Feasibility of in-progress drying guidelines for wheat ventilated with near-ambient air

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Dougan, K.D., Muir, W.E. and Jayas, D.S. 1995. Feasibility of in-progress drying guidelines for wheat ventilated with near-ambient air. Can. Agric. Eng. 37:183-187. There are few operational guidelines to assist grain managers to predict, on a year-to-year basis, the drying behaviour of a bulk of wheat which is continuously ventilated with near-ambient air. To study the variability of the time required for the drying front to pass completely through the top of the bulk (10th imaginary layer), simulations for each weather year were stopped when the drying front reached the third and fifth layers. For each case, drying was completed using all 28 years of historical weather data (1953-80 for Winnipeg, MB). The time to complete drying to the top layer was estimated within a 10 day range when the drying front had progressed to the midpoint of the bulk. The accuracy of the estimated time for the drying-front to pass completely through the top of the bulk increased with increasing bed depth, moisture content, or later storage date. When losses in drying time occurred during periods of "poor" drying, the time lost could not be recovered during periods of "good" drying because there was a maximum rate of drying.

Keywords: grain drying, stochastic modelling, weather

INTRODUCTION

The usual goal of continuous ventilation of stored grain with air at near-ambient conditions in Western Canada is to move the drying front through the top of the bulk before spoilage occurs or before November 15 (Friesen and Huminicki 1987). The term "near-ambient" refers to the slight increase in air temperature as air passes through the ventilation fan and over the motor.

Dependence of drying performance on fall weather conditions introduces variability and uncertainty with which the grain storage manager must contend. Simulations of a continuously ventilated bin of wheat using 33 years of historical weather data show a wide range of possible drying times (Kitson et al. 1991).

Continuous ventilation with near-ambient air is not a reliable drying system. The bulk can be severely overdried during hot and dry periods, or the rate of drying can be very slow during periods of cool or humid weather. Overdrying carries an economic penalty that the grain storage manager must pay if the average moisture content of the bulk is less than the "dry" market moisture content, 14.5% for wheat. Friesen and Huminicki (1987) recommended using supplemental heat only if it appears that the grain will not dry by November 15 or before spoilage occurs. Currently there is not any information available which the grain storage manager can use to identify "poor" drying years while drying is in progress.

Grain drying systems can be designed by computer programs, such as GRAIN89, which is available to Manitoba grain storage managers through the Manitoba Department of Agriculture (Huminicki et al. 1986). GRAIN89 presents an expected range of final drying times for a particular drying system design but information is not presented on drying system performance while drying is in progress.

There is a need for operational guidelines for continuous near-ambient ventilation. Because of uncertainties in weather conditions, drying system performance must be periodically evaluated while drying is in progress. If the grain storage manager has an accurate prediction of the performance, a decision can be made as to whether the current drying system meets the manager's requirements or whether another drying method should be used (eg. application of supplemental heat if drying is not guaranteed by November 15).

A computer simulation approach was used to meet the following objectives:

1) to determine, based on the initial rate of drying and with varying degrees of drying already completed, the probability distributions of the times required to complete drying to the top layer of a bulk of wheat, and

2) to assess the feasibility of using probability distribu-
to ensure drying by November 15 or before spoilage when its spoilage index by the maximum allowable spoilage index.

Therefore, drying by November 15 was not ensured.

The scope of this study included developing distributions for times required to completely dry a bulk of wheat ventilated continuously using recommended airflow rates required to ensure drying by November 15 or before spoilage occurs in the top of the bulk (Friesen and Huminicki 1987).

METHODS AND MATERIALS

A near-equilibrium grain drying model developed by Metzger and Muir (1983), which is based on the work of Thompson (1972), has been modified to include hysteresis during moisture sorption and has been extensively validated (Sanderson et al. 1989). The validated modified-model of Metzger and Muir (1983) was used to study continuous ventilation with near-ambient air.

