

The effect of a conical bin insert on flow patterns of ground feed in a model bin

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Zhang, Q., Bergen, J.I., and Britton, M.G. 1997. **The effect of a conical bin insert on low patterns of ground feed in a model bin.** *Can. Agric. Eng.* 39:215-219. Tests were conducted to study the flow behavior of ground feed in a corrugated steel bin with a bin insert (flow enhancing device). The bin was 1.5 m high by 1.0 m in diameter, with a 45° hopper and it was instrumented with diaphragm pressure transducers for measuring lateral pressures on the bin wall. The insert was tested at three locations: 260, 290, and 510 mm from the outlet. Ratholing occurred and flow stopped completely when the bin insert was not present in the bin. The material flow was continuous when the insert was installed at the bin-to-hopper transition. Installation of the bin insert did not cause any significant changes in either static or dynamic pressures on the bin wall. Keywords: flow, powder material, feed, bin insert.

Des tests ont été menés pour étudier l'écoulement de la moulée dans un silo en acier ondulé où un mécanisme pour améliorer l'écoulement avait été installé. Le silo avait 1.5 m de hauteur et 1.0 m de diamètre, était muni d'une trémie à 45° et équipé de capteurs de pression à diaphragme pour mesurer les pressions latérales sur les parois. Le mécanisme inséré fut testé en trois positions: 260, 290, et 510 mm de la sortie. Lorsque le mécanisme n'était pas installé dans le silo, l'écoulement s'arrêtait complètement. Cependant, lorsque le mécanisme était inséré entre la trémie et le silo, l'écoulement était continu. L'insertion du mécanisme dans le silo n'a pas changé de façon significative les pressions statiques ou dynamiques sur les parois. Mots-clefs: écoulement, matière pulvérisée, moulée, mécanisme inséré.

INTRODUCTION

Animal feed is usually stored in bulk in hopper bottomed bins both on farm and in feed mills. An economic way of moving feed out of bins is through gravity discharge. However, some feeds have very low flowability and bridging and ratholing often occur during gravity unloading, causing unpredictable material flow rate or complete stoppage of flow. Bridging results from stable arches formed above the discharge outlet and ratholing occurs when a vertical cavity empties out over the outlet while the rest of the material in the bin remains stagnant. Jenike pioneered the study of bulk solids flow in storage bins (Johanson 1982). He defined two distinct modes of material flow during gravity discharge, i.e., funnel-flow and mass-flow (Jenike and Johanson 1971). In the funnel-flow mode, the material moves through a central channel with no material flowing along the walls, whereas the entire bulk of the material is in motion in the mass-flow mode. Controlling the flow mode is often the key in solving many flow problems (Johanson 1982). The flow mode depends on both the flowability of the bulk solid material and the bin construction (e.g., shape of the bin hopper and surface

smoothness).

The flowability of material is related to several material properties, including particle size and shape, moisture content, internal friction, cohesion, and degree of compaction. These material properties are generally dictated by the feed formulation and it is impossible in most cases to change these properties to improve the flowability of the feed. In practice, the desirable flow mode is usually achieved through proper bin design. The selection of hopper shape is a key factor in how the material flows. Shallow hoppers, between 45° and horizontal, tend to produce a funnel type of flow, whereas steep hoppers are associated with mass flow (Schwedes 1983). In situations where shallow hoppers have to be used (e.g., for low headroom), flow enhancing devices, such as air blasters, vibrators, chain slingers, and bin inserts may be used to improve flow (Grossman et al. 1990; Johanson 1987). Most existing flow enhancing devices, however, do not provide a satisfactory solution if not installed properly.

The objectives of this research were: (1) to investigate the effectiveness of a bin insert in improving feed flow in a model corrugated steel bin, (2) to examine the effect of insert location on the flow behavior, and (3) to determine changes in lateral pressure on the bin wall due to presence of the insert.

EXPERIMENTAL METHODOLOGY

The experiment was conducted using a corrugated galvanized steel bin 1.0 m in diameter and 1.5 m in height (Fig. 1). The wall corrugations were 13 mm in depth and 64 mm in pitch. A 45° hopper with a 150 mm diameter discharge orifice was attached to the bottom of the bin. This relatively flat hopper was chosen so that material flow would be of funnel type if no flow enhancing devices were present. The bin was suspended from three load cells placed 120° apart. These load cells measured the in-bin material mass continuously during the test.

