Effect of fines on storage and handling properties of alfalfa pellets

O.O. FASINA and S. SOKHANSANJ

Department of Agricultural & Biosresource Engineering, University of Saskatchewan, Saskatoon, SK, S7N 5A9 Canada.
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Fasina, O.O. and Sokhansanj, S. 1996. **Effect of fines on storage and handling properties of alfalfa pellets**. Can. Agric. Eng. **38**:025-029. Bulk properties, airflow resistance, and moisture absorption rates are required for the design of storage and handling equipment. Bulk density, angle of repose, and airflow resistance of alfalfa pellets, as affected by fines concentrations in the bulk of the pellets, were determined experimentally. Fines concentrations were varied from 0 to 25%. The moisture absorption rate of fines of the pellets was also determined and compared to that of clean pellets. Bulk density and angle of repose of the pellets increased significantly with fines concentration. The pressure drop versus airflow data on a log-log plot were nearly linear and parallel for the various fines concentration. Increasing fines concentration from 0 to 25% increased the pressure drop three to eight fold depending on the level of airflow. Clean pellets absorbed 0.5 to 2.0% more moisture than fines over a 24 h period. The equilibrium moisture content values for fines as predicted by an exponential model were slightly greater than that of clean pellets.

Le design d'équipements d'entreposage et de manutention requiert la connaissance des propriétés volumétriques, de la résistance à l'écoulement de l'air et du taux d'absorption de l'humidité. La densité apparente, l'angle de repos et la résistance à l'écoulement de l'air des granules de luzerne, en fonction de la concentration de particules fines dans la masse des granules, ont été déterminés expérimentalement. Les concentrations de fractions fines ont varié de 0 à 25%. Le taux d'absorption de l'humidité de la fraction fine a également été mesuré et comparé à celui des granules propres. La densité apparente et l'angle de repos augmentaient de façon significative en fonction de la concentration de particules fines. Les courbes logarithmiques de la chute de pression en fonction de la résistance à l'écoulement de l'air étaient presque linéaires et parallèles pour les différentes concentrations de particules fines. Une augmentation de particules fines de 0 à 25%, a resulté en une augmentation de la résistance à l'écoulement de l'air de 3 à 8 fois, ceci dépendant are débit d'air utilisé. Dans une période de 24 heures, les granules propres ont absorbé de 0.5 à 2.0% plus d'humidité que les particules fines. Les taux d'humidité à l'équilibre des particules fines, tels que prédits par un modèle exponentiel, étaient légèrement supérieurs à ceux des granules propres.

INTRODUCTION

Alfalfa pellets produced in Western Canada for export are usually transported by rail cars for onward shipment and in bulk by ocean vessels to destination. This results in the handling of the pellets several times before final use. Moving of the pellets at the shipping ports often involves the use of heavy earth moving vehicles such as bulldozers and cranes. Also, it is common to fill storage bins and rail cars by dropping pellets from heights of 10 to 15 m. Fines are generated as a result of these handling techniques. Discussion with pellet exporters indicates that fines level of up to 10% (mass basis) can be found in alfalfa pellets at the time of export. No study has been carried out to quantify the effect of fines on the storage and handling properties of alfalfa pellets.

Properties relevant to storage and handling of alfalfa pellets include moisture absorption rate, bulk density, angle of repose, and resistance to airflow. Values for moisture absorption rate and bulk properties for clean alfalfa pellets were reported by Fasina and Sokhansanj (1992, 1993). Sokhansanj et al. (1993) reported the resistance of alfalfa pellets to airflow as affected by fines concentration. The effect of fines on bulk density and angle of repose of alfalfa pellets and data on moisture absorption rate of fines of alfalfa pellets are presented in this paper.

