Grain Flow Regulator for Dust Emission Control

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ABSTRACT

A grain flow regulator was designed and constructed at the U.S. Grain Marketing Research Laboratory for dust emission control. It consisted of a hopper with a grain level sensor, proportioning controller, and a swinging gate powered by a positioning motor. The regulator automatically adjusted the grain flow rate to maintain a constant level of grain in the hopper. When the flow regulator was used, dust concentration in air in the bin during loading was about 20% of that when a conventional spout was used. Use of the flow regulator resulted in more even distribution of fine material than when a conventional spout was used. Grain damage caused by the flow regulator was not significantly different from that observed when no flow regulator was used.

INTRODUCTION

Control of grain dust emission during bulk loading of bins, trucks, railroad cars, and ships is needed to improve air quality and reduce dust explosion hazards. Dust control during loading can be achieved by collecting emitted dust with air cleaning systems or by preventing dust from being emitted and retaining it within the grain stream. Retaining dust in the grain stream is advantageous to grain handlers because it reduces weight shrinkage and costs of equipment and operations of air cleaning systems. Retaining dust within grain during loading can be accomplished by spraying additives, such as water or oil, onto the grain stream (Cocke et al., 1978; Lai et al. 1979) or by using a mechanical flow control device that restricts grain flow so that grain is choke-fed through the device to form a mass flow grain stream (Martin et al. 1980a).

Previous experiments on loading of corn into a bin indicated that a grain stream emitted less dust when it was choke-fed through an orifice than when it was fed from a conventional gravity spout (Chang et al. 1981; Chang et al., 1983). Martin et al. (1980a) used a grain nozzle to control dust emission when loading grain into a bin. The opening of the nozzle was controlled by spring loaded arms. Dust emission was significantly reduced when choke-flow of grain was obtained; however, the nozzle was unable to obtain choke-flow when the velocity of grain entering the device was high.

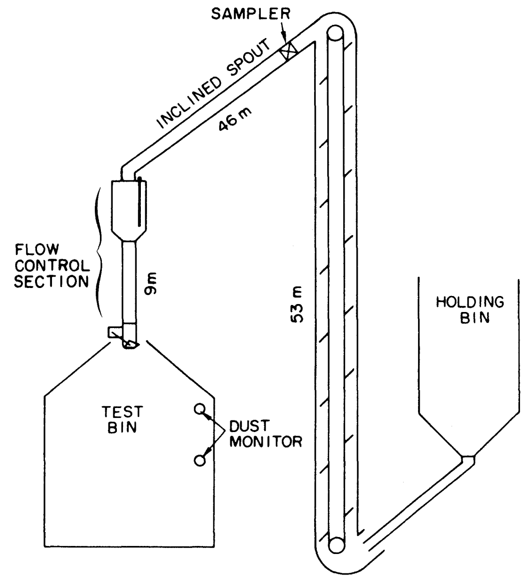

Fig. 1—Schematic of grain handling system for flow regulator tests.

The objectives of this study were (a) to develop a grain flow regulator and evaluate its effectiveness in controlling dust emission during loading, and (b) to evaluate bulk properties of grain as affected by the flow regulator.

MATERIAL AND EQUIPMENT

Grain and Grain Bin

Two test lots of corn at moisture content of 13.3%w.b. were used in the tests. Each of the two lots was considered a replication. An automatic spout sampler (Diverter Spout Sampler, CHCI No. 132, Carter-Day Co., Minneapolis, MN), located 3 m below the elevator discharge point (Fig. 1), was used to sample the grain stream. The test bin (Fig. 1) was 6.4 m in diameter with 5.5 m sidewall and a 7.4 m peak height. A mechanical unloading system with a bin sweep auger was used to remove grain from the bin after each test.

Flow Control Device

The grain flow regulator (Fig. 2) consisted of a hopper with a grain level sensor (Universal Level Transmitter Model Y509-25-0 with sensing element model 7090-202-2, Drexelbrook Engineering Co., Horsham, PA), proportioning controller (Electramax V., Leeds and Northrup, North Wales, PA), and a swinging gate (Fig. 3) which was powered by a positioning motor (Model 10267, Leeds and Northrup). The maximum opening of the swinging gate was 18 cm x 25 cm elliptic which provided a flow rate of about 80 t/h. A larger opening

