Resistance of bulk alfalfa seeds to airflow

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Li, W. and Sokhansanj, S. 1994. Resistance of bulk alfalfa seeds to airflow. Can. Agric. Eng. 36:025-028. The resistance of bulk alfalfa seeds variety Rambler (Medicago sativa, L.) to airflow was determined for airflow rates ranging from 7.54 x 10^{-5} m^3 s^{-1} m^{-2} to fluidization velocity of about 0.5 m^3 s^{-1} m^{-2}. For clean seed the relationship between pressure drop in Pa/m versus airflow in m^3 s^{-1} m^{-2} was \( \Delta P = 57931 \frac{Q^2}{1 + 2.993Q} \). The effects of seed moisture content, method of fill (or bulk density), and impurities on the resistance to airflow were investigated.

KEYWORDS: alfalfa seed, airflow, pressure drop, ventilation, drying

La résistance des grains de luzerne en masse, de la variété Rambler (Medicago sativa, L.) au déplacement d'air était déterminée pour des taux de déplacement d'air de 7.54 x 10^{-5} m^3 s^{-1} m^{-2} à une vitesse de fluidisation d'approximativement 0.5 m^3 s^{-1} m^{-2}. Pour des grains nets, la relation entre la diminution de la pression en Pa/m contre le déplacement d'air en m^3 s^{-1} m^{-2} était \( \Delta P = 57931 \frac{Q^2}{1 + 2.993Q} \). Les effets du taux de moiteur des grains, la méthode du remplissage (la densité en gros), et les impurites sur la résistance au déplacement d'air étaient rechercnes.

INTRODUCTION

The resistance to airflow of alfalfa seeds has been published as ASAE Data 272.3 (ASAE 1992a) based on the data of Shedd (1953). These data are limited to the airflow range of 5.6 x 10^{-3} to 0.152 m^3 s^{-1} m^{-2} and are only applicable to loose fill and clean dry alfalfa seeds at about 7% moisture content on wet basis (w.b.). New data are required to cover a wide range of airflow rates, moisture contents, and bulk densities. This paper presents experimental data on the resistance of alfalfa seeds to airflow in the range of 7.54 x 10^{-5} to about 0.5 m^3 s^{-1} m^{-2}.

EQUIPMENT AND PROCEDURE

Equipment

Experimental apparatus consisted of a cylindrical grain container and instruments for measuring the flow rates and static pressures. To cover a wide airflow range, two different systems shown in Figs. 1 and 2 were used. For airflow rates of higher than 0.02 m^3 s^{-1} m^{-2}, the system in Fig. 1 was used. A bench-top wind tunnel (Model 8390, TSI Corp., St. Paul, MN) was used to measure the airflow rate. A small fan was installed at one end of the wind tunnel to provide airflow rates between 0.02 and 0.3 m^3 s^{-1} m^{-2}. For airflow rates higher than 0.3 m^3 s^{-1} m^{-2}, a variable speed, high pressure centrifugal blower was also used to boost the air supply through the wind tunnel.

Air pressure was measured along the depth of grain column to a resolution of 0.34 Pa with a differential pressure transducer (Model DP103-26, Validyne Engineering Corp., Northridge, CA). The manufacturer's specified pressure range for Model DP103-26 was 0 to about 3.500 Pa.

For low airflow rates of less than 0.02 m^3 s^{-1} m^{-2}, the long column shown in Fig. 2 was used. The pressure taps were placed at two levels 2 m apart along the height of the grain column. Four pressure taps 90 degrees apart were installed at each level. The grain column was hinged at the mid-section to facilitate filling and emptying of the container. The supply airflow from the compressed air line passed through a series of filters and pressure regulators before entering the grain column. The airflow rates were measured by four rotameter tubes (Fisher and Porter Co., Warminster, PA) that measured airflow rates as low as 7.54 x 10^{-5} m^3 s^{-1} m^{-2}. The pressures along the depth of the grain column were measured using a pressure transducer (model DP103-12, plenum Model 8391 pressure transducer Fig. 1. Equipment for measuring the resistance of grain to high air flows.

Fig. 1. Equipment for measuring the resistance of grain to high air flows.

Fig. 2. Equipment for measuring the resistance of grain to low air flows.
Validyne Engineering Corp., Northridge, CA) to a resolution of 0.14 Pa. The full range of this transducer was 0 Pa to 1400 Pa.