Before embarking on the study, the authors believed it was necessary to verify the claim of the industry that up to 10% fines can be found in the pellets at the time of export. A preliminary study was carried out to determine the amount of fines that can be generated from alfalfa pellets dropped from a height. The results of the drop tests are included in this paper. In summary, the objectives of this study were to:

a) Quantify the amount of fines that are generated when alfalfa pellets are dropped from heights of 5.5 and 7.6 m onto various impact surfaces.

b) Quantify the effect of fines on bulk density and angle of repose of alfalfa pellets when the fines were included in bulk pellets at levels of 0 to 25%.

c) Compare the moisture absorption characteristics of fines with clean pellets.

MATERIALS AND METHODS

Alfalfa pellet samples used in the study were 6.4 mm diameter pellets obtained from commercial producers in Western Canada. The pellets were at initial moisture content of 7.5% (w.b.). Before a test, the pellets were cleaned manually by sieving through a 4.74 mm screen using 30 strokes.

Drop test

Pellet samples of 600 g size were dropped from a 76 mm diameter and 305 mm high cylindrical container having a removable bottom gate. The cylindrical container was fastened to an elevator. Impact surfaces were 3-mm thick steel plate, 100-mm thick concrete slab, plywood, and pellet on pellet. The surfaces were 0.91 m by 0.91 m square. To simulate filling conditions in an empty or partially filled bin, pellets were dropped on impact surfaces or on pellets, respectively. The effects of frequency of handling and moisture content were also investigated.

The pellets were placed in the cylindrical container. The elevator was used to carry the container and its contents to the desired height (drop height of 5.5 m or 7.6 m). Pellets were then dropped from the height onto the impact surface by removing the gate at the bottom of the cylindrical container. A wooden frame, 0.91 m by 0.91 m and 0.91 m high was placed around the impact surface. The sides of the wooden frame were covered with nylon to prevent pellets from spilling out after being dropped. The box was also used to hold 4 kg of pellets during the pellet on pellet drop test. The effect of frequency of handling on the amount of fines generated was carried out by repeatedly dropping the same sample of pellets and analyzing the sample after the last drop.

After a test, dropped pellets were carefully collected and sieved. The mass of pellets retained above the sieve was subtracted from the original mass of pellets (approximately 600 g) to give the amount of fines generated. Fines concentration was quantified as milligrams of fines per 100 g of pellets. Amount of fines generated by pellets dropped from a height of 7.6 m was also determined when the pellets were at moisture contents of 10.0 and 13.0% (w.b.). Moisture content of samples was adjusted by placing the samples in an environmental chamber set at relative humidity of 90% and temperature of 30°C.

Bulk properties, moisture absorption rate, and airflow resistance

Methodologies for determination of moisture absorption rate and bulk properties were described in Fasina and Sokhansanj (1992, 1993). Bulk density and angle of repose of alfalfa pellets mixed with fines were determined at fines level of 5, 10, 15, 20, and 25% (mass basis). The methodology used in the determination of resistance of the pellets to airflow at various fines levels (5, 10, 16, 20, and 25%) was reported by Sokhansanj et al. (1993).

Moisture absorption tests were carried out on fines only at air temperature and relative humidity combinations of 20°C and 80%, 30°C and 80%, and 10°C and 90%. The results obtained were compared to data for clean alfalfa pellets reported by Fasina and Sokhansanj (1992).

Fines samples were obtained by grinding the pellets. The fines samples had a geometric mean diameter of 0.366 mm and standard deviation of 2.30. Particle size analysis was carried out on the fines according to ASAE Standard S391.1 (ASAE 1994b). Mixture of fines and alfalfa pellets were obtained by mixing clean pellets with fines in a concrete mixer.

RESULTS AND DISCUSSION

Drop test

Analysis of variance using the SAS Statistical Package (SAS 1986) was performed at 5% level to test the effect of test factors - moisture content, drop height, and type of surface on the amount of fines generated due to free fall of alfalfa pellets. All independent variables significantly affect the amount of generated fines.

