THERMAL DISINFESTATION OF WHEAT IN A SPOUTED BED

by

J.K. Claflin[1], D.E. Evans[2], A.G. Fane[1] and R.J. Hill[2]
[1]School of Chemical Engineering and Industrial Chemistry, University of New South Wales, P O Box 1, Kensington, NSW 2033, Australia
[2]CSIRO Division of Entomology, GPO Box 1700, Canberra, ACT 2601, Australia

Introduction

Thermal disinfestation of wheat and other grains has been shown to be a feasible alternative to chemical methods (e.g. Winterbottom, 1922: Dzhorogyan, 1957: Dermott and Evans, 1978). Its main advantages are its rapidity and its residue-free product. Disinfestation is achieved by subjecting the grain to temperatures that are lethal to all developmental stages of insects within the grain. Typically this means heating the grain to temperatures of 55 to 65°C for periods of minutes or seconds. On the other hand, over-exposure is undesirable since it could impair grain quality. These criteria require a process in which individual grains experience the same temperature-time history.

Disinfestation has been achieved by direct-contact heating of the grain by hot air in fluidized beds (Dermott and Evans, 1978; Vardell and Tilton, 1981: Evans *et al.*, 1983; Thorpe *et al.*, in press) and pneumatic conveyors (Dzhorogyan, 1957: Fleurat-Lessard, 1980). In this paper we describe the use of an alternative gas-solids contactor, known as the spouted bed, that combines features of the fluidized and pneumatic systems. Following a brief review of spouted bed operation we discuss its disinfestation capabilities.

Spouted Bed Operation

Spouted beds were developed in the mid 1950s for wheat drying, and have been used subsequently in many other applications (Mathur and Epstein, 1974). The technique requires the gas (hot air) to be introduced as a high velocity jet into the base of a conical-bottomed vessel containing the bed of particles. Provided a minimum gas velocity is exceeded a 'spout' is formed which conveys particles upwards until they leave the bed. The particles then fall back to the 'annulus' region that surrounds the spout and resembles a downward-moving packed bed. Particles therefore tend to cycle around the bed, travelling up the spout and down the annulus. The incoming gas passes up the spout and also flares radially into the annulus, so that effective gas-solid contact is achieved.

Spouted beds are well suited to particles greater than 1 mm in size and they have proved popular for grain drying. Advantages over other systems are the lower pressure drop (typically 70% of that for a fluidized bed), the regular particle motion, and the ease of operation (Mathur and Epstein, 1974).

In an earlier paper (Claflin and Fane, 1981), we described the special features of a modified spouted bed fitted with a central draft-tube (Fig. 1). This system was designed to satisfy the requirements of thermal disinfestation since the draft-tube allows more precise control of particle motion. Draft-tube diameter, length and axial location provide additional design parameters, which we have discussed in detail elsewhere (Claflin and Fane, 1981 and 1983). The relevant characteristics of draft-tube spouted beds are:

1. Particle cycle times are well controlled. Plug flow is approached for continuous feed operation.
2. Minimum gas velocity required is less than for conventional spouted bed (which is less than minimum fluidization velocity).
3. Can be operated at lower pressure drop than conventional spouted bed and fluidized beds.
4. Air distribution (spout vs annulus) can be controlled by system geometry.
5. Is potentially easier to scale up than conventional spouted bed.

Equipment

Disinfestation was carried out in an insulated spouted bed 0.3 m diameter, fitted with a 60° cone with a 0.05 m diameter air inlet (Fig. 1). A solid-wall draft-tube 0.05 m diameter and 1.3 m long, was located axially with provision for adjustment of the separation distance (L_E in Fig. 1). During operation L_E was set at 0.15 m, and the bed height was about 0.4 m for an initial grain charge of 16 kg.

Air was supplied by two Hitachi vortex blowers (capacity of 0.15 m^3 s^{-1} at 25 kPa), and measured by a type 73 Annubar flow meter to $\pm$ 1%. A 7.5 kw in-line heater automatically controlled air inlet temperature at $\pm$ 1°C. System temperatures were continually monitored by copper-constantan thermocouples.

Experimental Procedure

Each batch to be treated was prepared by adding 0.5 kg of wheat infested with all stages of development of *Rhyzopertha dominica* (F.) to 15.5 kg of uninfested pesticide-free wheat (*R. dominica* was chosen for experimentation because it is the most heat tolerant of Australian grain pests). Before loading the grain into the bed, the inlet air temperature and air flow rate (0.05 m^3 s^{-1}) were set and allowed to stabilize. The draft-tube was also lowered (L_E = 0.0) to prevent initial choking of the spout.

