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Effect of Electric field on Dielectric Loads by Using the Electrode Plates for Exterminating Pests Applications

***Abstract**. This research was conducted to analyze the effect of electric field distribution and intensity in dielectric loads. The electric fields were caused by varying the electric power on electrode plates to improve the thermals temperatures of dielectric loads. The dielectric loads of the grains and pests, the rice and rice weevils were the target dielectric materials for analyzing the impact of thermal temperatures of the rice weevils and minimal thermal on the rice. To investigate the difference of electric power on heating predicted by the theoretical model, the electric field distribution and intensity were analyzed by using the finite difference time domain method. Theoretical analyzes was conducted to make power system effective for controlling the electric field distribution on the model. Theoretical and experimental investigations were carried out using dielectric load. The results demonstrated that the efficiency of the dielectric heating exterminated pests and temperature of grains without losing the quality. The advantage of the method is being able to be utilized for the dielectric heating applications to eliminate insects and control the appropriate temperature of the grains in the future.*

***Streszczenie.** Badania przeprowadzono w celu analizy wpływu rozkładu i natężenia pola elektrycznego w obciążeniach dielektrycznych. Pola elektryczne powstały w wyniku zmiany mocy elektrycznej na płytkach elektrod w celu poprawy temperatur termicznych obciążeń dielektrycznych. Obciążenia dielektryczne ziaren i szkodników, ryżu i wołków ryżowych były docelowymi materiałami dielektrycznymi do analizy wpływu temperatur termicznych wołków ryżowych i minimalnych temperatur termicznych na ryż. Aby zbadać różnicę mocy elektrycznej podczas ogrzewania przewidywaną przez model teoretyczny, przeanalizowano rozkład i natężenie pola elektrycznego, stosując metodę różnic skończonych w dziedzinie czasu. Przeprowadzono analizy teoretyczne mające na celu zapewnienie efektywności systemu elektroenergetycznego w sterowaniu rozkładem pola elektrycznego na modelu. Badania teoretyczne i eksperymentalne przeprowadzono przy obciążeniu dielektrycznym. Wyniki wykazały, że skuteczność ogrzewania dielektrycznego eksterminowała szkodniki i temperaturę ziarna bez utraty jego jakości. Zaletą tej metody jest możliwość wykorzystania jej w zastosowaniach związanych z ogrzewaniem dielektrycznym w celu wyeliminowania owadów i kontrolowania w przyszłości odpowiedniej temperatury ziarna. (**Wpływ pola elektrycznego na obciążenia dielektryczne przy użyciu płytek elektrodowych do tępienia szkodników**)*

Keywords: Dielectric properties, Electrode plate, Electric field
Słowa kluczowe: Właściwości dielektryczne, płytka elektrodowa, pole elektryczne

1. Introduction

Currently, there is an increasing interest in electromagnetic heating due to its ability to directly heat materials. This can be achieved through two methods: induction heating and dielectric heating, which involves a reaction with the metal. In the past year, there has been significant research and development in circuits and applications [1-3]. The dielectric heating technique is interested in the heating technology as the most important feature of thermal energy directly composed to the dielectric material with appropriate frequency range, thus, this technique does not affect other materials. The dielectric heating structure uses the frequency spectrum principle, which is applied as an electric field to transfer power into the dielectric material with polar molecules. The resonances of the molecules occurring in the dielectric material and dielectric heating are quickly and evenly generated. The dielectric heating is being applied in many applications [4-7] such as, dehydration industry and fruit pre serration industry. In addition, the dielectric heating can be also applied to eliminate the pests in agriculture since the structure of the pests contain high moisture or polar molecule which can induce the electric field to heating [8-11].

Nowadays, grains derived from the harvests are treated by chemical fumigation to control storage pests (methyl bromide and phosphine) [12-16] before being shipped to domestic and international markets. Most people have concerned about the side effects of chemical fumigation on consumers and environment, we, the researchers, are interested to develop the methods to pests control without using chemical, especially heating methods, but both making will be heating an impact on insects and grains. An important method to develop in thermal control at proper lethal temperature of the pest by using the electromagnetic energies are radio frequency (RF) or microwave (MW) dielectric heating to control the pests in grains before being shipped. In dielectric heating, it is believed that, the pests could be heated to their lethal temperature while the grain can only be slightly heated due to difference in dielectric properties.

The radio frequency and microwave heating, have been studied for several years to control pest heated by electromagnetic field distribution and energy absorb in the product. Researchers proposed thermal based on radio frequency and microwave energy to replace chemical fumigation in order to control the other pest's insect [17-25]. Moreover, they have reported the acceptable product quality after treating product with radio frequency energies to control pest's infestation [26-33]. The controlled features of pests when the material being heated are the mixture of different materials. There is the possibility for selective heating, and this was considered for the possibility that the pests may be heated at a faster rate than grains by using an electromagnetic field on radio frequency dielectric heating. In a mixture of pests and grains, both materials are subjected to fields of the same frequency, but the electric field intensity depends on the geometry and the dielectric constant and the heating is also proportional to the dielectric loss factor of each material. Thus, dielectric properties and wide frequency response ranges are being interested in heating the mixture of different materials.

