic tube (radius = 0.06 m) at the pulse power level ~ 1.0×10^6 W. Both radii are given from the coaxial-line axis to the point where the electric field is estimated inside the coaxial line processing zone. The experiments carried out on granary weevil (Sitophilus granarius L.) and microscopic fungi

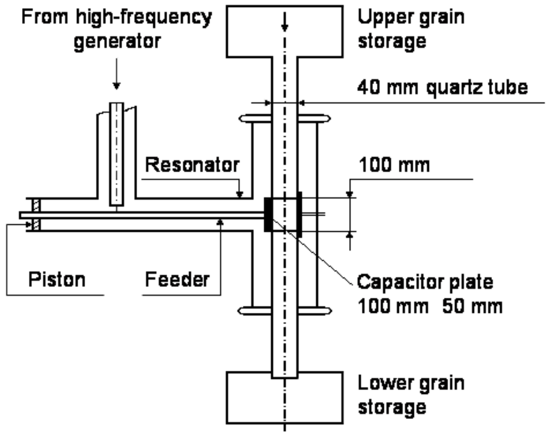

Fig. 2. The schematic diagram of the irradiation chamber with capacitor.

(Aspergillus fumigatus, Cladosporium cladosporioides, Aspergillus candidus) in the coaxial feeder chamber are given in TABLES I, II, IV and V.

2) *The irradiation chamber with a plane capacitor:* The schematic diagram, of the irradiation chamber with a plane capacitor is shown in Fig.2.

The main difference of this method from the coaxial system is that in the first type the traveling waves are used, and in the second type, the situation is stationary. This method of high electric field formation permits higher levels of electric field strength (>30×10^5 V/m in pulsed mode) and the improvement of the whole facilities efficiency. The experiments were carried out at the applied frequency of 47.5 MHz in this configuration (TABLE III). The pulse modulated RF-radiation at 47.5 MHz on granary weevil (Sitophilus granarius L.) in the irradiation chamber with a plane capacitor (TABLE III) gave good results at the field intensities 350, 700, 1,000 and 2,000 kV/m and time exposure varying from 0.5 to 30 s.

III. RESULTS

The investigations at 47.5 MHz (Fig.1) showed that the biological action of the RF electromagnetic field depends more on the generator power voltage (U, kV) than on treatment duration (TABLE I). The mortality of granary weevil (*Sitophilus granarius* L.) at 47.5 MHz treatment in the coaxial type irradiation chamber (Fig.1) is given in TABLE II.

TABLE I

ACTION OF RF-RADIATION AT 47.5 MHZ ON THE WAREHOUSE PEST GRANARY WEEVIL (SITOPHILUS GRANARIUS L.) IN THE COAXIAL FEEDER CHAMBER. PULSE MODULATED RADIATION TREATMENT; REPETITION RATE: TWO PULSES PER SECOND.

Exposure, seconds	U, kV	$\overline{E}$, kW/m	Radiating power, kJ/m^{2}in a pulse	Mortality of insects,%, (adult &larva)
5	10.5	350	9.4	85.5±8.0
10	10.5	350	9.4	96.2±2.7

IEEE Catalog Number:CFP09827
ISBN: 978-1-4244-4689-6
Library of Congress: 2009904789
978-14244-4689-6/09/$25.00 ©2009 IEEE

20	10.5	350	9.4	89.3±8.9
60	10.5	350	9.4	71.3±11.8
60	8.5	280	6.15	53.8±4.4
60	5.5	180	2.45	42.5±28.9

TABLE II
ACTION OF RF-RADIATION AT 47.5 MHZ ON THE WAREHOUSE PEST GRANARY WEEVIL (SITOPHILUS GRANARIUS L.) IN THE COAXIAL FEEDER CHAMBER. PULSE MODULATED RADIATION TREATMENT.

Exposure, seconds	Average mortality for two replications, per cent
7 kV. Field intensity at the sample location: 190-250 kV/m	
5	42.3
10	62.8
10 kV. Field intensity at the sample location: 270-350 kV/m	
2	61.6
3	66.7
10	71
15	66.3
25	86.3

As shown from experimental results (TABLES I and II) at 47.5 MHz, the biological effect is connected with power flow and voltage. Thus, increasing the voltage from U=3.5 kV to 10.5 kV increases the mortality from 42.5% to 71.3 % all with a treatment duration of 60 s. At the voltage U=10.5×10^3 V, increasing the treatment duration from 5 to 60 s did not increase the insect mortality Use of frequencies of 900 MHz and 2,450 MHz reveals the direct dependence on the irradiation time (TABLE IV). Results of RF-radiation treatment at 900 and 2,450 MHz (Fig.2) on granary weevil (*Sitophilus granarius* L.) in the coaxial irradiation chamber with stationary mode are presented in TABLE IV. Thus the RF-radiation treatment of the grain and insects during the short time periods provides insect suppression at a temperature level that does not influence the biological quality of the grain. In our investigations on microscopic fungi, sterilized corn meal was contaminated by fungi cultures. Then the contaminated samples were irradiated by RF-waves with different exposure times and power radiation levels. At frequencies of 900 and 2,450 MHz, some suppression of fungi was observed. At exposures of 120-180 s the fungi growth was suppressed 21-97 % for *Cladosporium cladosporioides* and *Aspergillus candidus*.

