CHAPTER 3

Heat disinfestation of wheat in a continuous-flow spouted bed

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Abstract - A continuous-flow spouted bed with a draft tube was developed and tested for heat disinfestation of grain. Fifty tonnes of wheat naturally infested with mixed age populations of *Rhyzopertha dominica*, *Cryptolestes ferrugineus* and *Liposcelis bostrychophila* were passed through the unit. The draft tube helped to achieve a comparatively uniform grain temperature (±4°C) and minimised heat losses. Three target grain temperatures (55, 57 and 60°C) were achieved during the experiment. After initial heating, the two lower temperatures were maintained for periods of time likely to ensure disinfestation of *R. dominica*. No live insects were found after heat treatment. The grain residence time was less than one second. The throughput of the system was 5t/h, which was limited by the capacity of the pneumatic conveyor used to feed the infested grain into the heating chamber. However, the maximum capacity of the system could be as much as 10t/h. Practical considerations for the scale up and commercialisation of the spouted bed disinfestor are the next steps in making this technology available to the end users.

1. Introduction

There is increasing pressure to develop alternatives to the current systems of grain preservation and pest control on which the grain industry is too reliant. Most of the Australian cereal grain, oilseeds and pulse crop (80%), is treated with phosphine as a fumigant at some stage to control infestation (Banks, 1998). A declining proportion (around 20% in 1997-98) is treated with pyrethroids, organophosphates or methoprene at receival. Market preference for residue free grain and signs of insect resistance to phosphine suggest the need to look at other alternatives. Workspace, environmental, and transport and handling regulations for pesticides are becoming stringent, and complex. Therefore, alternative approaches are urgently required. It is worth asking: 'what should we be using in the future for grain disinfestation, especially when MeBr is phased out in 2005? We believe that heat disinfestation in one or more forms will be widely used in the grain industry in the near future (10 years). Its use can be integrated with other measures to give a quality grain protection system.

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. Damage from a poorly controlled grain dyer is a well-known problem in the grain industry. Rapid cooling immediately after heat treatment of grain can be achieved without any significant damage to grain quality (Banks, 1998). Baking quality of dry wheat, malting quality of barley and oil quality of canola are all not significantly altered by a well-controlled heat treatment process at heat dosages that kill all stages of grain insect pests (Ghaly, 1981, 1988 and Sutherland, 1991).

However, large-scale application of this technique awaits the development of a suitable system. In the past, both fluidised bed and conduction (falling column) systems have been developed, but have not gained recent industrial acceptance. One is a spouted bed system, a modified form of fluidised bed system with air entering at high velocity through a nozzle located at the conical bottom of the bed. The grain fluidises above the air inlet and moves through the draft tube until it enters a cooling chamber. The power requirements of a sprouted bed are less than those of fluidised bed dryers/disinfestors (Bakker-Arkema et al, 1977). A spouted bed is an alternative technique to fluidised bed for gas/solid contact and was initially developed in Canada as a convenient means for drying grain before storage. In a conventional spouted bed, grain is circulated, first falling into the surrounding area of low air velocity, then re-entering the air stream. Spouted beds differ from fluidised beds in that the air is introduced as a high-velocity jet rather than as an evenly distributed low-velocity stream. 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 tremendously (Mathur and Gishler, 1955). This paper describes the use of a spouted bed with draft tube for thermal disinfestation of grain.

2. Materials and methods

The system was composed of two chambers (0.75 m x 0.75 m x 1.5 m) fitted with a 60° cone at the bottom of each (Fig. 1). The first chamber was used to heat the grain while the other was used for either cooling or heat soaking. The air inlet to each chamber was a 0.10m diameter opening at the base of the cone. The outlet air was allowed to escape through an opening at the top of the heating chamber and through an opening on the side of the cooling/heat soaking chamber. The infested grain was pneumatically conveyed into the heating chamber as shown in Figure 1. A solid draft tube (0.125 m) was maintained in a coaxial position by means of two 'yorks', which permitted its vertical movement. The vertical height of the draft tube was 1.4 m. The upper end of the tube was fitted with an elbow, which allowed the heat-treated grain to be directed into the cooling/heat soaking chamber. For high grain temperatures (>60°C) the cooling/heat soaking chamber was used solely for cooling, whereas at more moderate temperatures (eg 57 and 55°C) the chamber was used for heat soaking. That is, the grain was held for sufficient time after heating for complete insect kill before being released back into a continuous flow process. The total length of the conveying pipe was 2.50m. The separation distance from the air inlet jet to the bottom of the draft tube was 0.12m throughout the trial. Inlet air and grain temperatures were measured by thermocouples. Air was blown through a 15kW axial flow fan at 0.25 m^3/s into the heating and cooling chambers. For the heating chamber, a LPG gas 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 moving into the heating chamber through a sealed duct. Two thermocouples measured the wind box temperature and final grain temperature. Altering the flow of gas to the burner varied the inlet air temperature. The outlet air temperature was used as estimator of the final grain temperature. There was a 5-10°C difference between the outlet air and final grain temperature.

