THE POTENTIAL OF FLUIDIZED-BED TECHNIQUES IN INSECT CONTROL

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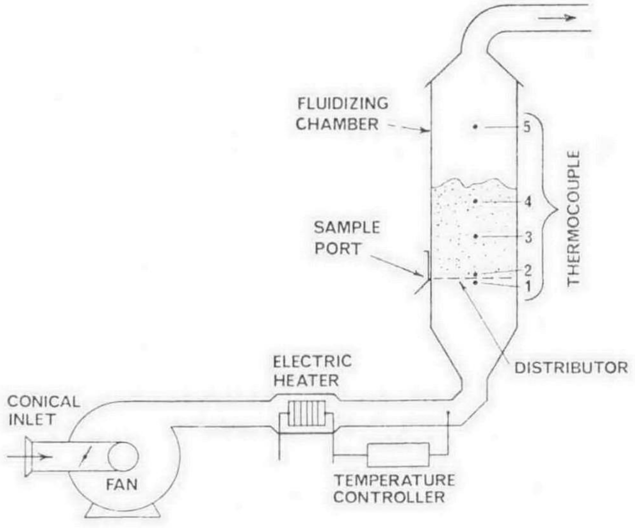
INTRODUCTION: In Australia, the growing resistance of stored grain insects to insecticides and increased social pressures against the use of potentially hazardous chemical treatments have led to increased interest in the development of physical methods of pest control. One of the physical methods being investigated is the use of high temperatures, which is regarded as a potential alternative to fumigation with, for example, methyl bromide.

Recent work (1 to 8) on the use of elevated temperatures to disinfest grain and cereal products has been largely concerned with infra-red, microwave, and dielectric heating. These studies have investigated the effectiveness of rapid heating followed by passive cooling, typically over several hours. Disinfestation processes that depend on the retention of heat for long periods have little potential in Australia where a continuous flow in-line system capable of matching shipping rates approaching 2000 tonnes h^{-1} is considered essential. Further requirements of a disinfestation process are that all developmental stages of the major pests must be killed, grain moisture content must not be appreciably changed, grain quality must not be affected and the method must be economically competitive and compatible with working conditions in a grain handling terminal. These criteria are likely to be met only in a process that exposes individual grains to the same temperature:time regime. Hot-air heating in a fluidized-bed appears to be a means of meeting the desired criteria because fluidized-bed heating offers high rates of heat transfer with accurate temperature control and has the potential for scale-up to high throughputs with relatively few engineering problems.

EXPERIMENTS WITH A BATCH-HEATING SYSTEM: A 340 mm diameter fluidized-bed capable of heating 10 kg of wheat was constructed (Figure 1) and batches of wheat infested with the immature stages of *Sitophilus oryzae, Rhyzopertha dominica,* and *Sitotroga cerealella* were subjected to a range of heat treatments (9). To assess insect mortality, samples of 500 g wheat were drawn off the bed at predetermined times and then cooled rapidly in a small fluidized-bed. Temperatures in the heating and cooling beds were measured continuously. Constant air temperatures of 60, 70, or 80° were used with an air-flow of 14.5 l kg^{-1} s^{-1} at 1.6 m s^{-1}. The samples were incubated for 6 weeks after treatment and the numbers of F_1 adults that emerged compared with the numbers emerging from un-heated but fluidized control samples. Drying curves were established in a similar manner for Olympid wheat of 11.5% m.c.



FLUIDIZED - BED HEAT TREATMENT APPARATUS

Figure 1. Fluidized-bed heating system

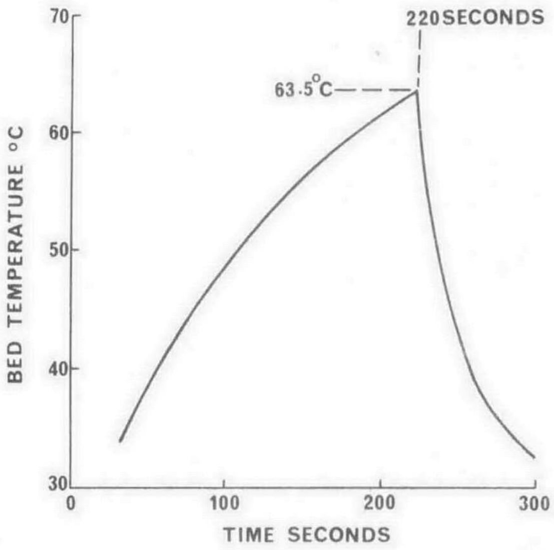
exposed to 60, 70, or 80°C air for up to 30 min. High and low protein wheats were checked for heat sensitivity using air inlet temperatures of 60 to 100°C and exposures of up to 30 min followed by dough characteristic and baking tests.

