Chapter 3: Section 5
Using High Temperature Air (i.e. Heat) for Stored Product Insect Control

The use of high temperature air or “heat”, that is greater than 120 dF, is not new to the food or milling industries. It was used in the early 1900’s to kill stored product insects (SPI) in flour mills, and while effective, was found by trial and error that equipment/structures could be damaged and it was difficult to control temperatures from getting too high. Early flour mills were built with a great deal of wood in the structure and flooring and repeated exposure to temperatures of 140 dF or greater, caused warping and cracking. While mill and food plant construction materials/techniques improved moving through the 1900’s, the discovery of effective and cheap fumigants like ethylene dibromide, carbon tetrachloride and methyl bromide shifted the focus away from heat treatments to actual fumigations for SPI control.   Now with the phase out of methyl bromide, heat treatments are becoming popular again.

The intent of this chapter is to give you a broad understanding of how heat treatments can and should be part of an integrated pest management (IPM) strategy, where applicable, and to provide links to already published scientific articles on heating’s efficacy against certain SPI.

Heat Treatment

Heat treatment involves raising and maintaining temperatures of grain storage structures, warehouses, and food-processing facilities between 50°-60°C (122°-140°F) to manage stored-product insect species. The duration of heat treatment is application-specific and may vary from 6 hours for an empty storage facility to 24 hours for an entire food-processing facility. Laboratory and commercial trials with high temperatures during the last decade, especially with forced air gas heaters, have resulted in a wealth of information on:

1) Understanding responses of insect species and life stages to heat
2) Heat distribution within a treated area
3) Techniques necessary for gauging effectiveness of commercial heat treatments.

Insect responses vary with the temperature, among species, and within a species among life stages.

Electric heaters, forced air gas heaters or steam heaters can be used to conduct a heat treatment. With the forced air gas heaters the building is placed under positive pressure during a heat treatment, and the entire air within the building is exchanged four to six times per hour. The number of air exchanges when using electric and steam heaters may be one or two per hour. The forced air allows heat to reach gaps in the building and equipment much better than electric or steam heaters. The forced air gas heaters can use natural gas or propane as fuel. Since these heaters have an open flame, they are placed outside a facility, and nylon ducts are placed within the facility to introduce heated air. Hot air has a tendency to stratify horizontally and vertically within a facility. Therefore, several fans should be placed on different floors of a facility to redistribute heat and to uniformly heat a facility.

Fan placement is an art, and during heat treatments, fans should be moved to eliminate cool spots-areas where the temperature is less than 50°C (122°F). In addition to food-processing facilities, heat treatment can also be used in empty storage structures (bins, silos), warehouses, feed mills, and bakeries. It is an environmentally benign method for managing insects. Hot air has a tendency to stratify horizontally and vertically within a facility. Therefore, several fans should be placed on different floors of a facility to redistribute heat and to uniformly heat a facility.

Heat treatment of commodities versus structures
Heat has also been used to disinfest perishable and dry, durable food products. High temperature treatments are used for disinfestations of dried fruits and nuts, perishable commodities (fruits) (Hansen and Sharp, 1998), and grains (Beckett and Morton, 2003). Facility heat treatments are distinctly different from heat treatment of fresh fruits, nuts, or grains. In facility heat treatments, heaters are used to slowly heat the ambient air. A long heat treatment period is necessary for the heat to penetrate wall voids and equipment to kill insects harboring in them. A typical heat treatment may last 24-36 hours (Mahroof et al., 2003a; Roesli et al., 2003). In heat treatments of fresh commodities, nuts, dried fruits, or grains, high temperatures of 60°-85°C (140°-185°F) are used for short time periods (in min). Typical heating rates during heat treatment of perishable commodities, nuts, dried fruits, and grains range from 1°-15°C (34°-59°F) per minute, whereas during facility heat treatments, heating rates should generally be around 3°-5°C (37°-41°F) per hour for effective disinfestation. However, in both cases the products are allowed to cool to ambient temperature, and this may take several hours. During heat treatments, it is important to remove all food products and packaging materials (bags) from the facility.