The response of a bulk of wheat to historical weather data for 28 years (1953-80) for Winnipeg was studied for several scenarios. The response was determined for three storage dates (August 15, September 1, and September 15), two storage moisture contents (18 and 20%) and two bed depths (3.65 and 7.30 m). Recommended rates of continuous airflow which ensure drying by November 15 were used (Friesen and Huminicki 1987). A fully perforated floor and level grain surface was assumed.

For each of the 28 years of historical weather data, drying was simulated until the drying front passed through layers 3, 4, or 5. (The simulation uses 10 layers; layer 10 is the top.) For each of these sets of conditions, continued drying was then simulated with weather data for each of the 28 years until the 10th layer (i.e. the top layer) was "dry".

Except for the maximum allowable spoilage index and "dry" moisture content, the models and their input parameters were unchanged from the software available from the Manitoba Department of Agriculture (Huminicki et al. 1986). A maximum allowable spoilage index of 1.5, as suggested by Sanderson et al. (1989), was used. A normalized indicator of spoilage, allowable storage time elapsed (ASTE), was calculated for the top layer of the bulk by dividing the accumulated spoilage index by the maximum allowable spoilage index.

The drying front was considered to be in a layer when its average moisture content first fell below 15.5%. The value of 15.5% moisture content was chosen instead of a "dry" moisture content of 14.5% because preliminary simulations showed moisture contents did not "bottom out" for long periods of cool or damp weather. For example, weather during the fall of 1968 was very poor for drying and moisture content in the layers through which the drying front had already passed rarely went below 15.0%. Therefore, drying by November 15 was not ensured.

RESULTS AND DISCUSSION

Temperature rise model

Predicted temperature rises of the ambient air as it passed through the fan and over the motor were large for a few scenarios. Temperature rise predicted for simulations of 7.30-m bed depths, storage dates of September 15, and initial moisture contents of 18 and 20% were 7.5 and 8.8°C, respectively (Table 1). These large temperature rises could not be compared with observed values for commercial ventilation equipment because the design software of Huminicki et al. (1986) did not allow for simulation of wheat bulks as deep as those used in this study.

Calculated temperature rises for most scenarios were within the range of observed temperature increases for typical ventilation equipment (Huminicki et al. 1986). The minimum temperature rise for commercially available ventilation equipment was typically greater than 1.0°C. Therefore, the calculated temperature rise of 0.5°C for a few scenarios in this study was low.

Effect of weather variation on drying

Figure 1 shows simulation results for wheat initially stored in Winnipeg on August 15 at 18% moisture content in a 3.65-m deep bed and ventilated with 10 L·s⁻¹·m⁻³ of near-ambient air. The estimated time for the top layer (layer 10) of a bulk of wheat to dry to 15.5% moisture content was between 22 and 83 days. A column of '+' (i.e. data points with the same x-axis value) contains final drying times in which the initial drying from layer 1 to layer 5 was simulated with the same weather year; drying from layer 6 to 10 was simulated with each of the 28 weather years to give the column of 28 data points.

Simulations using these synthetic combinations of weather data were reasonable because their percentile ranges compare well with the distribution of final drying times for the original weather data for the 28 historical years. Because Richardson (1981, 1982) showed that only the weather of the previous day affects the weather of the current day, any errors in simulation results introduced due to the "splicing" of weather data were likely small.

Percentile lines were added to show the distribution of the final drying times (--). Percentile lines were determined by collecting times to dry up to layer 5 (x-axis in Fig. 1a) into groups no greater than 5 days in width. Each group was to have a minimum of 3 times to dry up to layer 5; therefore, percentile ranges were not determined for regions with sparsely distributed data.

Times required for the drying front to reach layer 5 were used to develop a cumulative density function (c.d.f.) in Part

Table 1: Predicted temperature rise (°C) of inlet ventilation air based on fundamental thermodynamic principles. Also shown in parenthesis are the recommended airflow rates (L·s⁻¹·m⁻³) of Huminicki and Friesen (1987) which ensure drying by November 15.

