Hot legs:

Put the heat to insects in your mill

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Heat has been used to control insects in flour mills since the early 1900s. Because heat damaged the wooden structures, stretched line belts and degreased unsealed bearings, it was abandoned and soon replaced by inexpensive chemical pesticides, especially fumigants, which killed insects rapidly and effectively.

But, now many pesticides used in food and feed plants are being pulled from the market or severely restricted. Methyl bromide—a popular fumigant used in mills—is considered an ozone depleter under the U.S. Clean Air Act, and is scheduled to be phased-out in the USA by 2005.

The U.S. Environmental Protection Agency (EPA) increased restrictions on phosphine—a fumigant for stored raw agricultural commodities—use. Organophosphate pesticides, such as diazinon and chlorpyrifos—residual products used for spot treatments or for treating cracks and crevices to control insects—may be cancelled or severely restricted too.

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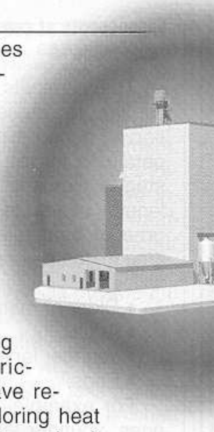

The impending phase-outs and restrictions of pesticides have renewed interest in exploring heat as a safe and viable alternative for managing insect pests associated with food and feed mills. Heat treatment involves heating a mill to 122°F (50°C) or slightly above 122°F and holding this temperature for 24 to 36 hours. The period of time ensures that the heat penetrates cracks and crevices in the mill as well as mill equipment where the insects seek refuge from the heat.

Proper heat distribution in the mill is critical to effectively kill insects. The heat source can be electric, steam, natural gas or propane.

What heat does to insects

The optimum temperatures for maximum insect survival, development and reproduction are between 82 and 90°F (see table *The effect of heat on stored-product insects.*) The lower and upper temperature limits for development, survival and reproduction of stored-product insects are generally between 65 and 105°F.

Temperatures 122°F or above can disrupt the ionic balances across cell membranes, injure cellular DNA, destroy protein synthesis machinery or denature enzymes. Any one of these factors or a combination thereof could cause death. Survival at higher temperatures depends on temperature, duration of exposure, species, life stage, relative humidity and acclimation period.

Heat kills red flour beetles

The red flour beetle (*Tribolium castaneum*) is an important pest in feed mills. We exposed eggs, larvae, pupae and adults of these beetles to high temperatures (122°F or higher) during steam heat treatment (March 17-21, 2000) at the Kansas State University (K-State) pilot flour mill. It took about 42 hours to reach the threshold temperature of 122°F. Temperatures stayed above 122°F for more than 42 hours and 143°F was the highest temperature recorded. In-

The effect of heat on stored-product insects.

Temperature, °F	Effects
143.6 or greater	Death in less than a minute
122-140	Death in less than an hour
113-122	Death in less than a day
95-107.6	Lower survival, prolonged development time, reduced egg production, sterility, insects seek cooler zones
86-95	Maximum temperature for reproduction
77-89.6	Optimum for development

Source: Modified from Paul Fields, 1992. Journal of Stored Products Research, Vol. 28, pp. 89-118.

Steam heat treatment's effect on red flour beetle mortality.

Hours after heat treatment began	Temperature attained, °F	Mortality (% mean)[a] Eggs	Younger larvae	Older larvae	Pupae	Adults
33.0	115.5	55.0	3.3	3.3	5.0	0.0
34.0	116.4	78.0	20.0	11.7	10.0	0.0
35.0	117.3	85.0	63.3	8.3	21.7	45.0
35.5	118.4	96.7	78.3	18.3	43.3	91.7
36.0	118.4	96.7	90.0	63.3	50.0	100
Control[b]	82.4	0.0	0.0	0.0	0.0	0.0

[a]Each mean is based on 3 replications (plastic boxes with 0.5 grams of whole wheat flour), and 20 insects were used at each replication.
[b]Growth chamber in the laboratory.

creasing exposure time increased the treatment's effectiveness (see table *Steam heat treatment's effect on red flour beetle mortality*).

All adults died when the temperature reached 118°F, but only 50% of the pupae died. Many adults emerging from pupae exposed to high temperatures had separated wings; a few dead pupae had pupal-adult characteristics. As the time of heat exposure increased, the proportion of adults with separated wings increased.

More adults emerged from older larvae exposed to heat than from younger larvae. Larvae emerging from eggs exposed to heat were smaller in size and weighed significantly less than those emerging from eggs that were not exposed to heat.

Temperature and time required to kill adult red flour beetles.

Temperature, °F	Minimum exposure time beyond which adults begin to die, hours[a]	Minimum exposure time to kill 100% of adults, hours
111.2	11.0	26.5
113.0	8.3	21.0
114.8	4.0	9.0
116.6	2.3	5.7
118.0	1.0	2.5
120.2	1.0	1.8
122.0	0.4	0.8

[a]Mortality at the indicated time is 0%.