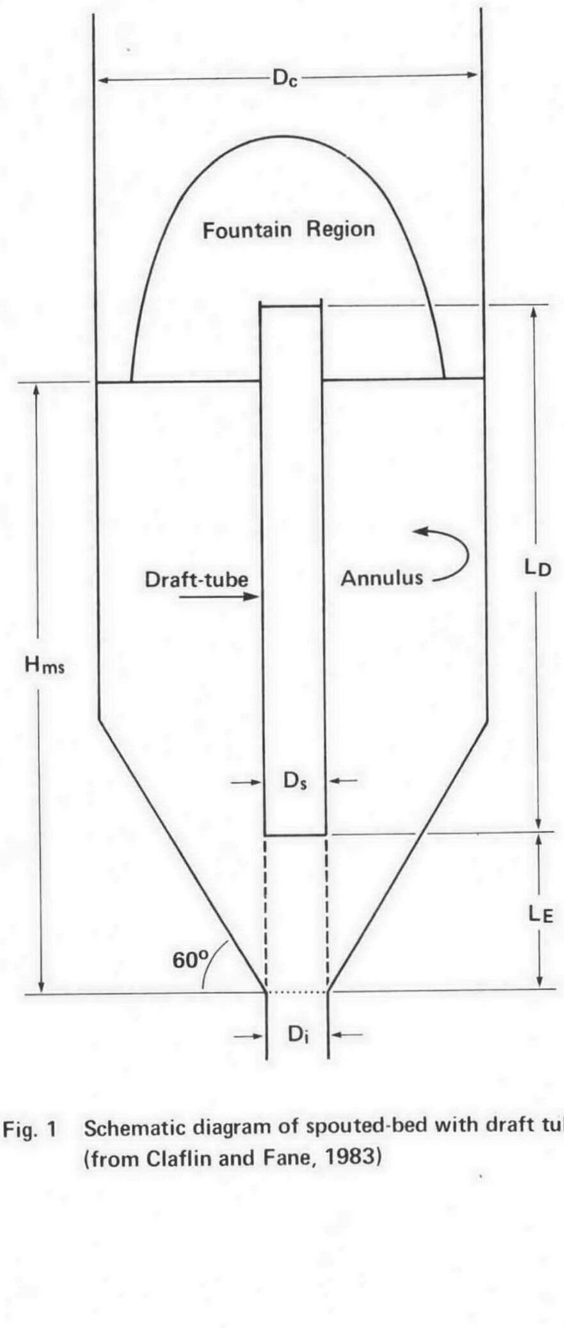

Fig. 1 Schematic diagram of spouted-bed with draft tube. (from Claflin and Fane, 1983)

To start treatment, a batch of infested wheat was rapidly loaded (< 5 s) into the bed from a hopper mounted above the bed. The separation distance was quickly adjusted to 0.15 m (< 5 s) at which time a stop-watch was started. Eight samples, each of about 0.35 kg, were run-off through a port in the cone section as the grain temperature increased. Each sample was rapidly cooled in a forced-flow packed bed. The samples were taken at predetermined intervals after the start of heating to provide grain temperatures increasing progressively from about 55 to about 65°C. Two batches were heated at each inlet air temperature. The initial temperature and moisture content of the wheat were 18°C and 11% respectively. The proportions of insects killed were estimated by comparing the numbers of adult beetles emerging after incubation (5 weeks at 32°C, 50% r.h.) of samples of heated grain with the numbers for spouted but unheated grain. Mortality-time relationships were determined by probit analysis using the pooled data for two batches.

Results

Heating curves for wheat exposed to inlet air temperatures of 70 and 160°C are shown in Fig. 2: quite rapid heating (i.e. circa 3.2 min to 65°C) was achieved with air at 160°C.

Interestingly, the numbers of adult *R. dominica* developing from unheated controls decreased with the period for which the grain was spouted (Fig. 3). This indicated that the spouting process itself was harmful when exposure was prolonged.

Mortality-time relationships for insects exposed to air at 80°C were computed, using either a constant or a progressively decreasing number of insects exposed, to differentiate the influence of heating plus spouting and heating alone. They showed, however, that the contribution of spouting itself was small when heating was rapid (Fig. 4).

As was to be expected (Dermott and Evans, 1978), the time to achieve 99.9% mortality ($LT_{99.9}$) decreased as inlet air temperature increased. Thus LT values ranged from 30.8 minutes to 3.0 minutes for inlet air temperatures of 70 and 160°C respectively. The influence of inlet air temperature on $LT_{99.9}$ (Fig. 5) was well described by the relationship $LT_{99.9} = a + be^{cx}$ where a, b and c are constants and x is inlet air temperature in °C. The maximal grain temperatures corresponding to those exposures were respectively 60 and 63°C (Fig. 2).