To generate the electromagnetic fields for dielectric heating, the plates were used as applicators to control generate electric field distributed between plates to heat the dielectric load. Many papers had reported characteristics of structures and patterns of the electrode plate with electric field distributions of circular and square plates. Because the characteristic of the plate model and the distribution of electromagnetic fields were symmetrically and evenly electric field; however the dielectric heating with the pests and grains in the circular and square plates which finitude structures are not appropriate for applications, due to the circular plate is designed to be suitable for the dielectric load of the circular structure and the square plate is designed to static dielectric load, but the pests and grains are flowed through the plate. Thus, the structures of rectangular plate are interested for conducting the research for pests control with gains embedded to influence the most effective applications because plate can expand the area and flow through the plate for the heating.

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2. Materials and Methods

2.1 The Concept and Construction of Dielectric Heating

The most effectiveness of applications of dielectric heating with mixture dielectric loads should comprise the structures and patterns for the appropriate heat and provide minimal thermal impact in the near materials. This research presented the structure of dielectric heating for exterminate pests applications shown in the fig. 1. The diagram configuration of the generated oscillator frequency with 39 MHz, transferred into the high-power amplifier, can control power watts; then transferred to the electrode plate. The electrode plates consisted of two plates: the upper electrode plate is anode for generating an electric field to the mixture dielectric loads, and the other lower electrode plate is cathode.

According to this simulation, the mixture of dielectric loads comprised the grain and pests, the rice and rice weevils as the target dielectric materials. The properties of materials were presented the guidelines, The dielectric loss factor and permeability of dielectric property of rice were 0.4 and 3.4, respectively; whereas, the dielectric loss factor and permeability of rice weevil were 2.24 and 7.2, respectively [34-36].

The dielectric heating technique of electrode plates materials used for generating the electric field can be divided into two ways as follows. (1) The electric power in electrode plates which was an important key to control the electric field generator for the dielectric load. It can control the voltage and the current flowing on the electrode plates, which are important for the electric fields to be generated. (2) Highly conductive materials could be able to generate electric field intensity which effective to provide heating. In this investigation, highly conductive materials had been selected. The conductivity and relative permeability of the different four materials: copper (Cu), aluminum (Al), steel (Fe) and iron, were illustrated in table 1 [37-39]. The higher conductivity the copper materials (Cu) the morepossibility of the maximum electric field was generated in the study.

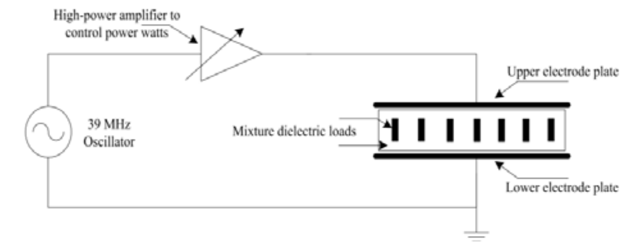

Fig. 1. The diagram of dielectric heating structure for exterminating pests' applications.

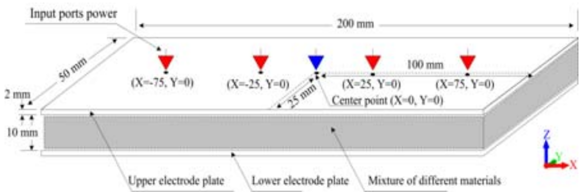

Fig. 2. The structural positions of excitation source in 1-port and 4-ports on the electrode plates to analyze of thermal temperature and electric field distribution.

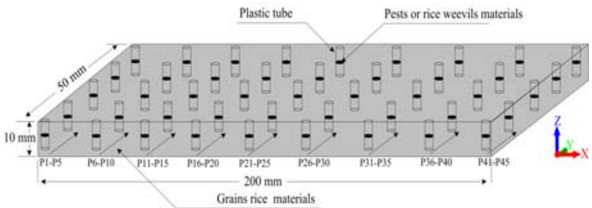

Fig. 3. The structural positions of the grains and the pests for analyzing the mortality rate of rice weevils, thermal temperature and electric field distribution.

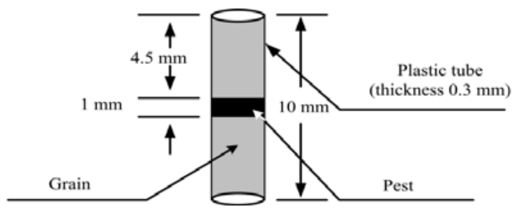

Fig. 4. The structure of plastic tube and the position of rice weevil setting to analysis.

The parameters of dielectric heating system were electrode plates composed into a rectangular applicator. This copper material had diameter, width, length, thickness, and distance of 200, 50, 2, and 10 mm., respectively, as shown in fig. 2. The investigate of simulation results can be comparing between the electric field distribution and intensity with 1 and 4 input-power ports were shown in table 2.

The mixture dielectric load materials in the electrode plates consisted of the material properties of rice (grains materials) and rice weevils (pest's materials). The material properties of rice were set as wide as the gap between the electrode plates and the rice weevils of adults were located in plastic tube with diameter and height of 4.8 and 10 mm, respectively, the location of 45 tubes were denoted in fig. 3 and concluded in table 3. The sizes of the rice weevils material in adults had the width, length, and height of 1, 4.8, and 1 mm., respectively, it can be located with the plastic tube as illustrated in fig. 4. The plastic tube was the polypropylene polymers (PP) that excellent electrical insulator properties.