Experiments at constant temperatures

These results were similar to those observed during exposure to variable temperatures for red flour beetles at all life stages exposed to 122°F for varying lengths of time in the laboratory. The degree of heat tolerance—expressed as time to death—was highest in pupae, followed by:

- Older or mature larvae;
- Adults;
- Younger larvae; and
- Eggs.

For example, for 100% mortality of eggs, younger larvae, older larvae, pupae, and adults, it took 30, 50, 65, 90 and 55 minutes, respectively.

In another experiment, red flour beetle adults were exposed to seven different constant temperatures between 111 and 122°F, and 20-21% relative humidity (RH). All adults exposed to 122°F died within 55 minutes. At 111°F, all adults died within 26 hours (see table *Temperature and time required to kill adult red flour beetles.*)

We are conducting additional tests at constant temperatures above 122°F using red flour beetles at various life stages.

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Insects caught before and after heat treatment.

	Just before heat treatment			Just after heat treatment		
Place	IMM[1]	ALM[2]	Beetles[3]	IMM[1]	ALM[2]	Beetles[3]
Inside	335	108	473	2	1	141
Outside	44	14	208	23	2	94
Roof	5	2	107	17	4	167

[1]Indianmeal moth; 5 Pherocon II traps outside the mill, 5 on the roof, and 5 in each of the 4 floors and basement of the mill.
[2]Almond moth; trap numbers similar to those given for Indianmeal moth.
[3]Several species of beetles; 7 Flit-Trak traps outside, on the roof, and inside each floor of the mill, including the basement.

We are also studying whether insects exposed to high temperatures can develop heat tolerance. We want to know if insects can acclimate to gradually increasing temperatures—that would occur during a heat treatment—and take longer to die than those suddenly exposed to high temperatures.

We have preliminary evidence to suggest that insects exposed to gradually increasing temperatures take slightly longer to die than those suddenly exposed to high temperatures. For example, all red flour beetle adults taken from a growth chamber at 82°F then exposed to 122°F died in 55 minutes. However, all adults acclimated for 24 hours to increasing temperatures between 82 and 111°F and then exposed to 122°C, died in 75 minutes. Our ultimate goal is to develop a degree-hour model to predict red flour beetle mortality by life stage then expand the model to other stored-product insects.

Heating up a feed mill

In August of 1999, we heat-treated the K-State pilot feed mill with gas heaters (TempAir, a division of Rupp Industries) for the first time. Before and after heat treatment, we monitored beetle and moth populations in the mill using food-baited and pheromone traps.

The target temperature was 122°F for this treatment. Ambient temperature was about 84°F and we maintained temperatures above 122°F for 28 to 35 hours. We caught 497 beetles and 118 moths just before treatment and—for the same time duration after heat treatment—caught 25 beetles and 2 moths just after treatment.

However, in 2 to 4 weeks, we noticed high insect activity levels. Insects outside the mill can reinfest the feed mill. Insects that took refuge in feed residues because heat does not penetrate raw grain or processed products well can reinfest the mill. Insects from infested ingredients brought into the mill after treatment can also reinfest the mill.

One more time

In August 2000, we conducted a second heat treatment. The mill reached 122°F within 4 to 8 hours, and maintained temperatures above 122°F for 29 to 33 hours. Our trapping results before and after the second heat treatment were similar to those from the first heat treatment. Fewer insects were captured in traps following the heat treatment (see table *Insects caught before and after heat treatment*). Since reinfestation could occur from insects present outside the mill, we also set traps for the insects outside the feed mill and on the roof.

Heat does not penetrate raw ingredients or finished products well. Therefore, before heating a feed mill, it is important to move these ingredients and finished products into a trailer and fumigate them. Sanitation and use of a residual product, such as Tempo, will improve heat treatment effectiveness.

Preventing reinfestation is the key to prolonging a heat treatment's effectiveness. Practicing good housekeeping, continuous monitoring, and just being vigilant about emerging insect problems can prevent reinfestation. Information from visual inspections, product sampling and trapping can identify incipient pest infestations. Because traps do not indicate the source of insects, using traps alone is not a good idea. Use visual inspections and product sampling to identify and destroy infestation sources.

Our treatments at the K-State pilot feed mill showed no evidence of any damage to the machinery, parts or the building structure. Certain areas, such as the control room, had to be sealed to protect the computer systems. However, during the first heat treatment, IBM and Macintosh computers were exposed to the heat and worked well afterwards. For more information on heat treating feed mills visit: www.oznet.ksu.edu/dp_grsi/2000heat-treatment/index.html.

Heat appears to be a safe and viable alternative to fumigation. However, we still need to develop information about the minimum temperature and times of exposure to kill other stored-product insects aside from the red flour beetle. This information will help determine the economics of heat treatment relative to fumigation. FM