EFFICACY OF COMPLEMENTARY MEASURES TO ASSIST HEAT DISINFESTATION OF STRUCTURES

C H Bell*, S T Conyers and D A Cook
Central Science Laboratory, Sand Hutton, York YO41 1LZ

Methyl bromide is still the fumigant most often chosen for whole site disinfestation of flour mills in much of the developed world and heat is one of the few alternatives offering a potentially equally rapid disinfestation procedure. However, to obtain target temperatures quickly and evenly throughout a structure is not easy and local conditions inevitably create problem areas for control. A three-year programme "Alternatives to methyl bromide for pest control in structures" sponsored by a government and industry consortium in the UK was completed in September 2003, and proposes a heating strategy based on mobile convection heaters supplemented by heat-conducting mats for positioning at concrete wall floor joints. The high target temperatures (48-50°C) required for disinfestation by heat alone within a 24-h period require a high energy input that can cause temperatures at some points to rise to levels that may cause damage to electronic equipment, or even to structural components. Combinants were therefore sought to enable some lowering of target temperatures. This presentation describes results obtained for some modified atmospheres that could theoretically be achieved in a structure such as a flour mill, and results obtained from exposing insect pests at raised temperatures to a diatomaceous earth (DE) formulation suitable for application to hidden crevices and voids in the mill structure.

Experimental – Tests comparing the effect of heat with and without added carbon dioxide (CO_2) were conducted on five insect species *Tribolium castaneum* (Herbst) (rust-red flour beetle), *T. confusum* du Val (confused flour beetle), *Cryptolestes turcicus* (Grouvelle) (Turkish grain beetle), *Liposcelis bostrycho-phila* (Badonnel) (book louse) and *Sitophilus granarius* (L.) (granary weevil), at 44°C. The first four species showed some evidence that the presence of 10-11% CO_2, rather than improving efficacy, actually increased the level of survival and duration of exposure survived at this temperature. However a small temperature difference was evident between the 44°C controls and the CO_2 treatments, the latter being up to 0.8°C cooler in some cases, and further tests were run with two of the species, *T. castaneum* and *S. granarius*, at 10, 20 and 30% CO_2, exposing older and younger stages (> or < 3 weeks from first oviposition).

Insect cultures were exposed in chambers or desiccators in constant temperature rooms. Carbon dioxide was supplied from a cylinder source via a Signal gas blender regulating the output to the required level in air. Humidity was maintained at 50% r.h. by passing the gas mixture over sulphuric acid at a flow rate of 1 l/min for chamber tests or through glycerol solution at a flow rate of 100 ml per minute for desiccators. For *S. granarius* there seemed to be some improvement in efficacy with the combination of heat and CO_2 but it was small (Table 1). However, a temperature increase of 0.5^oC from 44^oC had a similar effect to adding 20 or 30% CO_2. For *T. castaneum* it seemed that the survival of younger stages was actually prolonged at 44^oC in the presence of 10% CO_2 (Table 2). It was apparent that there was no real advantage of adding even 30% CO_2 to exposure at 44^oC in achieving control of either species.

To see whether the efficacy of heat was affected by oxygen (O_2) level, a test was run in a 30% O_2 atmosphere at 44^oC. Again, no advantage was evident in the modified atmosphere (Table 3).

The efficacy of a commercially available diatomaceous earth (DE) formulation 'Silico-Sec' was also assessed in controlled environment rooms at exposure conditions of 25°C/70% r.h., 30°C/50% r.h., 35°C/40% r.h. and 40°C/30% r.h. The progressive drop in r.h. simulated the effect of heating in a flour mill. For dosing in the laboratory the DE formulation was sieved through a 250 μm wire sieve to give an even coating on 14 cm diameter glass Petri dishes at 1, 5, 7.5 and 10 g/m^2 (n=5). For each experimental run, additional sets of untreated dishes at 25°C, 70% r.h. were set up as controls. The dishes were held overnight in controlled environment rooms at each condition before batches of twenty-five 2-4 week-old adults were added to each separate dish. Mortality was assessed 24 and 48 h after start of treatment, survivors then being transferred to jars containing wheat at 15.5% moisture content for a further 7 days at 25^oC.

In contrast to the results with modified atmospheres, the efficacy of applications of DE and heat was very much improved over heat alone or dust application at 25^oC (Tables 4 and 5). At 35^oC there was no survival of either species after 48 h at any of the applied dosage rates of DE. *T. castaneum*, the more tolerant species to heat alone, was in fact the more susceptible of the two species to dust exposures, all adults being killed after 48 h at 30^oC (Table 4). Surviving adults of both species held for a further 7 days to recover on food at 25^oC after the 48-h exposure to dust continued to be affected, and no *S. granarius* adults exposed at 30^oC survived this period (Table 5). There was some evidence of reduced efficacy of the 1g /m^2 dose level as compared to higher doses, but no evidence of any difference in efficacy at 5g /m^2 or above.

Thus heat treatment efficacy can be improved by the use of residual dusts in cracks and voids, where target temperatures are often hard to achieve, but there is no advantage in attempting to modify the balance of atmospheric gases in order to shorten treatment times or reduce target temperatures.

