LARGE SCALE EVALUATION OF FLUID-RED HEATING AS A MEANS OF DISINFESTING GRAIN

by

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Introduction

Fluidized bed heating with hot air is being evaluated as a rapid, safe and residue-free means of disinfesting grain. The disinfestation procedure comprises rapid heating to kill insects within the grain followed by rapid cooling to safe storage temperatures. Our aim is to develop robust, continuous-flow, in-line systems compatible with the handling rates prevailing in country sub-terminals and seaboard export terminals.

Fluid-bed heating offers rapid heat transfer combined with good mixing and temperature control likely to ensure appropriate treatment of all particles. It is a well established industrial technique that has potential for high throughputs with relatively few engineering problems.

Laboratory experiments (Dermott and Evans, 1978; Evans and Dermott, 1981; Evans, 1981; Evans \textit{et al.}, 1983) showed that wheat could be disinfested by heating it briefly in a fluidized bed and, furthermore, that the moisture content, germination and quality of the grain was not adversely affected by such treatment (Dermott and Evans, 1978; Ghaly and Taylor, 1982; Ghaly and van der Togt, 1982). Such studies indicated that it would be possible to disinfest continuous flows of grain under commercial conditions by heating it to 65°C, and that, by using inlet air temperatures of 100-200°C and evaporative cooling to restore the grain to safe storage temperatures, treatment could be completed within $< 4$ minutes.

This paper reports the results of experiments with a 50 to 150 t h\textsuperscript{-1} grain disinfestation pilot-plant installed by the Grain Elevators Board of Victoria at Dunkley, near Bendigo. The plant is being used to confirm laboratory-determined criteria for disinfestation, to study and model the biological and physical processes involved in disinfestation, to determine the economics of operation, and to consider how heat disinfectors can be integrated into grain handling systems.

The Pilot Plant

The plant consists of four parts, a preheating and dedusting chamber, a heating chamber, a heat-recovery and cooling chamber supplied by
Fig. 1. Process flow sheet for high temperature grain disinfector (Thorpe et al., in press).

Fig. 2. Plot of grain temperature (°C) vs distance (m) from entrance to fluidized bed (Thorpe et al., in press).
atmospheric air, and an evaporative cooling chamber (Figs 1 and 2). The grain stream (F11) and chaff and dust associated with it (F12) flows first into the preheating chamber. Chaff and dust are removed as the grain is warmed and subsequently separated from the fluidizing air by means of a cyclone. To kill any free-living insects that may be removed from the grain in the dedusting stage, chaff and dust leaving the cyclone (F12) are passed through a centrifugal impactor. After preheating, the grain passes into the main heating chamber where it is heated to disinfection temperatures. It is then partially cooled in the heat-recovery chamber before being finally cooled in the evaporative cooling chamber. Air for the cooling process (F7) is divided into two streams: one (F10) is fed to the evaporative cooling chamber before being expelled to atmosphere by means of a vent stack and the other (F9) is directed to the heat-recovery chamber where it is warmed by the hot grain and then (as stream F4) fed to the preheating and dedusting chamber. About 70% of the hot air from the main heating chamber is recirculated as a heat economy measure whilst the balance is vented to atmosphere (F3). The make-up combustion air (F6) enters the burner with stream F2 to join stream F8. The fuel for the process, liquefied petroleum gas, enters the burner (stream F15) through a gas meter. The cooling-water streams are shown as F13 and F14: the water is sprayed into the bed from nozzles located 120 mm above the distributor plate.

The plant is simple and safe to operate. Its instrumentation conforms to the high standard traditional in the chemical and process industries. Either the heated grain temperature or the heating air temperature may be automatically controlled. If the heated grain temperature varies from its set point by more than permitted margins, alarms are activated and the plant is automatically shut down. An explosion hatch on the dedusting section is provided for rapid pressure release in the event of explosion. If a rise in pressure above 2 kPa occurs in the dedusting section, a fire extinguishing system is activated. Should temperatures in the dedusting section exhaust and recirculation ducts exceed their set points, alarms are triggered and the fire extinguishing system is activated.

Details of the instrumentation used to monitor the disinfection process during experiments are given by Thorpe et al. (1982).

Experimental Regimes and Results

To date, five main trials to assess the efficacy of disinfection have been carried out using grain mass flow rates up to 150 t h⁻¹. Additional observations have been made to establish the operating limits of both the disinfecting and the associated grain handling system, and to examine problems such as the entrainment of husk in re-cycled air.