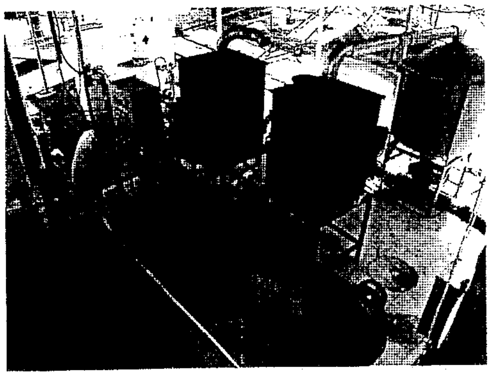

Figure 1: Continuous-flow spouted bed heat disinfestor – diagram of component

Grain samples were taken at the bottom of the infested silo before treatment (untreated controls), then between the heating chamber and the cooling/heat soaking chamber to determine the level of insect survival at three final grain treatment temperatures (60°C, 57°C and 55°C). Three insect species were identified from the infested grain. These were *Rhyzopertha dominica* (F.), *Cryptolestes ferrugineus* (Stephens) and *Liposcelis bostrychophila* (Badonnel). The grain used during this trial was at 7% moisture content. The temperature time relationships obtained from fluid beds (Table 1) were used as a guide for the pilot scale trial of the spouted bed heat disinfestation system. A grain temperature between 60 and 65°C is achieved in this system in a few seconds while conveying grain through the draft tube with inlet air temperature between 220 and 250°C. The grain samples taken after heat treatment to 60°C were cooled down rapidly, while those heated to 57°C and 55°C were left for 5 and 50 minutes respectively before cooling. These grain samples were then incubated under controlled conditions (30°C/60% r.h.). Survival of *Cryptolestes ferrugineus* and *Liposcelis bostrychophila* was assessed after 24 h and all three species assessed subsequently after one to five weeks. When reared at 30°C/60% r.h., the first weekly sample of *R. dominica* is made up of teneral adults, pupae and prepupae. Subsequent weekly counts represent increasingly younger overlapping instar stages with mainly eggs and some first instars representing stage one (Beckett et al, 1998). Grain temperatures were measured before conveying into the heating chamber, before entering the cooling chamber (final grain temperature), after passing through the cooling chamber and finally before entering the storage bin. The hot air conveying duct was insulated to minimise heat losses in the conveying system.

The output of the system as configured was 5t/h. This output could be increased to about 8t/h if the capacity of the conveyor used to feed infested grain into the system was increased. Increasing the number of heated cells rather than increasing the size of the units could also achieve higher throughput.

Heat dosages to kill insects

Heat dosages required to kill stored product pests vary with insect species, the various life cycle stages of these insects, the moisture content of the grain, rate of heating, final grain temperature, and time of exposure as shown in Table 1. Stored grain insect pests are killed within a few seconds when exposed to temperatures above 65°C (Beckett et al, 1998). The exposure time increases with decreases in grain temperature, taking a few hours at 50°C and days at 45°C. Below 42°C insects start to survive for considerable lengths of time. They stated that in wheat at 12% moisture content, *R. dominica* late larvae/pupae were the most heat tolerant stages requiring 96 hours for 99.9% mortality at 45°C,whereas at 53°C, eggs were the most tolerant to heat. They also found that treating wetter grain required longer exposure for complete kill.

Estimating the cost of heat disinfestation

The cost of heat treating grain in a continuous flow spouted bed was estimated by heating 26 t of wheat initially at 16°C to a final grain temperature of 61°C. The amount of gas consumed was measured and the time taken to heat treat grain was noted. This was then used to work out the throughput of the grain and the kWh of electricity used by the pneumatic conveyor, spouted bed and the grain auger. The operational cost was the combination of the cost of electricity and gas consumed.