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Table 1. Effect of added carbon dioxide (CO_2) on the efficacy of heat treatments at 50% r.h. against older and younger stages of *Sitophilus granarius*

Temperature (°C)	% CO_2 in air	Stage: Y = <3 weeks O = >3 weeks	Longest exposure survived (h)	Exposure (h) needed to give 100% kill
43.5	0	Y	16	20
43.5	10	Y	10	16
44	0	Y	8	16
44	20	Y	8	16
44	30	Y	8	16
44	0	O	24	32
44	11	O	20	>20
44	20	O	16	24
44	30	O	8	16
44.5	0	O	8	16

Table 2. Effect of added carbon dioxide (CO_2) on the efficacy of heat treatments at 50% r.h. against older and younger stages of *Tribolium castaneum*

Temperature (°C)	% CO_2 in air	Stage: Y = <3 weeks O = >3 weeks	Longest exposure survived (h)	Exposure (h) needed to give 100% kill
43	0	Y	48	>48
43	10	Y	48	>48
43	20	Y	48	>48
44	0	Y	40	48
44	10	Y	48	>48
44	20	Y	40	48
44	30	Y	40	48
44.5	0	Y	24	40
44	0	O	48	72
44	11	O	48	>48
44	20	O	48	>48
44	30	O	40	48
44.5	0	O	40	48

Table 3. Effect of adding 9% oxygen to air on the efficacy of treatment at 44°C, 50% r.h. against older and younger stages of *Tribolium castaneum*

% oxygen in air	Stage: Y = <3 weeks O = >3 weeks	Max exposure survived (h)	Exposure needed for 100% kill (h)
21	Y	40	48
30	Y	40	48
21	O	40	48
30	O	48	>48

Table 4. Mean % mortality for *Tribolium castaneum* after exposure to DE at 5 temperature/humidity combinations, simulating mill conditions during heating (range in parenthesis; n=5; * n=25).

Dose	24 hours exposure				48 hours exposure				48 h + 7 d on food	
	25°C 70%	30°C 50%	35°C 40%	40°C 30%	25°C 70%	30°C 50%	35°C 40%	40°C 30%	25°C 70%	30°C 50%
No DE	0* *a* (0)	0 *a* (0)	0 *a* (0)	0 *a* (0)	0* *a* (0)	0 *a* (0)	0 *a* (0)	1 *a* (0-4)	1* *a* (0-4)	0 *a* (0)
1 g/m^2	34 *b* (20-52)	88 *b* (80-92)	100 *b* (100)	100 *b* (100)	89 *b* (76-96)	100 *b* (100)	100 *b* (100)	100 *b* (100)	99 *b* (96-100)	100 *b* (100)
5 g/m^2	20 *bc* (4-29)	90 *b* (84-96)	99 *b* (96-100)	100 *b* (100)	87 *b* (78-96)	100 *b* (100)	100 *b* (100)	100 *b* (100)	98 *b* (96-100)	100 *b* (100)
7.5 g/m^2	19 *bc* (12-24)	85 *b* (80-88)	100 *b* (100)	100 *b* (100)	90 *b* (80-96)	100 *b* (100)	100 *b* (100)	100 *b* (100)	100 *b* (100)	100 *b* (100)
10 g/m^2	16 *c* (8-20)	82 *b* (76-96)	100 *b* (100)	100 *b* (100)	87 *b* (77-96)	100 *b* (100)	100 *b* (100)	100 *b* (100)	98 *b* (96-100)	100 *b* (100)

Proportions in the same column followed by the same letter are not significantly different at $p = 0.05$.

Table 5. Mean % mortality for *Sitophilus granarius* after exposure to DE at 5 temperature/humidity combinations, simulating mill conditions during heating (range in parenthesis; n=5; * n=25).

Dose	24 hours exposure				48 hours exposure				48 h + 7 d on food	
	25°C 70%	30°C 50%	35°C 40%	40°C 30%	25°C 70%	30°C 50%	35°C 40%	40°C 30%	25°C 70%	30°C 50%
No DE	0* *a* (0)	0 *a* (0)	0 *a* (0)	80 *a* (60-92)	0* *a* (0)	0 *a* (0)	21 *a* (16-28)	100 *a* (100)	1* *a* (0-4)	2 *a* (0-4)
1 g/m^2	0 *a* (0)	6 *b* (0-8)	50 *b* (28-84)	100 *b* (100)	16 *b* (4-24)	94 *b* (88-100)	100 *b* (100)	100 *a* (100)	82 *b* (72-96)	100 *b* (100)
5 g/m^2	0 *a* (0)	14 *b* (8-16)	91 *c* (84-100)	100 *b* (100)	40 *c* (36-44)	99 *b* (96-100)	100 *b* (100)	100 *a* (100)	96 *bc* (92-100)	100 *b* (100)
7.5 g/m^2	0 *a* (0)	13 *b* (4-20)	94 *c* (84-100)	100 *b* (100)	39 *c* (20-48)	99 *b* (96-100)	100 *b* (100)	100 *a* (100)	97 *c* (92-100)	100 *b* (100)
10 g/m^2	0 *a* (0)	11 *b* (0-16)	94 *c* (84-100)	100 *b* (100)	33 *c* (20-44)	98 *b* (92-100)	100 *b* (100)	100 *a* (100)	94 *c* (88-100)	100 *b* (100)

Proportions in the same column followed by the same letter are not significantly different at $p = 0.05$