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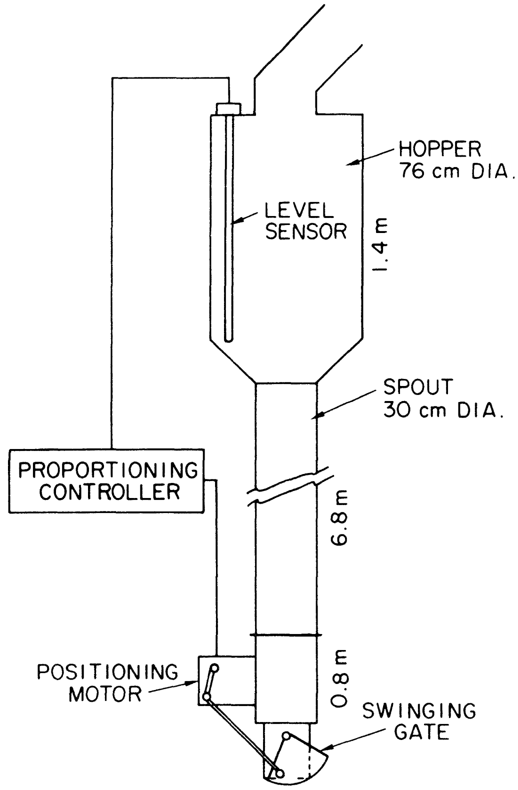

Fig. 2—Schematic of grain flow regulator.

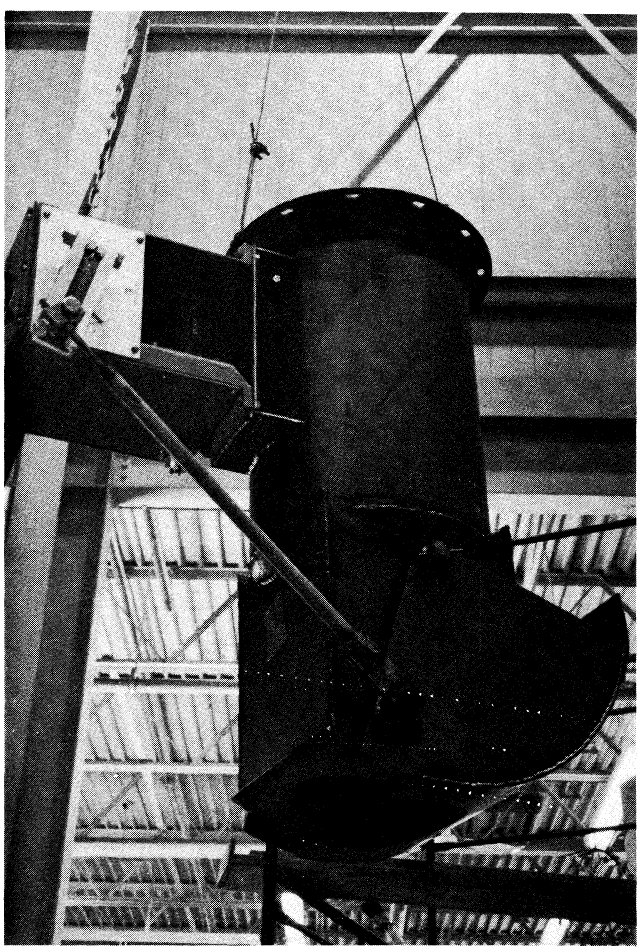

Fig. 3—Swinging gate powered by a positioning motor.

can be designed to handle a higher flow rate of grain. The proportioning controller was a microprocessor-based instrument providing operational settings, such as proportional band, reset (integral) control action, rate control action, and set point, and providing monitoring of process variables and deviations. A U-shaped steel shield was installed around the level sensor in the hopper to keep grain from striking the sensor. The shield was set 5 cm away from the sensor and covered a sector of about 120 deg. A 3 cm wide vertical clear plastic window was installed on the sidewall of the hopper so grain level in the hopper could be observed. The flow regulator provided an automatic adjustment of outgoing flow rate to maintain a constant level of grain in the hopper. The desired level of grain in the hopper was set from the controller. When the sensor detected a prescribed deviation from the set point, the controller energized the positioning motor to adjust the opening of the swinging gate. Adjustment continued until the grain level in the hopper returned to the set point and the flow became balanced. Due to flow restriction created by the gate, a choke-flow of grain through the gate was established. Grain flow from the gate into the bin was mass flow which is similar in appearance to liquid laminar flow.

For comparison, a 17.8-cm diameter orifice was installed at the end of a 30-cm diameter vertical spout as a second choke-flow device. Test control was provided by a 25-cm diameter vertical spout with no flow control device.

Optical Opacity Monitors

Two optical opacity monitors (Eckhoff and Fuhre, 1975; Lee et al., 1980), installed 20 cm from the bin wall at 3.5 and 5 m from the floor, were used to measure the dustiness of air in the bin during the filling operation. Each monitor consisted of a light emitting diode (LED) and a phototransistor (PT) mounted 1 m apart on a steel frame. The LED emitted a constant intensity of infrared radiation to the PT. Intensity of radiation received by the PT was proportional to dustiness of the air in the light path. Each optical opacity monitor was calibrated prior to the tests. Signals from each monitor were recorded every minute during each test.

