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Possible use of cross-flow dryers for heat disinfestation of grain

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Abstract. Trials on the performance of a cross-flow grain dryer were arranged in October 2002 in northern NSW. In the first two trials, two batches of 25 t of barley were dried from 9.4% and 11.6% to 8.2% and 10.2% moisture content using inlet air temperature of 82°C and 72°C, respectively. In the third trial, 25 t of wheat were dried from 14% to 10.5% moisture content using an inlet air temperature of 82°C. The aim was to explore the possibility of using this type of dryer for heat disinfestation of grain. The average final grain temperature and temperature distribution across the grain batch were measured during the trials, and compared with grain temperatures necessary to kill stored grain pests. Conditions were shown to be favourable for heat disinfesting grain in a cross-flow dryer. Germination tests on treated grain found no significant adverse effects on grain.

Introduction

A survey of grain dryers was conducted and the information on various types of dryers used by Australian grain growers was compiled. Based on this information, it was decided to assess cross-flow, radial-flow and mixed-flow grain dryers for heat disinfestation of grain. The decision to assess the cross-flow type was based on a number of factors including the number of dryers available in the field, the willingness of the owners and the manufacturers to participate in the assessment process, and the potential for heat-treating grain in these dryers with and without modifications.

Trials were performed in October 2002 to explore the possibility of using a cross-flow grain dryer for heat disinfestation. The trials were made in northern NSW on the properties of Mr Malcolm Doolan and Mr Malcolm McIntosh from North Star and Mr Daryn Radford from Moree.

General description of cross-flow dryers

In a cross-flow dryer, the grain flows by gravity from a holding bin into the drying zone consisting of one or several screened grain columns; hot air is forced perpendicularly from the air plenum through the grain in the columns. A similar process occurs in the cooling section where ambient air is employed. The width of the grain columns in cross-flow dryers is between 0.25 and 0.45 m and the length of grain columns in the drying section is between 3 and 30 m. In the cooling section, the columns are about 1–10 m long, depending upon the size of the dryer (Brooker et al. 1992). The drying air temperature depends on the type of grain to be dried and the grain quality requirements. Typically for food grains, the temperature ranges between 60°C and 75°C, and for feed grains between 80°C and 110°C. The airflow rate varies from 15 to 30 m^3/min-m^2 (1.33–2.33 m^3/s/t). One or two fans are employed in a conventional cross-flow dryer, depending on its size. The residence of grain in cross-flow dryers is controlled by the speed of the unloading augers and can be adjusted from zero to the maximum capacity of the dryer. The throughput rates vary according to the size of the dryer, plenum temperature, type of grain being dried, the ambient conditions, and whether the dryer is being used in either full or partial heat mode.

Because the hot air flows perpendicular to the direction of grain flow, a drying front exists and grain is over-dried at the near side and under-dried at the far side of the grain columns. In extreme cases, the moisture differential between the near side and the far side of the columns can be as high as 8% after cooling (Brooker et al. 1992). Finally, grain is mixed during unloading which equalises grain moisture contents.

Some cross-flow dryer manufacturers have designed an optional grain-turning mechanism. This device is normally positioned about midway along the vertical extent of the dryer heating zone and simply shifts grain from the inner area of the column to the outer area and vice-versa. This reduces the uneven drying problem, but does not eliminate it. Other manufacturers have used a number of baffles across the depth of grain columns to mix the grain while it flows down. However, the incorporation of mixing mechanisms is uncommon.

Materials and methods

Description of the dryer assessed

The three dryers assessed during the trials were model SD250V, manufactured by Quality Grain Dryers, Cambooya, Queensland, Australia. This dryer has a throughput rate of 10–15 t/h depending on grain type, initial and final moisture content, plenum temperature, and mode of operation (Figures 1 and 2). The dryer can be used both as a full-heat or a heat–cool system. In the full-heat system, cooling is done in storage using aeration. As a heat–cool system, the top section of the machine is used for heating/drying and the bottom section for cooling, with the two sections separated by a platform.

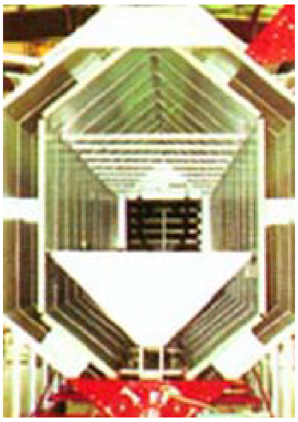


Figure 1. Cross-section of a cross-flow dryer configured to dry and cool the grain in one process. (Source: Quality Grain Dryer, Cambooya, Queensland, Australia).