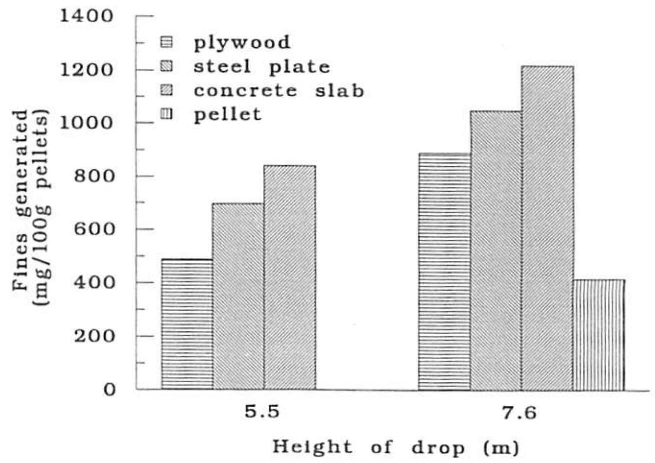

Fig. 1. Fines generated by alfalfa pellets dropped from heights of 5.5 and 7.6 m on to various surfaces.

Figure 1 shows that the quantity of fines generated was the highest when pellets were dropped onto the concrete surface from heights of 5.5 and 7.6 m. The plywood surface generated the least amount of dust. Drop height of 7.6 m consistently generated more fines than 5.5 m drop height. Impact energy on falling pellets increased with drop height. This resulted in more cracking and breaking of the pellets, hence, higher dust generation.

Increasing moisture content of alfalfa pellets resulted in a significant increase in the amount of fines generated (Fig. 2). Absorption of moisture caused swelling and less binding of the particles of the pellets. The particles therefore readily detached from the pellet upon impact on a hard surface.

Tests carried out on the frequency of handling showed that there was no significance change in the amount of fines generated when the pellets were dropped more than once

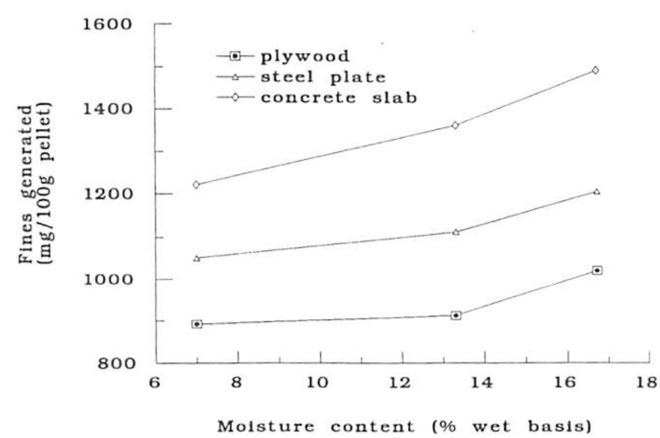

Fig. 2. Effect of moisture content on fines generated by alfalfa pellets dropped from a height of 7.6 m onto various surfaces.

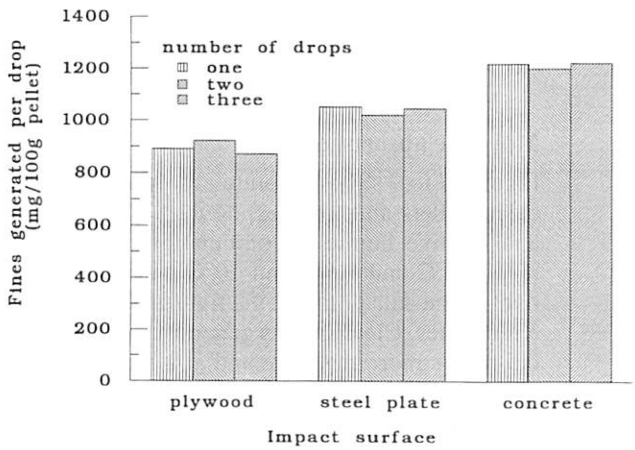

Fig. 3. Effect of number of handlings on fines generated by alfalfa pellets.

