MODELING AND ANALYZING THE MICOWAVE ENERGY ABSORPTION OF PADDYAND MORTALITY ASSESMENT OF INSECTS

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MODELING AND ANALYZING THE MICOWAVE ENERGY ABSORPTION OF PADDYAND MORTALITY ASSESMENT OF INSECTS

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LIST OF ABBREVIATION

d.b.	Dry basis
DE	Dielectric Constant
FBD	Fluidized Bed Dryer
IBD	Inclined Bed Dryer
LT	Lethal Time
MADA	Muda Agricultural Development Authority
MARDI	Malaysian Agricultural Research and Development Institute
MC	Moisture Content
MOA	Ministry of Agriculture & Agro-based Industry
MUT	Material Under Test
MW	Microwave
NRW	Nicholson-Ross-Weir
RF	Radio Frequency
Rhd	*Rhyzopertha dominica* (F.)
RSM	Response Surface Methods
SCL	Short Circuit Line
SD	Standard Deviation
TDR	Time-Domain Reflectometery
TDS	Time-Domain Spectroscopy
HTST	High Temperature and Short Time

LIST OF SYMBOLS

E = Electric field intensity (Vm^{-1})

E_0 = Rms electric field intensity at a point of reference

c_p = Specific heat (kJ kg^{-1} $^0C^{-1}$)

Δt = Time duration (s)

ΔT = Temperature rise in the material (°C)

ε^* = Complex relative permittivity

ε' = Dielectric constant

ε'' = Dielectric loss factor

P_{abs} = Power loss density (Wm^{-3})

dp = Penetration depth (m)

T = Transmission coefficient

Γ = Reflection coefficient

M_{accum} = Total lethal time (min)

T_{ref} = Reference temperature (^0C)

$\tan \delta$ = loss tangent or dissipation factor

MEMODELKAN DAN MENGANALISIS SERAPAN TENAGA GELOMBANG MIKRO UNTUK PADI DAN PENILAIAN KADAR KEMATIAN SERANGGA

ABSTRAK

Di dalam tesis ini, satu model dielektrik padi dan serangga (R. dominica) telah dihasilkan untuk menganalisis ciri-ciri rawatan pemanasan elektromagnetik terhadap hasil padi jenis MR219 di Malaysia. Medan elektromagnetik di frekuensi yang rendah (< 1GHz) adalah signifikasi yang terbaik bagi memanaskan padi, kerana mortality sehingga 100% bagi serangga jenis *lesser grain borer* atau *Rhyzopertha dominica* (F.) dan jenis weevil dapat diperolehi dengan sedikit kehilangan kualiti beras apabila diberikan medan elektromagnetik yang sama. Tindakbalas elektromagnetik dari model dielektrik padi dan kelongsong dengan ransangan pandu gelombang telah dianalisis untuk mensimulasikan penyebaran medan elektrik. Kebergantungan suhu ciri-ciri dielektrik bagi *R. dominica* (F.) dan padi jenis MR219 dianalisis masing-masing untuk julat frequensi 200 MHz – 20 GHz dan untuk julat suhu 24^0 C – 65^0 C. Kaedah respon permukaan digunakan untuk menghasilkan suatu jalinan antara ciri-ciri dielektrik dan faktor berkaitan (suhu, frekuensi, dan kelembapan) dalam kawasan berkenaan dan juga dalam bentuk pandangan 3D. Persamaan umum yang menggunakan frekuensi, suhu dan kelembapan telah dihasilkan untuk menerangkan ciri-ciri dielektriknya. Simulasi gelombang mikro telah digunakan untuk memodelkan nilai kematian R. dominica dan S oryzae dalam bentuk suhu kematian per unit serapan tenaga. Cadangan model dielektrik dan analisis simulasi gelombang mikro bagi gumpalan padi di dalam kelongsong gelombang mikro telah disahkan dengan pemanasan gelombang mikro yang sebenar, dengan itu mengesahkan lagi ketepatan kaedah ini dalam mensimulasikan gumpalan padi pasca tuai heterogenous yang baru di dalam kelongsong gelombang mikro. Mortaliti dan serapan tenaga telah dianalisis dan dimodelkan dalam bentuk peningkatan suhu. Seluruh dunia inginkan pengurangan penggunaan racun serangga bagi tujuan kesihatan dan pemanasan gelombang mikro adalah cara yang paling efektif dalam rawatan pemanasan untuk mengawal serangga perosak dalam padi pasca tuai atau beras yang telah ditampi. Hasil nutrisi bagi padi jenis MR219 menunjukkan sampel yang dirawat menggunakan gelombang mikro adalah sama seperti yang tidak dirawat. Kualiti sensor dan ciri-cirinya tidak mengalami sebarang kesan dari rawatan tersebut. Di dalam model yang dihasilkan, kesilapan piawaian adalah kecil dan factor-faktornya (frekuensi, suhu atau kelembapan) menunjukkan suatu penambahan yang penting kepada model ini.