A rocket-shaped bin insert (Wintech Inc., Winnipeg, MB) was installed in the bin (Fig. 2). The body of the insert was a hollow cone 400 mm high, with a 30° opening angle (θ). Six stabilizers (wings) were placed along the circumference of the cone at the base for dividing flow channels and maintaining the vertical position of the insert during flow. The insert was mold cast from plastic, resulting in smooth surfaces. A pivoting steel rod was used to mount the insert in the bin so that it was free to swing laterally. Three mounting locations were selected in the experiment. The lowest location, level 0,

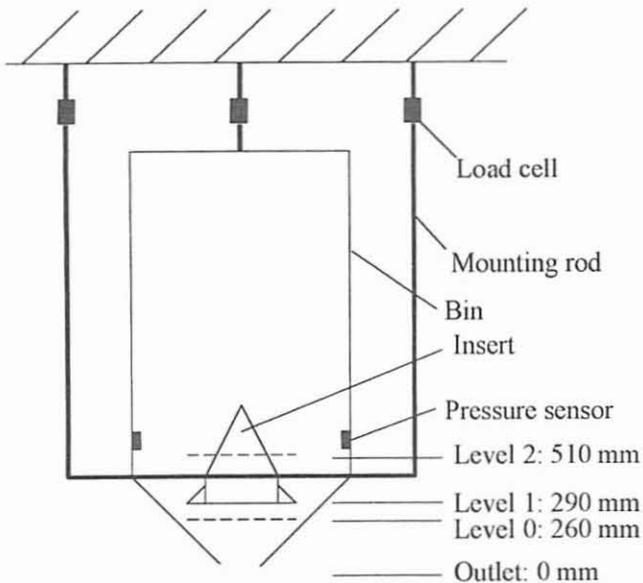


Fig. 1. Sketch of model bin test system.

was with the underside of the cone 260 mm above the discharge orifice. This level was the closest the insert could be located to the orifice without blocking the material flow. Levels 1 and 2 were located 290 and 510 mm above the orifice, respectively. At level 1, the underside of the insert was 210 mm below the bin-to-hopper transition, whereas the insert was entirely above the transition at level 2. For comparisons, tests were also conducted without the bin insert.

Ground feed was used as the test material. Composition and some physical properties of the feed are listed in Tables I and II, respectively. The moisture content of the feed was determined by drying the feed in a gravity-convection oven at 130°C for 20 h. The bulk density was determined by accurately weighing a 0.5 L cup. A tilting table device was used to measure friction between feed and corrugated steel (Mohsenin 1986). Direct shear tests were conducted to determine the angle of internal friction and cohesion (ASTM 1992). Four levels of normal pressure (20.36, 26.45, 32.53,

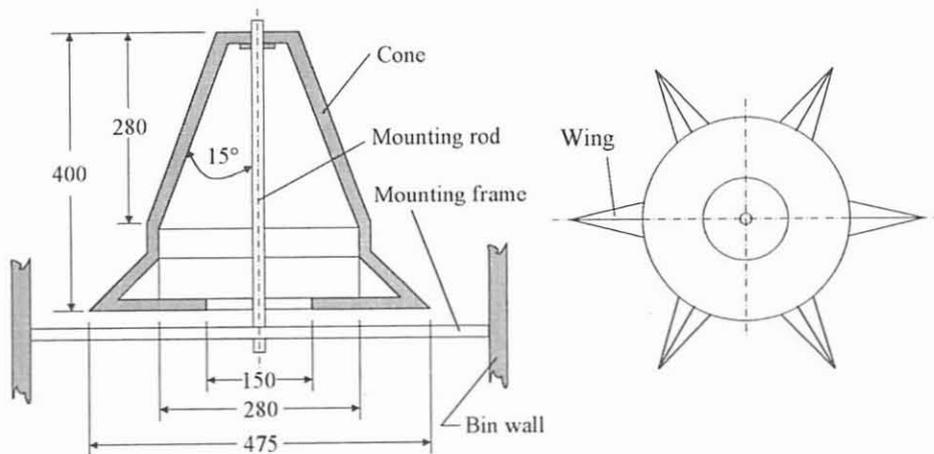


Fig. 2. Sketch of bin insert.

