THE USE OF ELECTROMAGNETIC ENERGY TO DETECT HIDDEN INSECT INFESTATION

W. A. BRUCE and M. W. STREET
Stored-Product Insects Research and Development Laboratory,
SEA, USDA
Savannah, Georgia, 31403
U. S. A.

INTRODUCTION: Historically, the detection of hidden insects in stored products has been accomplished by using a wide variety of methodologies such as chemical, flotation, aural, and, as a last resort, visual counts of penetration or emergence holes. As the world demand for food increases, the need to detect hidden insects accurately, quickly, and with a high degree of sensitivity becomes more urgent. The challenge will be met successfully only by reevaluating old methods and by incorporating new technologies into usable systems.

Electromagnetic energy, in the broad sense, appears capable of providing us with a variety of sophisticated methods or technologies for immediate use and also for future consideration (1). Recent developments in infrared CO_2 analysis have already provided regulatory agencies and private industry with a powerful tool for detecting insects and are thereby aiding us in our efforts to protect both the quality and quantity of our food, feed, seed, and fiber throughout the marketing channel.

Further developments in the areas of closed loop CO_2 sampling, IR CO_2 pyroelectric detectors, and large volume sampling (e.g. grain silo) could also be significant. Techniques that may be applicable and appear to offer great potential include thermal measurement, thermal imaging, and the pyroelectric vidicon. Photo-electron spectroscopy, nuclear magnetic resonance (NMR) imaging, far infrared imaging, and photoacoustic spectroscopy should be investigated and considered.

It is the intention of the authors to discuss the merits and/or potential of each of the aforementioned techniques as they relate to the detection of hidden insects. Also, a brief overview of detection methodologies is presented.

DETECTION TECHNIQUES: Detection techniques may be arbitrarily divided into two broad categories, active and passive. Active techniques involve the input of either external physical energy or a chemical reagent and require that the insects modify or otherwise react with the input to produce either meaningful visual information (a film image or colorimetric change in an indicator material) or an electronically measurable change (resistance, complex impedance, or proton spin). However, active techniques such as x-rays or chemical reagents, although generally reliable, could create personnel hazards, cause environmental pollution, or alter or destroy the sample. Passive techniques, on the other hand, simply monitor the presence of some type of "signal" produced by the insects; they do not introduce external physical energy or chemical inputs, but instead rely solely on the detection of outputs generated by the insect (e.g. IR energy given off by the insects, sounds produced by feeding, or vapor or gas produced by metabolism or respiration).

For these reasons, passive detection is more desirable than active detection, and efforts to develop methods using insect-produced data are continuing.

Present

X-ray - X-rays, though not a passive technique, certainly qualify as electromagnetic radiation. The method is included here primarily because it once enjoyed rather wide acceptance and because the instrumentation is both current and readily available.

The Hewlett-Packard Faxitron(R) x-ray unit will serve as a model. These units are especially suitable for observation of seeds, grains, and other small objects and are self-contained, radiation-shielded systems designed to give high resolution radiographs. In addition, they are simple to operate and are convenient and generally hazard-free. The simplicity of operation has been enhanced by the inclusion of an automatic exposure control and by making available various types of film such as self processing (Polaroid(R)) and cassettes. However, to achieve the necessary detail required for radiographs that permit critical inspection for insects, extra fine grain films are essential (2). This necessitates more complex and time-consuming film developing and processing. However, regardless of the time involved in obtaining an acceptable radiograph, it is the interpretation of that radiograph which makes the x-ray technique so difficult to use for routine, rapid inspections. In fact, the interpretation of radiographs is so difficult and time consuming that the United States Department of Agriculture's Federal Grain Inspection Service no longer uses this technique in inspection operations. Moreover, even with correct interpretation, there is little or no information as to whether the infestation is live.

Radiography, however, should not be ruled entirely out as a viable procedure. The recent announcement of the Lixiscope (low intensity x-ray imaging scope) developed in the U.S. at NASA's Goddard Space Flight Center reflects the rapid changes in the technology. This instrument is a small hand-held unit powered by a penlight battery. It uses a 10-20 millicurie radiation source and a high vacuum night vision image intensifier tube that enhances light intensity 40,000-fold. Fiber optics are used to carry the visible image to a viewing plate. Nevertheless the problem of image interpretation remains.

Acoustic inspection - Brief mention should be made of acoustical technology because the equipment is extremely sophisticated and readily available. The basic objections to the use of this technology for inspection stated by Street (3) are still valid for most applications: quiescent stages cannot be detected, and neither can eggs; great difficulties arise in the case of commodities such as flour; and background noise becomes a limiting factor in the case of large masses of grain because of settling. However, with smaller quantities of grain such as those used in routine inspection, settling should not be a problem, and the feeding stages could undoubtedly be detected. Instrumentation for this specific application is available as a commercial unit from SASAD Mg. Tsz., Budapest, Hungary, the so-called Insectofon(R). We have not seen this device as yet but eagerly await opportunity to test its effectiveness.