3. Results and Discussion

Thermal disinfestation requires heating the grain rapidly to 61°C to achieve 99.9% insect mortality, followed by rapid cooling. Alternatively grain may be heated up to 57°C or 55°C for a period of 7 or 30 minutes respectively to achieve 99.9% insect mortality. These temperatures were obtained during the trial at an inlet air temperature of between 220 and 250°C using the continuous flow spouted bed disinfestor. The final grain temperature was reasonably uniform (±4°C) throughout the trial. Figure 2 shows the final grain temperature achieved throughout the experiment at 60°C. Table 2 summarises the presence of insects in the control samples and the effect of heat treatment on insect survival. No live insects were found after passing the infested grain through the rig at any of the treatment temperatures. Insect mortality is due to both mechanical and heat damage, though heat damage is the major factor in killing these pests (Claflin, 1986).

Table 3 shows the operational cost associated with heat disinfestation of wheat. This is still not as cheap as fumigation but it has certain added advantages over the chemical control strategies. Firstly, it does not require a sealed storage for disinfestation. Secondly, it is rapid. Thirdly it does result in residue-free grain. Moreover, this technology can be applied while loading grain for transportation without waiting for days or weeks otherwise required to disinfest grain using fumigation.

Table 2: Temperature time mortality relationship (Beckett et al 1998)

The amount of grain moisture losses during the trial was not significant because of short exposure and residence times. A lower final grain temperature, somewhere around 54°C, would be desirable to avoid grain damage associated with leaving grain at higher temperatures for considerable amounts of time especially in the absence of a rapid cooling system.

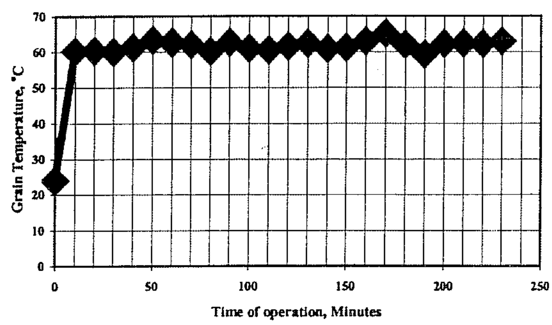

Figure 2: Average final grain temperature achieved during the experiment

Grain temperature rapidly rose to 60°C in the heating chamber, was rapidly cooled down to 53°C while passing through the cooling chamber. A further reduction of 5-7°C was noticed while the grain was conveyed back to the storage by an auger.

Figure 3 shows the grain temperature variation at various stages in the spouted bed disinfestor. Without evaporative cooling, the final grain temperature before entering the storage dropped down to 46°C. In this case the grain needs to be further cooled in storage to avoid damage to grain quality. This could be achieved by aeration, through evaporative cooling may be an alternative. The grain temperature dropped down to 30°C when a water mist was added to the air used to cool the grain in the cooling chamber. The evaporative cooling needs to be further investigated. The evaporative cooling technique is likely to be appropriate for a commercial unit.

4. Conclusions and Recommendations

The continuous-flow spouted bed has the potential to meet the requirements of the heat disinfestation process for wheat grain. Design considerations suggest that a multi-spouted system will be necessary for higher throughputs. The use of a draft tube to constrain the spout helps to regulate the grain flow paths and helps to achieve comparatively uniform final grain temperatures as shown in Figure 2.

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

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References

Bakker-Arkema, F.W., Brooker, R.C. and Lerew, L.E., 1977. Cereal Grain Drying. Adv. Cereal Sci. Technology 2: pp. 1-90.

Banks, H.J., 1998. Prospects for heat disinfestation. Proc. Australian Post Harvest Technical Conference, Canberra, May 1998: pp. 227-232.

Beckett, S.J., Morton R. and Darby, J.A., 1998. The mortality of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) and *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) at moderate temperatures. Journal of Stored Products Research: pp. 34, 363-376.

Ghaly, T.F., 1981. Heat-damage studies in relation to high temperature disinfestation of wheat. Proc. Aust. Stored Grain Pest Control Conference, Melbourne, Sep. 9: pp. 9-12.

Ghaly, T.F., 1988. Heat sensitivities of air-dried oilseeds. Proc. Aust. Sunflower Assoc. 7th Workshop, Moama, NSW: pp. 50-53.

