

HEAT TREATMENT OF FOOD PROCESSING PLANTS & SILOS: A GREEN ALTERNATIVE TO CHEMICALS

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Abstract:

Use of high temperatures to control stored product pests is increasing due to the need for pesticide free products, international treaties (Montreal Protocol), and increased resistance of insects to chemicals. Methyl bromide, a widely used ozone-depleting fumigant has been phased out but critical use exemption continues as alternatives like heat and sulfuryl fluoride are adopted by the industry.

Heat treatment involves raising temperatures inside whole or a part of the plant to 50 to 60°C and holding for up to 24 h. The 24 h is necessary for the heat to penetrate wall voids and equipment for effective kill of insects. Many processing plants are located in remote areas adjacent to crop production areas. Propane is readily available here and is a fuel of choice in absence of infrastructure for natural gas. Mobile propane fueled heaters were developed and demonstration trials conducted to convince the producers and processors on efficacy of heat to control pests. A propane fueled mobile heat treatment unit (MHT-1500) was designed, tested and field trials were conducted in empty farm bins at sites in Indiana and Kansas State. The objectives were to determine the mortality rates of all life stages of major stored product pests at 55°C and 65°C. Heat treated bins had lower insect populations compared to control bins over a year of storage. The time of heat treatment ranged between 3- 5 h and cost of propane per bin ranged from \$30.95 to \$46.19.

A commercial heat treatment of Sunflower plant was conducted at St. Louis, MO under the EPA grant. The temperature and insect mortality were monitored by Kansas State University researchers. Propane fired heaters were used for heat treatment. The heat treatment was effective in killing all the life stages of insects.

Introduction:

The contamination of high-value identity-preserved food and specialty grains (as well as conventional commodity grains and oilseeds) due to residual insect populations below the perforated floor (plenum) of corrugated steel farm bins (as well as tanks, silos and flat storage buildings at grain elevators) is a major concern of growers, handlers and processors. Empty bin treatment with residual protectants such as inert diatomaceous earth dusts (ProtectIT) and cyfluthrin (Tempo) products have shown limited success because of the inherent inaccessibility of the plenum area. Although inert dusts can be blown into the plenum via the fan, they are not widely used by producers because dusts are ineffective under humid conditions that develop when high moisture grain is placed in a bin for drying (Le Patourel, 1986). Similarly, the dousing of the perforated drying floor with cyfluthrin spray generally does not result in a uniform drip-through application of the hidden concrete floor and bin sidewalls.

Disassembling the floor before filling a bin in order to clean and treat the plenum area is a labor intensive and dangerous alternative. If a floor is not properly reassembled, the plenum can collapse under the weight of the grain mass and the bin walls can be damaged. Bin manufacturers generally warn farmers not to do so otherwise they will forfeit any warranty claims if damage to the bin should result. Fumigating under the floor is possible but is costly because it usually requires hiring a commercial applicator. In the past, chloropicrin (or tear gas; Chlor-O-Pic) has been the product of choice for under-the-floor fumigation of farm and elevator bins. It is available in liquid form, is heavier than air, and can be applied by emptying the bottle onto the perforated floor. As the liquid vaporizes, it settles below the floor and kills all insect life stages. Although still a legal product for empty bin treatment, it is no longer available to licensed fumigators because the manufacturer (Great Lakes Chemical Company) will no longer allow shipment of small bottled product quantities through normal commercial channels. The use of phosphine as the only other legal fumigant product is generally limited to grain applications rather than empty bin treatment. Due to resistance concerns, it is primarily reserved for the control of primary stored product insect outbreaks above the economic threshold level in the grain mass. Therefore, a more effective method is needed to prevent contamination due to residual insect populations in empty bins.