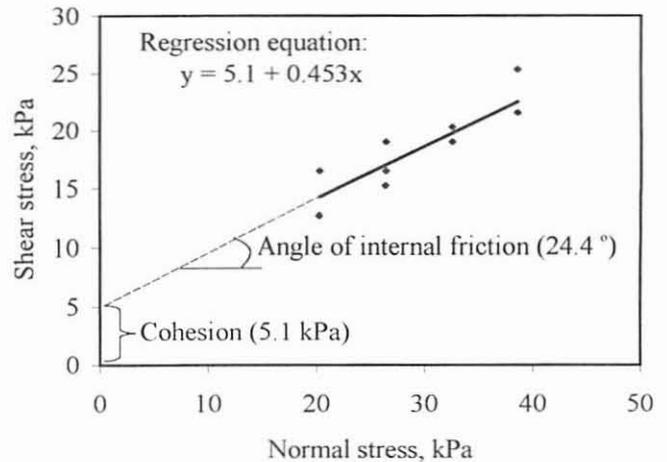


Fig. 3. Shear stresses measured from direct shear tests for ground feed.

and 38.61 kPa) were used in direct shear tests. The angles of internal friction and cohesion were determined from the plot of shear stress versus normal stress (Fig. 3).

The material flow pattern affects dynamic loads on bin structures. Three diaphragm pressure transducers were mounted on the inside surface of the bin wall to measure lateral pressures exerted by the feed. These sensors were 120° apart and 150 mm above the hopper-to-bin transition (Fig. 1). The diaphragm pressure transducers were made with aluminum diaphragms 0.89 mm thick and 60 mm in diameter. Four strain gages were mounted on the inside surface of the diaphragm. The pressure transducers were calibrated using a water column from 0 to 7.1 kPa with $R^2 > 0.98$. An HP 8532A data acquisition system was used to log data from the pressure transducers, as well as data from three load cells which measured the in-bin mass of feed.

Tests were replicated three times for each of the four test configurations (three insert locations and no insert). In each test, the bin was filled with ground feed using an auger which had a spout located 350 mm above the bin and discharged into the center of the bin. The feed was allowed to settle until pressure readings stabilized (about one hour) before being discharged. During filling, settling and discharging, pressures were recorded every 10 s. To record the initial peak dynamic pressure when discharge was initiated, pressures were recorded every 0.3 s for one minute. Photographs were taken from the top of the bin during discharge to record flow patterns. Sketches were then drawn from these photographs to illustrate the development of flow channels in the bin.

Table I: Composition of feed used in experiment

Crushed barley	59.1%
Soya meal	12%
Canola meal	10%
Fish meal	2%
Tallow	6.4%
Calcium carbonate	8.25%
Calcium phosphate	0.75%
Vitamin premix	1%
Mineral premix	0.5%

Table II: Some physical properties of feed used in experiment

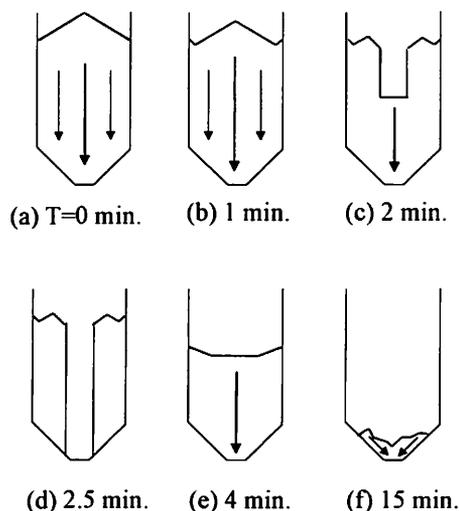
Moisture content	10.8 % wb*
Bulk density	570.4 kg/m ³
Feed-corrugated steel friction angle	31.8°
Angle of internal friction	24.4°
Cohesion	5.1 kPa