A typical heating and cooling curve is shown in Figure 2 for wheat exposed to 80°C air for 3 min 40 sec with an air flow of 14.5 $l\ kg^{-1}\ sec^{-1}$ at 1.6 $m\ s^{-1}$. The heating and cooling curves were readily described by a perfect mixing model (9).

Exposures of 12, 6, and 4 min respectively to air at 60, 70, and 80°C produced grain surface temperatures of 59, 62, and 65°C respectively and gave complete disinfestation. The heat tolerance of *R. dominica* was greater than that of the other species. Additional experiments showed that these treatments gave complete kills of the adults of all three species.

Drying curves for Olympic wheat of 11.5% m.c. exposed to air of 60 to 80°C for up to 30 min are shown in Figure 3. The reduction in moisture content of wheat heated at 60°C for 12 min, at 70°C for 6 min and at 80°C for 4 min was respectively 0.8, 0.6, and 0.6%.

Baking and dough characteristic tests on flour milled from heated and unheated wheat showed that heating with 80°C air



Batch heating and cooling of wheat to kill all stages of *Rhyzopertha dominica.*
Air inlet temperature – 80°C
Air flow rate – 14.5 ℓ kg^{-1}s^{-1}

FIGURE 2. Heating and cooling curve for wheat exposed to 80°C for 220 seconds

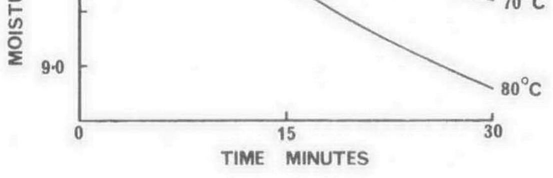


FIGURE 3. Drying curves for Olympic wheat of 11.5% m.c. exposed to air at 60, 70, and 80°C

for up to 30 min did not adversely affect baking quality whereas heating with 100°C air for longer than 5 min did. At 90°C, heating for 15 min did not significantly alter baking quality although Extensograph and Viscograph data indicated some heat damage (9).

It was concluded that fluidized-bed heating gave good kills of insect infestations in relatively short periods of time without significantly affecting grain moisture content or baking quality.

The two main components of operating cost are the energy needed to heat the wheat and the power required for fluidization. Assuming that a 4 min exposure to 80°C is required for complete disinfestation in a continuous-flow system with recirculation, 90% thermal efficiency, and no heat recovery from the grain, the energy required to raise one tonne of wheat from 25 to 65°C would be 69 MJ. The power required to supply fluidizing air at 14.5 l kg^{-1} s^{-1} at 5 kPa with typical fin and motor efficiencies would be 8 kWh tonne^{-1}. On present prices in Victoria, the cost of the heating cycle would be about 34c tonne^{-1}. Cooling would be required and, when aided by water injection evaporation would cost, say, 10c tonne^{-1}to give a total of about 44 c tonne^{-1}. This compares favourably with a labour + materials cost of about 40c tonne^{-1} for a 24 h recirculated fumigation with methyl bromide at 24 g m^{-3} in 2000 tonne vertical cells.

MORTALITY:DOSAGE RELATIONSHIPS: An understanding of the relationship between insect mortality and the two dosage variables, temperature and time, would clearly be useful in planning heating strategies and in designing disinfestation equipment. Dermott and Evans (9) showed that for a given level of mortality, the LT99.9 for instance, the relationship between exposure time and air temperature was described by a hyperbola i.e. $\underline{T}\ (\underline{t}-\underline{c}) = \underline{K}$ where $\underline{T}$ and $\underline{t}$ represent exposure time and air temperature respectively and $\underline{c}$ and $\underline{K}$ are constants (Figure 4).