Literature Review:

Heat treatment of processing facilities and other structures to kill stored product pests is a widely used pest control technique (Mueller, 1998; Burks et al., 2000). According to Fields (1992), all insect life stages will be killed if exposed to 43-46°C (109-115°F) for hours, to 50-60°C (122-140°F) for minutes, and to over 60°C (140°F) for seconds. Recent research conducted at the U.S. Grain Marketing & Production Research Center (Manhattan, KS) utilized five commercial propane (19 and 29 kW) and electric heaters (15 and 18 kW) to determine their effectiveness in heat treatment of a typical farm (Tilley et al., 2007). The bins were heated for 12 to 40 hours using the electric system and 2 to 8 hrs using the propane system that raised bin temperature to at least 50°C. The drying floor had to be covered with a tarp in order to concentrate the heat near the concrete floor. The system using a 29 kW propane heater produced 100% mortality in 2 hours for caged adult red flour beetle, rice weevil, and lesser grain borer for all test locations. Traps were used to monitor insects at 11 locations near the floor and the eaves inside the bin. Similarly, 100% insect mortality was achieved with the 18 kW electric duct heater system after 40 hours, but a complicated interior heat-distribution system had to be utilized. The rest of the systems produced less than 100% mortality ($\geq 47\%$).

Similarly, Beckett and Qaisrani (2002) recently reported on the successful heat disinfestation of empty farm bins in Australia. A hopper-bottom 50 tonne (1,970 bu) bin (3.6 m diameter x 6 m tall) was heated with a 54 kW (51 BTU/s) electric heater. Air was heated to 60-90°C (140-194°F) and distributed with an 11 kW (14.75 Hp) fan at 0.5 m³/s (17.7 ft³/s) airflow into the bin. Insect cages filled with grain and larvae and adult life stages of the red flour beetle and lesser grain borer were suspended. Mortality was observed within 1-3 hours of exposure after the temperature in the cages reached 54-55°C (129-131°F).

Objectives:

The project evaluated performance and efficacy of propane fueled mobile heat treatment unit (MHT-1500) to control stored product pests in bins and silos under funding from PERC. Under the grant awarded by the EPA (Environmental Protection Agency) to

PERC, direct-fired propane fueled heaters were used in heat treating food processing plant. The specific objectives were:

1. To evaluate heat treatment of empty steel bins using Temp Air's MHT-1500 (Mobile Heat Treatment) unit at the Post-Harvest Education & Research Center (PHERC) at Purdue University and farms in Indiana and Kansas.
2. To undertake a long-term grain storage trial comparing stored product pest populations in a heat-treated versus non heat-treated bin at the Purdue University Post-Harvest Education & Research Center (PHERC).
3. To conduct laboratory tests aimed at quantifying the mortality rates for adult maize weevil, red flour beetle, and lesser grain borer constrained within corn and flour filled pouches and exposed to temperatures of 40 to 55°C
4. To conduct full-scale commercial trial at a processing plant and evaluate efficacy of heat to kill all life stages of stored product pests placed in bioassays throughout the plant during heat treatment.

Materials and Methods:

Locations for heat treatment of bins:

The heat treatment of bins using the propane fueled MHT-1500 was performed at number of farms in Indiana and Kansas storing corn, wheat, popcorn, and beans. The sites were selected considering demonstration aspect to the farmers, producers and processors and also the ease of collecting data and the number of replicates. The locations of bins, crop stored, bin capacity and period of heat treatment is indicated in Table 1.

Table 1. Summary of schedule of heat treatment trials done in Indiana and Kansas

SN	Location	Product Stored	Bin Capacity (Bushels)	Month/Year
1	PHERC, West Lafayette, IN	Corn	3,200	October 2006
2	SEPAC, Butlerville, IN	Wheat/corn	14,000	June 2007
3	PHERC, West Lafayette, IN	Corn	3,200	September 2007
4	Greensburg, IN	Popcorn	10,000	September 2007
5	Greensburg, IN	Popcorn	14,000	September 2007
6	Clauson's Farm, Rochester, IN	Corn	10,000	October 2007
7	Hoover Farm, Abilene, KS	Beans/ wheat	17,000	September 2008
8	Bathurst Farm, Abilene, KS	Wheat	3,000	October 2008
9	Bathurst Farm, Abilene, KS	Wheat	22,000	October 2008