Mathur, K.B. and Gishler, P.E., 1955. A technique for contacting gases with coarse solid particles. AIChE J, 1, pp: 157-164.

Sutherland, J.W., 1991. Drying oilseeds in a fluidised bed. Sub-project 4. In 'Safe Storage of Rapeseed and other Oilseeds'. Oilseeds Research Council: Canberra: 9 pp.

Claflin, J.K. (1986). Transport process in spouted bed. Ph.D. Thesis, University of New South Wales.

Table 1: No of insects found before and after heat treatment of grain

Insects	Final Grain Temperature, °C, Time	Live insects/kg before treatment	Time after treatment					
			Day 1	Week 1	Week 2	Week 3	Week 4	Week 5
R.dominica	**61.6 (1 min)**	**244**	**-**	**0**	**0**	**0**	**0**	**0**
	57(1-13min)	**172**	**-**	**0**	**0**	**0**	**0**	**0**
	55 (35 min)	**124**	**-**	**0**	**0**	**0**	**0**	**0**
	53.5(50 min)	**124**	**-**	**0**	**0**	**0**	**0**	**0**
C.ferrugineus	**61.6 (1 min)**	**68**	**0**	**0**	**0**	**0**	**0**	**0**
	57(1-13min)	**40**	**0**	**0**	**0**	**0**	**0**	**0**
	55 (35 min)	**130**	**0**	**0**	**0**	**0**	**0**	**0**
	53.5(50 min)	**130**	**0**	**0**	**0**	**0**	**0**	**0**
L.bostrychophila	**61.6 (1 min)**	**6**	**0**	**0**	**0**	**0**	**0**	**0**
	57(1-13min)	**6**	**0**	**0**	**0**	**0**	**0**	**0**
	55 (35 min)	**40**	**0**	**0**	**0**	**0**	**0**	**0**
	53.5(50min)	**40**	**0**	**0**	**0**	**0**	**0**	**0**

Table 2: Temperature time mortality relationship

99.9% mortality is reached in	**at a temperature of**
Less than one minute	60°C
5 minutes	57°C
20 minutes	55°C
29 hours	50°C
About 96 hours	45°C

Table 3: Comparative costs of heat disinfestation using different techniques

Heat Disinfestation System	**Operational Costs A$/t**
In-situ (45t partially sealed steel silo)	2.10
Fluidised bed (30t/h)	1.45
Spouted bed (10t/h)	1.30
Pneumatic Conveyor	1.50

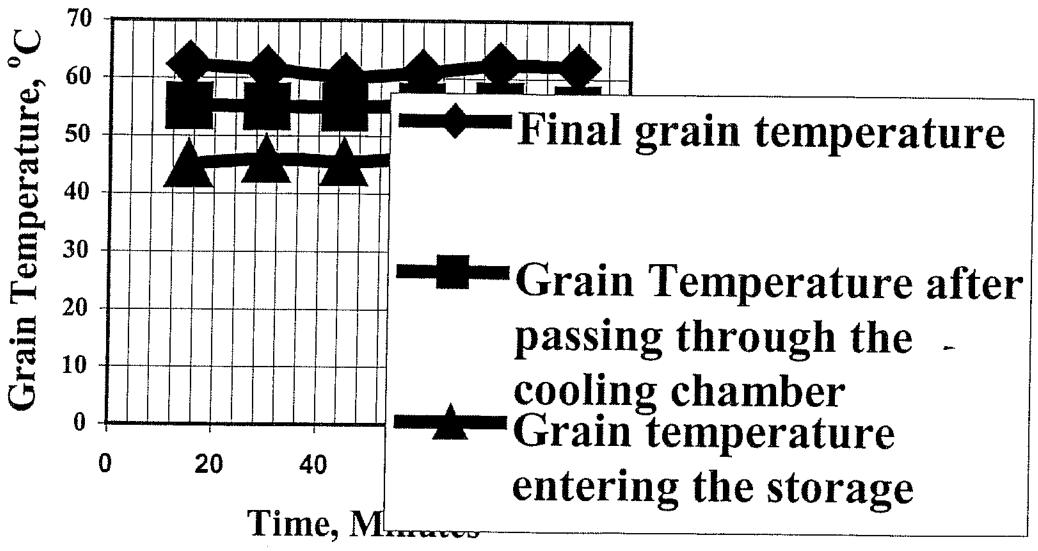

Figure 3: Grain temperatures at various stages in the spouted bed disinfestor