Discussion

The results show that heating in a spouted bed is an effective method of thermal disinfestation, with disinfestation being attained at temperatures of 60 to 63°C. Except with inlet air at 70°C, mortality provided by spouting, presumably through impact (Bailey, 1962), was small compared with that due to heating.

Operating costs for spouted bed disinfestation, although not yet established, are likely to be substantially similar to fluidized bed dis-

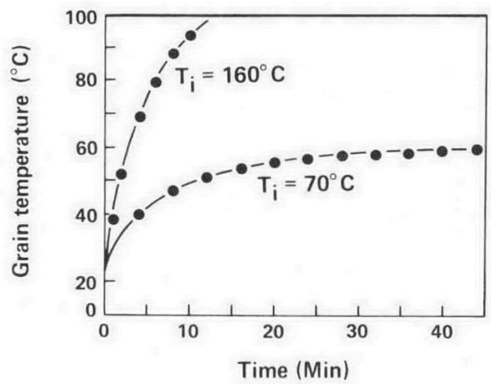

Fig. 2 Heating curve for wheat exposed to inlet air temperatures of 70 and 160°C.

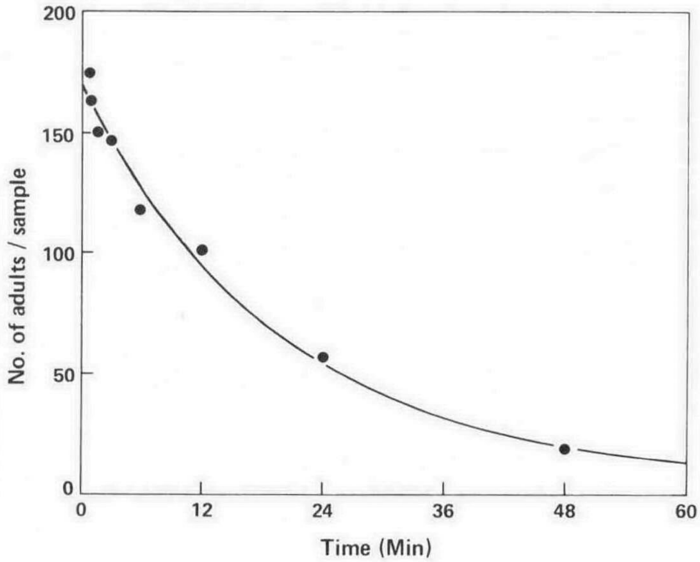

Fig. 3 Numbers of adult R. dominica from unheated wheat spouted for various periods.

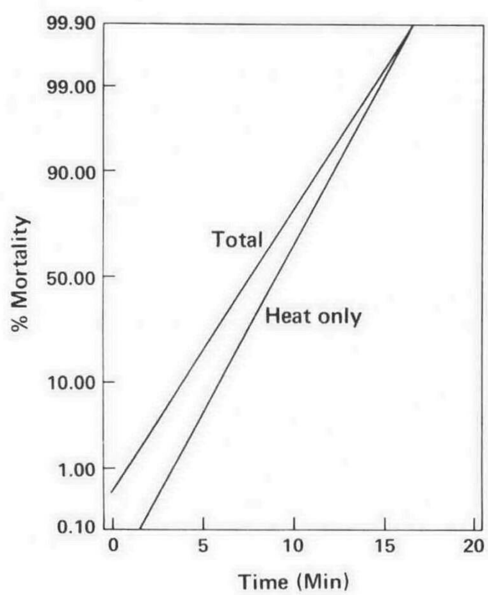

Fig. 4 Mortality–time relationships for R. dominica exposed to 80°C, showing influence of heating plus spouting and heating only.

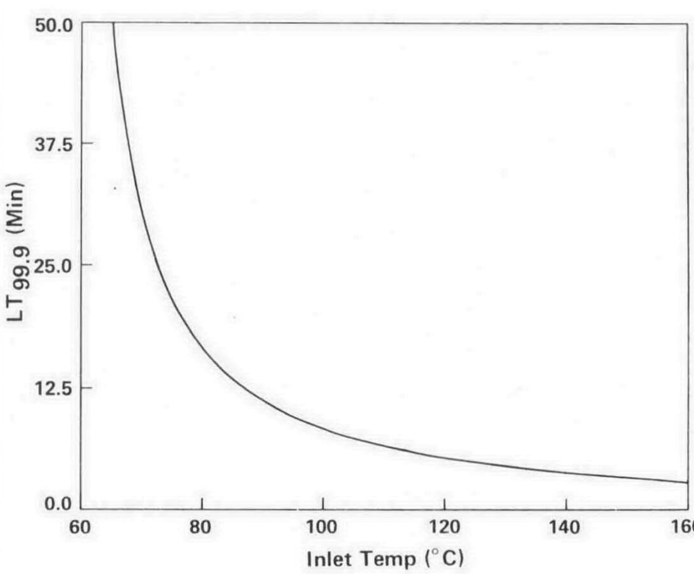

Fig. 5 Relationship of $LT_{99.9}$ for R. dominica to inlet-air temperature.