PHERC –Post harvest Education Research Center, SEPAC - South East Purdue Agricultural Center

Temperatures and variable measurements for Empty bin heat treatment trials:

For the empty bin heat treatment trials, two temperatures (55°C vs. 65°C; 131°F vs 149°F) resulting in two different exposure times were used. Required exposure times based on literature

values are 3 hours and 5 min for 55°C (131°F) vs. 65°C (149°F), respectively (Hagstrum and Subramanyan, 2006). Exposure temperatures were measured in the flour and corn of the cages and required time was measured once the critical treatment temperatures (i.e., 55°C/131°F and 65°C/149°F) had been reached. A heat treatment trial was considered complete once the required exposure time at the critical treatment temperature was reached. The lower temperature heat treatment trial was repeated three times. Due to limited time and relatively low ambient temperature, the higher temperature heat treatment was only duplicated. Temperatures were monitored using thermocouples and recorded using FLUKE model 2625A (Fluke Corp., Everett, WA) and HOBO model H08-003-02 (Hobo Data Logger Co., Pocasset, MA) data loggers. In addition to placing sensors inside the live insect cages, additional sensors were placed at the outlet of the MHT 1500 unit to measure leaving air temperature, under the perforated floor to measure plenum air temperature, and at suitable heights above the perforated floor to measure the stratified air temperatures inside the empty bin. Ambient air temperature and relative humidity were also recorded. Real-time monitoring of temperature using the FLUKE data logger was done for the insect cages placed in cardinal directions, the air leaving MHT-1500 unit, and the plenum. The propane consumption of MHT 1500 unit was recorded from the fuel gauge mounted on the tank.

Mobile Heat treatment (MHT-1500) Unit for bin treatments:

The unit was designed, fabricated and built at the Temp Air facility in Burnsville, MN and handed over to Project coordinator, Dr, Dirk Maier, Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, IN for evaluation and testing at various locations in Indiana and Kansas (Table 1).

The MHT-1500 (Fig. 1) is equipped with a propane-fueled heater rated to generate 1.5 million BTUs/h. At the rated burner and fan capacity, the potential heat rise above the ambient air is 93°C (200°F) at a fuel consumption of approximately 15 gallons of propane per hour. Air was pushed through a 2-foot diameter flexible duct by a 7.5 Hp fan with a variable drive capable of generating airflow from 3,750 to 7,500 cfm powered by an on-board propane generator and a fuel tank of 150 gallons. The self contained MHT-1500 can be towed to the bin on farm for heat treatment. The flexible duct was attached to the inlet of the blower or aeration transition of bin to allow heated air to pass through the plenum.



Fig. 1. The MHT-1500 unit

Insect bioassays for the bin heat treatments:

For Indiana locations: During the empty bin heat treatment trials in Indiana locations, live stored grain insects (red flour beetle, maize weevil) placed in PVC pipe cages were used. While red flour beetle was found to be more resistant to heat (Roesli et al., 2003) other insects that could be investigated include rice weevil and lesser grain borer. However, at Indiana locations, bioassays of red flour beetle (RFB), maize weevil (MW), and lesser grain borer (LGB) were used and the effect of heat on other insects was investigated under laboratory conditions (Objective 3). Fifteen to thirty adult insects of each species were placed in each cage containing 300 g (0.67 lb) of flour. Both ends of the PVC pipe cages were closed by double layers of fine mesh cloth to prevent escape of insects. The flour and empty cages were kept in a freezer ($<0^{\circ}\text{C}$; $<-32^{\circ}\text{F}$) for at least 72 hours to ensure that there was no prior contamination of insects. Cages were placed under the perforated floor in four locations (N, S, E, and W) of each bin. On top of the perforated floor, four additional cages were placed but these cages were filled with whole corn kernels instead of flour. Once heat treatment was completed, cages were collected and live and dead insects were counted for each cage.

