ADVANCES IN THE USE OF EHF ENERGY AS A FUMIGANT FOR STORED PRODUCTS

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Summary

During the past year studies of the effectiveness and economics of controlling stared-gram insects with microwave energy at specific frequencies above 1.0 GHz have continued. This range of frequencies was previously believed to be less effective than frequencies in the 10 to 100 MHz range (Nelson and Stetson 1974; Nelson et al. 1996). Based on recent tests Halverson et al. (1997) and Plarre et al. (1997) concluded that selective heating of the insect increases nonlinearly at frequencies above 10.6 GM and that relaxation processes associated with free water in the insect and increased energy transfer at frequencies > 24 GHz would produce enhanced selective heating since the stared cereal gains contain only water in the bound form- Recently both dynamic (continuous process) and static (batch process) tests were conducted at 28 GHz at the Oak Ridge National Laboratory (ORNL) Fusion Engineering Division's 200 kW microwave test facility on samples of soft white wheat, *Triticum aestivum* (L.), infested with adults and larvae of the maize weevil, *Stiophilus zeamais* Motschulsky It was intended to demonstrate the practicability of continuous processing of stored products at high mass flowrates.

The dynamic tests were conducted to verify that control of the air-to-product volume ratio in a detuned resonant cavity applicator would result in deeper penetration of energy into a diffused dynamic flowing product and to determine the relationship between energy, product temperature, and insect mortality in the flowing product. A prototype applicator to treat the infested dynamic product was designed and constructed for treatment at a frequency of 28 GHz A means of controlling the volume ratio of the product in the applicator was provided and hence the depth of penetration of the flowing bulk product could be controlled. Exposure time in the prototype applicator was determined by the length of time for a single gram to fall under the force of gravity through the I in long applicator Tea samples were released from a test hopper and flowed through a detuned resonant cavity applicator where they were exposed to the microwave energy for the fixed 600 ms time-of-transit period and then collected in a sample holder at the output. The results indicated 100 % kill of adults, pupae and old larvae, and >99% of the young larvae and eggs over a minimum energy range per unit mass of product over a range of ~ 20 to 75 J/g at minimum product temperatures of ≤ 36 °C, ~ 44 °C and ~ 52 °C as shown in Figs. 1(a) and 1(b). A comparison of the dynamic 28 GHz adult mortality at 7d versus temperature data with that of static tests at 39 MHz at 8 d (Nelson and Stetson 1974) for adult rice weevils indicates that mortality at 28 GHz as a function of maximum gram temperature for the adult maize weevils appears to be identical within the statistical variance of the data. However, Since the load energy was not reduced to the level where 50% mortality occurred, the dynamic test could not demonstrate clear superiority to the 39 MHz case. No comparisons of mortality as a function of load energy could be made because comparable published data at 39 MHz were not available.

For the static tests at 28 GHz where exposure time was variable, a -3 dB thick layer of product (7 mm) containing capsules of infested soft white wheat was exposed for various periods of time from 250 ms to 2 s to determine the relationship between mortality and exposure time at various input energies. The results shown in Table 1 confirmed that energy was the dominant factor in determining mortality for exposure times as short as 500 ms. It also indicated that the knee of the logistic mortality curve for the 7 d adult mortality was lower than temperatures reported by others at 39 MHz. This supports the thesis that coupling to the five water in the insect is a more efficient way of transferring energy than by coupling to bound water.

In both dynamic and static treatment at 28 GHz the adults and older lam are killed more easily at lower input energies and lower product temperatures than the younger lam This implies that in the am of adults and older larvae the dominant energy transfer mechanism to the insect is by direct radiation rather

than indirectly by conduction from the heated product. In the case of the younger larvae radiation coupling may be diminished because of its much smaller cross section and the shielding effects of the wheat kernel in which it resides. Nevertheless exposure times of 600 ms were sufficiently long to kill the larvae but required greater energy input to do so with resulting higher product temperatures Older lame are also somewhat shielded by the kernel but less than the younger because the older larvae have already excavated most of the inner matter in the kernel and thus are only shielded by a very thin layer. In actual treatment at a storage facility, in order to keep energy requirements at a minimum, it is advisable to IMP a two stage treatment where the adults and older larvae would be killed in the first treatment followed by a later identical treatment at a time before the young larvae surviving the first treatment emerge as adults.