Equipment should be opened and thoroughly cleaned of any food product where possible. It is important during heat treatments of products to ensure that the quality is not affected. Similarly, in the case of structural heat treatments, it is important to ensure that there is no damage to the equipment, uninfested materials stored within the facility, and the structure

Issues to consider before a heat treatment

Dosland et al. (2006) gave detailed step-by-step procedures for conducting and evaluating a facility heat treatment. One important aspect of conducting an effective heat treatment involves calculating how much heat energy is required after accounting for heat losses due to exposed surfaces, equipment, and infiltration. Research at Kansas State University and discussions with heat service providers showed that the amount of heat energy should range from 0.074-0.102 kW per cubic meter of the facility per h, and during a 2009 heat treatment of a flour mill at Kansas State University, the heat energy used was as high as 0.16 kW per cubic meter per hour. An indirect method of determining whether or not adequate heat energy is being used is by observing how quickly ambient temperatures reached 50°C. In proper heat treatments, the time to reach 50°C (122°F) should usually take about 8-10 hours, and depending on the time of year and the leakiness of a structure, this time can take as long as 15 hours.

The time to reach 50°C (122°F) is important to determine the heating rate, which is calculated as the difference between 50°C (122°F) and the ambient temperature at the start of the heat treatment divided by the time to 50°C (122°F). This rate should be between 3°-5°C (37°-41°F) per hour in properly conducted heat treatments for effective disinfestation. Temperatures should be held at least for several hours above 50°C to kill insects. The maximum temperature should not exceed 60°C (140°F) to prevent any structural damage or damage to equipment. Information broken down in this fashion can be related to insect mortality if live insects confined in cards or vials are used to gauge the effectiveness of a heat treatment.

Lethality in insects at high temperatures depends on both the temperature and time of exposure (Denlinger and Yocum, 1999; Evans and Dermott, 1981; Fields, 1992; Mahroof et al., 2003b). Temperature and exposure time to achieve a certain percentage of insect kill are inversely related. At high temperatures insect cuticular wax becomes compromised allowing loss of water. This affects water balance in insects, leading to death by desiccation as well (Hepburn, 1985). High temperature exposure denatures proteins, affects hemolymph ionic balance and pH, and adversely affects enzyme activity (Denlinger and Yocum, 1999; Neven, 2000). High temperatures that do not kill insects can adversely affect the insect's reproduction.

To gauge heat treatment effectiveness, it is important to identify critical areas in the facility. These areas are usually places where insects can hide and breed or places where temperatures cannot penetrate or reach at least 50°C (122°F). Such places are usually identified through inspections. Temperature sensors should be placed in these areas to measure temperatures. Cards with insects such as those marketed by Alteca or insects in vials with food should be placed in critical areas and examined during or after a heat treatment to determine effectiveness against insects. Insects in the cards are usually without food and, therefore, these stressed or starved insects tend to succumb quickly to a heat treatment and may falsely indicate that the treatment was effective, when in fact it was not.

In some facilities such as flour mills, it is possible to sample tailings to determine insect load. These observations should occur every week and should be resumed soon after a heat treatment. The trapping or visual observations of products/tailings following a heat treatment should be done at least on a daily basis for the first week and should continue weekly for at least 8-16 weeks. These data provide valuable information on the degree and duration of control obtained after a heat treatment intervention.

The use of heat treatment for disinfesting facilities is not a new idea. However, research in the last decade and half has shed new light on how to improve heat treatment effectiveness against insects. The susceptibility of other economically important insect species not reported here should be evaluated both at constant elevated temperatures in the laboratory and in commercial facilities subjected to heat treatments where temperatures are changing dynamically over time. There is still scope for lot of research to be done on improving heat treatment effectiveness, especially in commercial facilities. In large commercial facilities, it is difficult to maintain temperatures between 50°-60°C (122°F-140°F) in all locations. Methods for controlling insects in locations where temperatures are less than 50°C (122°F) should be explored. The methods may include application of chemical or non-chemical insecticides - or thorough inspection and sanitation. The rate of heating and development of heat tolerance in specific life stages of stored-product insects needs to be explored further. The sub-lethal effects of commercial heat treatments on population rebounds of insects should be verified through carefully designed experiments. The impact of high temperatures or repeated heat treatments on the performance of equipment and on adverse effects to structural components should be scientifically documented. It is important to recognize that heat treatment may not be suitable for all facilities. However, where it is suitable, heat treatment can be a viable methyl bromide alternative.

References

AAOC. 2006. Temperature Modification for Insect Control, Chapter 10. In: Jerry Heaps, Ed. Insect management for food storage and processing, 2nd ed.