<table>
<thead>
<tr>
<th>Moisture content (% w.b.)</th>
<th>Bed depth (m)</th>
<th>Predicted temp. rise (°C) (Airflow rate (L·s⁻¹·m⁻³))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August 15</td>
<td>September 1</td>
</tr>
<tr>
<td>18</td>
<td>3.65</td>
<td>0.5 (10)</td>
</tr>
<tr>
<td>18</td>
<td>7.30</td>
<td>2.3 (10)</td>
</tr>
<tr>
<td>20</td>
<td>3.65</td>
<td>1.0 (20)</td>
</tr>
<tr>
<td>20</td>
<td>7.30</td>
<td>4.3 (20)</td>
</tr>
</tbody>
</table>

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Spoilage would have been predicted in some simulations. The average ASTE for the top layer is given because the variation for each set of 28 simulations was small (± 0.1). Spoilage was not predicted in any of the simulations. If the maximum allowable spoilage index had not been increased by 1.5, as recommended by Sanderson et al. (1989), then spoilage would have been predicted in some simulations.

Figure 1 shows a skewed cumulative density function in the time required to dry up to a particular layer. For example, wheat stored on August 15 at 18% moisture content in a 3.65-m deep bed (Fig. 1b), required 10 to 38 d for the drying front to reach layer 5, with 86% of the simulations between 10 and 21 d. As well, the times required to dry the top layer were also skewed to the bottom of the ranges (i.e. 28 drying times ‘+’ within a column in Fig. 1a).

The skewness in drying times can be attributed to several factors. The historical weather data used in this study included the years 1965 and 1968, which were poor drying years. The rate of drying during periods of poor drying was slower than the typical rate but the rate of drying during good drying periods was limited by a maximum rate of drying. Therefore, losses in drying time were not regained at a later period.

The weather during the period of initial drying, (i.e. during drying of the first 5 layers) and not just the time to dry to layer 5, had a significant effect on the range of final drying times. For example, if initial drying was simulated with weather year 1973 (at 16 days on the horizontal-axis in Fig. 1), then all final drying times were in the 0 to 60 percentile range. That is, even when drying of layers 6 to 10 was simulated with weather during the poor drying year 1968, the final drying times were below the 60th percentile. (This can be seen more clearly in Fig. 2 which is an enlargement of a portion of Fig. 1). Simulations for years 1960, 1964, 1972, and 1973 indicate that the simulated grain was predisposed to dry quickly, regardless of weather existing during drying of layers 6 to 10. Simulations in which drying of layers 1 to 5 was carried out during 1965 and 1968 showed greater sensitivity to weather existing during drying of the remaining 5 layers. The cause of the above mentioned effects was not studied.

### Varying amount of initial drying

Variability in time to dry the top layer to 15.5% moisture content increased as the number of layers dried during the initial period was reduced from 5 to 3 (Figs. 1 and 3). That is, the smaller the amount of initial drying, the greater the fanout of final drying times. For wheat stored August 15 in a 3.65-m bed at 18% moisture content, if the drying front had progressed to layer 3, then the time to dry the top layer could be estimated to occur within a 25 day range (i.e. the maximum vertical distance between 0 and 100 percentile lines at any initial drying time in Fig. 3). If the drying front had
Varying initial moisture content

Increasing initial storage moisture content from 18% to 20% required doubling the airflow rate to 20 L·s⁻¹·m⁻³ and resulted in reduced variability in final drying times from 15 days (Fig. 1a) to 10 days. Wheat with a high moisture content must be dried more rapidly than wheat with a low moisture content to avoid spoilage particularly for wheat stored early in the fall when ambient air temperatures are high. Calculated temperature rise of ventilation air increased with increased airflow rate. The mean drying rates increased with the higher airflows recommended for increased bed depths or increased moisture contents.

The above results must be interpreted carefully. The results are not meant to encourage storage at high moisture contents or harvesting late in the fall. Recommended airflow rates are based on a constant temperature rise whereas for this study the recommended airflow rates were used with a varying temperature rise.