TABLE III
ACTION OF PULSE MODULATED RF-RADIATION AT 47.5 MHZ ON THE WAREHOUSE PEST GRANARY WEEVIL (SITOPHILUS GRANARIUS L.) IN THE IRRADIATION CHAMBER WITH A PLANE CAPACITOR

Exposure, seconds	Insect mortality, %	
	Separate investigations	Average
Field intensity: 350 kV/m		
0.5	50, 60, 75, 85	67.5
1	50, 100, 100	83.3
5	100, 100, 100	100
10	100, 100, 100	100
20	100, 100, 100	100
30	85, 90, 100	89.5
Field intensity: 700 kV/m		
0.5	60, 80, 90	80
1	100, 100, 100	100
5	65, 100, 100	91.5
10	100, 100, 100	100
20	90, 100, 100	96.6
30	100, 100, 100	100
Field intensity: 1,000 kV/m		
0.5	70, 80, 100	72.0
1	100, 100, 100	100
5	100, 55, 100	88.0
10	50, 80, 90	76.1
20	100, 100, 100	100
30	100, 100, 100	100
Field intensity: 2,000 kV/m		
1	100, 100, 100	100
3	100, 100, 100	100
5	100, 100, 100	100
10	100, 100, 100	100

IEEE Catalog Number:CFP09827
ISBN: 978-1-4244-4689-6
Library of Congress: 2009904789
978-14244-4689-6/09/$25.00 ©2009 IEEE

20	100, 100, 100	100
30	100, 100, 100	100

TABLE IV
ACTION OF RF-RADIATION AT 900 AND 2,450 MHZ ON THE WAREHOUSE PEST GRANARY WEEVIL (SITOPHILUS GRANARIUS L.) IN THE COAXIAL FEEDER CHAMBER WITH STATIONARY MODE

Frequency, MHz	Exposure, seconds	Specific power radiation, MW/m^3	Exposure dose, kJ/kg	Mortality, per cent
900	5	2.3-2.8	5.05	68.3±19.4
900	10	2.3-2.8	11.0	80±28.3
900	15	2.3-2.8	16.6	79.3±7.9
900	30	2.3-2.8	33.1	97.1±2.0
900	60	2.3-2.8	66.2	100±0
2,450	60-90	0.8-1.1	66-122	90 - 100
2,450	120	0.8-1.1	136-155	100

TABLE V
ACTION OF CONTINUOUS-WAVE RF-RADIATION AT 47.5, 900 AND 2,450 MHZ ON MICROSCOPIC FUNGI (MICROMICTETS)

Fungi species	$\times 10^6$ spores of fungi species in 1 kg of grain			
	Untreated control	Exposure, s		
		60	120	180
900 and 2,450 MHz, stationary mode				
Aspergillus fumigatus	23.78±1.7	17.37±3.19	23.95±3.17	18.8±2.94
Cladosporium cladosporioides	5.72± 0.73	1.05± 0.21	0.55± 0.33	2.62± 1.12
Cladosporium cladosporioides	7.30± 0.94	1.96± 0.29	0.25± 0.25	0.05± 0.05
Aspergillus candidus	11.5 0.5	7.36 1.50	5.27± 1.08	2.12± 1.28
Aspergillus fumigatus	13.26± 0.71	6.85± 0.76	2.64± 0.33	0.62± 0.12
47.5 MHz, 2 pulses/second, U=5.75 KV				
Aspergillus fumigatus	13.64± 0.62	19.94± 3.54	15.44± 1.38	15.5± 1.84
Cladosporium cladosporioides	5.72± 073	2.94± 1.54	5.16± 2.13	4.31± 1.38
Cladosporium cladosporioides	7.30± 0.94	1.95± 0.31	2.25± 0.28	1.60± 0.17
Aspergillus candidus	11.44± 1.14	3.80± 0.73	3.65± 0.53	3.88± 1.63

IV. DISCUSSION

There are two interpretations for the reaction to the application of the RF-fields. For the first, the RF fields influence on the treated material causes considerable heating of the organisms thus resulting in their death. The second possible explanation is of great interest as it does not attribute the action to heating of the organisms. For example, the application of RF-fields of $10^7 - 10^8$ Hz, which satisfies the relationship $h\upsilon < kT$, where $h\upsilon$ is the quantum energy of the RF-fields, k is Boltzmann's constant and T is the absolute temperature of the treated body, has a specific effect on the biological objects that cannot be explained only from the thermal influence of the RF fields. For insects treated by short pulses of RF-radiation, one can consider the following: Insects have higher structural organization than lower biological forms and have higher sensitivity to RF-radiation. During the realization of the selective overheating effect, insect death directly depends on nervous system damage and is related with electromagnetic irradiation parameters: frequency and intensity (strength) of the electric field. At the selected exposures the reproductive capability disappears and the biotype population does not multiply.