Table 1. The properties of electrode plate's materials

Materials	Conductivity (S/m)	Relative permeability
Copper (Cu)	59.6×10^{6}	1
Aluminum (Al)	35.0×10^{6}	1
Steel (Fe)	1.45×10^{6}	4000
Iron	10.0×10^{6}	200000

Table 2.The appropriate position of excitation sources in 1-port and 4-ports on the rectangular electrode plates

Number of feed	Port 1 (X,Y)	Port 2 (X,Y)	Port 3 (X,Y)	Port 4 (X,Y)
1	0,0	-	-	-
4	-75,0	-25,0	25,0	75,0

Table 3. The position of plastic tube setting for analyze of mortality rate of rice weevils and electric field distribution

Number of point	Center of position (X,Y)	Number of point	Center of position (X,Y)	Number of point	Center of position (X,Y)
P1	-99,-24	P16	-25,-24	P31	50,-24
P2	-99,-12.5	P17	-25,-12.5	P32	50,-12.5
P3	-99,0	P18	-25,0	P33	50,0
P4	-99,12.5	P19	-25,12.5	P34	50,12.5
P5	-99,24	P20	-25,24	P35	50,24
P6	-75,-24	P21	0,-24	P36	75,-24
P7	-75,-12.5	P22	0,-12.5	P37	75,-12.5
P8	-75,0	P23	0,0	P38	75,0
P9	-75,12.5	P24	0,12.5	P39	75,12.5
P10	-75,24	P25	0,24	P40	75,24
P11	-50,-24	P26	25,-24	P41	99,-24
P12	-50,-12.5	P27	25,-12.5	P42	99,-12.5
P13	-50,0	P28	25,0	P43	99,0
P14	-50,12.5	P29	25,12.5	P44	99,12.5
P15	-50,24	P30	25,24	P45	99,24

2.2. **Temperature Analysis of Dielectric Heating**

The material property known as the loss factor $\varepsilon^{"}$ is the ability of the dielectric material to convert the applied electric field into heat. The higher loss factor was the dielectric material, which was easier to be affected by dielectric heating; the loss factor of material was the greater than 0.2. This was generally considered to be dielectric heating [40]. However, sometimes the temperature of the material heated can be increase by the loss factor of some materials. The permittivity denoted by the symbol ε is the ability of the dielectric material to be polarized. Dividing the permittivity of free space $\varepsilon_{o} = 8.85 \times 10^{-12}$ F/m resulted on the relative permittivity of dielectric constancy $\varepsilon^{'}$ can be calculated as follows: equations 1.

(1) $$\varepsilon^{'} = \frac{\varepsilon}{\varepsilon_{o}}$$

The permittivity of a material could be expressed as a complex quantity, the real part was associated with the capability of the material for storing energy, and the imaginary part was associated with the dissipation of electric energy in the material by conversion of electric energy to heat. The complex permittivity is shown in equations 2, where j represents the complex operator, as $\sqrt{-1}$.

(2) $$\varepsilon^{*} = \varepsilon^{'} - j\varepsilon^{"}$$

For polarized materials, the friction between molecules is generated from the reaction toward the electric field applied and yields increased in material temperature. However, the delay between the penetration of the electric field and the material of heat that is called the loss angle . The electrical conductivity associated with the dielectric loss in the material in S/m, where is the angular frequency. The loss angle was expressed as a component of the loss factor as shown equations 3. The loss tangent and the dielectric constant were varied with the frequency applied and the temperature of the material. The power that the material absorbed was the value of heat generated through the material as represented as follows:

(3) $$\tan\delta = \varepsilon^{"} / \varepsilon^{'}$$

(4) $$P = E^{2}\sigma = 2\pi f E^{2}\varepsilon_{o}\varepsilon^{"}$$

Where E is the rms of electric field strength on the material (V/m), P is the power density (W/m^{3}), σ is conductivity, f is frequency (Hz), ε_{o} = permittivity of free space (F/m), $\varepsilon^{"}$ is loss factor of material. The changing rate of the temperature increased, $\Delta T / \Delta t$ in ^{o}C/s, in the dielectric material caused by the conversion of energy from the electric field to heat in the material as follows:

(5) $$\frac{\Delta T}{\Delta t} = \frac{P}{\rho c_{p}}$$

where, c_{p} is specified heat of the material (kJ/kg ^{o}C), ρ is density of the material (kg/m^{3}) The penetration of skin depth was the depth that the energies had decayed to 0.368 (l/e) of its maximum value and might be varied, depending on the loss factor and the frequency of used. Usually, the higher the loss factor as a result to the lower penetration of skin depth and the wavelength to increase as a result to the penetration of skin depth increased. The relationship between wavelength and penetration depth is expressed as follows:

(6) $$d_{p} = \frac{c}{2\pi f\sqrt{2\varepsilon^{'}\left[\sqrt{1+(\varepsilon^{"}/\varepsilon^{'})^{2}} - 1\right]}}$$

where d_{p} is penetration of skin depth in cm, c is speed of light (3×10^{8}). The dielectric heating was the high efficiency-heating technique, using the alteration principle of noting electric field between anode and cathode of capacitor plates. The heating material was placed between anode and cathode of electric field while the molecular of dielectric material was continually reversing the pole at the resonance frequency for the reversed direction of the pole. Because of the fiction of molecular movement, the dielectric material was rapidly heated. The structure of the capacitor of parallel plate was as illustrated in fig. 5. The capacitance of plates can be calculated as in equations 7, and the electric field between two large parallel plates is given by equations 8.

$$C = \frac{\varepsilon A}{d} \tag{7}$$

$$E = \frac{\sigma}{\varepsilon} = \frac{V}{d} \tag{8}$$

Where *A* is plate area (mm^2), *d* is distance between the plates (m), ε is permittivity of material, σ is conductivity of dielectric material, *V* is voltage difference between the two plates (V)

Dielectric heating analysis applied in the mixture dielectric load to exterminate the pest's applications needed for the parameter in Equations 4 and 5, can generate the effective heating for dielectric load. In equation 5, the power absorbed could be obtained in the dielectric load when *T*, *t*, and ρ are temperature, time, and characteristic load, respectively. In this paper, the rice weevils and the rice are the dielectric load of the mixture dielectric material in the electrode plates to be eliminated by dielectric heating techniques. According to Robinson's research, the rice weevils are clearly eliminated when the inside temperature absorbed is estimated to 60^{o}C, moreover it also represented the specification of rice weevil with the width, the length, and the height of about 1, 3.1-4.8, and 1 mm, respectively [41]. In addition, Wang represented that the individual specified heat and densities of the insects were 450.3 kJ/kg^{o}C and 1000 kg/m^3, respectively [42]. Therefore, the power absorption of rice weevils can be calculated as in Equation 5, when the initial temperature is 24^{o}C and increased to maximum temperature of 60^{o}C, thus the Temperature variations ΔT are 36^{o}C and the eliminating times of rice weevils Δt between 1 to 20 seconds are used for analyzers. The power absorption from the calculation is the parameter to calculate electric field strength of the dielectric heating as shown in Equation 4. The result calculated by Equation 4 and 5, showed that the electric field strength and period times to eliminate the rice weevils as illustrated in fig. 6, were the higher rate of electric field strength whereas the the specified heat is 2.510 kJ/kg^{o}C and the density is 900 kg/m^3 [42]. In the seems that, the power absorption and electric field strength was calculated by equation 4 and 5, when the rice had the width, length, and height are 2-3, 5-12, and 2-3 mm, respectively. These were the dimensions selected to be calculated and the thermal temperature impact results of rice could be obtained.

3. The Simulation results

To study the heating efficiency in dielectric load for exterminating the pest's applications, the electric field distributions and intensity in electrode plates are considered by using the finite difference time domain method. The simulations of electric field distributions and excitation source in anode plate are divided into two cases, which are 1-port and 4-ports to compare the distributions efficiency. The parameters setup to simulation, as shown in Section 2, are specification of the electric powers which are varied from 50 W until the rice weevils reaching 100% mortality rates of rice weevils of eliminated times ranging between 1 s to 20 s. The results of the simulations illustrated in fig. 7 and 8 demonstrated the electric field distributions and electric flux density on the mixture dielectric load in the electrode plates of excitation sourced in 1-port and 4-ports, respectively. As showing that the cross section of mixture dielectric loads at Z-axis was 5 mm, (It's the habitat of rice weevils) and it used the eliminated time of 10 s as referred to fig. 6. The eliminated time of 10 s is the electric field strength at 110.8 V/m. The results of excitation source in 1-port was generated at the center of anode plate, the power watt at 0.960 kW and excitation source in 4-ports had the 0.530 kW of power watt that could be able to eliminate the rice weevils with the increase of mortality rate up to 100%. The radiation of electric field surrounded the dielectric load mortality rates of rice weevils were much faster than eliminate time.

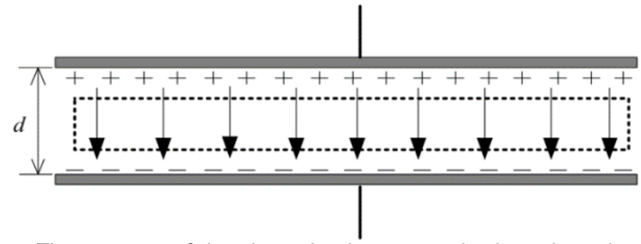

Fig.5. The structure of the electrode plates comprised anode and cathode, as considering the parallel capacitance.

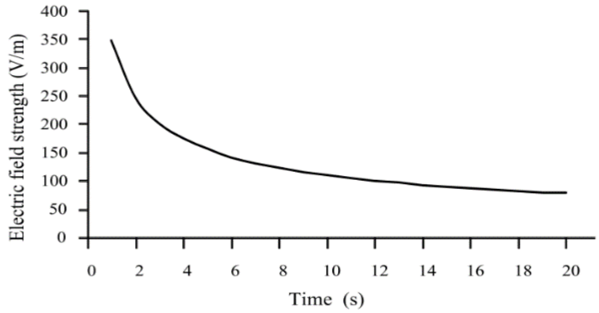

Fig. 6. The result of the electric field strength and period times to eliminate the rice weevils calculated.

