THE DEVELOPMENT OF A CONTINUOUS-FLOW FLUIDIZED-BED HIGH-TEMPERATURE GRAIN DISINFESTATION PROCESS

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ABSTRACT

Laboratory-scale experiments on a continuous flow high temperature disinfestation plant demonstrated the technical viability of the process, and indicated its economic soundness. In order to determine problems of scale-up, to ascertain realistic cost data and to illustrate how such novel equipment may be easily integrated into the grain handling system, a 50 tonne per hour plant was installed at Dunolly, Victoria. The plant was extensively instrumented to determine its entomological and thermodynamic performance. Early results show that heating grain to 65°C or more results in the total kill of all developmental stages of insects. Furthermore, the process causes no detectable change in either grain quality or moisture content. Total energy costs have been measured to be 62 cents per tonne of grain treated using LPG as the heating source; if natural gas were to be used the cost would be 46 cents per tonne. The plant is easily integrated into the existing grain handling system. Husk and straw entrainment in an air recirculation duct proved to be an unexpected problem, but a simple modification to the plant will overcome this.

INTRODUCTION

Fluidized bed heating offers a rapid and residue-free method of disinfesting grain. In continuous flow form, the process relies on heating grain to temperatures that are lethal to all developmental stages of insects within the grain and then cooling it rapidly to safe storage temperatures. Heating in fluidized beds was chosen because the good mixing of solids allows high inlet air temperatures to be used, yet individual grains are not overheated. Large scale fluidized beds are commonly found in the process industries and scaling up disinfestors to handle the high grain throughputs at export and large subterminals should not present problems. Furthermore, fluidized beds are simple and rugged and their operational stability renders them ideal for integration into the grain handling system.

LABORATORY EXPERIMENTS

Initial experiments were aimed at demonstrating the entomological efficacy of the process, and establishing heating regimes that result in no detectable grain damage yet are lethal to insects. It was shown that 10kg batches of wheat were disinfested of immature stages of *Rhyzopertha dominica*

(F.), *Sitophilus oryzae* (L.) and *Sitotroga cerealella* (Oliv.) when exposed to inlet air temperatures of either 80°C, 70°C or 60°C for periods of 4, 6 and 12 minutes respectively. Such exposures gave respective maximal grain temperatures of 65°C, 62°C and 59°C and did not impair baking quality or germination, and the grain moisture content was not changed appreciably (Dermott and Evans 1978).

Further experiments with a batch heater were carried out in which the influence of varying bed depth and inlet air temperature on the mortality of *R. dominica*, the most heat tolerant species, was examined. The results clearly indicated that insect mortality was related to a heat dosage factor incorporating both temperature and time components (Evans & Dermott 1981).

The importance of the heat dosage factor was highlighted in an experiment in which wheat was heated to 56-58°/C and then allowed to stand unfluidized for up to 15 minutes before cooling. The soaking period increased the insect mortality from about 50% to greater then 99.9%.

Experiments were also made with a continuous-flow disinfestor. The heating chamber had an area of 200 x 400 mm and grain flowed through it in a zig-zag horizontal path. Baffles were fitted to reduce the spread about mean residence time and hence approximate the plug-flow conditions of the batch systems. The cooling chamber had an area 100 x 360 mm and was fitted with a water spray for evaporative cooling. Repeated trials showed that grain infested with *R. dominica* flowing at 360-500 kg h^{-1} at depths of 100-250 mm could be disinfested by exposure to air inlet temperatures of 80-90°C for periods of 2-5 min. that provided maximal grain temperatures up to about 65°C (Evans, Thorpe and Dermott (in press)).

50 TONNE PER HOUR PILOT-PLANT

The laboratory-scale experiments on a continuous-flow, fluidized-bed, high-temperature, disinfestation plant demonstrated the technical viability of the process, and indicated that it was likely to be competitive in cost with pesticide treatments commonly used. However, it was clearly important to build a plant capable of handling commercial quantites of grain to determine possible problems of scale-up, to ascertain realistic cost data and, together with the grain handling industry, determine how such novel equipment may be integrated into the existing grain handling system.

Good progress in achieving these objectives has been made with a nominally 50 tonne per hour plant installed by the Grain Elevators Board of Victoria at Dunolly, near Bendigo.

