

On-farm heat disinfestation trials using a continuous-flow spouted bed

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Abstract. A continuous-flow spouted-bed disinfector developed at the Stored Grain Research Laboratory was tested for on-farm heat disinfestation of barley. About 30 t of barley naturally infested with mixed-age populations of *Rhyzopertha dominica* (F.) and *Tribolium castaneum* (Herbst) were passed through the unit. The incorporation of a draft tube helped to achieve a comparatively uniform grain temperature ($\pm 2^\circ\text{C}$) and minimised heat loss. Four target grain temperatures (57, 58, 62.2 and 63.3°C) were achieved during these trials. After initial heating, the grain temperature was maintained at each temperature for 5, 3, 1 and 1 minutes, respectively. Previous studies suggested these treatments were likely to ensure complete disinfestation of *R. dominica* and indeed no live insects were found after heat treatment. The operational cost of the treatment was about \$1.30/t. The heat treatment did affect germination because the grain was not actively cooled afterwards. Cooling was not considered necessary as the grain was being used for stockfeed.

Introduction

Chemicals residues in food are becoming less acceptable to markets and their application is being increasingly regulated. Furthermore, there is growing insect resistance to contact pesticides and fumigants. For these reasons, people are looking at physical methods of pest control, such as heating and cooling. Heat is a non-chemical alternative to fumigation which offers a rapid and residue-free method of controlling stored grain pests.

A window of opportunity exists between the heat dosage required to kill insects and that which causes significant damage to grain. It is quite possible to damage grain without proper management of the heat-treatment process. However, rapid cooling immediately after heat treatment of grain can significantly reduce the risk of damage to grain quality (Banks 1998). Baking quality of dry wheat, malting quality of dry barley, and oil quality of canola are not significantly altered by a well-controlled heat-treatment process at heat dosages that kill all stages of grain insect pests (Ghaly 1981, 1988; Sutherland 1991).

In the past, both fluidised-bed and conduction (falling column) systems have been developed, but currently have no industrial acceptance. A spouted-bed system, which is a modified form of fluidised bed with air entering at high velocity through a nozzle located at the conical bottom of the grain bed, is another option. The grain fluidises above the air inlet and moves through a draft tube until it eventually enters an adjacent cooling chamber. The power requirements of a spouted bed are lower than those of fluidised bed dryers/disinfestors (Bakker-Arkema et al. 1977). Spouted beds operate at lower air pressures than fluidised

beds and can be used for larger grains, such as maize, which are otherwise difficult to fluidise. The introduction of a draft tube into the conventional spouted bed improves its performance significantly (Mathur and Gishler 1955). This paper describes the use of a semi-commercial continuous-flow spouted bed with draft tube for on-farm thermal disinfestation of grain.

Description of the system

The system is composed of two rectangular chambers (0.75 m \times 0.75 m \times 1.5 m) fitted with a 60° cone at the bottom of each. The first chamber is used to heat the grain while the other is used to hold the grain at a given temperature for a given length of time (heat-soak), or cool it immediately with ambient air. The air inlet to each chamber is via a 0.1 m diameter opening at the bottom of the cone. The outlet air is allowed to escape through an opening at the top of the heating chamber and through an opening on the side near the top of the heat-soaking/cooling chamber. The infested grain is pneumatically conveyed into the heating chamber (Figure 1). In each chamber, a rigid, non-porous draft tube is positioned coaxially by means of a clamp, which prevents vertical movement. The vertical height of the draft tube is 1.4 m. The upper end of the tube in the heating chamber is fitted with an elbow, which allows the heat-treated grain to be directed into the heat-soaking/cooling chamber. The second chamber is used solely for cooling when grain is treated at high temperatures ($>60^\circ\text{C}$). At temperatures below 60°C, the chamber is used for heat-soaking, where

grain is held for sufficient time after heating for complete insect kill before being returned into a continuous flow process. The total length of the heated air conveying pipe, including the draft tube, is 3.5 m.

During the trials, the separation distance from the air inlet jet to the bottom of the draft tube was 120 mm. Inlet air and grain temperatures were measured using thermocouples. Air was blown through a 15 kW axial-flow fan at a total rate of 0.30 m³/s into the heating chamber. A liquid petroleum gas (LPG) burner was used to heat the air sufficiently to achieve a given target grain temperature. The air was mixed in a wind box using a baffle before it entered the heating chamber through an insulated duct. Two thermocouples respectively measured the wind box temperature and the final grain temperature. Altering the fuel supply to the burner varied the inlet air temperature, which was held between 220°C and 250°C. The outlet air temperature was used to estimate the final grain temperature. Typically, the outlet air temperature was 5–10°C higher than the final grain temperature.

