Insect-Control Possibilities of Electromagnetic Energy[1]

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ANYONE TROUBLED WITH product losses because of insects is well aware of present-day concern about environmental contamination and pesticide residues. Manufacturers of food products must exercise particular care to keep such chemical agents out of their finished products. Yet, insect fragments and contamination must also be kept at low levels, and consumers are becoming even more demanding in this regard. New ways of controlling insects without any possibility of chemical contamination are, therefore, of real interest. For this reason, various kinds of electromagnetic energy have been considered for insect control. It is the purpose of this paper to review the findings that may be of general interest in the milling and baking industries and to explain briefly the nature of such possibilities.

The Electromagnetic Spectrum

First of all, some general background information on electromagnetic energy may be helpful. Figure 1 is a chart of the electromagnetic spectrum. The different kinds of radiation making up this spectrum are shown, along with their characteristic quantum energies, frequencies, and wavelengths. All types of electromagnetic energy travel through free space as waves with the velocity of light, about 3×10^8 m./sec. Frequency, ν, and wavelength, λ, are related as $\lambda\nu = c$, where c is the velocity of light in vacuum (free space). The energy, E, associated with each photon, or quantum of electromagnetic energy, is $E = h\nu$, where h is Planck's constant, a fundamental constant of 6.625×10^{-27} erg-sec. Thus, the quantum or photon energy is directly proportional to the frequency and inversely proportional to the wavelength.

It is the differences in quantum energy or other wavelength-related characteristic which make electromagnetic energy from certain ranges of the spectrum seem different from one another. Photons in the visible region of the spectrum have proper energy levels to excite receptor cells in the retina of the eye and are, therefore, perceived as light. Energy of infrared radiation is absorbed on the surface by the human body and sensed as it is converted to heat energy. Human senses do not generally detect the longer wavelength radio waves or the shorter wavelength ultraviolet and X- and gamma radiation, but such kinds of energy are absorbed by the body and can be dangerous since we are not directly aware of them.

Intense light or infrared radiation can be damaging, but we are aware of the presence of these types of energy. Intense radio-wave fields, particularly at microwave frequencies, can cause physical damage to humans through internal heating and possibly through other mechanisms. Everyone is familiar with sunburning as a result of too much ultraviolet exposure. The high-energy X- and gamma radiations are very penetrating, and the quantum energies are sufficiently high that they produce ionization in body tissues, which may have severe consequences if safe exposure levels are exceeded.

With this background, let us consider insect-control possibilities with these different kinds of electromagnetic energy. Detailed reviews have been published on insect control in general through use of electromagnetic energy (1,2,3). This brief review will, therefore, be limited to those insect species of concern in the baking and milling industries, principally stored-product insects. For greater depth and technical detail, the reader is referred to an earlier review (3).

Ionizing Radiations

Starting at the high-energy end of the spectrum,

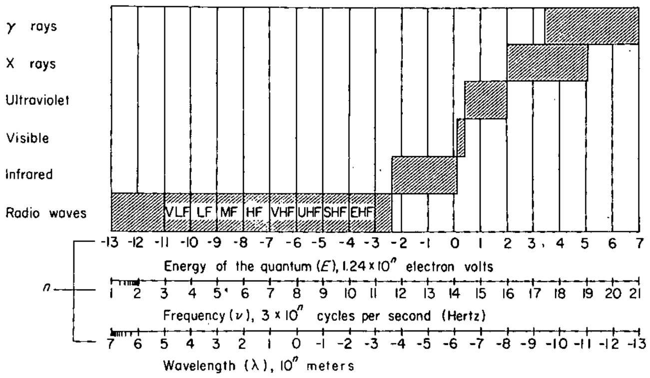

Fig. 1. Chart of the electromagnetic spectrum showing associated quantum energies, frequencies, and wavelengths for the various types of radiation.

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consider first the ionizing X- and gamma radiations. X-rays, which are produced by bombarding a metal target with a beam of electrons in a vacuum tube, are used as an important diagnostic tool in many familiar ways. X-rays have also been useful in detecting hidden insect infestations in grain. The sterilizing and lethal effects of X-rays on insects have been studied extensively. Since X-ray production is inefficient and expensive, practical use for insect control has never held much promise. Gamma radiation, which produces the same effect, has been more interesting because it is abundantly available from certain radioisotopes. Gamma sources, while still expensive, can be produced to handle irradiation of large quantities of material. Electron accelerators can also be used to provide ionizing radiation in the form of electron beams which will control insects with about the same effectiveness as gamma rays.