MODELING AND ANALYZING THE MICOWAVE ENERGY ABSORPTION OF PADDYAND MORTALITY ASSESMENT OF INSECTS

ABSTRACT

In this thesis, dielectric modeling of paddy and insect (*R. dominica*) was developed to analyze the characteristics for microwave heat treatment to the Malaysian paddy MR219. Electromagnetic fields at lower frequencies (< 1GHz) are of great significance for heating the paddy, because 100% mortality of lesser grain borer, *R. dominica* (F.) and weevil, *S. oryzae* may be obtained with minimal losses of rice quality when subjected to the same electromagnetic field. The electromagnetic behavior of the dielectric modeling of paddy and cavity with excitation waveguide was analyzed to simulate the electric field distribution. The temperature dependency of the dielectric properties of *R. dominica* (F.) and paddy MR219 were analyzed for the frequency range of 200 MHz – 20 GHz and for the temperature range of 24^0 C – 65^0 C. The response surface method was used to develop the relationship between the dielectric properties and related factors (i.e., temperature, frequency and moisture) in terms of regional and 3D views. General equations that utilize frequency, temperature and moisture, were developed to describe the dielectric properties. Microwave simulation was used to model the lethal value of *R. dominica* and *S. oryzae* in terms of lethal temperature per unit absorbed energy. The proposed dielectric modeling and microwave simulation analysis of bulk paddy in the microwave cavity were validated with the actual microwave heating, thereby confirming the accuracy of this approach in simulating the novel heterogeneous post-harvest bulk paddy inside the microwave cavity. Mortality and energy absorption were analyzed and modeled in terms of increasing temperature. The world-wide interest in reduced pesticide use for secure health and microwave heating is the possible effective means in heat treatments to control insects in post harvest paddy or milled rice. The nutritional results of paddy MR219 showed that the microwave-treated samples are significantly the same as the microwave untreated sample. Sensory qualities and characteristics were not affected by the treatment. In the modeling, standard errors were small and factors (i.e., frequency, temperature or moisture) proved a meaningful addition to this model.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Rice - (*Oryza sativa* L.) - is the most important staple food crop in the world and it is a major commodity for international and domestic trade. However, rice production paddy and milled rice are adversely affected by many insects and fungi, destroying the viability, nutritional quality and rendering them useless for the rice production. The dielectric properties of agricultural or biological materials are of significant interest in the research field related to the microwave or radio frequency (RF) processing of agricultural commodities and food. Electromagnetic heat treatment method leaves no chemical residue on the commodities, ensures acceptable quality of the commodities, and causes minimal impact on the environment (Tang et al., 2000). Many studies have explored the feasibility of using electromagnetic energy to eliminate insects from various agricultural commodities. Andreuccetti et al. (1994) reported on the possibility of using 2450MHz microwaves to kill woodworms by heating the larvae to 52–53 ^{0}C in less than 3 min. Treatments were developed using microwaves to control codling moths in cherries (Ikediala et al., 1999), RF energy to control the codling moth (Wang et al., 2001) and navel orangeworm (Wang et al., 2002c) in in–shell walnuts, all with acceptable product quality. Wang and Tang (2004) summarized research on the application of RF and microwave treatments to kill selected pests in many postharvest crops. Wang et al. (2007a, b) analyzed the industrial-scale radio frequency treatments for insect control in walnuts, insect mortality, heating uniformity and product quality. Marra et al. (2009) reviewed the recent advances to post-harvest treatment and disinfestations of fruits using radio frequency. However, none of these studies have focused on the control of insects in rice production paddies or in stored rice.

Several researchers used fundamental kinetic model to describe thermal kill of insects (Wang et al., 2002a, c). Empirical model was also used to estimate the lethal time for codling moth (Jones and Waddell, 1997) and for fruit fly (Waddell et al., 2000). Mortality of insects depends on temperature of bulk paddy when infested paddy subjected to microwave environment. Microwave heating ability is higher if moisture of paddy increases (Jasim Ahmed et al., 2007), indicating the higher mortality of insects can be achieved. Therefore, Microwave simulation and dielectric modeling of bulk paddy can be described the lethal region of lesser grain borer (*R. dominica*) and rice weevil (*S. oryzae*), in terms of electric field and power loss distribution. There are few literatures on heterogeneous substance to estimate the electric field intensity and power loss density inside the cavity. Dev et al. (2010), Calò et al. (2008) and Plaza et al. (2007) followed similar approach to simulate and estimate the electric field intensity and power loss density in a cavity, whereas there models did not take into consideration the bulk heterogeneous substance like paddy sample. Besides, they did not consider thermodynamically changing properties, porosity and moisture.