For Kansas locations: Insect bioassays were placed in the plenum and at the West, East, Center, and South area of the perforated floor. The bioassay insects used for this demonstration included red flour beetle larvae and adults, rice weevil adults, lesser grain borer adults, and Indianmeal moth eggs. Bioassays were prepared in laboratory using small plastic vials (2" \times 1" diameter cylinder) with fine mesh screen on the lid (Fig.2). Additional bioassays were made with 12" \times 8" pouches (same as in previous experiments) containing either wheat or broken wheat materials and were placed in the west, east side of the perforated floor and one in the plenum near the inlet of the heated air. At each location, 15 bioassays were placed representing three replicates of five temperatures. Bioassays were removed at five temperature levels to show the mortality curve as temperature increases. During the heat treatment, bioassays were collected when temperatures at the floor level reached 85, 95, 110, 135, and 145 $^{\circ}\text{F}$ (or 29, 35, 43, 57, and 63 $^{\circ}\text{C}$). These collected bioassays were then placed in individual plastic containers. The heat treatment was terminated at 2:30 PM after 130 $^{\circ}\text{F}$ (54 $^{\circ}\text{C}$) had been maintained for at least 30 minutes.



Fig. 2. Trays with the insect bioassays consisting of small plastic containers

Procedure for the empty bin heat treatments (Objective 1):

At each of the sites (Table 1 above), two identical bins were selected. One bin was heat treated while the other bin was used as a control or treated in a traditional way to compare the efficacy of heat. Generally, the bins were cleaned before heat treatment using broom and vacuum. The insect bioassays were placed on perforated floor in four cardinal directions and at the center. Similarly, the insect bioassays were placed under the perforated floor, if access underneath the perforated floor was easily available. For mold infection, grain and fines accumulated under the perforated floor were collected the week prior to heat treatment and were plated in malt salt agar for seven days to determine both percent kernel infection and degree of dust infection. After the heat treatment process, additional samples of grain and fines were collected for mold analysis.

Procedure for the long-term storage studies after heat treatment (Objective 2):

In order to evaluate the efficacy of the empty bin heat treatment, a long-term grain storage experiment was initiated after in-bin drying of the wet corn was completed in at PHERC (Post Harvest Education Research Center) in Purdue University using one bin for heat treatment and the other as a control. The trial lasted through the end of August 2007 and the extent by which the empty bin heat treatment prevented stored grain insects from infesting (especially the plenum and bottom grain layers) and minimized damage to the corn (especially in the bottom layers) was compared to the corn in the control bin.

During the long-term storage trial, insect traps were placed below the false floor (dome traps and cardboard rolls), near the grain surface (pitfall traps), at the grain surface (cardboard rolls) and in the headspace above the grain surface (flight traps) for monitoring. Sealable port holes were cut into the bottom ring of corrugated metal sheets of both bins at four locations (E, W, S, N) in order to access the plenum below the perforated floor and place and retrieve insects traps. During the cold weather months (January through April), the traps were replaced monthly and during the warm weather months (May through September), the traps were replaced bi-weekly. Each time traps were replaced, insect counts were conducted.

In order to maintain the quality of the stored grain, standard best management practices were implemented. These included aeration cooling and maintenance aeration of the grain during the cold weather period (goal was to cool corn stepwise to around 0°C (32°F) by late December, early January), keeping the cooled grain cool during the spring and summer months, and monitoring the grain using insect traps such as flight, pitfall and cardboard roll traps.

Laboratory procedure and variables for temperature versus exposure time mortality studies (Objective 3):

Insect pouches of fine mesh nylon (80 x 80 mesh) were made into 8 in x 12 in bags by sealing the sides with a plastic clamp type sealer. The pouches were filled with 500 g of wheat flour or yellow dent corn which was initially placed in a freezer for at least 72 hours. This assured elimination of any prior contamination of samples with other insects. Fifty adult insects of either maize weevil (*Sitophilus maize*), red flour beetle (*Tribolium castaneum*), or lesser grain borer (*Rhyzopertha dominica*) were placed in separate corn (maize weevil) and flour (red flour beetle, lesser grain borer) filled pouches. These pouches were placed in a convection oven set at 60°C and removed once temperature at the center of each pouch reached 40°C, 45°C, 50°C or