In addition, the analysis dielectric heating of the thermal temperature impact in cereal, the rice as the targets dielectric materials for analyze of thermal temperatures. The researcher by Wang represents the individual specified heat and densities of the cereal areclosed to the excitation source then the electric flux density was directed to the rice weevils than the rice.

The excitation power watts and period times of the simulation were generated by excitation source in 1-port and 4-ports to eliminate the rice weevils with up to 100% of mortality rate illustrated in fig. 9. This suggested that the excitation source of 4-ports can be able to save more energies than the excitation source of 1-port. The result of the excitation power watts and mortality rate in eliminating the rice weevils during 5, 10, 15 and 20 s of excitation source in 1-port and 4-ports it was showing that the higher power watts, mortality rates of rice weevils which were much faster than eliminate time, such as, the percentage of mortality at eliminated time of 10 s illustrated in fig. 10, the input power watt was 0.300 kW, the mortality of rice weevils was approximately 28% and 53% with 1-port and 4-ports, respectively. Moreover, the input power watt increased to 0.530 kW, the mortality of rice weevils was approximately 48% and 100% with 1-port and 4-ports, respectively. It seemed that the excitation source in 1-port used more power than the excitation source in 4-ports, thus the excitation source in 4-ports was appropriate to the applications for the dielectric heating to exterminating pests since it can save more energies and cover the active area of heating.

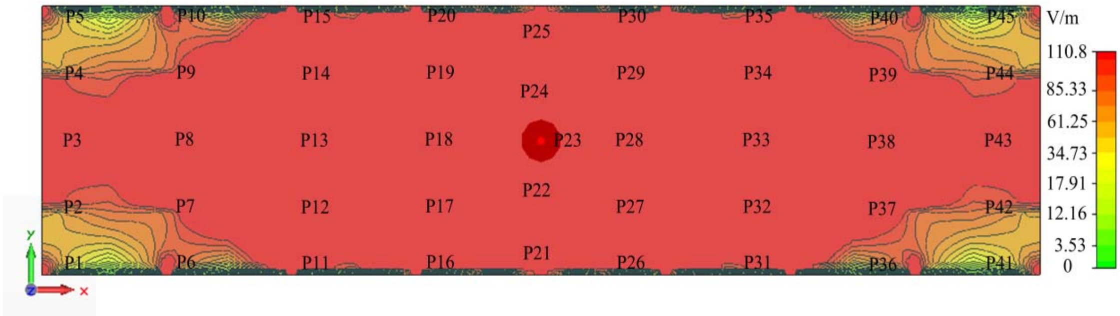

Fig. 7. Electric field distribution on dielectric load for excitation source in 1-port and the cross section of mixture dielectric loads at Z-axis equal to 5 mm.

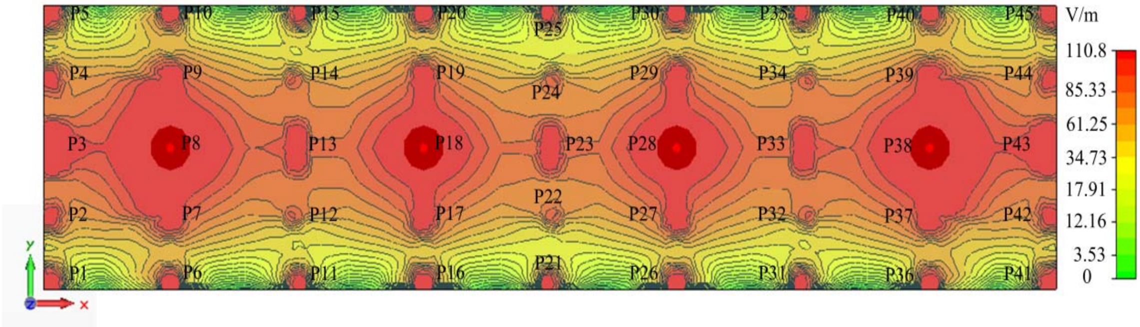

Fig. 8. Electric field distribution on dielectric load for excitation source in 4-port and the cross section of mixture dielectric loads at Z-axis equal to 5 mm.

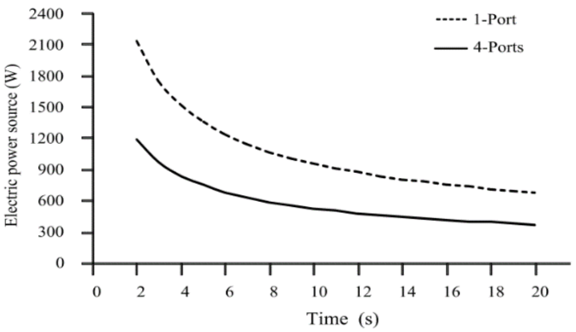

Fig. 9. The simulation of electric power source for the heating to period of time that the rice weevils are eliminated 100% of excitation source in 1-port and 4 ports