Extensive studies on the possible use of gamma radiation for controlling stored-grain insects have been reported (4). Generally, two approaches have been considered. One method is to irradiate infested material with a radiation dose sufficient to kill all insects present. The other approach is to use a lower radiation dose, which will result in reproductive sterilization of the insects. Release of sterile males, the principle which worked so successfully in controlling the screwworm, has also been considered for stored-grain insect species, but does not appear very promising for these kinds of insects.

Studies have revealed differences in susceptibility of different species and developmental stages of insects to control by ionizing radiation. A dosage of 16 kilorads was found effective for controlling most species of stored-grain insects through complete sterilization of the population treated, but some of the lepidoptera species require a higher radiation dose for control. A dosage level between 20 and 30 kilorads would probably be required to control all stored-grain insect species which might be encountered. A dose of 25 kilorads was effective for sterilizing several species in other studies (5).

The basic information needed to put ionizing radiation to use for insect control in grain has been pretty well determined. Such methods appear to be completely workable. The U.S. Food and Drug Administration has approved prescribed gamma radiation for use in treating wheat and wheat flour. The reason it has not been put into practice is principally an economic one. Chemical controls have been doing the necessary job cheaper. We cannot expect to see much more developmental work on radiation treatment for insect control in grain unless regulations controlling the use of chemicals become more restrictive or unless the costs of radiation treatment equipment and facilities become more competitive.

Research on insects infesting dried fruit has shown that ionizing radiations can also control insects without producing any damage to these products (6). A 40-kilorad treatment was found effective, and, while treatment of such products does not now have FDA approval, this dosage lies within the 20- to 50-kilorad dose approved for wheat and wheat flour.

Ultraviolet and Visible Radiation

Down scale from the X-ray region, in respect to quantum-energy, is the ultraviolet region; and just below this lies the region of visible radiation. Ultraviolet radiation, often called blacklight, has been used to detect contamination in cereal products because rodent excreta and some other contaminants fluoresce under ultraviolet illumination. Principal interest in using visible and ultraviolet radiation for insect-control applications has centered on the use of such radiant energy to attract certain insect species. Many nocturnal moths are strongly attracted to sources of light and ultraviolet radiation. Numerous studies have shown that "vision" for insects extends to much shorter wavelengths than it does for humans. The visible range for the human eye extends from about 380 to 770 nm. (violet to red light), but the sensitivity of insect eyes extends into the ultraviolet region. The wavelength most attractive for some insects is about 360 nm. in the near ultraviolet. Experiments with stored-grain insects have shown that the Indian-meal moth responds to that wavelength region. Some other species which were attracted by this wavelength responded better to 500-nm. radiation.

Most of the research on attracting insects with radiant energy and trapping them either for detection and survey purposes or for attempted control has been conducted for field insects rather than stored-product insects. Detection of insect infestations in warehouses may be a useful application for such insect light traps if the troublesome species exhibit photopositive responses. Control of stored-product insects by such traps, however, seems unlikely to be successful.

Infrared Radiation

Below the visible-radiation region on the energy scale lies the infrared region of the electromagnetic spectrum. Research has shown that infrared radiation from electric infrared lamps or gas-fired infrared-radiation sources can effectively control stored-grain insects. Infested material can be passed under an infrared source on a conveyor with the speed set to provide the proper exposure. For wheat and rice, exposures which produce grain temperatures in the 65° to 70°C. range are necessary to obtain complete control of all developmental stages of stored-grain insects. The cost of such treatment has apparently been the factor preventing practical application of infrared insect-control methods.

Very little work has been done on the influence of wavelength of the infrared radiation. Some improvement in efficiency for such a treatment might be achieved through a study of the infrared-absorption characteristics of materials to be treated and tailoring the spectral distribution of the infrared source to accomplish the desired job.

There has also been some speculation that insects utilize infrared radiation in their communication processes. If this should be verified, new approaches for insect control might be considered; but at present such possibilities appear unlikely for stored-product insects.