55°C. In a second set of experiments, pouches were removed at a 1°C increment between 50°C and 55°C. During each experiment, a control pouch was placed in ambient temperature of about 25°C. Times of reaching the desired temperatures were recorded. Real-time temperature was monitored by thermocouples placed in the center of each pouch and attached to a data logger (Fluke Hydra logger, Fluke Corporation). All thermocouples were calibrated against a mercury thermometer. Once pouches were removed, insects were sieved and numbers of live and dead insects were recorded. Beetles were observed and the ones that were on their backs and immobile were classified as dead. Results were analyzed statistically based on three replicates of each test. Tests were repeated until the time variability to reach a desired temperature in the center of a pouch was reduced to an acceptable level of ± 10 min.

Procedure for heat treatment of full-scale commercial facility (Objective 4):

Under the EPA Region 7 grant awarded to PERC, a sunflower seed roasting facility in St Louis, Missouri was heat treated. Various sections of the plant such as the receiving area, pit area and the production area with volumetric measurements of 3568.0 m³ (126,000 ft³), 61.0 m³ (2160 ft³), 2218.0 m³ (78,336 ft³), respectively were heat treated. The heat treatment was performed on 25th and 26th September, 2009. The heaters used were LP fueled, direct-fired make-up air heaters using the principle of positive pressurization of space being heat treated (Temp Air's patented process – US Patent # 6,141,901.) The process involved placing the heaters outside the facility (Fig. 3) so that 100% fresh air intake is used, heated by a burner and hot air is passed over a high velocity fan into the structure being heat treated. The mean targeted temperature was 130°F (54°C). The temperatures inside the facility were gradually increased (4 to 6°C per hour) till the targeted mean temperatures were reached and then held for a period of 24 hours.

The temperatures inside the facility were monitored using the wireless temperature monitoring system. The air flow management for a uniform temperature profile was done by placement of number of fans in the heat treated area. The insect bioassays (Fig. 4) consisting of various life stages of red flour beetle were placed and later analyzed for efficacy of by the Department of Grain Science & Industry, Kansas State University, Manhattan, KS.



Fig. 3. Heater Placed outside receiving area



Fig. 4. Insect bioassays

Results:

Objective 1 – Efficacy of heat using the MHT1500 to control stored product pests and molds:

In terms of evaluating heat treatment of empty steel bins using the MHT 1500, trials during fall 2006 and 2007 in Indiana farm bins showed that when a core temperature of 55°C was reached inside insect cages and that temperature was held for three hours, 100% mortality of maize weevil, red flour beetle and lesser grain borer adults was achieved in the plenum and above the perforated floor repeatedly and consistently. Similarly in 2008 Kansas farm bin trials, 100% mortality was achieved for the same insects placed at the plenum when the minimum temperature of 55°C was reached. In cases when the target temperature was not reached, 100% mortality was not achieved due to a combination of factors such as clogged perforated floors and low ambient temperatures that kept bin walls and floors from heating up within a reasonable treatment time.

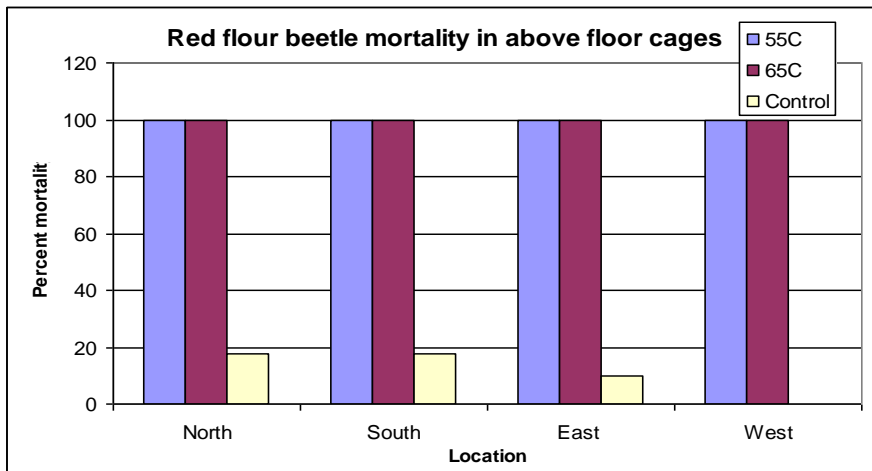


Figure 5. Mortality of red flour beetle in cages placed above the floor during heat treatment at 55°C (131°F) and 65°C (149°F) in West Lafayette, Indiana, October 2006.

