SHF AND EHF MICROWAVE RADIATION AS A PESTICIDE ALTERNATIVE FOR STORED PRODUCTS

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The search for an operating frequency which would lead to the enhanced selective heating of insects in the SHF and EHF range is motivated by the need to develop alternatives to certain important agricultural chemical pesticides for the treatment of stored products which are to be banned by the Clean Air Act by the year 2001. Operation at discrete frequencies in the microwave and millimeter wave ranges, including Industrial Scientific and Medical (ISM) frequencies (specified in CFR 47, part 2), is attractive because of the availability of recently developed high-power oscillators with high continuous outputs and efficiencies at those frequencies. Unlike the relatively low-power microwave and lower frequency heaters, operating at frequencies ≤ 2.45 GHz, the SHF and EHF high-power sources offer the possibility of continuous processing of the treated-product at high throughput rates while taking advantage of the inherent electromagnetic shielding inherent in the waveguide-like piping or ducting systems that is common in transport systems at grain storage facilities. Proof-of-principle experiments indicated that selective heating of the insect increases at frequencies above 2.45 GHz and is not limited to frequencies below 1 GHz (Nelson and Stetson 1974). Further analytical studies predicted that microwave energy at high power levels and frequencies in the SHF and EHF bands will produce increased selective heating and lethal effects on insects in stored products efficiently and economically. Halverson et al. (in press), concluded that selective heating of the insect increases at frequencies above 2.45 GHz and that relaxation processes associated with free water in the insect and increased energy transfer could account for the observed effect. An analytical study, based on the test results, predicted that one maximum in the insect-to-grain dissipation ratio in selective heating of the maize weevil (*Sitophilus zeamais* Motschulsky) adult (Halverson et al. 1995) would occur in the vicinity of 15 GHz and others at higher frequencies as shown in Fig. 1.

Recent tests were conducted at SHF at 12, 15, 17.9 GHz and at EHF at 55 GHz on samples of soft white wheat *Triticum aestivum* (L.), infested with adults and larvae of *S. zeamais* to provide better frequency resolution of the predicted phenomenon and to validate the model predictions. Uninfested wheat was also exposed to determine if germination was affected by exposure to energies at the level necessary to produce high mortality. The highest frequency was selected because of the availability of the 55 GHz source and because it was in an EHF range where low-power microwave network analyzer measurements indicated that the loss factor for *S. zeamais* was much greater than for soft white wheat. Replicated samples of adults and two age stages of larvae were exposed to microwave radiation in an untuned cavity to determine the mortality of the various ages as a function of input energy and the resulting product temperatures. The results indicate that 15 GHz produced the greater mortality among adults as a function of input energy than at 12 and 17.9 GHz but that 55 GHz produced the greatest mortality for the three age groups studied (Halverson et al., 1996). Plots of the maximum temperature at the 90 % mortality level of each age group, with frequency as a parameter, are shown in Fig 2(a). This plot shows that 15 and 17.9 GHz produced higher mortality than that at 12 GHz for all ages, with 15 GHz being the most effective for adults of the SHF frequencies studied, and that 55 GHz produced that mortality at the lowest temperature at all ages. No significant statistical difference between effects on adults and older larvae was noted at any frequency. A similar plot for the specific input energy, defined as at the 90 % mortality level is shown in Fig 2(b). In this case specific input energy, defined as the quantity U_{in} / m (where: U_{in} is the energy input to the applicator, and m is the sample mass) was plotted at each frequency. (This may be converted to the specific energy delivered to the sample per unit mass (U_{load}) by multiplying by the energy coupling coefficient (k). In this test the average value for k varied from 19 to 27 %). The specific input energy at 12 GHz was the highest with lower and statistically similar values at the other frequencies.

The power levels of the 12 to 55 GHz tests were different at each of the frequencies. Therefore, subsequent tests were performed for these age groups at 14.25 GHz at four different input power levels and exposure times at constant input energies to determine the dependency of mortality on those factors. Preliminary results indicate that mortality may be a nonlinear function of power level and exposure time.

The germination of wheat was only affected slightly, even at the highest energy levels used in these tests. A minimum mean value of 84 % occurred at 12 GHz and a maximum mean value of 89 % occurred at 17.9 GHz over the entire range of temperatures and energies in these tests. This slight degradation in the germination of wheat, at high levels of insect mortality, is believed to be acceptable.

In the most recent tests, the complex dielectric properties of samples of uninfested soft white wheat, wheat infested with larvae of each of two age groups and adults of *S.zeamais* and *Tribolium castaneum* (Herbst) were also measured with a microwave network analyzer over a frequency range of 18 to 75 GHz in an effort to determine frequency where the insect-to-grain loss factor ratio maximizes and to further validate the model used to obtain Fig. 1. Preliminary results indicate that a maximum greater than 20:1 occurs in the frequency range between 24 and 35 GHz, somewhat greater than the model predictions. Therefore, greater selective heating is expected in that range. Both the ISM frequency of 24.125 GHz and the existing 28 GHz gyrotron are within this band and are being considered for use in a practicable system. High-power (200 kW, continuous) gyrotron tests at 28 GHz, under simulated dynamic product conditions, are planned for October 1996. Preliminary results will be reported at this meeting.