Agricultural Research Service. United States Department of Agriculture. Stored-grain insects. 1978. Washington, D.C.

Beckett SJ and Morton R. 2003. The mortality of three species of Psocoptera, *Liposcelis bostrychophila* Bandonnel, *Liposcelis decolor* Pearman and *Liposcelis paeta* Pearman, at moderately elevated temperatures. Journal of Stored Products Research 39:103-15.

Brijwani M, Subramanyam S, and Flinn P. 2012. Impact of varying levels of sanitation on mortality of Tribolium castaneum eggs and adults during heat treatment of a pilot floor mill. Journal of Economic Entomology. 105 (2): 703-08.

Brijwani M, Subramanyam S, Flinn P, Langemeier M, Hartzer M, and Hulasare R. 2012. Susceptibility of Tribolium castaneum life stages exposed to elevated temperatures during heat treatments of a pilot flour Mill: Influence of sanitation, temperatures attained among mills floors, and costs. Journal of Economic Entomology. 105(2): 709-17.

Denlinger DL and Yocum GD. 1999. Physiology of heat sensitivity. In: Hallman GJ, Denlinger, DL, editors. Temperature sensitivity in insects and application in integrated pest management, Boulder: Westview Press. p 6-53.

Dosland O, Subramanyam B, Sheppard G, and Mahroof R. 2006. Temperature modification for insect control. In: Heaps J, editor. Insect management for food storage and processing, 2nd ed. St. Paul Mn: American Association of Cereal Chemists International. p 89-103.

Evans DE, Dermott T, 1981. Dosage-mortality relationships for *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) exposed to heat in a fluidized bed. Journal of Stored Products Research 17:53-64.

Fields PG. 1992. The control of stored product insects and mites with extreme temperatures. Journal of Stored Products Research 28(2):89-118.

Grain Science & Industry. Kansas State University. Heat and IPM. Accessed on 2012 Nov 16 from: http://www.ksre.ksu.edu/grsc_subi/Research/Current_Research_Projects/Heat_IPM/heat_and_ipm1.htm.

Hansen JD and Sharp JL. 1998. Thermal death studies of third instar Carribean fruit fly (Diptera: Tephritidae). Journal of Economic Entomology 91:968-73.

Hepburn HR. 1985. Structure of the integument. In: Comprehensive insect physiology, biochemistry and pharmacology, Vol 3. Kerkut GA and Gilbert LI editors. London: Pergamon Press. p 1-58.

Hulasare R, Subramanyam B, Fields PG, and Abdelghany AY. 2010. Heat treatment: A viable methyl bromide alternative for managing stored-product insects in food-processing facilities. 10th International Working Conference on Stored Product Protection.

Imholte, TJ and Imholte-Tauscher TK. 1999. Pest Control Systems. In: Engineering for Food Safety and Sanitation: A Guide to the Sanitary Design of Food Plants and Food Plant Equipment. 2nd ed. Medfield, MA: Technical Institute of Food Safety. p 292-317.

Mahroof R, Subramanyam B, and Eustace D. 2003a. Temperature and relative humidity profiles during heat treatment of mills and its efficacy against *Tribolium castaneum* (Herbst) life stages. Journal of Stored Products Research 39:555-69.

Mahroof R, Subramanyam B, Throne JE and Menon A. 2003b. Time-mortality relationships for *Tribolium castaneum* (Coleoptera: Tenebrionidae) life stages exposed to elevated temperatures. Journal of Economic Entomology 96:1345-51.

Mueller DK. 1998. Stored product protection… a period of transition. 351 p.

Neven LG. 2000. Physiological responses of insects to heat. Postharvest Biology and Technology 21:103-11.

Roesli R, Subramanyam B, Fairchild FJ, and Behnke KC. 2003. Trap catches of stored-product insects before and after heat treatment in a pilot feed mill. Journal of Stored Products Research 39:521-40.

Subramanyam B. Impact Machines: A Look Back. 2007. Milling Journal. Third Quarter. 38-39

Subramanyam B. Impact Machines: Experiments. 2007. Milling Journal. Fourth Quarter. 36-38.

Subramanyam B, Mahroof R and Brijwani M. 2011. Heat treatment of grain-processing facilities for insect management: a historical overview of recent advances In: Stewart Postharvest Review. 3(1): 1-11.