INTRODUCTION

The drying of farm crops is an integral part of agricultural production systems. The current trend is to dry farm crops, including canola, using near-ambient temperature air. Aeration is the most commonly used method for cooling stored grains and oilseeds. In both the near-ambient drying and the aeration systems, air in varying quantities, 10-30 L/(s m²) for near-ambient drying and 1-2 L/(s m²) for aeration systems (Friesen et al. 1984), is forced through a perforated area and is then distributed throughout the grain mass. The success of the systems is highly dependent on uniformity of the airflow within the stored mass. The uniformity of airflow is affected by the configuration of the perforated area used for introduction of the air, bin geometry, resistance to airflow of the product, and the amount, size, and distribution of foreign material in the stored bulk. If a clean product at known moisture content is used to fill the storage bins, then the design of the perforated area and the bin geometry can be predicted reasonably well using the mathematical models of several investigators (Brooker 1969; Marchant 1976; Segerlind 1982; Singh (Jayas) and Sokhansanj 1985; Miketic et al. 1986).

The effect of the amount, size, and distribution of foreign material on uniformity of airflow can be also incorporated in the mathematical models if the distribution of foreign materials in storage bins can be estimated. Chang et al. (1981, 1983, 1984) studied the distribution of foreign material in corn and wheat bins. To our knowledge, studies on the distribution of foreign materials in other stored crops have not been reported in the literature.

Canola is an economically important oilseed crop for Canada. In 1984, about 3.2 million tonnes of canola worth 1.2 billion dollars were produced in Canada (Anonymous 1984). Depending on the weather conditions during harvest, drying of canola may be a necessity. High-temperature air drying is undesirable for canola because of the fear of contamination from burnt kernels, and nonuniform airflow distribution in near-ambient drying systems can result in localized regions of wet seeds causing moldy or heated kernels. Both the burnt and heated kernels complicate refining of the canola oil. As a first step in an attempt to predict the uniformity of airflow within stored canola, this study was undertaken to investigate the distribution patterns of foreign material (chaff and fines) in canola bins as affected by the method used to fill the bin. Based on average particle diameter of Tobin canola, chaff was defined as overflow of No. 12 mesh US Standard sieve and fines as underflow of No. 16 mesh US Standard sieve.

MATERIALS AND METHODS

Sampling for Foreign Material Distribution

The amount, size and distribution of foreign material was studied in a 4.6-m-diameter bin filled with Tobin canola. The bin was filled twice using a central spout and once using a conical spreader. The distribution of chaff and fines can be described using a quadratic equation with radial coordinates. The use of a conical spreader to fill the bin with canola increased the uniformity of chaff and fines distribution only slightly. Contrary to general belief, fines were not highly concentrated in the center of the bin for either of the fill methods. The variation of chaff and fines with height was insignificant.
used in the present study for several reasons. First, it was decided that the opening through which the sample enters the probe is small and could prevent entering of the chaff due to bridging. Second, if a probe with a large opening and diameter is used it disturbs the sampling area during insertion; also, the difficulty in inserting the probe increases significantly with probe diameter. From studies of Stephens and Foster (1976, 1978) and Chang et al. (1981, 1983, 1984) it can be assumed that the distribution of foreign material is symmetrical about the vertical axis of the bin when bins are filled using spreaders or a central spout. Therefore, sampling of a bin along one radius was considered sufficient instead of along the bin diameter. The method of sampling a bin along its radius is described below. This method could be extended to sample along the bin diameter.

The first truck load (about 8 t) of canola was transferred into the bin using the unloading system shown in Fig. 1. A plywood platform (250 mm wide and 2500 mm long) was hung from an inside ladder in the bin. The platform was parallel and close to the canola profile in the bin but was not touching the canola surface. This arrangement allowed easy sampling of canola at all sampling locations spaced 372 mm apart along the bin radius. The samples were collected using a circular sampler 100 mm in diameter and 145 mm long. The sampler was inserted at the point of sampling and then was covered using an aluminum sheet at the bottom and lifted. The disturbance caused by sampling at one point was not transferred to the adjacent sampling point. The amount of sample collected at each point was about 800 g except near the bin wall where it was about 600 g. The samples near the bin wall weighed less because of the presence of higher amounts of lighter chaff. As shown in Fig. 2, the grid of sampling points in this method followed the profile of the canola. The platform was removed after sampling and was reintroduced after unloading the next truck. Four truck loads were used for the first bin fill and five truck loads were used for the second bin fill.