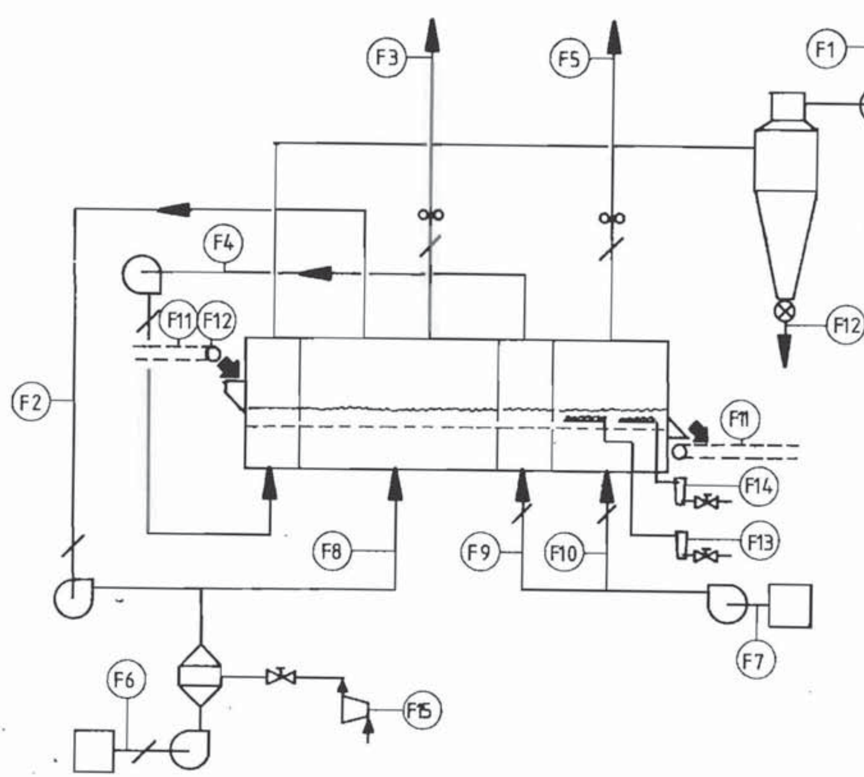

Figure 1. Process flow sheet of 50 tph high temperature disinfestation plant showing process flow streams referred to in text.

The plant consists of four chambers, 1 a preheating and de-dusting section, 2 a heating chamber, 3 a cooling section supplied by atmospheric air and 4 an evaporative cooling stage. The process flow sheet is shown in Figure 1. The grain stream, F11, and any chaff and dust associated with it, F12, enters the pre-heating chamber; this chamber also cleans the grain and the dust is subsequently separated from the fluidizing air by means of a cyclone. From the pre-heating stage the grain flows into the main heating bed in which it is heated to disinfestation temperatures before it is partially cooled in the heat recovery stage and then finally cooled in an evaporative cooling section. Cooling air for the process, F7, is divided into two streams: F10 is fed to the evaporative cooling chamber before being expelled to atmosphere by means of a vent stack; the other component of the cooling air, F9, is fed to the heat recovery section where it is heated by the hot grain and then, as stream F4, enters the pre-heating and de-dusting section. Hot air from the main heating chamber is re-circulated as a heat economy measure whilst the exhaust gases are vented as stream F3, and the make-up combustion air, F6, enters the burner. The fuel for the process, liquefied petroleum gas, enters the burner, stream F15, through a turbine gas meter. F13 and F14 are the cooling water streams.

In order to kill any free living insect stages that may be removed from the grain in the de-dusting stage, the dust leaving the cyclone is passed through an entoleter that kills the insects by impact.

The plant was designed to be very simple and safe to operate. The plant instrumentation housed in a control room conforms to the high standard traditional in the chemical and process industries and the key process variables such as plenum and free board pressures, air temperatures leaving the burner and entering the heating bed and the heated and cooled grain temperatures are clearly displayed. Either the heated grain temperature or the heating air temperature may be automatically controlled, and investigations are being carried out to determine which of these is the more suitable.