To examine further the mortality-heat dosage relationship, a small-scale fluidized-bed has been built which can fluidize up to 2 kg wheat and can be switched instantaneously from heating to cooling. Experiments have been designed to examine the relationships at two rates of heating achieved by varying the load of grain rather than the airflow. Results with 1 kg loads fluidized in air of 60-80°C confirm previous findings. Experiments with 0.5 kg loads have not been completed but have given gratifying results in that treatment times have been greatly reduced. Thus, the respective LT99.9s for *R. dominica* immatures exposed to 80°C air in loads of 1 kg and 500 g were 2.98 and 1.70 min. If final results with 0.5 kg loads follow the same trend as those with 1 kg loads, it will be clear that, for a given rate of heating a simple hyperbolic relationship exists between exposure time and air temperature. Thermal summations can then be used to consider the relative merits of different temperature-time regimes during fluidization and of heat soaking - i.e. leaving the grain at the same temperature for a period before cooling.

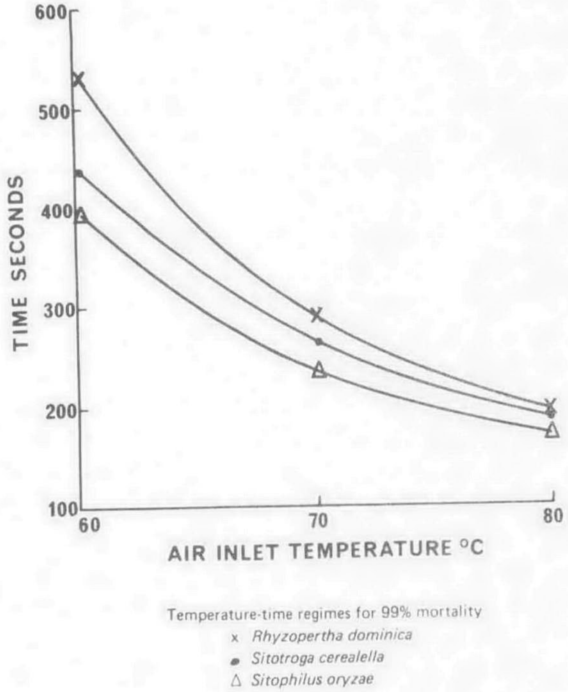


Figure 4. The relationship between insect mortality (LT99) and air inlet temperature

The small scale apparatus is also being used to explore some of the biological and physical variables that may affect heat-tolerance. Previous acclimation, population age-structure and between population differences in heat-tolerance could perhaps have some effect on heat-tolerance and hence the temperature-time regimes to be recommended for use by the grain industry. The initial temperature and moisture content of the grain may also alter apparent tolerances.

Although current experiments are based on *R. dominica*, the most heat tolerant of the primary pests, additional work is being done to ensure that regimes recommended for *Rhyzopertha* will deal also with other pests such as *Cryptolestes*, *Oryzaephilus*, and *Tribolium*. Results to date indicate that these pests, as is to be expected from their biology, are easier to kill than *Rhyzopertha*.

EXPERIMENTS WITH A CONTINUOUS-FLOW SYSTEM: A pilot plant with a design capacity of 1 tonne/h^{-1} has been constructed (Figure 5) to demonstrate that thermal disinfestation can be carried out in a continuous-flow system. The heating chamber has an area of 200 x 800 mm and up to seven vertical baffles can be installed. The cooling chamber is 100 x 200 mm in area and is fitted with water