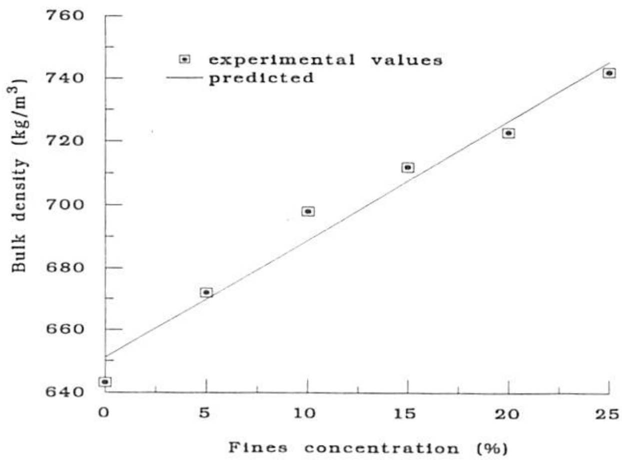

Fig. 5. Bulk density of alfalfa pellets as affected by fines concentration.

(Fig. 3). The cumulative fines generated after handling the pellets three times were in the 4 to 5% range. Similar fines quantity could possibly be in overseas pellet shipments due to loading in storage bins, cars, and holding containers. However, fines level of 4-5% is a low value since (a) pellets are sometimes loaded into containers at heights greater than 10.0 m, (b) pneumatic conveying of the pellets are often used resulting in higher initial and transport velocities, and (c) pellets are handled more than three times before they are consumed.

Bulk density and angle of repose

Figures 4 and 5, respectively, show the influence of fines on the angle of repose and bulk density of alfalfa pellets. Presence of fines in pellets resulted in less air space between individual pellets thereby causing more resistance of the pellets to relative movement. Angles of repose when emptying were consistently higher than when filling at the various dust concentrations. This was because during emptying the samples were originally in a stationary state and therefore offered higher resistance to motion than when dumped (filling angle of repose). Center discharge had the highest values of angle of repose.

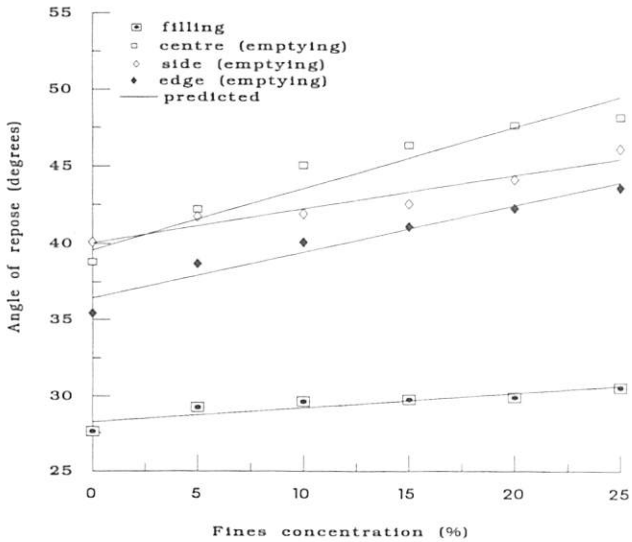

Fig. 4. Angle of repose (emptying and filling) of alfalfa pellets as affected by fines concentration.

Analysis of variance showed that bulk density and angle of repose (emptying and filling) were significantly ($P < 0.05$) affected by the fines concentration. Statistical testing also showed that the values of the different types of angles of repose were significantly different from each other. The Generalized Linear Model (GLM) procedure in the statistical package was used to relate the bulk properties to fines concentrations. The resulting equations are:

$$BU = 651.15 + 3.77 f_m \qquad r^2 = 0.97 \qquad (1)$$

$$FI = 28.24 + 0.096 f_m \qquad r^2 = 0.81 \qquad (2)$$

$$CE = 39.57 + 0.398 f_m \qquad r^2 = 0.89 \qquad (3)$$

$$ED = 36.41 + 0.303 f_m \qquad r^2 = 0.95 \qquad (4)$$

$$SD = 40.05 + 0.218 f_m \qquad r^2 = 0.93 \qquad (5)$$

where

BU = bulk density (kg/m^3),
FI = filling angle of repose (degrees),
CE = center emptying angle of repose (degrees),
ED = edge emptying angle of repose (degrees),
SD = side emptying angle of repose (degrees), and
f_m = fines concentration (% mass basis).