The dryer is equipped with automatic moisture controls that adjust the variable-speed drive to insure uniformly dried grain regardless of incoming moistures, and to prevent costly over-drying of grain. The variable-speed drive system varies the speed of the unloading auger directly with the speed of the metering rolls and improves grain quality by running the augers always full.

This type of dryer comes with variable column width. Near the top of the dryer, where the drying air is fully saturated, a 25.4 cm width column is used to exhaust excess. A 30.5 cm column is used as the optimum width in the lower portion of the drying section. The detailed specifications of the dryer type assessed are presented in Table 1.

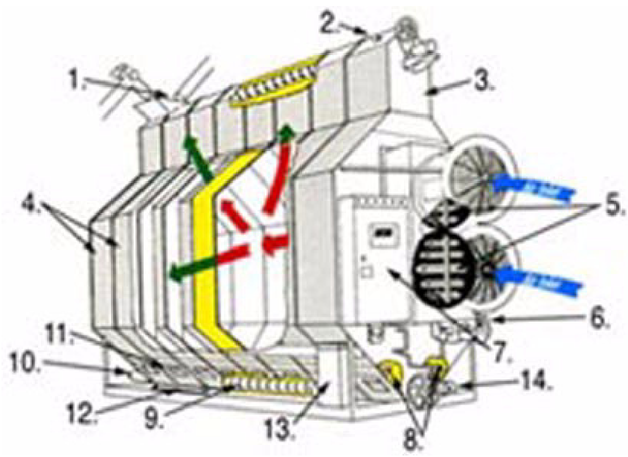
In the rear of the plenum area, a clean-out chute is installed to allow for automatic plenum cleaning of fines or any other material. The clean-out chute directs the materials back into the grain stream as it is being metered out of the dryer. This reduces the need for internal cleaning of the dryer.

Table 1. Specifications of Quality Grain Dryers SD250V (full-heat, vanexial fan) model.

Grain column length (m)	3.73
Overall length (m)	5.96
Overall width (m)	2.23
Overall operating height (m)	4.14
Weight (approx., kg w/o grain)	3000.00
Total volume held (m^3, approx.)	8.46
Burner ratings up to (kW)	1465.5
Fan motor (kW)	9.0
Top auger (kW)	1.70
Bottom auger and metering (kW)	0.75
Throughput rate (wet basis, t/h)	
Maize, 25.5–17.5%	10.22
Maize, 23.0 to 18.0%	15.86
Rice, 3% removal (t/h)	10

Experimental procedure used during the assessment of a cross-flow dryer

The cross-flow dryer was assessed while drying 25 t of either wheat and barley. The dryer in this case was used as a full-heat system (Figure 2).



1. Inlet grain hopper
2. Freeze-proof mercury switch
3. Perforated wet garner bin
4. Compartmentalised variable grain columns
5. Full flamewall burners
6. Fuel flow control stabilizer
7. Weatherproof automatic control centre
8. Heavy-duty metering rolls
9. Heavy-duty augers
10. Discharge tube
11. Quick cleanout
12. Toe trip
13. Factory installed disconnect
14. Totally enclosed electric motors

Figure 2. Model SD500V, illustrating a full-heat dryer used to dry grain without cooling. (Source: Quality Grain Dryer, Cambooya, Queensland, Australia.) (Note: this model was not assessed in the trial but is included for operational information.)

The operational parameters (plenum temperature, average grain moisture content, airflow rate, and final grain temperature) were set as per the manufacturer's recommendations. The plenum temperature was maintained at an almost constant 72°C during the first two trials and 82°C during the third trial. This was achieved by employing a proportional controller on the liquefied petroleum gas supply line, which continuously varied the gas pressure and thus its flow. The dryer was mostly unattended after selecting the appropriate drying parameters.

During the trials, average grain temperatures were recorded at four locations using thermocouples. These were placed near the plenum, in the middle of the grain column, near the outer screen, and finally as hot dried grain came out of the dryer. The grain was then mechanically conveyed to a storage bin. Three grain samples were taken both before and after treatment and germination tests were conducted in the laboratory to assess possible effects on quality. The samples of hot grain taken after treatment were left in plastic bags for about 30 minutes before cooling to ambient conditions. Initial and final grain moisture contents were measured using two different grain moisture meters (Riceter J308 and Graintec HE 50).