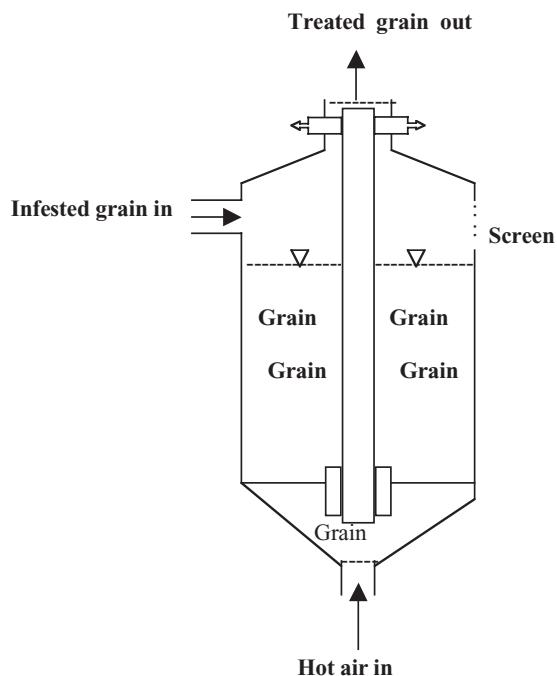


Figure 1. Schematic diagram of a continuous-flow, spouted-bed heat disinfector.

Methods

A trial-run over two days was conducted at a property near Lockhart, NSW in March 2003. A 30-t batch of barley to be used for stockfeed was found to be heavily infested with *Rhyzopertha dominica* (F.) and *Tribolium castaneum* (Herbst). The grain was stored in an unsealed silo and the grower repeatedly applied residual pesticide to the grain and around the silo. Following discussion with the

growers, the Stored Grain Research Laboratory suggested the use of thermal disinfestation to control the insect problem.

Three control grain samples were taken at the outlet of the silo at the beginning, the middle and the end of the trials. Further samples of treated grain were taken between the heating chamber and the heat-soaking/cooling chamber to determine the level of insect survival at four final grain treatment temperatures (63.3°C, 62.2°C, 58°C and 57.2°C). The grain samples were held at the respective temperatures for times sufficient for complete disinfection, and then rapidly cooled by being spread out and cooled under ambient conditions. The samples were then incubated under controlled conditions (30°C/60% relative humidity). Adult insect survival was assessed after 24 h for both species and immature survival assessed subsequently every week for 5 weeks. The grain disinfested during the trial was at 10.2% moisture content. The temperature/time relationships obtained in laboratory trials (Beckett et al. 1998) were used as a guide for the on-farm field trials (Table 1). To assess effects on quality, samples for germination testing were collected from the treated grain that had been stored on a truck and allowed to cool naturally. The throughput rate of the system as configured was 5 t/h. This could be increased to about 8 t/h if the capacity of the grain conveyor used to feed infested grain into the system was increased.

Table 1. Temperature/time mortality relationship for the most heat-tolerant species, *Rhyzopertha dominica* (Beckett et al. 1998)

Time to achieve 99.9% mortality	Temperature (°C)
Less than one minute	60
5 minutes	57
20 minutes	55
29 hours	50
About 96 hours	45

Results and discussion

Thermal disinfestation requires heating the grain rapidly to about 62°C to achieve 99.9% insect mortality, followed by rapid cooling to avoid grain damage. Alternatively, grain may be heated up to 58°C or 57°C for a period of 5 or 7 minutes, respectively, to achieve the same level of mortality. These temperatures were obtained with the continuous-flow spouted-bed disinfector during the trial and were reasonably uniform ($\pm 2^\circ\text{C}$) throughout. Figure 2 shows the final grain temperatures achieved during the trial. Table 2 summarises the presence of insects in the samples before treatment and the effect of heat treatment on insect survival. No live insects were found after passing the infested grain through the system at any of the treatment temperatures. Insect mortality is due to both

mechanical and heat damage, though heat damage is the major mortality factor (Claflin 1986).