In general, the amount of variability in the scenarios is determined by the recommended airflow rates and the total bed depth. Because it is assumed for this study that the grain storage manager is using only recommended airflow rates, times from 15 days to 10 days. Calculated temperature rise of the ventilation air as it passed over the fan and motor increased from 0.5°C to 2.3°C when the bed depth was doubled (Table I). The effect of rewetting was reduced in the deeper beds compared with shallower beds because of the increased temperature and drying potential of the ventilation air.

Varying bed depth

Increasing bed depth from 3.65 to 7.30 m reduced the range of time to dry layer 5 from 10 to 39 days (Fig. 4a) to 10 to 27 days (Fig. 4a), and the variability in predicted final drying times from 15 days to 10 days.
reduced variability can be achieved by maximizing total bed depth. In other words, if the equipment is available, bins could be filled to the eaves for increased accuracy in predicting final drying times but at increased costs of larger fans and power requirements, and increased electrical energy consumptions.

Assessing drying performance

By using results presented above, the grain storage manager would have knowledge about possible future occurrences for a specific drying system, particularly those with large variability. Suppose a grain storage manager has stored 18% moisture content wheat on August 15 in a 3.65-m bed. On the day of storage, Fig. 1 indicates to the manager that the best possible drying time would be 22 days while the worst would be 80 days. The manager would also know there was no risk of spoilage and the grain would dry by November 15.

The best time to take samples from the grain bulk can also be determined from the figures. The c.d.f. in Fig. 3 indicates that the drying front reaches layer 3 in 5 to 15 days, 90% of the time, with the other 10% of the years requiring up to 32 days. The time for the drying front to reach layer 5 for 90% of the years would be 10 to 25 days after storage (Fig. 1). For 100% of all cases, time for the drying front to reach layer 5 would be 10 to 39 days after storage. The best time and locations to take grain samples would be 10 to 15 days after storage in layers 3, 4, and 5. The drying front should be detected in layers 3, 4, or 5 at that time because the drying front would not have progressed past layer 5 after 10 to 14 days. If the drying front is not detected in or has not passed through layers 3, 4, or 5, then drying performance is poor.

When drying front location is known, the manager can gauge the drying performance using similar figures. The same procedures as above can be used to determine the best next sampling date.

CONCLUSIONS

The following conclusions can be made based on the results of this study in which continuous ventilation of wheat using recommended airflow rates for Winnipeg, Manitoba, was simulated:

1) The distribution of times required to complete drying of the top layer of a bulk of wheat showed that increased bed depth, moisture content, or late storage date of September 15 reduces variability in estimating the final drying time. Variability in final drying times was reduced from 20 to 10 days for August 15/September 15 storage dates compared with September 1, respectively, because airflow rates are large. Also, the greater the amount of initial drying (drying completed to layer 5 compared with layer 3) the less the variability in final drying times (15 days compared with 25 days, respectively, for August 15 storage at 18% m.c.(w.b.)). Stochastic analysis has shown that there is a maximum rate of drying for each drying scenario and that when losses in drying time occur during periods of "poor" drying, time lost cannot be recovered when periods of "good" drying follow these periods of "poor" drying.

2) Although the grain storage manager has no control over the harvest date and harvest moisture content, bed depth (of 7.30 m compared with 3.65 m) can be used to reduce the amount of variability (from 15 days to 10 days, respectively) in estimating final drying time but at the cost of increased fan size and energy consumption. By monitoring the time at which the drying front reaches the midpoint of the bulk, an accurate estimate of the final drying time can be made for drying systems with wide variability. Operational guidelines have been developed which can be used to estimate, within 10 days or less, the time at which the drying front would reach the top of a bulk of wheat.

FUTURE RESEARCH

Future work is needed to evaluate and develop operational guidelines for a wider range of grain drying scenarios, particularly non-design scenarios. The study should focus on current drying practices and the value of such operational guidelines to grain storage managers.

REFERENCES