Radio Waves

The low-energy end of the electromagnetic spectrum (Fig. 1) is occupied by the radio waves. Energy in this portion of the spectrum is converted to heat when absorbed in biological materials. Radiofrequency (RF) energy has also been explored for its insect-control capability. The RF spectrum includes a wide range of frequencies. Most insect-control studies have been conducted in what may be called the radiofrequency dielectric-heating range, often at frequencies of 27 and 40 MHz. Some studies have also been conducted at microwave frequencies, usually 915 and 2,450 MHz for microwave heating applications.

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Insect Control

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Materials such as grain can be exposed to high-frequency electric fields between electrodes coupled to RF electronic power oscillators. At microwave frequencies, such materials are exposed to the energy in microwave oven enclosures or waveguide applicators.

Experimental work has shown that stored-grain insects can be controlled by proper exposures which do not damage the grain. The methods, however, are several times more costly than currently used chemical-control methods. Costs could be lowered if efficiency of the method might be improved. Detailed studies at 40 MHz have established the role of numerous entomological and physical factors influencing the effectiveness of RF treatment for insect control. Less information is available on microwave treatments. The same general principles apply to energy absorption in either of the two frequency ranges, but effectiveness of high-frequency dielectric heating and microwave heating may be different because of frequency-dependent factors.

The electrical characteristics (dielectric properties) of materials determine, to a large extent, the rate of energy absorption from RF electric fields. Since the dielectric properties of insects can be quite different from those of grain, there is an opportunity to heat the insects selectively if the dielectric properties of the two different materials bear the proper relationship to each other. Specifically, a high insect-to-grain dielectric-loss-factor ratio is desired. A low insect-to-grain dielectric-constant ratio is also preferable, but it is not nearly as important a factor as the dielectric-loss-factor ratio.

These dielectric properties of materials are frequency dependent. Therefore, a knowledge of the values for the particular insect in question and those for the host material over a wide range of frequencies might identify the best frequency choice for selective heating of the insect. Recent measurements of the dielectric properties of hard red winter wheat and adult rice weevils over a range of frequencies from 250 Hz to 12 GHz (12×10^9 Hz) have revealed that the greatest selectivity for killing the insects through heating should be obtained in the frequency range between 10 and 100 MHz. This includes the region where most experimental work has been conducted with stored-grain insects. On the basis of these measurements, it would not appear likely that more efficient treatments could be achieved by working at other frequencies. Some evidence has been obtained that factors other than heating may be involved in effects of RF fields on biological materials. If some lethal effect of this kind can be demonstrated for insects, there may be possibilities for developing more efficient RF insect-control methods.

Assessment of Potential Electromagnetic Methods

The preceding brief review has identified three regions of the electromagnetic spectrum in which potential control methods have already been demonstrated for stored-product insects, namely, the radiofrequency-, infrared-, and gamma-radiation regions. All three types of radiation appear to be more costly to use than currently employed methods. They do, however, possess the advantage of achieving control of existing insect infestations without damaging the host product or leaving undesirable residues. Post-treatment sanitation practices would have to be followed to prevent reinfestation with any of the electromagnetic methods, for they have no residual protection as a result of radiation treatment.

Cost factors can change with time and developing technology. Consumer acceptance of products is also a factor which must be evaluated. In any processing application, the value of the product and volume of material handled are also important factors. Therefore, blanket statements concerning the cost of any particular process are likely to be misleading, and separate evaluations must be made for any particular case in question.

The use of electromagnetic energy for possible stored-product insect control should be kept in mind for new applications. A few of the pertinent characteristics which may be of interest in considering new applications might be mentioned. RF electric fields have good penetration of the product and offer possible selective energy absorption. Operation should be nearly automatic in a well-designed system, and safety of operation should be no problem. The power source is relatively expensive. Conveying equipment may be simple. Infrared radiation is absorbed at or near the surface of materials, and absorption depends upon the infrared emissivity of the surface of material being treated. The same remarks concerning automation and safety for RF energy apply for an infrared installation. The energy source is less expensive than RF power equipment, but conveying equipment is probably a more expensive item. Gamma radiation has good product penetration, and radioisotope sources for handling large masses of material can be obtained. Radiation shielding for protection of operating personnel is essential, and rather elaborate facilities are required for handling such treatments. Processing of products other than wheat or wheat flour would first require obtaining Government approval.

The potential for application of electromagnetic energy to insect-control problems presently hinges on economic factors and continued acceptability of current practical methods. Continuing research on the interaction of electromagnetic radiation with biological systems may uncover new mechanisms which may eventually be useful in insect-control programs. Progressive operators will remain alert to such new possibilities.

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