The operating parameters for the trials are given in Table 1 and a typical temperature regime within the bed is shown in Fig. 2.
Table 1. Operating conditions during trials

<table>
<thead>
<tr>
<th>Trial number</th>
<th>Grain flow rate (t h⁻¹)</th>
<th>Maximal grain temperature (°C)</th>
<th>Air flow rate (kg s⁻¹ m⁻²)</th>
<th>Mean grain residence time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>60, 65, 70</td>
<td>2.4</td>
<td>4.45</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>60, 65, 70</td>
<td>1.9</td>
<td>2.94</td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>60, 65, 70</td>
<td>2.4</td>
<td>4.07</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>65, 70</td>
<td>2.4</td>
<td>3.33</td>
</tr>
<tr>
<td>5</td>
<td>150</td>
<td>65, 70</td>
<td>2.1</td>
<td>2.21</td>
</tr>
</tbody>
</table>

Entomological efficacy. To determine the temperature needed to achieve disinfestation, pesticide-free wheat to which cultures of *Rhysopertha dominica* (F.) (the most heat tolerant of Australian grain pests) are added is heated in the pilot-plant to 60°C, 65°C or 70°C. The proportions of insects killed are estimated by comparing the numbers of adult beetles emerging after incubation of samples of fluidized and heated grain with the numbers emerging from fluidized but unheated grain.

Table 2. Mortality of *Rhysopertha dominica* in Trials 1 to 5

<table>
<thead>
<tr>
<th>Maximal grain temp. (nominal) (°C)</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Percentage mortality *</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>61</td>
<td>51</td>
<td>74</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>65</td>
<td>100</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>70</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

* Mean of 3 replicates, each comprising 14 samples of circa 1 kg.
- Not used.

As expected (Evans et al., in press), heating the grain to 60°C gave high but not complete kills (Table 2). Heating to 65°C gave complete kills in all but Trial 2. Heating to 70°C gave complete kills in all trials. Temperature data for Trial 2 showed that although the mean temperature to which the grain was heated were indeed 60, 65 and 70°C there were points in the grain bed near the exit of the heating chamber that varied by two or three degrees about the means. Clearly, some of the grain did not reach the desired temperatures, and this allowed some insects to survive when heated to a nominal 65°C. The cause of the variation in temperatures in this trial was the relatively low air flow (Table 1), which resulted in poor fluidization.

Grain quality and moisture content. To ensure acceptance by industry, it is important that the heat disinfestation process neither damages the wheat nor significantly decreases its moisture content. Previous laboratory experiments indicated that neither effect would be manifested when
wheat of 12% moisture content was heated to either 65 or 70°C (Dermott and Evans, 1978; Ghaly and Taylor, 1982; Ghaly and van der Touw, 1982). To determine whether this would also be in practice, the grain was sampled in Trials 1 and 2 as it entered the unit, at the end of the heating bed, and as it left the evaporative cooling chamber. The germination of grain (a very sensitive measure of heat damage (Ghaly and Taylor, 1982)) taken from the exit of the disinfester was compared with that of grain entering the unit. Viability was effected in none of the treatments. As an independent check, a sample of wheat heated to 70°C was tested by the Bread Research Institute and showed no deterioration in dough properties or baking quality. Further spot checks have shown that inlet air temperatures as high as 230°C can be used to heat grain to 65°C without germination being influenced. In these and subsequent trials, the moisture contents of disinfested wheat were remarkable in their uniformity and showed that the grain lost 0.1% of moisture during heating and gained 0.1% of moisture during cooling, in other words, the process caused no net change in moisture content.

Energy consumption and running costs. When the plant operates at 150 t h⁻¹ and the initial temperature of the grain is 25°C, the energy required to treat each tonne of grain is 1.13 kWh of electricity and 26.6 kWh of gas. In Australia, this is equivalent to a total energy cost of the order of US 63 cents t⁻¹ using LPG, and US 45 cents t⁻¹ if natural gas is used.

Husk entrainment. The entrainment of husk in the heating-air recirculation duct (Φ) leads to the holes in the distributor plate becoming blocked and thus prevents proper fluidization of the grain. There appear to be two engineering solutions to this problem. The first, a relatively simple and inexpensive approach is to use the recirculation fan as a centrifugal separator. The second, and more costly solution, is to insert a cyclone in the recirculation duct. Once the husk is removed from the air stream the plant will be able to operate for prolonged periods without attention. Under commercial conditions, entrained husk and straw could be returned to the grain stream, to minimize change in weight during disinfestation.

Using the Disinfester as a Drier

Investment in a heat disinfester would possibly be more attractive to industry if the same equipment could be used to dry grain. The disinfester at Nunolly could be used as a drier simply by modifying its operating conditions. To maximize the rate of drying the wheat should be heated to the maximum safe temperature, about 70°C (Ghaly and van der Touw, 1982), and residence time increased. For a given plant and throughput the latter can be achieved by increasing bed depth.