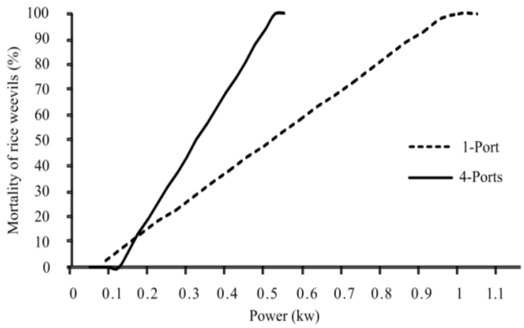

Fig. 10. The simulation results of the excitation source in 1-port and 4-ports to comparative mortality of rice weevil of 10 s with varying electrical power source

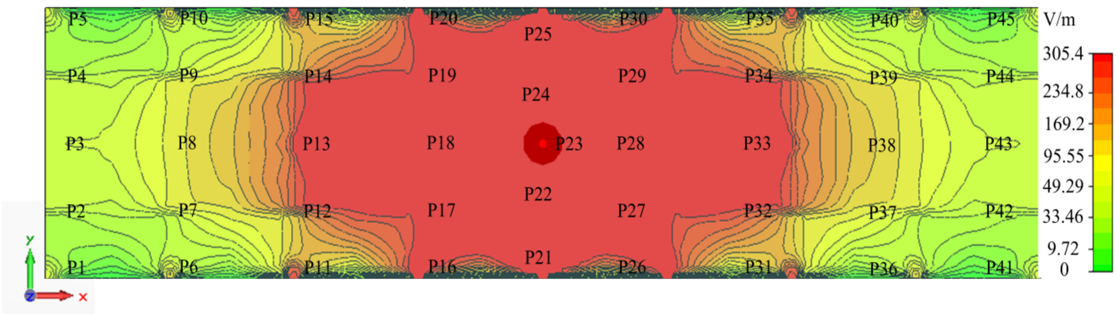

Fig. 11. Electric field distribution on dielectric load for excitation source in 1-port and the cross section of mixture dielectric loads at Z-axis equal to 5 mm.

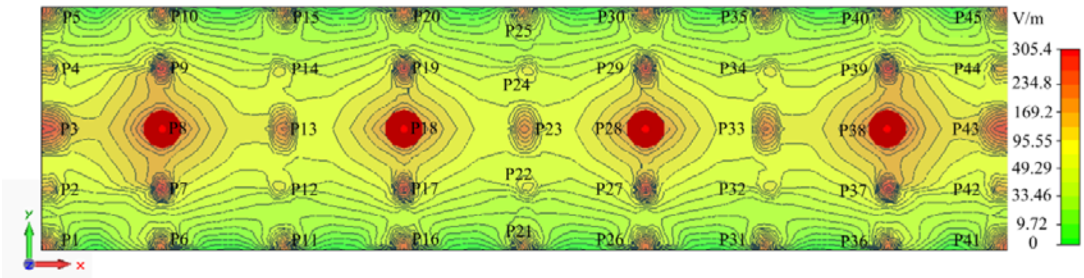

Fig. 12. Electric field distribution on dielectric load for excitation source in 4-port and the cross section of mixture dielectric loads at Z-axis equal to 5 mm.

To analyze the thermal temperature of rice, fig. 11 and 12 demonstrated the electric field distributions and electric flux density of excitation source in 1-port and 4-ports, respectively. As showing that the cross section of mixture dielectric loads at Z-axis was 5 mm, (It's the habitats near of the rice weevils) and elimination power watt was about 0.530 kW, the rice weevil was absolutely 100% mortal with eliminated time at 10 s. The maximum electric fielddistribution of excitation source in 4-ports, the dielectric load maximum of electric flux density was 305.4 V/m then the compression of the excitation source in 1-port as well as the electric flux density of rice became approximately 50% lower than in dielectric load. The increasing of electric flux density was affected by the thermal temperature of dielectric load was damaged. The results of fig. 13 and 14 represented the excitation source in 1-port and 4-ports when comparing between temperatures of rice at the differently eliminated time at 5, 10, 15 and 20 s with varying electric power watts. When the power watts increased higher, the eliminated time to increase temperature of rice was higher as well. However, the excitation source in 1-port had the highest thermal temperature. The compression of elimination time affected on increasing the temperature of rice at 10 s as illustrated in fig. 15. According to the figure, the input power watt was 0.300 kW, the temperature of rice was approximately 29^{o}C and 25.39^{o}C. At the same time, the input power watt of the excitation source in 1-port and 4-ports increased to 0.530 kW, the temperatures of rice was approximately 39^{o}C and 28^{o}C, respectively. However, when replacing the electric flux density as mentioned in Eq.4, the heating of power density in W/m^3 obtained and replaced the power density into the last term of eq.5, then the heating temperature unit per time was obtained in degree Celsius. For example, at 0.300 kW the maximum value of electric flux and density of rice was 263.12 V/m; in order to generate the power density to be 60.08 W/m^3, the temperature from rice needed to increase up to 29 ^{o}C.

4. The Heating Experiment and Measurement Results

As results of the dielectric heating, the effect of electric field distribution and intensity in the mixture dielectric loads was used for the electrode plates to create the electric field and transfer energy conversion to the power absorbed in the dielectric load. The rectangular plates can increase the area and control flowing rate through of pasts and grains in the plates to be heated suitably for agricultural industry applications. Furthermore, the symmetric of excitation source technique is suitable to produce the high efficiency of these applications. The higher of power watts and the eliminated time cause the higher temperature of dielectric load. The calculation and simulation results of the experiment and the measurement of the dielectric heating are presented in the next section.