The profile after filling the bin using the conical spreader was not a cone but had the shape of a doughnut. The sampling grid for the spreader-filled bin is shown in Fig. 3. In preliminary tests, filling with the conical spreader did not give an axisymmetric fill, rather canola sloped in a heap from one side of the bin wall. The problem was in the design of the spreader. The opening between the two cones was too wide. Therefore, a slight angle from the vertical of the dropping canola guided it to one side. The spreader was modified so that the top cone was nearly full during emptying. Also, the hanging portion of the dropping-spout was tied so that it discharged vertically downward. The modifications resulted in axisymmetric distribution of foreign material. Many farmers may not notice this problem and the conical spreader would result in bins having all the chaff accumulated on one side.

**Analysis of Samples for Foreign Material**

Collected samples were subdivided using a Boerner divider into samples of 250 g each. The 250-g sample was fractionated into three components using two Tyler woven wire mesh sieves (No. 12 and 16). The opening of No. 12 sieve was 1.70 mm and of No. 16 was 1.18 mm. The sieves were 51 mm in depth and 203 mm in diameter. The samples were shaken for 5 min using a Ro-Tap shaker. The shaking time was determined based on preliminary tests in which material on sieves was...
recorded at 2-min intervals. The difference between amounts of material retained on the various sieves after 4 and 6 min was negligible. Hence, 5 min was arbitrarily chosen as the shaking time.

The material retained on the No. 12 sieve was defined as chaff, the underflow of No. 12 and overflow of No. 16 was defined as canola and the material that passed through No. 16 and was retained on the pan was defined as fines. Canola at this point contained a small amount of needle-like particles of plant residue. These particles were separated as overflow using riddle screen No. 000 with a feed rate set at 3 on a Carter Dockage Tester (Simon Day Ltd., Winnipeg, Man.). This small fraction was added to the chaff because it looked similar. The masses of fines, canola and chaff were recorded and were used to give the distribution of foreign material in the bin as affected by the method used to fill the bin.

Normalization of Foreign Materials

The amounts of fines and chaff determined at seven locations along the radius of the bin were used to estimate the weighted average of chaff and fines for each truck load. The volumes of canola in the bin represented by each sample were taken into account when means of chaff and fines were estimated.

The individual amounts of chaff and fines were divided by the mean values of chaff and fines to determine the normalized chaff and fines.

RESULTS AND DISCUSSION

Distribution in Spout-filled Bins

The radial distributions of chaff and fines in the mass of canola for spout-filled bins are shown in Figs. 4 and 5, respectively. The lines were drawn through the mean values of chaff and fines. The means were calculated from triplicate samples collected 372 mm apart (radially), except for the sampling location, farthest from the center, where only duplicates were used. The quantity of chaff and fines were normalized by dividing the measured value at each point by the mass average quantity at the same level. The plotted lines represent two bin fills. The lines numbered 1 to 4 are for first bin fill and 5 to 9 are for second bin fill.
The distribution of chaff in spout-filled canola bins can be described by a quadratic equation:

\[ \frac{C_s}{\bar{C}_s} = 0.722 - 0.740 r + 0.535 r^2 \]  

(correlation coefficient = 0.98)

where \( \bar{C}_s \) = mean chaff content for spout-filled bin; \( C_s \) = chaff at radius \( r \) for spout-filled bin; and \( r \) = location along bin radius measured from central axis (m).

Chang et al. (1981, 1983) have reported very high concentrations of fines around the center of the bins filled with corn and wheat. We did not observe very high concentration of fines near the center of the bin. Rather, we observed that the concentration of fines in canola bins near the bin center was almost equal to that near the sides of the bin. The minimum fines were found about midway between the center and the bin wall. The canola particles are very small, and hence distinction between canola and fines is not as markedly defined as in the studies of Chang et al. (1981, 1983) with corn and wheat. The distribution of fines in spout-filled canola bins can mathematically be given by:

\[ F_s/F_s = 1.093 - 0.474 r + 0.241 r^2 \]  

(correlation coefficient = 0.88)

where \( F_s \) = mean fines for spout-filled bins; and \( F_s \) = fines at radius \( r \) for spout-filled bins.

**Distribution in Spreader-filled Bins**

Normalized distribution of chaff and fines for spreader fill are given in Figs. 8 and 9, respectively. The lines were drawn through the mean values of chaff and fines. The means were calculated from triplicate samples collected 372 mm apart (radially), except for the sampling location, farthest from the center, where only duplicates were used. Lines numbered 1, 2 and 3 represent the samples taken after transferring first, second and third truck loads of canola. The detailed data are given elsewhere (Jayas 1987). As additional canola was added in each filling, the drop height decreased for successive additions. The effect of drop height on radial distribution of either chaff or fines is negligible. Hence, the chaff and fines were averaged for all samples at each sampling point along the bin radius.