To explore quantitatively the factors that affect the drying performance of the Nunolly pilot plant, a simple mathematical model of the fluidized bed system was formulated (Thorpe and Evans, 1983). The model was used to determine combinations of inlet air temperature, unexpanded bed depth and moist grain flow rate that allow grain to be dried from 14%
moisture content (wet basis) to 12% moisture content (wet basis) when the grain is heated to an assigned maximum temperature (Table 3).

Table 3. Performance of fluidized bed disinfestor operating in a drying mode with air temperature entering de-dusting section at 60°C, and the cooling air and grain inlet temperature both 20°C. Grain moisture content is reduced from 14% (wet basis) to 12% (wet basis).

<table>
<thead>
<tr>
<th>Maximum grain temperature (°C)</th>
<th>Unexpanded bed depth (m)</th>
<th>Mean residence time (min)</th>
<th>Inlet air temperature (°C)</th>
<th>Final grain temperature (°C)</th>
<th>Grain throughput (t h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>0.50</td>
<td>24.6</td>
<td>87</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>65</td>
<td>1.00</td>
<td>24.6</td>
<td>123</td>
<td>31</td>
<td>38</td>
</tr>
<tr>
<td>70</td>
<td>0.50</td>
<td>19.5</td>
<td>102</td>
<td>28</td>
<td>24</td>
</tr>
<tr>
<td>70</td>
<td>1.00</td>
<td>18.7</td>
<td>165</td>
<td>36</td>
<td>50</td>
</tr>
<tr>
<td>85</td>
<td>0.50</td>
<td>10.0</td>
<td>188</td>
<td>42</td>
<td>47</td>
</tr>
<tr>
<td>85</td>
<td>1.00</td>
<td>10.0</td>
<td>410</td>
<td>51</td>
<td>94</td>
</tr>
</tbody>
</table>

Because residence time remains almost constant, throughput is almost linearly proportional to the unexpanded bed depth, when grain is heated to a given temperature. For heating to 65°C, mean residence time is about 24 minutes. When grain is heated to 70°C the drying rate of the kernels is increased, and the required residence time falls to about 19 minutes thus permitting a greater grain throughput for a given bed depth. Sorghum may be heated to 85°C (D. Law, pers. comm.). At this relatively high temperature, drying of the individual kernels is very rapid and throughput correspondingly high. Energy costs using natural gas as the heating fuel are typically US 45 cents per tonne per percentage drop in moisture content.

Discussion

In spite of the unexpected problem of husk entrainment, we are confident that fluidized bed heating can be used to disinfest grain under commercial conditions. In addition, fluid-beds can be used to dry grain, to clean it, to cool it, and, if appropriate, to increase its moisture content. Our confidence is shared by at least one manufacturer, who is prepared, on the basis of experience with the Dunolly plant, to design and guarantee the performance of a 500 t h⁻¹ plant. Further research would be needed, however, to maximize the thermal efficiency and to minimize capital cost of such a unit. Thus, we need to determine the maximum inlet air temperature that may be used without damaging the grain and, under practical conditions, to learn whether grain must spend a certain minimum period within the heating chamber to ensure disinfestation. These factors influence the size and, hence, capital cost of a fluidized bed.
Because the temperature of the grain must be raised by 40°C, say, the running cost of heat disinfestation in which there is no net change in grain moisture content is always likely to exceed that of fumigation. Nevertheless, heat disinfestation has advantages in that it can be used as a high capacity, in-line, continuous-flow process with almost instantaneous start-up. With proper attention to dust-control and method of heating, the process will present no hazard to either operator or plant. The process leaves no residues, and the likelihood of insects becoming tolerant to the heating process is small.

At present, capital costs are hard to estimate because of the need for further information on inlet air temperature, the possible requirement for indirect-heating, and between-site variation in grain pathways. We estimate that a 500 t h⁻¹ plant (probably the minimum useful capacity for Australia) and associated facilities would cost about US $1 million. The actual price would vary in either direction depending on the importance placed on thermal efficiency: high thermal efficiency, and hence low running cost, being associated with increased capital cost.

Acknowledgements

We wish to thank the Grain Elevators Board of Victoria for financing the building of the pilot-plant and for their cooperation during the trials. The support of the Australian Wheat Board and the Wheat Industry Research Council is also acknowledged. Thanks are due also to Niro Atomizer (Australasia) Limited, contractor to the Grain Elevators Board for the pilot-plant, for their comments and advice on this project.
References