Measurement of germination

Germination as an index of wheat and barley quality was determined in the laboratory on all samples from inloading and outloading using the International Seed Testing Association method (Anon. 1993) for wheat and the Doran Briggs methods (Doran and Briggs 1992) for barley. For wheat, germination tests were performed on four replicates of 100 seeds each per sample. Seeds were wrapped in rolled filter paper and counts were made after 4 and 8 days to assess germination energy and germination capacity. For barley, seeds were set out on agar and counts were made up to 3 days to assess germination energy.

Results and discussion

The grain temperature across the grain batch varied between locations in the dryer. The highest grain temperature was recorded near the plenum and the lowest temperature (which was not insecticidal) was recorded near the outside edges. The grain temperatures recorded at the four locations are shown in Figures 3 to 5. The average grain temperature recorded at the outlet after mixing the grain was uniform throughout the trials and was lethal to stored grain pests. The grain near the plenum was heated to high temperatures (80°C and 70°C depending on the plenum temperature used) and this may affect grain quality if heating is not followed by an effective cooling. The drying characteristics in the drying section of a conventional cross-flow dryer (Brooker el al. 1992) are shown in Figure 6. The grain temperature and grain moisture content are plotted against the location in the grain column. The curve shows that the grain is dried non-uniformly. The grain at the air inlet side of the grain column is over-dried and exits from the dryer nearly at the inlet air temperature. The grain at the exhaust side (outer side) of the column remains well below the inlet air temperature and is under-dried. Mixing of the low moisture–high temperature grain with high moisture–low temperature grain in the outloading augers produces grain at the desired average moisture content and temperature (Figures 3 to 5) similar to the finding of Brooker et al. (1992).

According to the manufacturer's recommendations, heating and cooling in the same dryer reduces throughput, and rapid cooling may damage the grain as well. However, in a full-heat mode, cooling is done in the silo by aeration, which allows a further reduction in grain moisture. This further reduces the cost of drying and is a common mode of drying grain using cross-flow dryers in Australia. Problems which potentially may arise from this type of system if higher plenum temperatures are used are kernel stress cracking, shrivelling, susceptibility to breakage, and heat damage or discoloration.

In this study, the germination test results showed the effects of heating wheat and barley in a cross-flow dryer were negligible under the conditions used (Tables 2 and 3).

The average grain temperatures achieved during these trials were about 63°C for wheat, and 60°C and 57°C for barley at plenum temperatures of 82°C for wheat and 82°C and 72°C for barley, respectively. Although these temperatures are insecticidal and the most heat-tolerant species will be killed almost instantly at 63°C, they have to be maintained at 57°C for at least 5 minutes (Beckett et al. 1998). These results suggest that cross-flow dryers can be used for heat disinfestation of grain. However, some modification, such as an additional mixing mechanism as the grain flows downward and the use of wet heat instead of dry heat, are likely to improve the performance (efficiency) of the system.

Conclusion and recommendations

Uniform disinfestation temperatures can be achieved using a SD250V cross-flow dryer after the hot, treated grain is properly mixed. However, below 62°C the grain should be held at temperature for a time sufficient for complete disinfestation (57°C for at least 5 minutes). No damage to grain quality as measured by germination was observed. The treatment in this case can be considered quite severe since grain was held at a high temperature for at least 30 minutes before cooling. It would be safer in terms of maintaining quality to use the lower plenum temperature (72°C) which raised the grain temperature to insecticidal levels with less effect on grain germination during subsequent slow cooling. Conditions used during the trials are common drying treatments. If any deleterious effects on quality were to occur, they are likely to happen whether or not insect disinfestation was a requirement.