Airflow resistance

Figure 6 shows the test data for airflow resistance of alfalfa pellets mixed with fines. The lines are nearly parallel for the different fines concentrations. Pressure drop increased more rapidly at higher airflows with increasing level of fines in the pellets. Increasing fines concentration from 0 to 25% increased the pressure drop three to more than eight fold depending on the level of airflow.

When the pressure gradient reached 1000 Pa/m, there was

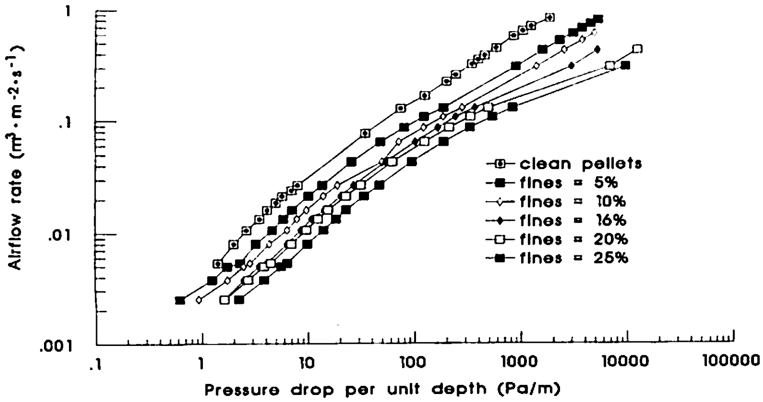

Fig. 6. Effect of fines on airflow resistance of alfalfa pellets.

an increase in airflow rate when the fines concentration was less than 10%, possibly because fines within the bulk were fluidized at these pressures. At higher fines concentrations, this change in airflow was not noticed but there was an increase in pressure drop. Most of the void spaces were therefore filled by fines and no room was available for fluidization. As the fines concentration increased, the pressure drop curve for pellets mixed with fines increasingly deviated from the straight line relationship reported for other products (ASAE 1994a). At low airflow, the resistance of pellets mixed with 25% fines was similar to that of rough rice while at high airflow the resistance was similar to that of flax seed.

To incorporate the effect of fines on pressure drop, Eq. 6 proposed by Haque et. al. (1978) and given in ASAE data D272.2 (ASAE 1994a) was determined.

$$(\Delta P)_{\text{fines}} = (\Delta P)_{\text{clean}} [1 + (0.361 + 1.298\,Q) f_m] \qquad r^2 = 0.87 \qquad (6)$$

where
- ΔP = pressure drop (Pa/m),
- Q = airflow rate ($m^3 \bullet s^{-1} \bullet m^{-2}$), and
- fm = fines concentration (% mass basis).

The ratio of pressure drop for fines mixed with pellets to that for samples of clean pellets increased with fines concentration and airflow rate. A maximum value of about 27 was obtained at airflow rate of 0.299 $m^3 \bullet s^{-1} \bullet m^{-2}$ and fines concentration of 25%. The same observation was obtained by Haque et al. (1978) while studying airflow resistance of corn mixed with fines. However, for canola mixed with fines, Jayas and Sokhansanj (1989) found that the ratio was relatively constant with airflow rate. This is because of the small difference in size of canola and its fines.

Sokhansanj et al. (1993) showed that Shedd's Equation (Shedd 1953) (Eq. 7) predicted best the airflow resistance of fines mixed alfalfa pellets. This equation is traditionally used for numerical solution of pressure patterns and airflow lines (Segerlind 1983).

$$Q = A(\Delta P)^B \qquad (7)$$

Constant A was related to fines concentration while constant B was found not to vary significantly with fines concentration. The average value for constant B was 0.520. The relationship between constant A and fines concentration was found as:

$$A = 0.0121 - 6.02 \times 10^{-4} f_m + 9.12 \times 10^{-6} f_m 2$$
$$r^2 = 0.97, \qquad s.e. = 0.0066 \qquad (8)$$