References Cited

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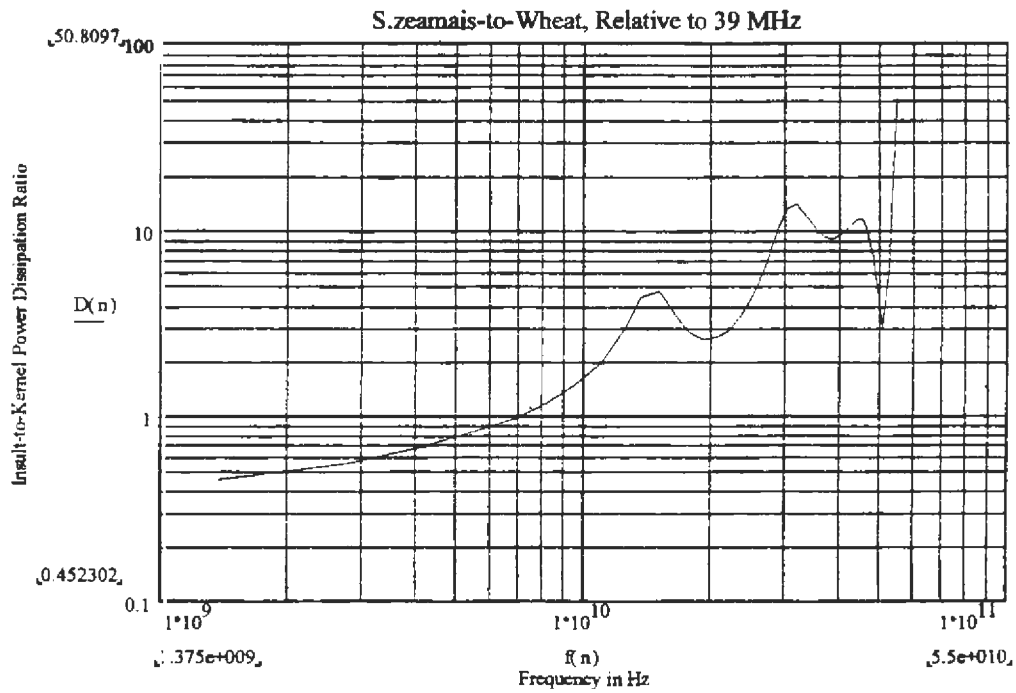
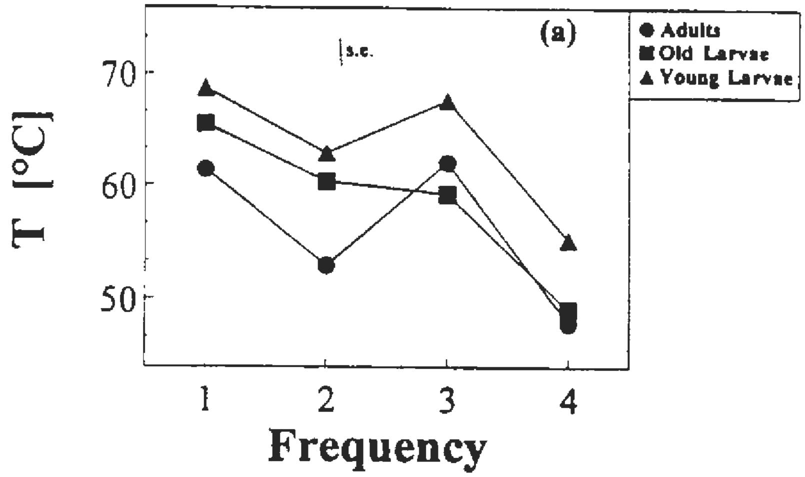


Fig.1. Analytical model plot of *S. zeamais* adult Insect-to-grain Power Dissipation Ratio, D(n), as a function of frequency f(n), n = 1.375 GHz to 55 GHz, normalized with respect to D(n) at n = 39 MHz.



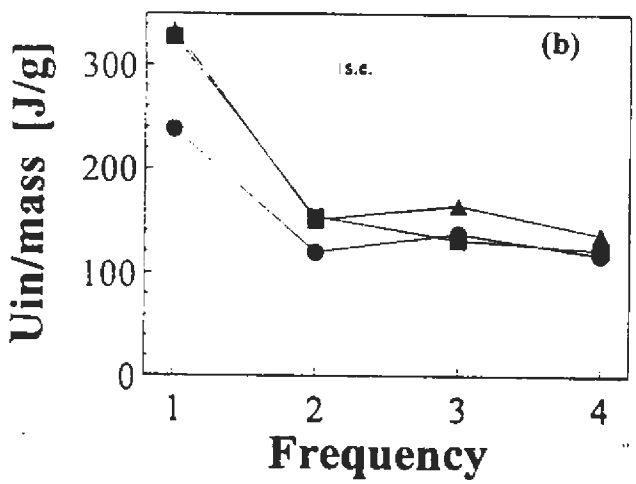


Fig. 2. Plots of maximum temperature (a) and specific input energy (b) needed top achieve ninety percent mortality at (1)12 GHz, (2) 15 GHz, (3) 17.9 GHz, and (4) 55 GHz. Values plotted are least square means based on logistic fits to the data. Values are plotted versus frequency for each age group. The lines labeled s.e. are estimates of the standard error for each point. The errors for the points at 55 GHz. are double that shown.