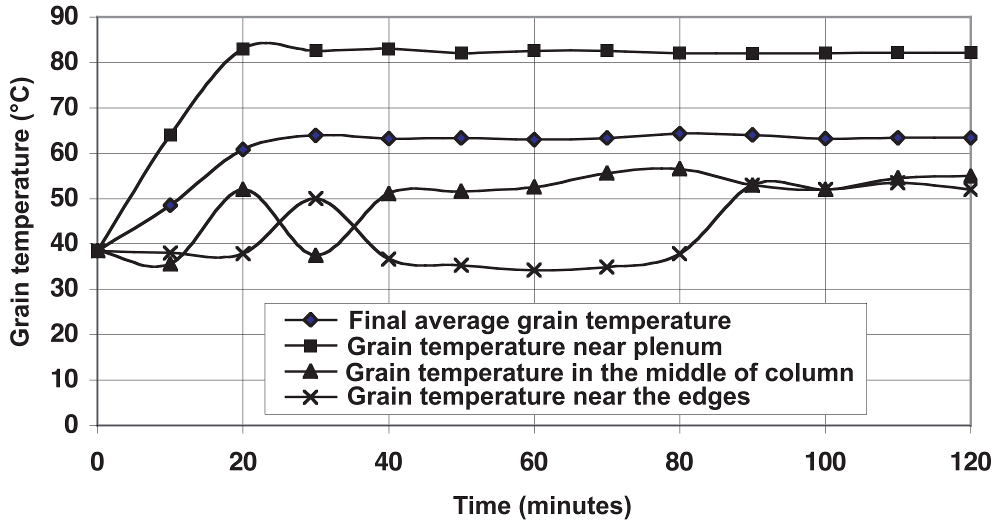


Figure 3. Grain temperatures achieved while drying wheat from 14% to 10.5% moisture content.

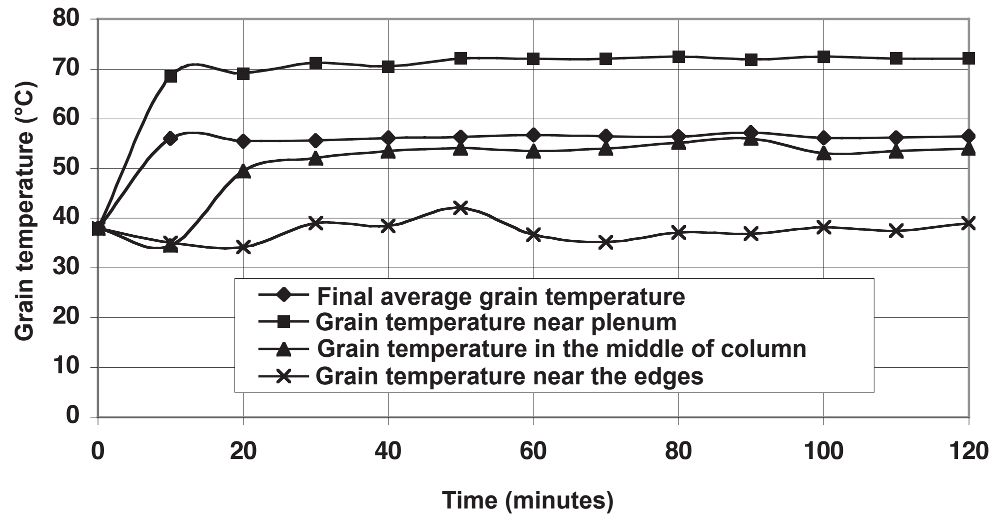


Figure 4. Grain temperatures achieved while drying barley from 11.6% to 10.2% moisture content.

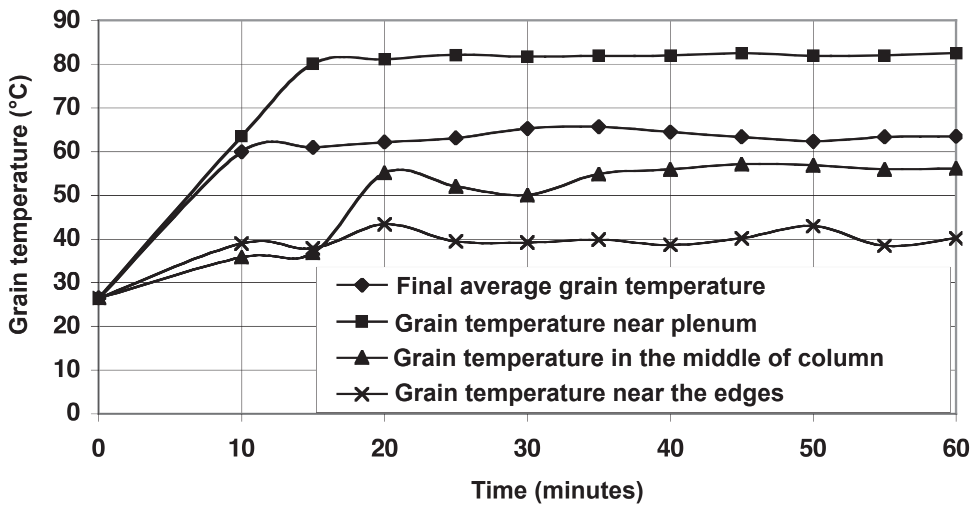


Figure 5. Grain temperatures achieved while drying barley from 9.4% to 8.2% moisture content.