Acoustic microscopy is another new approach that bears close watching for possible application to insect detection. This technique involves the use of very high frequency ultrasound (ca. 100 mHz) in a scanning laser acoustic microscope. Such sound has different velocities in tissues of different densities, so insect tissue might be differentiated from plant tissue.

IR CO_2 analyisis - The differential infrared (IR) CO_2 analyzer with intermittent airflow under slight negative pressure (4, 5) is a promising method of detecting hidden infestations of insects. Prior to the development of this system, our attempts to use insect-produced CO_2 as an indicator of insect presence have been complicated by 1) the CO_2 in the air, which comprises about 300 ppm, and 2) by the fact that an insect produces so little CO_2 per unit time. Currently two commercial prototypes based on our original concept are being tested. Technicon Instruments, Inc., of the United States and Horiba Instruments, Inc., of Japan have both produced instruments (both systems use Horiba $IRCO_2$ analyzers) for use in routine grain inspections. The Technicon system simultaneously processes 3 samples, which makes the system larger and more stationary. The Horiba system is much smaller and processes only one sample at a time, but it is very portable.

Currently, several new approaches to the use of CO_2 for detection are being developed for both specific and general applications. A "closed loop" concept being studied would eliminate the problem of system air contamination and make more efficient use of the CO_2 analyzer which is designed to use continuous airflow. As a result of the continuous recirculation of air, the insect-produced CO_2 steadily increases the concentration of CO_2 within the sealed system. Insect presence is noted by a positive change in slope on a strip chart recorder, or by a rising meter reading.

It is proposed that the CO_2 detection be used in continuous surveillance of large grain bin storage facilities. Also a microcomputer-controlled sampling routine is being studied in which probes are dispersed at intervals throughout the grain mass. Computer comparisons will be made of the current CO_2

concentration at each probe site with respect to the previous concentration and the total CO_2 profile of the storage facility.

Finally, the Lawrence Livermore Laboratories of the U.S. propose to continue development of their miniaturized atmospheric carbon dioxide detector system (MACDS). Their system is a CO_2 detector with extreme sensitivity, yet the entire package including optics and electronics can be held virtually in the palm of your hand.

Future

At this juncture it seems appropriate to provide some background into infrared radiation detection of hidden insects because many new and exciting possibilities now exist and the field is generally unfamiliar to stored-product entomologists.

All physical bodies that have a temperature greater than absolute zero have an infrared radiation spectrum referred to as a black body curve. The particular wavelength location of this curve is a function of the body's absolute temperature. Since living metabolizing tissue (e.g., an insect) generally has a higher temperature than its surrounding environment (a grain kernel), the possibility exists of detecting the different radiation characteristics of an infested commodity. A variety of detectors is available for the detection of infrared radiation.

In general, IR detectors are either quantum or thermal devices. Quantum devices (photon detectors) are used to detect the IR radiation that results when incident radiation quanta interact with the electrons in a solid and thus excite these electrons to a higher energy state. Although such detectors are extremely sensitive, random thermal excitation of the electrons in the solid produces the problem of electrical noise. Systems utilizing these detectors must usually be cooled to reach adequate sensitivity and do not seem appropriate for examining foods for live insects. Thermal detectors, on the other hand, function by absorption of IR radiation that changes the temperature of the detector material. This change in temperature may be manifested as a thermal electromotive force (thermocouples and thin-film thermopile detectors), a change in resistance (bolometers), expansion of a gas that causes a diaphragm to move (Golay cell), or a change in electrical polarization of a crystal produced by changes in temperature (pyroelectric detectors). Thermal detectors, therefore, seem more appropriate for the assay of biological material.

Unfortunatuely, most of the thermal detectors mentioned are <u>relatively</u> insensitive and are wavelength independent. In addition, these devices (with the notable exception of the pyroelectrics and some thin-film thermopiles) respond slowly. However, these two apparent disadvantages are offset by the fact that these instruments can be used at room temperature so there are no critical cooling requirements.

The fast-response pyroelectric detector appears to be a most advantageous alternative for IR detection. This detector is a thermal sensor of electromagnetic radiation that contains a permanently polarized dielectric crystal. Incoming radiation causes the temperature of the crystal to rise. The increased temperature alters the lattice structure through expansion, thereby changing the magnitude of polarization. These changes in electrical polarization are sensed as an electrical current directly proportional to the rate of change in the temperature of the material (6). Optical scanning of an area of interest results in a varying electrical signal from the detector. This signal is then used to create a television-like display that is actually a visible image of the infrared profile of the scanned area. Either shades of gray or different colors may be used to indicate areas of varying IR wavelength and hence of varying thermal temperature.