If the heated grain temperature should vary from its set point by more than $\pm 3^{\circ}C$, audible and visual alarms are activated. However, if the grain temperature should deviate by more than $10^{\circ}C$ indicating either over-heating or poor insect control the plant is automatically shut down. An explosion hatch on the de-dusting section is provided for rapid pressure release in the event of explosion. Should a rise in pressure above 2kPa occur in the de-dusting section a pressure sensor activates a fire extinguishing system and the fluidizing chambers are sprayed with water at a rate of 350 litres per minute. Temperature sensors are located in the de-ducting section exhaust and recirculation ducts and should the temperature at either of these sites exceed $100^{\circ}C$ an audio and visual alarm is activated; should either temperature exceed $150^{\circ}C$ the fire extinguishing system is also activated.

The CSIRO has augmented the standard plant instrumentation so that comprehensive measurements may be taken that allow the entomological efficacy of the plant to be determined and to enable us to accurately determine the thermodynamic states and flow rates of the process streams. Details of the CSIRO instrumenation system are given by Thorpe et al (1982).

PRELIMINARY RESULTS

Results obtained from the plant to date are encouraging and they vindicate the laboratory experiments which showed that all developmental stages of insects are killed if the grain is heated to temperatures of $65^{\circ}C$ or more. In the first trial 50 tonnes per hour of wheat were heated to $60^{\circ}C$, $65^{\circ}C$ and $70^{\circ}C$ with a total residence time in the unit of about 4 minutes. Complete kills of *R. dominica* were obtained except when the wheat was heated at $60^{\circ}C$. It must be stressed that our results are preliminary but measurements show that there is no detectable change in the moisture content of the grain as it passes through the unit. Measurements also indicate that there is no change in grain quality as determined by germination; this result is in accordance with laboratory studies (Ghaly and Taylor, 1982).

The fluidizing air velocity in the unit was typically greater than 2 m/s and in order to heat 50 tonnes per hour of wheat to 65°C the heating air temperature in the plenum was found to be 100°C, exactly the design figure. Initial energy consumption figures for the plant operating with a grain throughput of 50 tonnes per hour are respectively 2 kWh and 20 kWh of electrical and gas energy per tonne of grain treated. On the basis of 7 cents per kWh for electricity and LPG priced at 34 cents per kg the total energy cost to treat one tonne of wheat is 62 cents. If natural gas were to be used, as is likely at seaboard terminals, then the energy cost would be 46 cents per tonne of grain treated assuming a gas tariff of 0.45 cents per MJ. The total capital cost of the plant, including the provision of services was $400,000.

Presently the plant is operating in a sub-optimal mode in so far as the air flow rates are severely throttled by dampers, hence there is scope to reduce the electricity consumption by slowing down the fans. The electrical energy cost per tonne would also be reduced if the throughput of the plant were to be increased. To date the highest grain throughput achieved at Dunolly is 70 tonnes per hour, which is the maximum capacity of the grain handling system presently servicing the unit. There is no apparent reason why the grain throughput cannot be increased further.

The plant performance is very stable as evidence by the fact that the heated grain temperature remains steady for prolonged periods without any operator intervention, even when the system is under manual control. This leads to the conclusion that once such a plant is properly integrated into the grain handling system it will operate with minimal attention, and would not require a full-time operator assigned exclusively to the plant.

A serious, but tracable problem that has emerged during the trials is the blocking of the distributor plates with husk and straw. This is most serious in the heating chamber where husks and straw are carried over in the air re-circulation duct. For the purposes of the entomological trials the problem was overcome by pre-cleaning the grain. This would not be an economically feasible system for commercial use. A more elegant method of eliminating the unwanted husk and straw would be to insert a cyclone in the re-circulation duct.

FUTURE RESEARCH

In the immediate future, work will be aimed at eliminating the entrainment of husk and straw in the air re-circulation duct, and investigating the range of operating conditions which yield complete insect mortality. These latter experiments will allow the plant operation to be optimized. it is also planned to carry out further trials to confirm that wheat is in no way damaged by the disinfestation process.

Work is also aimed at evaluating alternative hardware for heating grain such as spouted beds, which are a special form of fluidized bed, and pneumatic conveyors which simultaneously convey and heat the grain, and minimizes dust extraction problems. Fundamental studies of heat, mass and momentum transfer in high temperature disinfestation processes will be made.

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