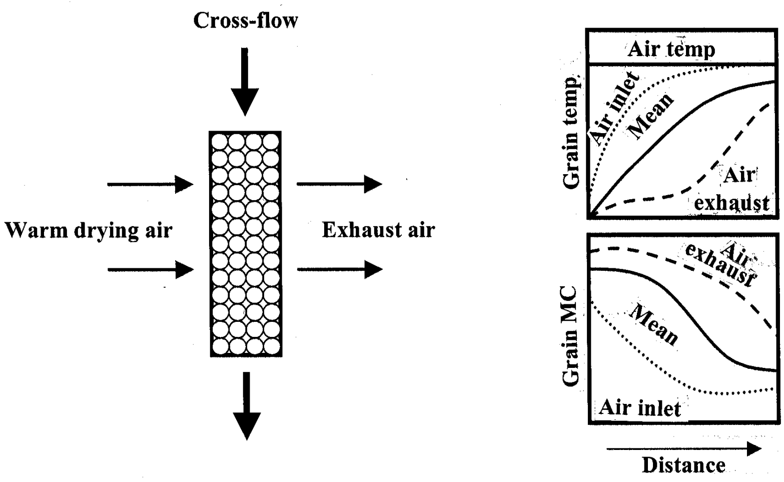


Figure 6. Grain and moisture changes in a cross-flow dryer.

Table 2. Results of the germination test conducted on treated wheat.

Sample	Germination energy		Germination capacity		
	% of germinated seeds	% of ungerminated seeds	% of abnormal seeds	% of low vigour seeds	% of normal seedlings
Heated to 63.5°C	95	1	5	7	88
Control	95	1	4	5	89

This type of dryer has several disadvantages compared with some other types of continuous-flow dryers, such as the cascade mixed-flow system. Grain tends to flow down between the screens without much horizontal movement. This means that the grain close to the plenum is always exposed to the hottest air and dries more than the grain next to the screen near the air exhaust. Furthermore, grain next to the screens flows slower than the grain further away. This uneven movement of grain leads to more variability in the amount of drying/heating experienced by individual grain kernels.

Table 3. Results of the germination test conducted on treated barley.

Sample	Germination energy	
	% of germinated seeds	% of ungerminated seeds
Heated to 57.0°C	99.0	1.0
Heated to 60.0°C	98.0	2.0
Control	98.0	2.0

The drying rate obtained in these trials varied with the initial grain moisture content, plenum temperature and the grain type being dried. Increasing the inlet air temperature and airflow rate would increase the drying rate. The final average grain temperature achieved during the trials was reasonably uniform. Nellist (1982) and Richey (1961) determined safe grain temperatures for drying various cereals. These are 43°C for malting barley, paddy rice and grain meant for germination, 54°C for maize, 60°C for milling wheat, and 82°C for stockfeed. Ghaly and Sutherland (1984) determined the safe grain temperatures for sunflower seed, safflower seed, rapeseed and soybeans with initial moisture contents ranging from 18% to 12% (wet basis; wb) were from 55°C to 65°C. Ghaly and van der Touw (1982) reported that when drying paddy from 20% to 14% (wb), grain temperatures up to 65°C are possible by using intermittent drying and tempering. It is possible, therefore, to heat up grain to temperatures that are lethal to insects by using lower plenum temperatures without significantly affecting grain quality. The plenum temperature needs to be carefully selected since grain near to it is heated to temperatures which may affect its quality, such as germination and baking properties in wheat, or malting in the case of barley.

Possible modifications

1. Use of super-heated steam instead of dry hot air would improve the heat disinfestation process.
2. Provision of an active cooling process after rapid heating (use the dryer in heat–cool mode).
3. Use of lower plenum temperature would decrease the risk of any grain quality losses associated with the heating process.
4. Addition of a mixing mechanism for the grain as it flows downward. One way of mixing grain during heat treatment is installing baffles that cause the grain to flow in a zigzag pattern. The heated air would flow through horizontal openings between baffles.

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