Far infrared imaging - The use of radiation in the far infrared (FIR) portion of the spectrum for purposes of imaging has only recently been demonstrated (7). If imaging objects within various materials now proves to be feasible, its potential for detecting hidden insects is apparent. Previously the use of this portion of the spectrum was restricted because of the lack of effective radiation sources and detectors and the fact that resolution is poor relative to other techniques. However, developments in laser and IR detector fields have made FIR imaging possible. Because many substances have IR "windows," (i.e., areas in the spectrum where IR radiation can be transmitted), it is possible to penetrate materials that cannot be penetrated by other methods.

Photoacoustic spectroscopy - As early as 1888, inventors such as Bell, Tyndall, and Roentgen were well aware of the scientific potential of photoacoustic spectroscopy (8, 9). This unusual technique enables one to obtain spectra similar to optical absorption spectra for any type of solid or semisolid material whether it is crystalline, powder, amorphous gel, etc. (10).

Briefly, the process is as follows. The sample to be studied is placed in an airtight chamber equipped with a sensitive microphone and exposed to intermittent monochromatic light. Any light absorbed by the sample is converted to heat, and the resulting temperature at the surface of the sample fluctuates at the frequency of the chopped light. These fluctuations create pressure changes in the chamber that can be detected by the microphone and converted to an electrical signal. As the wavelength of the monochromatic light is varied, the amplitude of the electrical signal varies in direct proportion to the surface optical properties of the sample. The presence of an insect-produced contaminant on the surface should be readily detectable. Further, the use of long wavelength infrared light should permit penetration of the interior of the kernel and the detection of an actual hidden insect.

Results in our laboratory and conversations with Dr. Rosencwaig (personal communication) suggest a real potential for this technique in the detection of hidden insects. Currently, two commercial instruments are available, but these have not been tested with our specific needs in mind. The advantages of such a technique to stored-product entomology would seem to lie with the virtually unlimited number of wavelengths of light available and the fact that effectiveness is not limited by the physical state of the sample.

Pyroelectric vidicon - Recent advances in the field of thermal imaging have given rise to a device known as the pyroelectric vidicon. This imaging detector has two unique properties: 1) it is capable of operating at ambient temperature and 2) it detects only changes in temperature, not differences. This latter characteristic is considered by some to be a disadvantage, since it does require that the incoming signal be chopped or that the detector be scanned (1).

Basically the vidicon consists of a glass envelope fitted with a germanium faceplate, a pyroelectric target, an electron gun, and beam-shaping electrodes, as in standard vidicons. When an IR image is focused on the target, the absorbed heat energy creates a temperature change that causes changes in charge distribution of the pyroelectric material. The resulting distribution, which reproduces the thermal image, can be read by an electron beam.

CONCLUSION: We should be ever mindful that technologies may exist outside the realm of stored-product entomology that could be most beneficial in the detection of hidden insects. For example, photoelectron spectrometry is a technique that measures the energies of electrons emitted by a sample that is bombarded with x-rays: commercially available spectrometers that presently permit the identification and quantification of different amino acids in seed samples might be adaptable to insect detection. Nuclear magnetic resonance (NMR) imaging too is a recent development. It makes use of the proton spin characteristics in the atomic nucleus. Although the present instrumentation is probably prohibitively expensive, the field should be watched for technological developments that may permit a cost breakthrough. There is little doubt that techniques such as these and others not yet discovered could be adapted to solve the specific problems of hidden insect detection.

REFERENCES:

(1) Bruce, W. A., Street, M. W. Jr., Kvenberg, J. E., Potential use of infrared devices for detecting hidden insects, FDA By-Lines No. 1 (1978).

(2) Kirkpatrick, R. L., X-ray analysis of stored commodities, USDA series (in manuscript).

(3) Street, M. W. Jr., A method for aural monitoring of in-kernel insect activity, J. Ga. Entomol. Soc. 6 2 (1971) 72.
(4) Bruce, W. A., Street, M. W. Jr., Infrared CO_2 detection of hidden insects, Ibid. 9 4 (1974) 260.
(5) Street, M. W. Jr., Bruce, W. A., Hidden insect detection by infrared carbon dioxide gas analysis, Principles of system design, U.S. Dep. Agric., Agric. Res. Ser.-S-85 (1976) 10 pp.
(6) Tiffany, W. B., Introduction and review of pyroelectric detectors, SPIE Infrared Technol. 62 (1975) 153.
(7) Anonymous, Applications ahead for far IR imaging, Ind. Res. (January 1977).
(8) Callahan, P. S., Tyndall, J. Unifier of 19th Century Science, Appl. Opt. (In press).
(9) Vengerov, M., An optical-acoustic method of gas analysis, Nature 158 4001 (1946) 28.
(10) Rosencwaig, A., Photoacoustic spectroscopy, A new tool for investigation of solids, Ann. Chem. 47 6 (1975) 592.
(11) Foreman, J. R., Pyroelectric technology in modern thermal imaging systems, Electron. Eng. (January 1977) 38.