To verify the calculation and simulation results of the dielectric heating, the system was constructed and tested, as illustrated in fig. 16. The components and parameters of dielectric heating system consisted of four parts which were excitation source, power amplifier, electrode plates, and dielectric load. The excitation sources were 1-port and 4-port inputs and resonant frequency of 39 MHz was generated. The power watts varying from 50 to 1000 watts were controlled by the high-power amplifier. In addition, the series LC resonance circuit, important to analyze the system efficiency, consisted of conductor (C), inductor (L), and resonant frequency. The conductor was composed with two electrode plates and the gap between the plates was filled up with the dielectric loads of rice and rice weevils. The parameters of electrode plates and dielectric load, illustrated in fig. 2, could be designs and calculated as in Equation 7. The calculation result found that the capacitor of electrode plates and dielectric loads were 30.10 pF and the inductor for matching had a value 27.553 nH as the resonance circuit was tested for setting up the dielectric heating. The construction of dielectric heating system was illustrated in fig. 17 and the arrangement of dielectric load was illustrated in fig. 17 (a). The rice weevils were placed at the center of plastic tube with diameter of 4.8 mm and array of 5 × 9 points to be set and placed between two electrode plates. The dielectric material of rice was dispersed around the plastic power of excitation sources investigated with a thermograph (FLIR SYSTEMS Model T360).

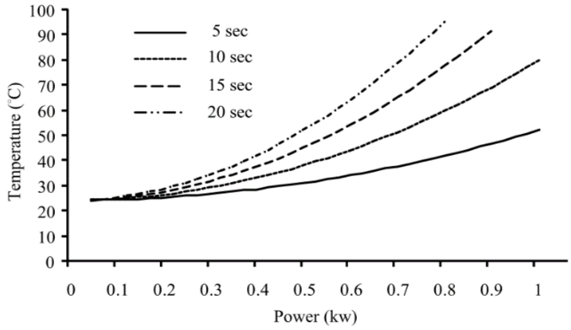

Fig. 13. The maximum temperature of excitation source in 1-port to comparative rice temperature of 5, 10, 15, and 20 s with varying power source.

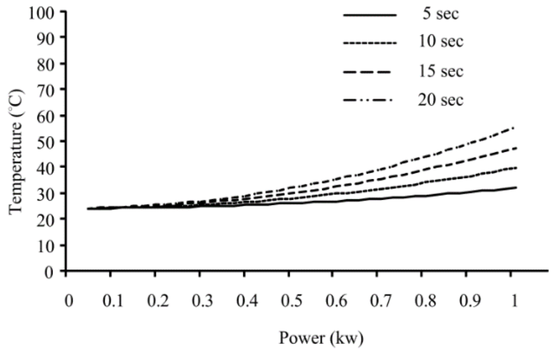

Fig. 14. The maximum temperature of excitation source in 4-ports to comparative rice temperature of 5, 10, 15, and 20 s with varying power source.

The experimental results, the mortality of rice weevils affected by excitation sources: 1-port and 4-port inputs, within the heating time of 10 s, and the electric power watts variably adjusted to control the heat was illustrated in fig. 18. The higher power watts increased were the higher mortality rates of rice weevils increased as well. For example, if the excitation sources of 1-port case power watt were 0.560 kW, the 50% mortality rates of tube, as illustrated in figure 17 (b). The result of thermal temperature distribution was observed for the dielectric load with period of heating time. The varied power watt increased to 960 kW then the mortality rate became 100%. However, the excitation sources of 4-port case with the power watt of 0.560 kW had 100% of mortality rates; this suggested that the excitation source of 4-port can save more energy than the excitation source of 1-port. The compression the temperature of rice in fig. 19, it was found that the higher power watts the higher the temperature increased as well. For instance, the input power watt was 0.300 kW, the temperature of rice was approximately 25.2^{o}C and 24.9^{o}C for excitation source in 1-port and 4-port powers, respectively, and the input power watt increased to 0.560 kW, the temperature of rice would be approximately 42.1^{o}Cand 30.1^{o}C, respectively. All above results can be confirmed that the dielectric heating for exterminating pests, using the rectangular plate to generate the electric field and flux with symmetrical technique.

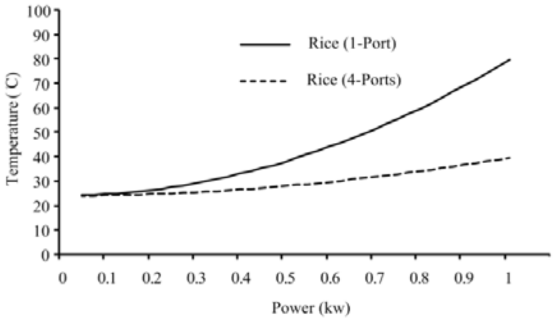

Fig. 15. The maximum temperature of excitation sources in 1-port and 4-ports to comparative rice temperature of 10 s with varying electrical power source.