Moisture absorption

Figures 7 to 9 show moisture absorption curves for clean pellets and fines exposed to air temperature and relative humidity combinations of 20°C and 80%, 30°C and 80%, and 10°C and 90%, respectively. The data points in the figures are averages of 5 replicates. Clean pellets generally absorbed about 0.5 to 2% more moisture and at a higher rate than the fines. This was verified by the results of the exponential model (Eq. 8) fitted to the moisture absorption data for clean pellets and fines.

$$\frac{M - M_i}{M_i - M_e} = \exp(-kt) \qquad (9)$$

where
- M = instantaneous moisture content (% dry basis),
- k = moisture absorption rate constant (h^{-1}),
- t = time (h),
- M_i = initial moisture content, and
- M_e = equilibrium moisture content.

The non-linear regression (NLIN) procedure in the statistical package was used to estimate k and M_e. The estimates are listed in Table I for clean pellets and fines. The standard error of estimate of fit of Eq. 9 to experimental data was less than 0.75%, while the correlation coefficient, r^2, was greater than 0.98. Prediction of moisture change, $M - M_i$, using Eq. 9 are shown in Figs. 7 to 9.

The moisture absorption rate constant, k, of clean pellets was higher than that of fines. Alfalfa pellets seemed to have more pores than fines which therefore provide absorption sites for moisture. However, the equilibrium moisture content of clean pellets as predicted by Eq. 9 was lower than those of fines. As

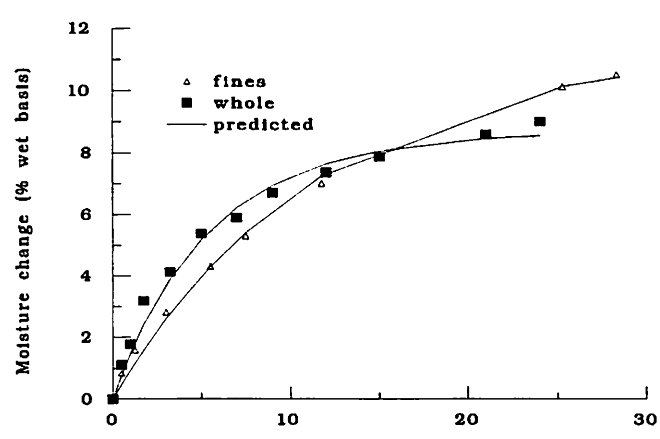

Fig. 7. Moisture change of fines and whole alfalfa pellets exposed to air temperature of 20°C and relative humidity of 80%.

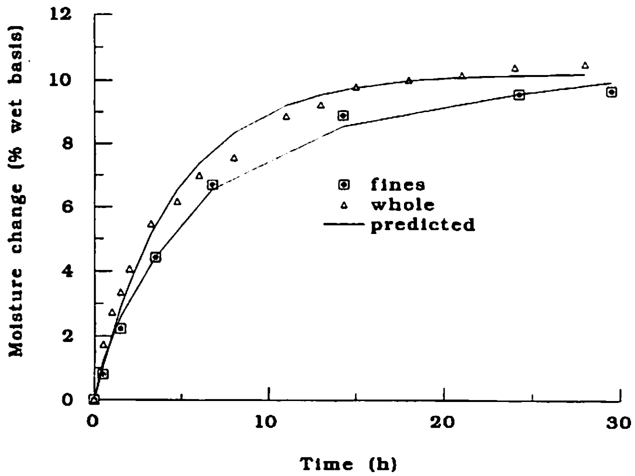

Fig. 8. Moisture change of whole and fines of alfalfa pellets exposed to air temperature of 30°C and relative humidity of 80%.