*wet basis

RESULTS AND DISCUSSION

Observed flow patterns without bin insert

Stable ratholes formed consistently during discharge when the insert was not installed. These ratholes had to be manually broken for discharge to continue. Collapsing of ratholes exerted impact forces on the material in the lower portion of the bin. These impact forces were sufficiently high to cause stable bridges to form above the discharge orifice. Stages of flow are illustrated in Fig. 4, with Fig. 4a depicting the full bin before discharge began (T=0 min.). In the first minute of discharge, almost the entire upper surface moved downward, except a relatively stagnant layer of feed along the bin wall, approximately 25 mm high and 25 mm thick (Fig. 4b). The existence of a stagnant layer near the wall was attributed to

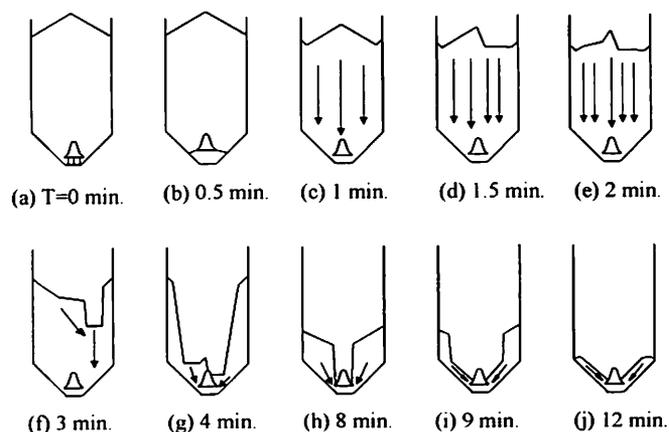
**Fig. 4. Flow patterns sketched from photographs for the case without bin insert.**

high friction between the bin wall and feed. After the initial downward flow, a cylinder twice the diameter of the discharge orifice started to flow, while feed beside the flowing cylinder remained stationary (Fig. 4c). When the cylinder of feed was completely discharged, a stable rathole formed (Fig. 4d). This rathole was manually broken to allow discharge to continue (Fig. 4e). This cycle of formation of ratholes and manual intervention repeated until the feed level reached the bin-to-hopper transition. At this point, the feed slid along the hopper wall to the discharge outlet (Fig. 4f).

Observed flow patterns with bin insert

Insert at level 0 Because the insert was very close to the discharge orifice at level 0, a bridge formed right underneath the cone (Fig. 5b) after a small amount of material, initially between the insert and the orifice, had flowed out of the bin (Fig. 5a). Manual intervention was needed to break this bridge. After the bridge was broken, there was a downward movement of the top surface (Fig. 5c). Similar to the case without the insert, a thin layer of feed near the wall did not move because of high friction between the wall and feed. As the downward flow continued, a channel of feed that moved faster than the surrounding feed formed (Fig. 5d). The channel did not occur in the center of the bin. After about two minutes of discharge, another higher speed flowing channel formed (Figs. 5e and 5f). The two flow channels then merged into one large channel (Fig. 5g). As this large channel expanded, the feed that was against the bin wall fell to fill the channel and a new small flow channel formed around the insert (Fig. 5h). This newly formed flow channel grew and collapsed (Fig. 5i). When the feed level was below the bin-to-hopper transition, feed slid along the hopper wall (Fig. 5j). The last bit of feed below the insert had trouble flowing out of the bin. It was observed that the feed against the bin wall never flowed along the wall, but collapsed as flow channels became sufficiently large.

Insert at level 1 The entire emptying process continued without any human intervention when the bin insert was installed at this level. The initial phase of flow occurred in a

**Fig. 5. Flow patterns sketched from photographs for bin insert at level 0.**

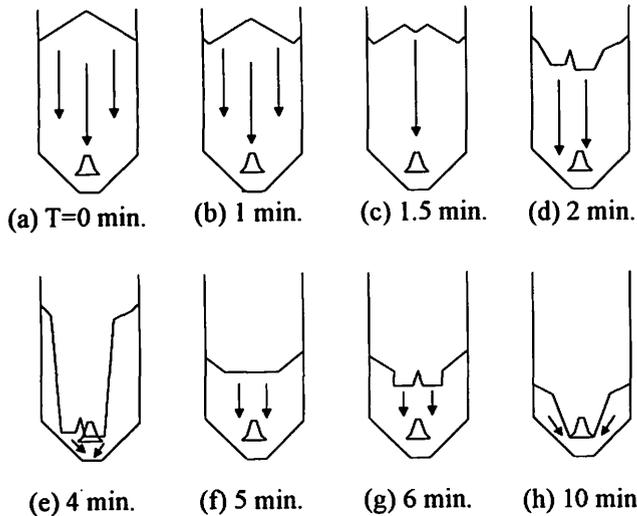


Fig. 6. Flow patterns sketched from photographs for bin insert at level 1.