5. Conclusion

In this paper, the effect of the distribution and intensity of electric field on the mixture dielectric loads for dielectric heating was presented. The electric field distributions caused the electric power varied to provide those pests with appropriate dielectric heating in cereal by radio frequency. Moreover, the Theoretical study results regarding the application of finite difference time domain method and experimental demonstration of the dielectric heating efficiency in exterminating pests and providing appropriate temperatures for grains without losing quality can confirm the effectiveness of the dielectric heating for exterminating pests by using the rectangular plate to generate the electric field and flux with symmetrical technique. The advantage of the method is that it can be utilized as the dielectric heating applications for exterminating pests and controlling the temperature of grains in the future.

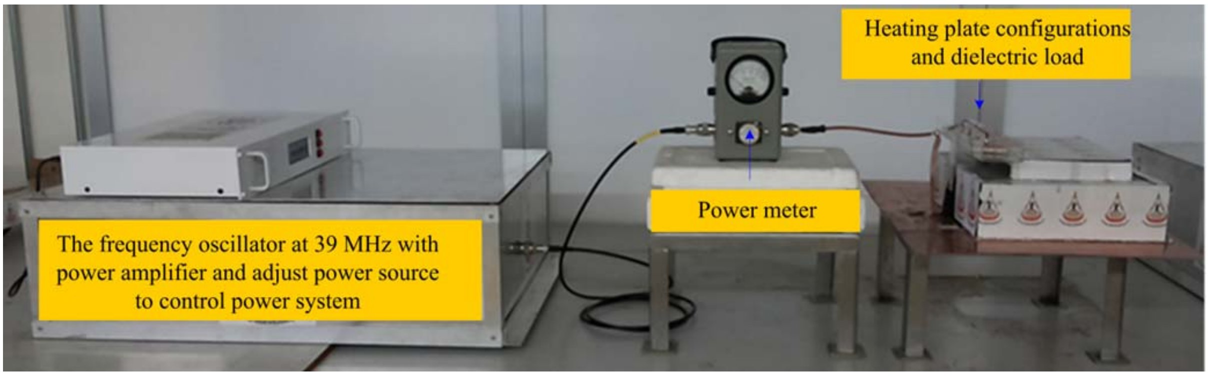

Fig. 16. Constructions of dielectric heating system to verify the numerical and simulation results, in the experiment of proposed system consists of the frequency oscillator at 39 MHz

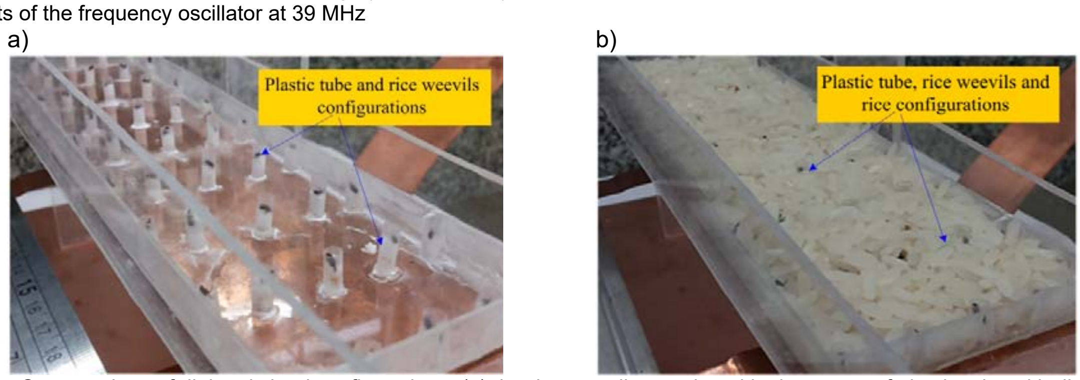

Fig.17. Constructions of dielectric load configurations, (a) the rice weevils are placed in the center of plastic tube with diameter of 4.8 mm and arrayed of 5 × 9 points (b) The dielectric material of rice is dispersed around the plastic tube

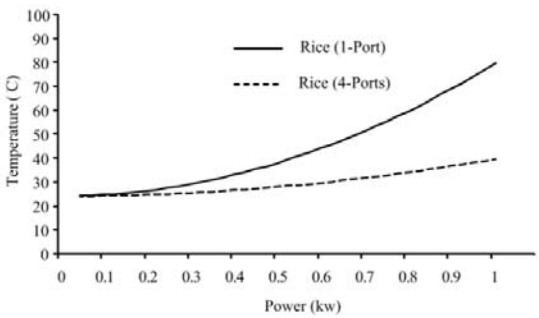

Fig.18. The maximum temperature of excitation sources in 1-port and 4-ports to comparative rice temperature of 10 s with varying power source.

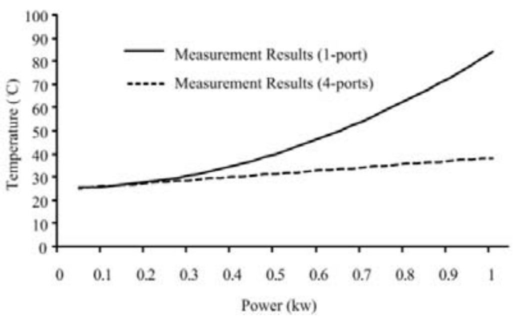

Fig. 19. The experimental and measurement results of the excitation sources are 1-port and 4-ports to comparative rice temperature of 10 s.

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