infestation, for which values of about US 55 cents t^{-1} have been estimated for Australian conditions (Thorpe *et al.*, in press). Some savings may accrue from the lower pressure drop requirement.

For large-scale operations, such as dock-side installations, a multi-spout unit would be required. High throughput could be achieved by continuous feed to spouted 'cells' arranged in parallel. Using an inlet air temperature of 160°C and an air flow of 0.05 m^3 s^{-1}, say, the residence time needed to achieve a grain temperature of 65°C would necessitate up to five 'cells' in series. The unique design of the draft-tube spouted bed is well-suited to a series system with grain particles conveyed from cell to cell by the draft-tubes. Recycling the heating air would improve heat transfer efficiency. The relatively large diameter spout inlets should be free from blockage due to husks entrained in the recycled air. Blocking of the air distributor with entrained debris can be a problem with fluidized systems (Thorpe *et al.*, in press).

Spouted bed disinfestation of grains should be attractive in small-scale use in less developed countries. Its simplicity and ease of control make it well suited to such environments. Capacities of 500 to 1000 kg h^{-1} would be feasible in batch operation using a single bed. For certain grains, such as rice, the spouted bed may provide a thermally more regular and less damaging procedure for heat disinfestation. It is of interest to note that draft-tube spouted beds have been developed for rice drying (Khoe and van Brakel, 1980). A combined treatment giving both disinfestation and grain drying may be of particular interest.

Further experiments are planned to study the effect of operating variables, such as air flow rate and separation distance (L_E), on LT value, to determine the influence of heating on grain moisture content and quality, and to evaluate the suitability of the spouted bed disinfestor for treating a wide range of grains.

Acknowledgements

The financial support of the Australian Wheat Industry Research Council, the Australian Bulk Grain Handling Authorities Conference and the Australian Wheat Board is gratefully acknowledged.

References

Bailey S.W. (1962) The effects of percussion on insect pests of grain. *J. econ. Entomol.* 55, 301-304.

Claflin J.K. and Fane A.G. (1981) The use of spouted beds for the heat treatment of grains. *Proc. CHEMECA 81, 9th Australasian Conference on Chemical Engineering,* 65-72.

Claflin J.K. and Fane A.G. (1983) Spouting with a porous draft tube. *Can. J. Chem. Eng.* 61, 356-363.

Dermott T. and Evans D.E. (1978) An evaluation of fluidized bed heating as a means of disinfesting wheat. *J. stored Prod. Res.* 14, 1-12.

Dzhorogyan G.A. (1957) Disinfestation of grain in a flow of hot gases (in Russian). *Mukom-elevat. Prom.* 8, 29-30.

Evans D.E., Thorpe G.R. and Dermott T. (1983) The disinfestation of wheat in a continuous-flow fluidized bed. *J. stored Prod. Res.* 19, 125-137.

Fleurat-Lessard F. (1980) Lutte physique par l'air chaud ou les hautes fréquencies contre les insects des grains et des produit céréaliers. *Bull. Tech. Inf. Desinsectisation Stock.* 349, 345-352.

Khoe G.K. and von Brakel J. (1980) A draft-tube spouted bed as small scale grain drier. *Solids Sep. Process, I. Chem. E. Symp. Ser.* No. 59, 6/1-6/13.

Mathur K. and Epstein N. (1974) *Spouted Beds.* 304 pp. Academic Press, New York.

Thorpe G.R., Evans D.E. and Sutherland J.W. (in press) The development of a continuous-flow fluidized bed high temperature grain disinfestation process. *Proc. Int. Symp. on Practical Aspects of Controlled Atmosphere and Fumigation in Grain Storage, Perth, 1983.*

Vardell H.H. and Tilton E.W. (1981) Control of the lesser grain borer *Rhyzopertha dominica* (F.), and the rice weevil, *Sitophilus oryzae* (L.), in rough rice with a heated fluidized bed. *J. Georgia Entomol. Soc.* 16, 521-524.

Winterbottom D.C. (1922) *Weevil in wheat and storage of grain in bags; a record of Australian experience during the War period (1915-19).* 122 pp. Government Printer, Adelaide.