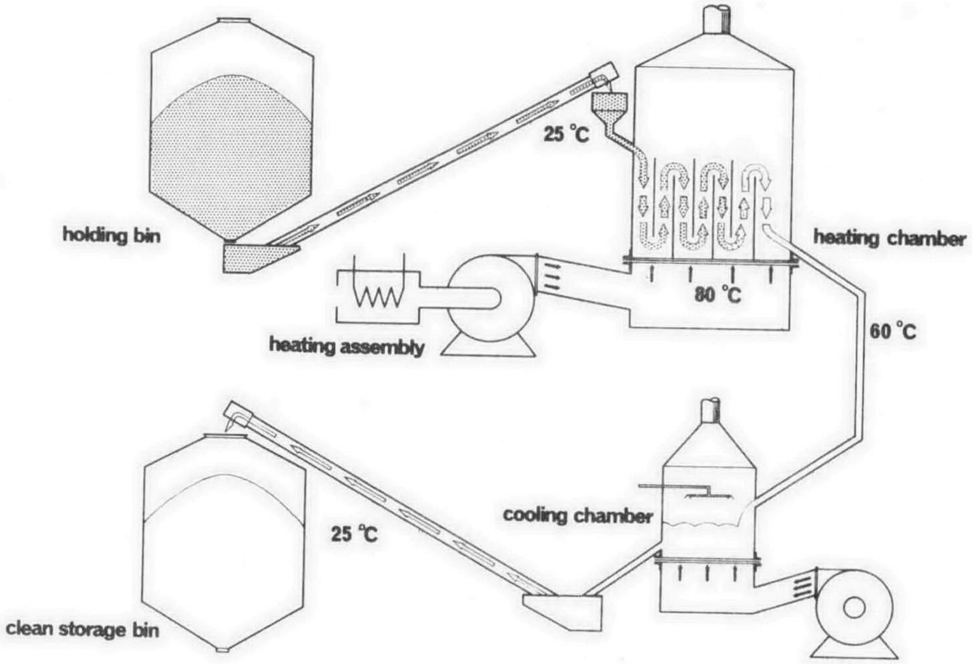


FIGURE 5: Flow chart for experimental continuous flow fluidized-bed heating plant

sprays for evaporative cooling. Air-inlet temperature, air and grain flow rates and bed-depth can be varied to change the heat dosage applied. Heat is provided by a natural gas burner on the air inlet and air inlet temperature is regulated by a modulating controller on the gas line.

Preliminary experiments using overall (both heating and cooling) mean residence times of 4 and 5 min and an air inlet temperature of 80°C have given good kills (up to 99.6%) of immature *R. dominica*. Mortality should be increased as the variance about mean residence time is reduced by changed baffle configuration.

CONCLUSIONS: It appears that wheat can be rapidly disinfested in both batch- and continuous-flow fluidized-bed heating systems. The moisture content of the grain is little changed by the heating process and any loss can be restored in a continuous flow system by evaporative cooling. There appears to be an adequate safety margin between the heat dose that will kill the pests within the grain and the dose that will cause detectable deterioration of baking properties. Cost estimates based on batch-heating suggest that fluidized-bed heating will be cost competitive with chemical fumigation. It is expected that, in practice, a continuous flow disinfestation unit will give higher rates of heating than batch systems since, under steady-state conditions, the wheat will be added to a bed of wheat with a considerable thermal capacity. Thus shorter exposure times could be expected to be effective with a continuous flow process than with batch heating. Our running cost estimates may be somewhat pessimistic and this reinforces our conclusion regarding the likely competitiveness of continuous flow high temperature disinfestation.

The procedure uses existing technology which the Australian grain industry is capable of operating: equipment is currently commercially available in Europe that would suit the needs of food packers wishing to disinfest relatively small quantities of cereals and legumes. Fluidized-bed heating systems can utilize any suitable energy source and can be made inherently safe by fluidizing with recirculated inert combustion gases.

The use of fluidized-beds has ancillary potential in that aspiration allows dust removal and evaporative cooling permits the moisture content of the grain to be increased if so desired. Such procedures could be used to give a clean, safe and uniform product.

The procedures developed for a fluidized-bed heater could be modified for application to other heat transfer systems, such as a rotating drum or pneumatic conveyor. Alternative systems should ensure that, as with a fluidized-bed, all the particles receive a minimum heat dosage sufficient to give disinfestation.

Fluidized-bed technology is available to developing countries, but its implementation in rural areas may present insurmountable problems. Economical implementation of fluidized-bed disinfestation requires plentiful supplies of electrical energy or oil; both of these are relatively low cost in Australia but are usually at a premium in developing countries. Furthermore, the fine control and high throughputs required in the export oriented Australian grain industry may not be justified in consumer countries. Alternative systems using low level technology with manual control and perhaps utilizing animal or human power could be attractive in many rural economies.

Heat could be supplied by burning crop residues or from simple solar collectors. Mixing the grain to ensure uniform heat dosage could take place in locally manufactured drums rotated by a small petrol engine, or say animal or human power. In this way batches of 50 to 100 kg could be disinfested quite rapidly. Instrumentation and control could be as simple as maintaining an air inlet temperature between the melting points of two waxes. Air flow could be supplied by a bellows or chimney. Obviously a low air pressure drop system would be preferable for very simple systems.

Although completely different systems to those in Australia would have to be developed to meet the needs of developing countries, these systems could be designed by interpretation of the data presented in this paper.

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