All tests in this study were conducted in three replicates. For the low airflow range test (7.54 x 10^{-5} to 0.02 m^3 s^{-1} m^{-2}), air pressures were measured at 19 different airflow rates. For the high airflow range test (greater than 0.02 m^3 s^{-1} m^{-2}), air pressures were measured at 18 different airflow rates. The atmospheric temperature and pressure were recorded during each test. The error of airflow rate measurement was about 5% due to the change of environmental temperature and pressure.

Grain sample preparation
Alfalfa seeds variety Rambler (Medicago sativa, L.) were used in this study. The moisture content of cleaned seeds at the time of purchase was about 7% wet basis (w.b.). The length and width of one hundred seeds measured using a computer-based imaging were 2.37 mm (s.d. = 0.23 mm) and 1.42 mm (s.d. = 0.15 mm), respectively. The kernel density of cleaned alfalfa seeds was measured using a Beckman Model 913 air-comparison pycnometer. The average of five measurements taken was 1130 kg/m^3 at 7% moisture content.

Moisture content
To investigate the effect of moisture content of seeds on pressure drop, grain samples were conditioned to five moisture levels: 10%, 14%, 18%, 22%, and 26% (w.b.). Water was sprayed onto the seeds while seeds were tumbling in a concrete mixer to raise the moisture content of grain to the desired level. The wetted samples were kept in sealed containers for at least 48 hours at room temperature before each test. The moisture content of alfalfa seeds was determined by the oven method (ASAE Standard S352.2, ASAE 1992c).

Fill method
Three fill methods were used: loose fill, semi-dense fill, and dense fill. For the loose fill, seeds were allowed to flow out of a telescopic loading pipe into the test chamber with zero height of fall. For the semi-dense fill and dense fill, seeds were allowed to fall from 0.75 m and 1.5 m heights, respectively. The filled sample container was weighed in situ and the volume of the grain column was calculated by measuring the height and the diameter of the container. The ratio of grain mass to its bulk volume was considered in situ bulk density.

Fines and chaff
A mixture of fines and chaff was obtained from a local seed cleaning plant. Fines were separated from the chaff by sieving. Fines were smaller in size than the alfalfa seed. The geometric mean diameter (determined according to ASAE Standard S319.1, ASAE 1992b) of the fines was 0.64 mm (s.d. = 0.33 mm). Fines were mixed with 10% moisture content grain in a concrete mixer. The mixing period varied from 10 to 20 minutes increasing in duration with the amount of fines in the mixture. Five levels of mixtures were prepared: 5%, 10%, 15%, 20%, and 25% fines on mass basis. The geometric mean diameter of the chaff materials was 1.72 mm (s.d. = 0.47 mm). Grain samples of 10% moisture content were mixed with 5%, 10%, 15%, 20%, and 25% (on mass basis) chaff materials in the same way as for the fines. Before mixing, the moisture contents of fines and chaff materials were adjusted to the same moisture content of the grain sample. The dense fill method was used to fill the sample mixed with fines and chaff.

RESULTS AND DISCUSSION
The equation developed by Hukill and Ives (1955) was used to represent the experimental data of the present study.

\[
\Delta P = \frac{aQ^2}{\ln(1 + bQ)}
\]

where:
\(\Delta P\) = pressure drop per unit length (Pa/m),
\(Q\) = airflow rate (m^3 s^{-1} m^{-2}),
\(a, b\) = constants.

Constants \(a\) and \(b\) were estimated using the non-linear (NLIN) procedure of the SAS package (SAS 1982). The average pressure drop of the three replicates was used in the estimation. The standard errors of the three replicated pressure drops varied between 1.94 x 10^{-3} Pa/m and 558 Pa/m for the measured pressure drop varying from about 1 Pa/m to 9000 Pa/m. Table I lists the estimated values of \(a\) and \(b\) for each test group.

The in situ bulk densities of clean alfalfa seeds at 10% moisture content were 822 kg/m^3 for loose fill, 846 kg/m^3 for semi-dense fill, and 866 kg/m^3 for dense fill. The dense fill and semi-dense fill resulted in a pressure drop 53% and 29% higher, respectively, than that of loose fill at 10% moisture content.

Figure 3 shows a plot of the pressure drop-airflow data for cleaned seeds along with the ASAE data D272.2 (ASAE 1992a). The graph shows that the loose fill data were in close agreement with the ASAE D272.2 data. An average of 19% difference between the predicted pressure drops of the loose fill and those of the ASAE data over the airflow range of 5.6 x 10^{-3} to 0.15 m^3 s^{-1} m^{-2} could be due to differences in bulk density, moisture content, grain variety, or any combination of these factors.