The mean values for chaff and fines are shown in Figs. 6 and 7, respectively. In calculating mean values, data points marked "5" were not used. No explanation for such a distinct behavior in transferring the first load during the second bin fill can be given. Most of the chaff was concentrated near the wall of the bin (Fig. 6), and minimum chaff occurred between 0.6 and 0.8 m from the center of the bin. This trend was also confirmed by visually observing the canola profile after the addition of each load. The cleanest spot was not the center of the bin but rather it was the annular area between 1.2 and 1.6 m diameter of the bin. It was expected that minimum chaff should occur in the center of the bin. During filling using the central spout, particles larger than canola have a tendency to slide along the slope, but some of these particles did not have enough time and were trapped in the falling stream. This trapping was probably the main reason for higher chaff at the center compared to 0.6–0.8 m away from the center. The distribution of chaff in spreader-filled canola bins can be described by a quadratic equation:

\[ \frac{C_c}{\bar{C}_c} = 0.960 - 0.866 r + 0.520 r^2 \]  

(correlation coefficient = 0.94)

where \( \bar{C}_c \) = mean chaff content for spreader-filled bins; \( C_c \) = chaff content of chaff in spreader-filled bins; and \( C_c \) = chaff content of chaff in spreader-filled bins.
tient at radius \( r \) for spreader-filled bins and radial distribution of fines in spreader-filled bins is given by

\[
F_{c} / \bar{F}_{c} = 1.269 - 0.466 \, r + 0.166 \, r^2
\]

(4)

where \( \bar{F}_{c} \) = mean fines content for spreader-filled bins; and \( F_{c} \) = fines content at radius \( r \) for spreader-filled bins.

The effect of the conical spreader on the distribution of chaff is to increase chaff concentration at the center and reduce it near the bin wall (Fig. 6), as compared to spout-filled bins. The main reason for this shift is the doughnut-shaped profile which resulted during bin filling using the conical spreader. The chaff did not have enough energy to cross the ridge formed and was trapped in the center portion of the bin.

The fines are more concentrated in the center when a conical spreader is used to fill the bins (Fig. 7). This also happens because of trapping of fines in the central portion of the doughnut-shaped profile. These observations contradict the manufacturers claim that use of their spreader will result in better distribution of fines than spout fill. Some spreaders do result in more uniform distribution of fines in other crops (Chang et al. 1981, 1983).

Figure 8. Distribution of chaff along the radius of a bin which was filled axisymmetrically using a grain spreader. The radial distances were measured from the bin center.

Figure 9. Distribution of fines along radius of a bin which was filled axisymmetrically using a grain spreader. The radial distances were measured from the bin center.

Utility of the Results
To use Eqs. 1–4 for predicting radial distribution of chaff and fines a representative sample from a bin must be fractionated to find chaff and fines means for that bin. By substituting values for radial coordinates, mean chaff and mean fines in an appropriate equation, the distribution of foreign material in the bins can be predicted. In the event a representative sample cannot be obtained and analyzed, an estimate of total foreign material in canola can be used. The estimated foreign material can be divided by 2 to obtain chaff and fines means.

Equations 1, 2, 3 and 4 are developed from experimental data for 4.6-m-diameter bins. The use of the equations to predict distribution of foreign material should be limited to the bins having diameters of about 4.6 m. The main reason to limit this study to a 4.6-m-diameter bin was its availability and its commonness on most farms in western Canada. An extensive study with different diameter bins would require substantial cooperation from the farmers and a significant amount of financial resources. If funds become available a general equation should be developed for prediction of chaff and fines not only in canola bins but also in bins filled with other cereals and oilseeds.

CONCLUSIONS
The distribution of chaff and fines in a 4.6-m-diameter bin can be modelled using quadratic equations relating the fraction of chaff or fines to the radial coordinate. Contrary to general belief, fines were not highly concentrated in the center of the bin for either of the fill methods. The use of a grain spreader concentrated more fines near the center and resulted in only slightly more uniform distribution of fines than use of spout fill. We experienced that unsupervised use of the spreader may cause filling of the bin towards one side and result in most of the chaff being concentrated towards the opposite side.

REFERENCES