When working with radiation it is important to be conscious about the maximum permissible radiation dose limits for humans. Adults occupational exposure: 1) whole body: 5 rem/yr = 0.05 Sv/yr; 2) skin of whole body or extremity: 50 rem/yr = 0.5 Sv/yr; 3) eye: 15 rem/yr = 0.15 Sv/yr; 4) Embryo/fetus: 0.5 rem/gestation period = 0.005 Sv/gestation period. Minors' occupational exposure: 10% of adult limits. Member of general public: 0.1 rem/yr = 1 mSv/yr. Lethal whole body dose of radiation for a human: 400-500 rem = 4-5 Sv (instantaneously).

V. CONCLUSION

Physical and biological investigation showed that electric field intensity increasing in the processed zone is one of the most important factors for insect control. The experiment on granary weevil at 47.5 MHz in pulse modulated radiation regime in the coaxial feeder chamber depends on both the generator power voltage and exposure time. If the electric field intensity is not sufficiently high, the time of exposure has very little influence. If it is high enough to be effective, then no longer expose time than what is necessary to achieve 100% insect mortality should be used. The system is economically profitable due to the comparatively low

IEEE Catalog Number:CFP09827
ISBN: 978-1-4244-4689-6
Library of Congress: 2009904789
978-14244-4689-6/09/$25.00 ©2009 IEEE

energy consumption. The system with the irradiation chamber with a plane capacitor reaches the best results (100% insect mortality) at higher field intensities such as 2,000 kV/m at the exposures 1-30 s. Continuous-wave RF-radiation at frequencies 900 and 2,450 MHz of granary weevil *(Sitophilus granarius)* in the coaxial irradiation chamber with stationary mode reaches 100% of insect mortality at major exposure times for both frequencies (TABLE IV). If frequency and exposure time are sufficiently high, it requires less of power radiation to achieve 100% of insect mortality. Fungi suppression is normally very difficult to predict, because at certain conditions (frequency, exposure time) some species (*Aspergillus fumigatus)* continue to reproduce. Further investigation is needed for microscopic fungi control. The experiments show that the RF-technology for fodder and product treatment to destroy contaminating micro flora and pests is promising, since it is the safest method for environmental protection.

REFERENCES

[1] A.A. Mishchenko, O.A. Malinin, V.M. Rashkovan, "Complex High-Frequency Technology for Protection of Grain from Pests", *Journal of Microwave Power and Electromagnetic Energy*, 35: (3), pp. 179-184, 2000.

[2] S.O. Nelson and B.H. Kantack, "Stored-Grain Insect Control Studies with Radio-Frequency Energy", *J.Economic Entomology*, 59(3), pp. 588-594, 1966.

[3] S. O. Nelson and L. F. Charity, "Frequency Dependence of Energy Absorption by Insects and Grain in Electric Fields", *Transactions of the ASAE*, 15(6), pp. 1099-1102, 1972.

[4] S.O. Nelson, "Insect Control Studies with Microwaves and Other Radio-Frequency Energy", *Bulletin of the Entomological Society of America*, 19(3), pp. 157-163, 1973.

[5] S.O. Nelson, "Review of Factors Influencing the Dielectric Properties of Cereal Grains", *Cereal Chem*. Vol.58, No 6, pp. 487-492, 1981.

[6] S. O. Nelson, "Review and Assessment of Radio-Frequency Microwave Energy for Stored-Grain Insect Control", *Transactions of the ASAE,* Vol. 39, No 4, pp. 1475-1484, 1996.

[7] S.O. Nelson, "Radio-Frequency and Microwave Dielectric Properties of Insects", *Journal of Microwave Power and Electromagnetic Energy*, Vol.36, No 1, pp. 47-56, 2001.

[8] A. S. Presman and S.M. Rappoport, "Electromagnetic Fields and Biology", *Bulletin for Experimental Biology*, 59(4), p. 48, 1965.

IEEE Catalog Number:CFP09827
ISBN: 978-1-4244-4689-6
Library of Congress: 2009904789
978-14244-4689-6/09/$25.00 ©2009 IEEE