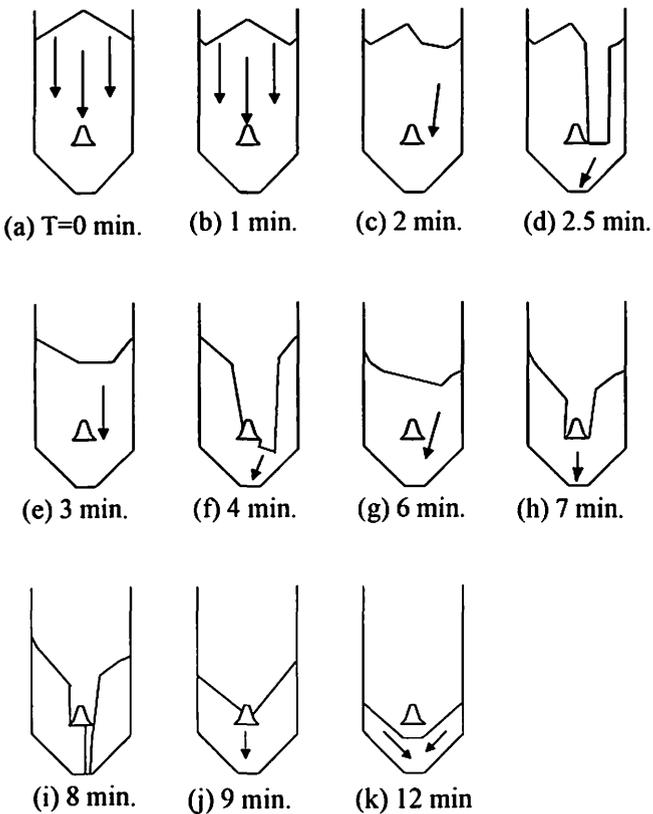


Fig. 7. Flow patterns sketched from photographs for bin insert at level 2.

fashion similar to the level 0 mounting configuration, i.e., there was a downward movement of the top surface and a thin stagnant layer near the wall (Fig. 6b). Flow then changed to a single channel flow (Fig. 6c), which then split into two channels (Fig. 6d). These two channels collapsed on their own when the insert was exposed (Figs. 6e and 6f). As flow continued, two new flow channels formed (Fig. 6g). When the insert was completely exposed, the feed slid along the

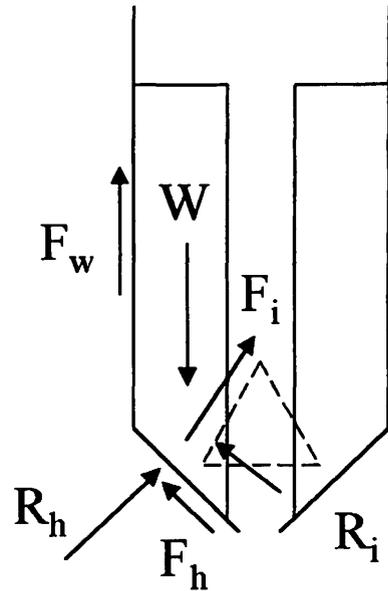


Fig. 8. Illustration of force balance on a block of stagnant material.

hopper bottom (Fig. 6h). During the entire discharge process, the feed against the wall did not slide down along the wall, but collapsed into flow channels.

Insert at level 2 The initial flow was similar to that which occurred in the previous two insert locations (Figs. 7a and 7b). A flow channel started to form after about one minute of discharge (Figs. 7c and 7d). This initial channel collapsed (Fig. 7e) and another flow channel formed on the same side of the insert (Fig. 7f). The cycle of formation and collapsing of flow channels repeated (Figs. 6g and 6h). When there was not enough feed in the bin to completely cover the insert after channel collapsing, a stable rathole formed under the insert (Fig. 7i). Manual intervention was necessary to break this rathole. The flow continued below the cone after the rathole was broken (Figs. 7j and 7k).