Mold infection of residual kernels and dust particles under the perforated floor (plenum) was reduced from 86% to 37% and from 99% to less than 75%, respectively. These results were confirmed in additional on-farm heat treatment trials near Rochester and Greensburg, Indiana in fall 2007 using the MHT 1500, and with propane-fueled burners installed on in-bin dryers at the Southeast Purdue Agricultural Center (SEPAC) in summer 2007.



Figure 6. Effect of heat treatment on mold infection of kernels and dust particles at 55°C (131°F) for three hours from trial in West Lafayette, Indiana, October 2006.

During all field trials, the MHT 1500 performed efficiently at the set point parameters of discharge temperature and airflow to heat treat empty grain storage bins in Indiana and Kansas. At colder temperatures in Kansas, the unit performed equally well but treatment time would have to be extended to reach 100% efficacy. The unit has proven the efficacy of heat to control stored products pests in on-farm bins. Although we are not aware of the cost of the unit, we can easily envision for the unit to be purchased/leased by farmer co-operatives, grain companies, buyers of specialty grains, and pest control companies to provide heat treatment of empty grain bins and silos during the pre-harvest season as a paid service to their customers.

Propane consumption of the MHT 1500 during heat treatment of the empty farm bins in Indiana and Kansas was 7.5 gal/h at the maximum, which given a typical heat treatment time of 4 hours would result in total fuel costs of just under \$45 per bin. The propane consumption for heat treatment of bins in Indiana and Kansas is indicated in Table 2.

Table 2. Comparison of propane consumption for bins in Kansas and Indiana

S.N.	Location	Bin Capacity (bu)	Propane Used (gal)	Total Fuel Cost* (\$)
1	Popcorn Bin Greensburg, IN	15,000	22.1	41.95
2	Popcorn Bin Greensburg, IN	15,000	28.5	45.12
3	Clauson's Farm Rochester, IN	10,000	24.3	46.19
4	Hoover Farm, Abilene, KS	5,000	16.3	30.95
5	Bathurst Farm, Abilene, KS	22,000	17.3	32.85
6	Bathurst Farm, Abilene, KS	3,000	17.1	32.40

* Note: total fuel cost estimated at \$1.90/gal

Objective 2 – Comparison of insect populations in heat-treated and control bins in long-term storage trials:

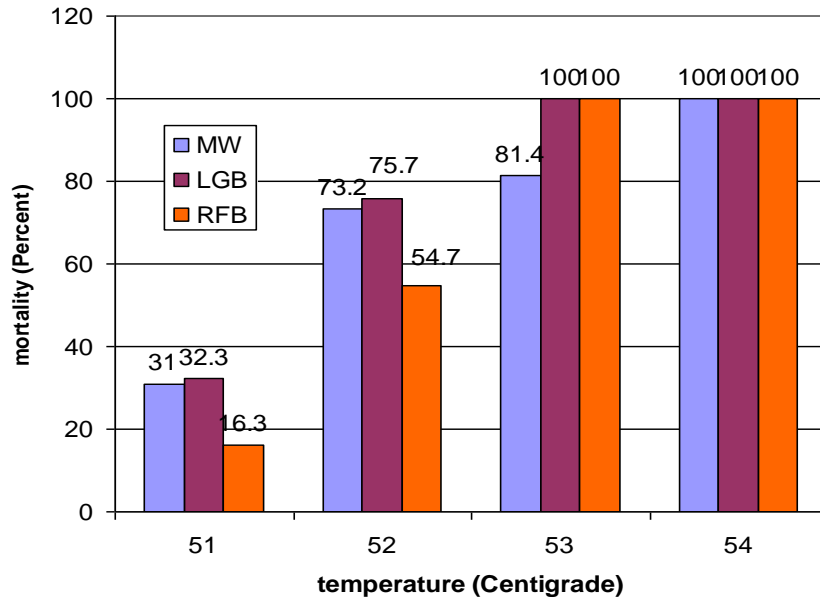
Efficacy of heat treatment in long term storage trials was confirmed by comparing insect populations over a year in heat-treated versus control bins. Overall, the insect populations in the heat-treated bin were lower than in the control bin (not heat treated). Pitfall traps placed in the plenum gave an indication of efficacy of heat treatment as all other monitoring devices were placed at the grain surface. Insect populations in the heat-treated bin were consistently lower compared to the control bin. Higher insect population in August in the heat-treated bin was attributed to increased pest pressure and a combination of higher moisture content of stored grain resulting in higher number of hairy fungus beetles.