The product quality after microwave treatments is rarely examined (Ikediala et al. 1999, Wang et al. 2002a, Wang et al., 2007a, b). Hence, dielectric modeling of paddy will elucidate the internal heating mechanism and provide the basis for further development and advancement of appropriate protocols for the use of microwave treatment for insect control.

1.2 Problem Statement - Electromagnetic Heat Treatment is the Possible Effective Mean

Microwave heating is the possible effective means in heat treatments to control insect pests in post harvest paddy or milled rice. The microwave energies directly interact with commodities interior to quickly raise the centre temperature. Electromagnetic heat treatment is a new thermal method for post-harvest treatment of agricultural commodities. This method leaves no chemical residue on the commodities, ensures acceptable quality of the commodities, and causes minimal impact on the environment (Wang et al., 2001). Hence, determining the dielectric properties of paddy and insect pests will clarify the internal heating mechanism and provide the basis for further development, improvement, and scale-up of appropriate protocols for the use of microwave treatment for pest control. Frequency-temperature mapping with respect to dielectric properties will show the susceptibility of insects to heat and provide important information for selecting the optimal ranges for the frequency-temperature relationship (Wang and Tang, 2004). Many studies have explored the feasibility of using electromagnetic energy to eliminate insect pests from various agricultural commodities. However, very few of these studies have focused on the control of insect pests in rice production paddies or in stored rice.

1.3 Objectives

1. Analyze the behavior of the dielectric properties of paddy with resonance frequencies and coaxial probe technique. Then, model the temperature–frequency relationship with the dielectric properties of both Malaysian paddy MR219 and *R. dominica* (F.) to acquire optimal mapping.

2. Apply the electromagnetic heat to the infested paddy; quality assessment of microwave-treated infested paddy that ensures the physical and nutritional acceptance. Then, analyze the cumulative effect of ramp period, holding period and mortality of insects.

3. Microwave simulation model of the heterogeneous complex geometry like that of bulk paddy in the microwave cavity. After that, Energy absorption and lethal region modeling of lesser grain borer, *R. dominica* (F.) and weevils, (*S. oryzae*).

4. Experimental evaluation to validate the dielectric modeling, simulation of the bulk paddy in microwave cavity and proposed lethal region modeling.

1.4 Research Scopes to Control Insect Pests in Agricultural Commodities

The thermal death kinetics of many studies has been conducted to explore the feasibility of using electromagnetic energies to control insect pests in agricultural commodities. But still has not focused effectively on post harvested paddy and milled rice insects.

Higher heating rate should provide greater mortality (smaller lethal time) because of a lack of non-lethal temperature conditioning of the insects (Wang, 2001). Reversely, holing time must be minimized. Therefore, the frequency rate needs to be increased that may kill insects which ensure the minimal impact on product quality. It is reported that higher microwave (2.45 GHz) is very effective and need very less time and temperature to heat the agricultural commodities, without significantly reducing the product quality (Kraszewski and Nelson, 2004).

The marketability of treated commodities depends upon their quality. There are few research has reported the quality of microwave exposed commodities. Insect pests are much more sensitive to increase in treatment temperatures than most fruit quality aspects. Janhang et al. (2005) controlled the insect *Rhyzopertha dominica* (F.) during Storage in Rice Seed (*Oryza sativa* L.) but the quality of seed was reduced.

The proper design of Microwave heat treatment is very important for quality control of agricultural commodities. Because the activation energy for quality changes in agricultural commodities is generally smaller than that of insect mortality (wang, 2001), so if the exposed energy to the commodities is not properly distribute then the quality may be damaged. Therefore uniform electromagnet field is necessary in microwave heat treatment apparatus.

Previously no research has been conducted to control the insect pests in post harvested paddy and milled rice. However, new research is needed to develop an electromagnetic heat treatment protocol which determines the suitable temperature of the electromagnetic heat treatment in order to gain sufficient elimination of insects, without significantly reducing the viability of the post harvested paddy and milled rice.

1.5 Methodology

Samples were prepared for dielectric property measurement of paddy and *R. dominica*. Then empirical modeling of the dielectric properties was done in terms of frequency, temperature and moisture. This dielectric modeling was then used to simulate the low loss heterogeneous dielectric medium (bulk paddy) in microwave cavity, and to model the lethal region of *R. dominica* and *S. oryzae* in terms of energy absorption. Figure 1.1 shows the flow chart of methodology.