Figure 4 shows the effect of moisture content on the resistance of air flow to the clean bulk alfalfa seeds. Increasing the moisture content of alfalfa seeds from 10% to 26% resulted in 77% decrease in resistance to airflow, or about 4.8% decrease in pressure drop for each percentage point increase in moisture content.

The relation between the pressure drop versus airflow for alfalfa seeds mixed with fines or chaff was linear on log-log scale. The resistance to airflow increased with increased fines and decreased with increasing chaff. Compared to the pressure drop for the dense filled clean seeds at 0.1 m^3 s^{-1} m^{-2} flow rate, an increase in fines content from 5% to 25% resulted in an increase in resistance to airflow from 13% to 57%, about 2.5% increase in pressure drop for a one percentage point increase in fines content. Increased chaff content from 5% to 25% resulted in a decrease in resistance to airflow from 3% to 31%, about 0.9% decrease in pressure drop for a one percentage point increase in chaff content.

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Table I. Estimated constants $a$ and $b$ in Hukill-Ives' Eq. 1 for alfalfa seeds

<table>
<thead>
<tr>
<th>Fine Chaff</th>
<th>F.M.</th>
<th>M</th>
<th>$\rho_b$ kg/m$^3$</th>
<th>Constants</th>
<th>Standard errors</th>
<th>Airflow range $\text{m}^3\cdot\text{s}^{-1}\cdot\text{m}^{-2}$</th>
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<tr>
<td>%</td>
<td>%</td>
<td>% w.b.</td>
<td>5.79 x 10$^4$</td>
<td>$a$ 2.99</td>
<td>$b$ 1.31 x 10$^4$</td>
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L = Loose fill, SD = Semi-dense fill, D = Dense fill.

Fig. 3. Resistance of bulk clean alfalfa seeds to air flow for three fill conditions at M = 10%.

Haque et al. (1978) developed an equation to relate the pressure drop in corn mixed with fines to the pressure drop in clean seeds:

$$\Delta P' = \Delta P \left[ 1 + (g + hQ) F \right]$$

where:

- $\Delta P'$ = pressure drop in clean corn seeds (Pa/m),
- $\Delta P'$ = pressure drop in corn mixed with fines (Pa/m),
- $F$ = fines content on a mass basis (%), and
- $g, h$ = constants.

To develop a similar equation for alfalfa seeds mixed with fines, Eq. 2 was rearranged as:

$$\frac{\Delta P'}{\Delta P} - 1 = A \cdot F$$

where:

- $A = g + hQ$
- $P = 57931 \cdot Q^2 / \ln(1 + 2.993Q)$

Experimental values of $(\Delta P'/\Delta P - 1)$ were plotted against $F$ for six airflow rates ranging from 0.0001 to 0.2 m$^3$·s$^{-1}$·m$^{-2}$ to obtain the slope A. A linear regression between A and Q was used to estimate constants $g$ and $h$ as:

- $g = 0.0686$, s.e. = 0.7 x 10$^{-3}$
- $h = -0.0834$, s.e. = 0.4 x 10$^{-2}$

Fig. 4. Resistance of bulk clean alfalfa seeds to air flow at different moisture contents.
To account for the effect of moisture content on the pressure drop, an equation similar to Eq. 2 was developed

$$
\Delta P' = \Delta P [1 + (k + lQ)M]
$$

(4)

where:

- $M$ = moisture content, wet basis (%), and
- $k, l = \text{constants.}$

A procedure similar to Eq. 3 was used to estimate the constants $k$ and $l$ as:

- $k = 0.0066, \quad \text{s.e.} = 0.46 \times 10^{-3}$
- $l = -0.025, \quad \text{s.e.} = 0.7 \times 10^{-4}$

It is noted that the range of airflow used in development of Eq. 4 and its associate constant was from $7.5 \times 10^{-5}$ to $0.4 \text{m}^3 \text{s}^{-1} \text{m}^{-2}$. Since chaff had the least effect on pressure drop, we suggest to use a conservative value of 1% decrease in pressure drop for each percent increase in the chaff content.

CONCLUSIONS

From the present study the following conclusions can be drawn:

1. Airflow resistance increases with fines concentration and decreases with seed moisture content and chaff concentration.

2. For the clean alfalfa seeds at 10% moisture content, the dense fill, as compared to the loose fill, increases the bulk density by about 5%. This results in an increase in airflow resistance of alfalfa seeds by 53%.

3. The effect of moisture content on the pressure drop of bulk alfalfa seeds is the most significant and chaff content has the lowest effect.

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