Objective 3 –Laboratory tests for temperature-mortality studies with stored product pests:

Laboratory tests using adults of maize weevil, red flour beetle and lesser grain borer constrained within corn and flour filled pouches and exposed to temperatures of 40 to 55°C indicated that 100% mortality was achieved consistently once a temperature of 54°C was reached

at the core of a pouch. Exposure time was defined as the time to reach 54°C. No additional exposure needed for mortality

time was 100% once that



temperature was reached.

Figure 7. Mortality of adult maize weevil (MW), lesser grain borer (LGB), and red flour beetle (RFB) constrained in corn and flour filled pouches at 51°C to 54°C in replicated tests conducted in a convection oven set at 60°C.

Objective 4 – Full scale commercial heat treatment of processing plant:

The heat treatment at the Sunflower roasting plant in St Louis, MO was successfully performed using the propane fueled make-up air heaters. The temperature profiles of the heated space are indicated in figures 8 and 9 and indicate that the lethal temperatures lethal to insects (> 120°F or 50°C) were maintained for approximately 24 hours.

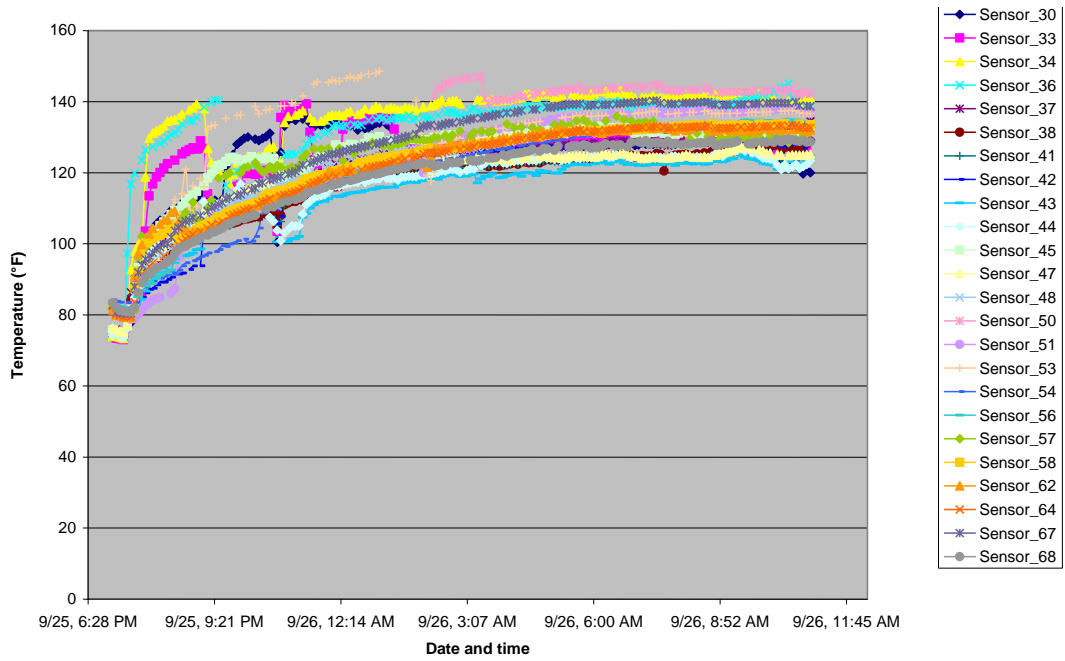


Figure 8. Overall temperature profile in Sunflower roasting plant on 9/25/2009, 7:00 PM to 9/26/2009, 10:00 AM