Germination tests conducted on control and treated samples showed that germination of treated samples was reduced by about 3% relative to controls (Table 3). The grain temperature leaving the system was between 57°C and 63°C throughout the trial. Cooling was not considered necessary because the grain was to be used for stockfeed. It is well documented that exposure of grain to high temperature for an extended time will affect grain quality, and cooling to a lower final grain temperature, around 56°C, would be desirable to avoid damage, especially in the absence of a rapid cooling system. The loss of germination capacity would have been minimised using the present system by cooling the grain down as it passed through the heat-soaking/cooling chamber using ambient air and then further cooling using aeration in storage. The use of evaporative cooling by wetting the grain as it enters the cooling chamber would greatly benefit the cooling process. In earlier trials, the grain temperature decreased

to 30°C when a water mist was added to the air used to cool the grain in the cooling chamber (Qaisrani and Beckett 2003). The evaporative-cooling technique needs to be further investigated and has potential for a commercial unit.

Table 3. Barley germination test results.

Grain samples	Total seeds	Total germinated (%)	Total ungerminated (%)
Treated	100	96	4
Control	100	99	1

Conclusions and recommendations

The continuous-flow spouted bed has the potential to meet the requirements of a heat disinfestation process for most of the cereal grains. Design considerations suggest that a multi-spouted system will be necessary for higher

Table 2. Number of live insects found before and after heat treatment of grain.

Insects	Final grain temperature (°C)	Exposure time (min)	Live insects before treatment/kg	Live insects after treatment at time (days) after treatment				
				1	7	14	21	28
<i>Rhyzopertha dominica</i>	57.2	5	2	–	0	0	0	0
	58.0	3	5	–	0	0	0	0
	62.2	1	3	–	0	0	0	0
	63.3	1	6	–	0	0	0	0
<i>Tribolium castaneum</i>	57.2	5	12	0	0	0	0	0
	58.0	3	15	0	0	0	0	0
	62.2	1	25	0	0	0	0	0
	63.3	1	60	0	0	0	0	0

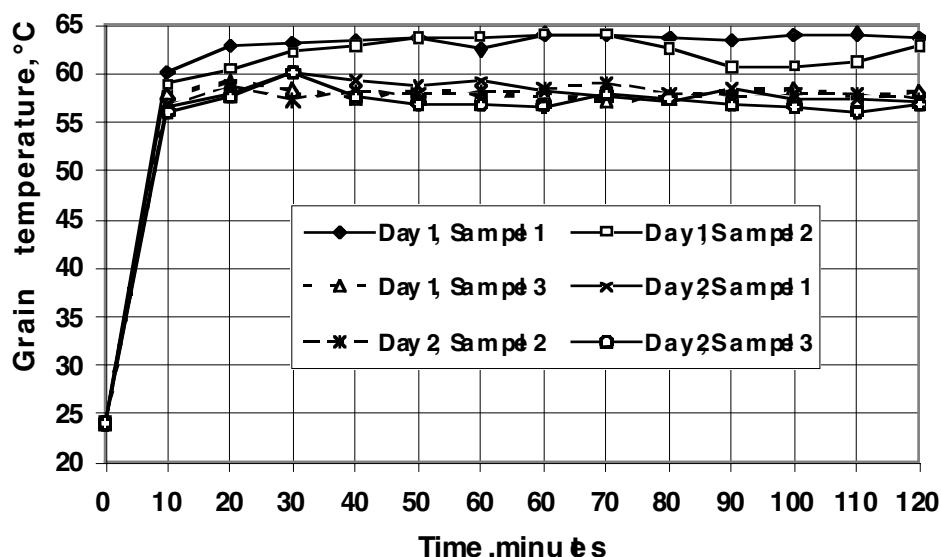


Figure 2. Average final grain temperature achieved during the trial.

throughputs. For example, the use of a double-bedded system could result in doubling the throughput rate without affecting the operational cost of the system. The use of a draft tube to constrain the spouting grain helps to regulate the flow paths and also assists in achieving comparatively uniform final grain temperatures as shown in Figure 2.

The high inlet air temperature (220–250°C) in combination with high grain temperature (>65°C) could affect grain quality if treated grain is not rapidly cooled down. Rapid heating of grain to 60°C followed by rapid cooling to safer storage temperatures (below 30°C) would minimise the effect of heating on grain quality. There is no additional cost associated with cooling if heating and cooling are done simultaneously in the heating and heat-soaking/cooling chambers, because the same fan is used to supply air to each chamber. Incorporating evaporative cooling into the system would enhance the cooling effect of ambient air. The operational cost of treatment based on a grain treatment of 63°C was calculated to be \$1.30/t. This cost could be reduced approximately to \$1.20/t if the grain was heated to 57°C, with the inclusion of a heat-soak period (about 3–5 minutes).

The addition of a dust collector will further improve the operation of the system as considerable amounts of dust are generated while conveying heavily infested grain into the heating chamber.

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