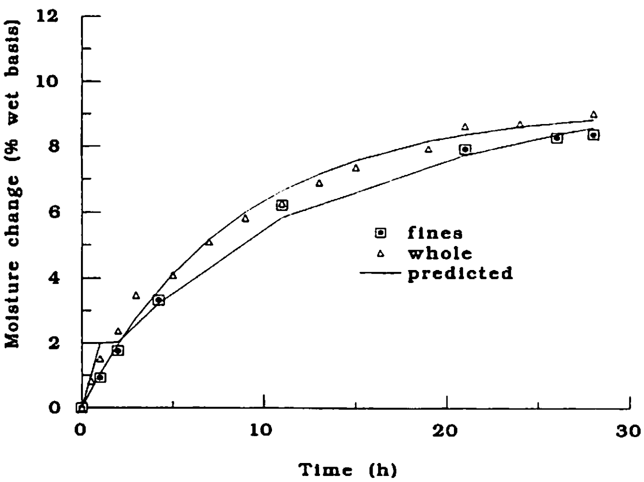

Fig. 9. Moisture change of whole and fines of alfalfa pellets exposed to air temperature of 10°C and relative humidity of 90%.

Table I: Values of k and M_e obtained from non-linear regression analysis of Eq. 8 for clean and fines of alfalfa pellets.

		k (h^{-1})		M_e (% wet basis)	
rh (%)	T (°C)	clean	fines	clean	fines
80	20	0.17	0.12	15.0	16.3
80	30	0.20	0.18	16.3	17.2
90	10	0.11	0.09	15.5	19.0

absorption progresses, the more dense nature of the pellets forced it to offer higher resistance to moisture absorption. The surface of the pellets will be at near-equilibrium conditions thereby making the absorption curve approach an asymptotic condition faster than the fines of the pellets.

Observation during the moisture absorption experiment showed that the fines exhibited a tendency to agglomerate resulting in cake formation. This is important for managing the storage and holding of pellets mixed with fines in bins and transportation cars. Usually the fines accumulate at the discharge ports of the silos and containers and may therefore clog the discharge ports if moisture uptake occurs.

CONCLUSIONS

The following conclusions can be drawn from this study:

a) Presence of fines in alfalfa pellets increased the bulk density and angles of repose of alfalfa pellets.

b) Moisture absorption and its rates are higher for clean pellets than fines. Fines tend to agglomerate as a result of moisture.

c) The pressure drop versus airflow curves for fines mixed pellets were nearly linear on a log-log scale and parallel for the various fines concentration.

REFERENCES

ASAE. 1994a. Data D272.2 - Resistance to airflow of grains, seeds, other agricultural products, and perforated metal sheets. In *ASAE Standards 1994*, 452-456. St. Joseph, MI: ASAE.

ASAE. 1994b. Standard S319.2 - Method of determining and expressing fineness of feed materials by sieving. In *ASAE Standards 1994*, 467-468. St. Joseph, MI: ASAE.

Fasina, O.O. and S. Sokhansanj. 1992. Hygroscopic moisture absorption by alfalfa cubes and pellets. *Transactions of the ASAE* 35(5):1615-1619.

Fasina, O.O. and S. Sokhansanj. 1993. Effect of moisture content on bulk properties of alfalfa pellets. *Canadian Agricultural Engineering* 35:269-273.

Haque, E., G.H. Foster, D.S. Chung and F.S. Lai. 1978. Static pressure drop across a bed of corn mixed with fines. *Transactions of the ASAE* 21(5):997-1000.

Jayas, D.S. and S. Sokhansanj. 1989. Design data of resistance of airflow through canola/rapeseed. Technical Notes. *Transactions of the ASAE* 32(1):295-296.

SAS 1986. SAS User's Guide: Statistical Analysis Systems, Inc., Cary, NC.

Segerlind, L.J. 1983. Presenting velocity-pressure gradient data for use in mathematical models. *Transactions of the ASAE* 26(1):1245-1248.

Shedd, C.K. 1953. Resistance of grains and seed to airflow. *Agricultural Engineering* 34(9):617-619.

Sokhansanj, S., W. Li and O.O. Fasina. 1993. Resistance of alfalfa cubes, pellets and compressed herbage to airflow. *Canadian Agricultural Engineering* 35(3):207-213.