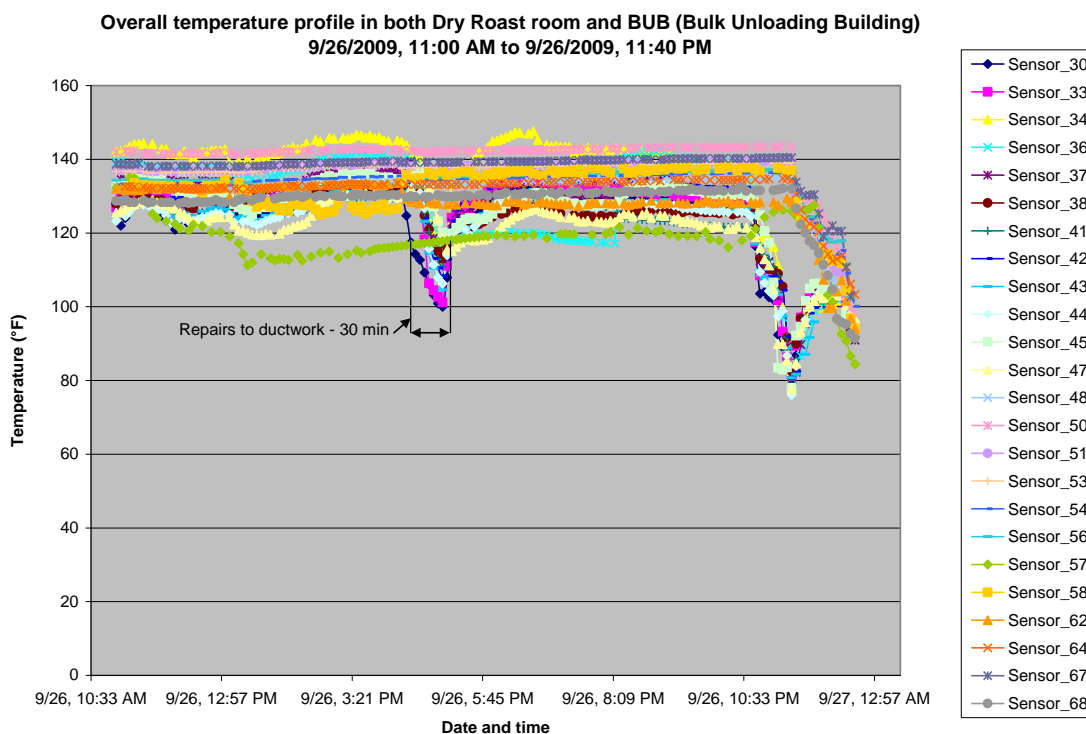


Figure 9. Overall temperature profile in Sunflower roasting plant on 9/26/2009, 11:00 AM to 9/26/2009, 11:40 AM

The insect bioassays were analyzed after the heat treatment. The bioassays consisted of adults, larvae, pupae, and eggs of red flour beetle and a 100% mortality was observed for all the life stages of insects. The mortality of next generation was confirmed by sifting out the dead adults from flour and incubating at 27°C and 65% relative humidity in a chamber. There was no emergence of any life after three weeks confirming that the eggs were totally killed.

The pest pressure before and after the heat treatment was monitored by placement of various insect trapping devices such as flight traps and dome traps. Preliminary analysis of the data suggests that heat treatment effectively reduced the trap catch and that the insect rebound rate was significantly reduced compared to traditional methods of chemical pest control.

Acknowledgements:

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