Discussion When the bin insert was present in the bin, feed flowed around the cone instead of directly down to the discharge orifice. The six wings on the insert divided the flow into multiple channels which were smaller than the single channel which would form if the insert was not present. These small channels were not stable and therefore collapsed on their own in most cases. Collapsing of these flow channels was attributed to the smoothness of the insert surfaces and swing of the insert. For arches or stable ratholes to form in the bin without the insert, the frictional force from the bin (F_w) and from the hopper wall (F_h) and reaction force from the hopper (R_h) must be sufficient to support the stagnant material (W) (Fig. 8). This suggests that ratholing may be avoided by reducing the friction of the bin and hopper wall surfaces, or by increasing the hopper angle.

When the insert is present in the bin, the stagnant material is supported by the bin and hopper walls, as well as the insert (F_i and R_i) (Fig. 8). The portion of support provided by the insert depends on the location of the insert and the design of the insert and hopper. If the insert is installed too high, it has little effect on the stress field near the hopper wall, and thus

the support provided by the hopper would be approximately the same as that without the insert. In other words, the insert would not be effective. If the insert is too low, the passage between the insert and the hopper wall becomes too narrow and bridging may occur. When the insert is installed at a proper height, the material is forced to flow along the hopper wall, causing changes in the stress field near the hopper wall. Consequently, the supporting force may shift significantly from the hopper wall to the insert and the formation of arches and ratholes becomes dependent on the supporting force from the insert. The insert used in this study had smooth (low friction) surfaces, a steep cone angle (θ), and freedom to move laterally. Therefore it could not provide sufficient forces to support the stagnant material and thus stable ratholes could not form when the insert was installed in the bin.

It was observed that most flow channels formed off the bin center. One possible reason was the tilting of the cone during filling because it was difficult to fill the bin perfectly in the center. Off-center flow channels also indicate that there was an unbalanced force acting on the insert which might cause the insert to swing laterally to break ratholes.

Installation of the bin insert increased the discharge rate considerably. The average rate was 43, 55, 61, and 57 kg/min. for no insert, level 0, level 1, and level 2 locations, respectively. The maximum increase in discharge rate was 42% when the insert was installed at level 1.

Bin wall pressures

Measured lateral pressures were compared to determine if the flow enhancing device caused any significant changes in bin loads. Table III shows the mean static lateral pressures that occurred in the bin at the end of filling and after one hour of settling for each test configuration. The analysis of variance on the data indicates that the introduction of the bin insert did not cause significant (at a significance level of $\alpha = 0.05$) changes in the static pressure.

When feed was discharged from the bin, dynamic pressures were induced on the bin wall. Dynamic to static pressure ratios were calculated for comparing dynamic loads between test configurations (Table III). The insert did not cause any significant (at $\alpha = 0.05$) changes in the dynamic

Table III: Measured static pressures on the wall of a model bin filled with chop feed

Test configuration	Static pressure (kPa)*		Dynamic to static pressure ratio *
	End of filling	After settling	
No insert	2.08	1.86	1.44
Insert at level 0	2.13	1.93	1.28
Insert at level 1	2.32	2.07	1.39
Insert at level 2	2.16	1.91	1.32
Test statistic, F	0.32	0.24	0.19
Critical F at $\alpha = 0.05$	2.90	2.90	2.90

* means of 9 measurements

pressure ratio. It is also interesting to notice that ratios obtained in this study compared very closely to a ratio of 1.4 recommended by the ASAE Standards (ASAE 1996) for grain storage bins. According to the National Farm Building Code of Canada (NRC 1995), the overpressure factor is 1.0 if the model bin is filled with grains.

CONCLUSIONS

The introduction of the bin insert noticeably improved the flow of ground feed in a corrugated steel bin with a shallow hopper. There was a critical region (height) where the insert should be installed for the maximum effectiveness.

The bin insert did not cause any significant changes in either static pressure or dynamic pressures in a corrugated steel bin filled with ground feed.

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