Ancillary static tests were performed at the University of Wisconsin at Madison on the Computer and Electrical Engineering Department's 14.25 GHz facility (Plarre et al. 1997) to verify the relationship between exposure time and mortality at a constant energy input. This test also involved exposure of samples of soft white wheat infested with maize weevils. The exposed samples were observed for mortality over a 35 d period. The results indicated that exposure time, expressed in terms of a kAt/m ratio, has a lower limit in producing a high mortality with low variability A comparison with data taken in the static test at 28 GHz indicates that the minimum exposure time appears to be correlated with microwave power coupling efficiency, and therefore may be facility and frequency specific. Hence, for the constant energy case mortality appears to be a nonlinear function of exposure time once the lower exposure time limit has been reached. This limit was unique for each of the two test facilities and protocols studied here.

One-way path attenuation teas were conducted recently on dynamic samples over a range of 18 to 50 GHz to validate previous calculations of increased penetration for the dynamic state. This provided a direct measure of the depth of penetration of a singly traveling wave through the flowing product over a path length of 10. 16 cm. Three replicates of cultivars of hard red wheat, soft white wheat and brown rice were tested in the dynamic state over each of three swept frequency ranges, 18 to 26.5 GHz, 26.5 to 40 GHz and 33 to 50 GHz and the one-way path attenuation between transmitting and receiving horns was measured directly Prior to the direct measurement, penetration depth had been inferred from measurements of the dielectric properties of the bulk product by using the Landau, Lifschitz and Looyenga equations for dielectric mixtures. The depth of penetration was then calculated from the attenuation constant for a specified air-product mixture. The direct measurements of soft white wheat were in agreement with the calculated values and demonstrated the random complex scattering properties of the flowing mass. Initial results indicate average penetration depths of ~ 30 cm were achieved at 28 GHz for volume ratios ~ 4 %. It was also noted that both scattering and absorption occur within the flowing product and that it tends to act as a mode stirrer thus leading to greater field uniformity within the applicator. The microwave energy within the detuned cavity applicator may be thought of as a photon gas fumigant.

The coupling between the gyrotron and the treated product in a dynamic state is greater than for the static mass as determined by the calculated coupling coefficient. implies greater system efficiency in dynamic treatment and consequently indicates the practicability and advantages of continuous processing of a diffused infested product. By taking the advantage of the extremely high continuous power generation of the gyrotron, the process throughput rate can be increased substantially thereby eliminating the limitations of batch processing at lower powers.

As a consequence of the results obtained in these tests, the prototype dynamic test facility will be modified to permit processing at a rate of 4 1/2 to 9 kg/s. Preliminary, design of the modified facility has already been undertaken to achieve this. Successful completion of a dynamic test on the modified facility is a necessary precursor to the development of a demonstration facility capable of processing at a rate required by a typical storage Facility by the year 2000. Efforts are also being undertaken to adapt the applicator to the treatment of a processed product. such as mined grain.

Table 1. Linear mortality curve fitting for the variables of load energy per unit product, m and time/mass, static test at 28 GHz

Age	$M(U_{load})$% $22 \le U_{load} < 44$ J/g	$M(T_{max})$ $35 < T_{max} \le 46$ °C	$M(\Delta t)$ at U'_{in}= constant) $414u < k\Delta t/m \le 6.63$ m [s/g]
Young larvae	$0.28\ U_{load} + 84.4$	$0.57T_{max}+70.23$	$2.23k\Delta t/m+84.4$
Older larvae	100	100	100
Adults	100	100	100

where:

$U^1_{in} = U_{in}$ / m [J/g] is the specific energy input in terms of U_{in} per unit mass of product

$U_{load} =\ kU'_{in}$

$C\Delta T$ [J/g] is the amount of energy delivered to the sample per unit mass

$k=Cm\Delta T/U_{in}$ is the cowling coefficient

$U_{in} = P\Delta t$ [W-s] or [J]

m is the measured sample mass in grams [g]

Δt is the measured exposure time in seconds [s]

T_{max} is the measured maximum sample temperature in °C

P is the measured input power in watts [W]

C is the specific hat of soft white wheat

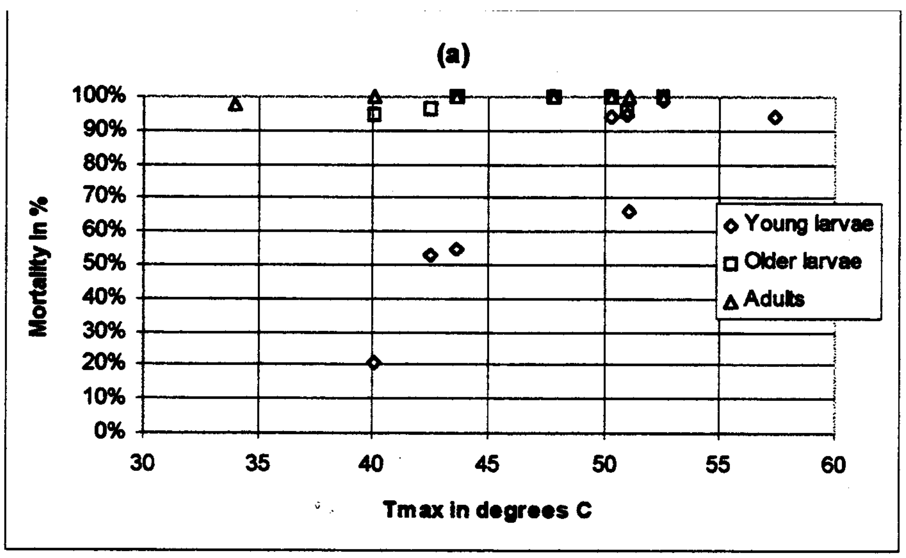

Fig 1(a). Mortality of maize weevils in soft white wheat in the dynamic test at 28 GHz versus maximum product temperature T_{max}.

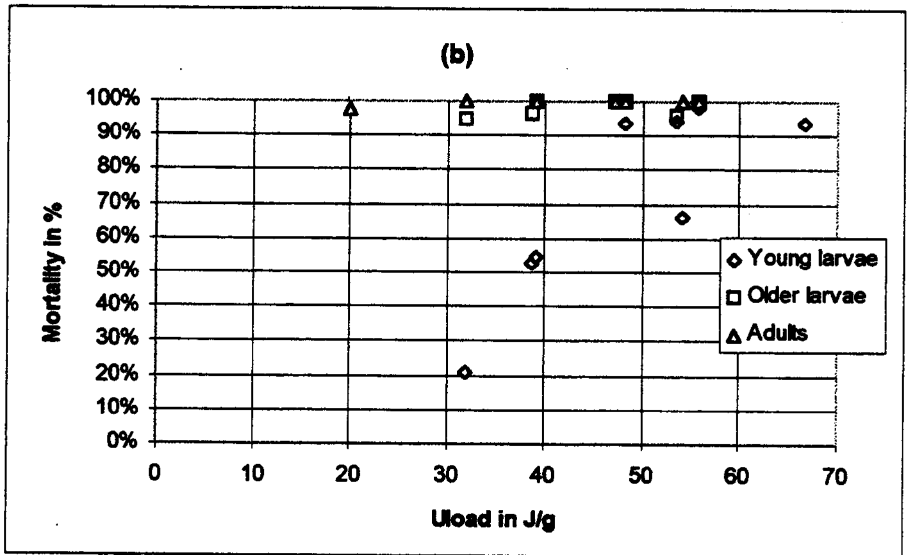

Fig I(b). Mortality of maize weevils in soft white wheat in the dynamic test at 28 GHz versus U_{load}.

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