PROCEDURE

Each test lot of corn (1200 bu) weighed 30.5 t which filled the test bin to an average depth of 1.2 m. The same two lots of corn were used to test each device and each lot was run through the device once. The flow regulator was tested first, the spout second, and orifice last. Corn lots were not screened after each test. Grain was transferred from the holding bin to the test bin through a bucket elevator, spouting system, and a flow control section that ended at the peak of the bin roof (Fig. 1). The flow control section consisted of either the flow regulator or the orifice with an iris valve above it.

In tests with the flow regulator, the swinging gate was closed initially. When incoming grain filled up the vertical section of the spout and the grain level approached the set point in the hopper, the swinging gate started to open to permit grain to flow to the test bin. The proportioning controller adjusted flow rate automatically and maintained the grain level in the hopper near the set point. Average grain flow rate was about 53 t/h.

TABLE 1. DUST CONCENTRATION, FINE MATERIAL CONTENT, AND BULK DENSITY OF CORN PLACED IN THE BIN BY VARIOUS FLOW CONTROL DEVICES.*

Flow control device	Dust concentration, g/m^3	Fine material content: Range, %	Mean, %	Coefficient of variability %	Increase in fine material content, % point	Bulk density, kg/m^3	Test weight, kg/m^3
Flow Regulator	0.43[a]	1.5-14.1	5.74	56	0.22[a]	789[cd]	780
Orifice	0.57[a]	1.4-16.7	6.40	60	0.34[a]	779[c]	778
Spout	2.57[b]	3.3-21.7	5.75	81	0.26[a]	805[d]	780

*All values shown are an average of two tests.
a,bDifferent superscripts in same column indicate significant differences at 5% level (LSD test).
c,dDifferent superscripts in same column indicate significant differences at 10% level (LSD test).

In tests with an orifice, the iris valve was closed before each test. When incoming grain filled up the vertical section of the spout, the iris valve was opened to permit grain to flow through the orifice into the bin. The orifice was 17.8 cm in diameter which provided a constant flow rate of about 50 t/h.

In tests with a spout only, flow rate of grain was adjusted to about 53 t/h by regulating a sliding gate at the bottom of the holding bin. Without any flow control device, the velocity of grain leaving the spout was relatively high.

The automatic spout sampler was set to sample the grain stream every 2 min. Consecutive groups of four samples were combined for analysis of test weight, moisture content, and fine material content. Test weight and moisture content were determined by a grain analysis computer (Model GAC II, Dickey-john Corporation, Auburn, IL). Fine material content was determined with a 4.76 mm round-hole sieve placed on a Gamet shaker (Dean Gamet Manufacturing Co., Minneapolis, MN) that was operated for 30 strokes (USDA, 1980). Particles which passed through the sieve were considered fine material.

After grain was placed in the bin, a standard compartmentalized grain probe was used to obtain grain samples along the diameter of the bin at 30-cm intervals, starting at a point 15 cm from the bin wall. The grain probe was 3 m long, with compartments at 14-cm intervals. Samples from each two adjacent compartments in the probe were combined and screened with a sieve to determine fine material content. The percentage of fine material content in each sample was used to establish the distribution of fine material in the bin.

Whenever grain was sampled, the depth of grain was measured to determined shape of the grain pile and volume of grain in the bin. The average bulk density of grain in the bin was calculated from those data and the weight of the grain lot.

RESULTS AND DISCUSSION

Dust concentration

Data obtained from optical opacity monitors were analyzed, employing methods developed by Martin et al. (1980b), to determine the average dust concentration of air in the bin during loading. Results are given in Table 1. When the flow regulator or orifice was used, dust concentration of air in the bin was about 20% of that when a conventional spout was used. Differences in dust concentration of air were small between use of the flow regulator and the orifice.

When a flow control device was used, dust concentration of air in the bin during loading was significantly reduced. This was due to the fact that when grain was choke-fed through a flow control device the velocity of grain leaving the device was relatively low and the grain stream appeared as a solid grain column with little separation of dust, fine materials, and grain kernels during the fall. In the conventional spout flow, velocities of grain and air leaving the spout were relatively high. The flow pattern of grain was similar to that of water from a full cone spray nozzle. Dust separated from grain kernels during the fall. Furthermore, high velocity air from the spout blew this dust further away from the grain stream and suspended it in the air.

Distribution of Fine Material

Distribution of fine material in corn transferred to the bin with and without a flow control device are given in Table 1 and Fig. 4. Values in Fig. 4 were obtained by dividing the local fine material contents by the mean fine material content and are expressed in dimensionless form. Volumes of grain in the bin represented by each sample were considered when means for fine material were calculated. As reflected by coefficient of variability the distribution of fine material for corn transferred by the flow regulator or the orifice was more uniform than that of corn transferred by the spout. Flow regulator and

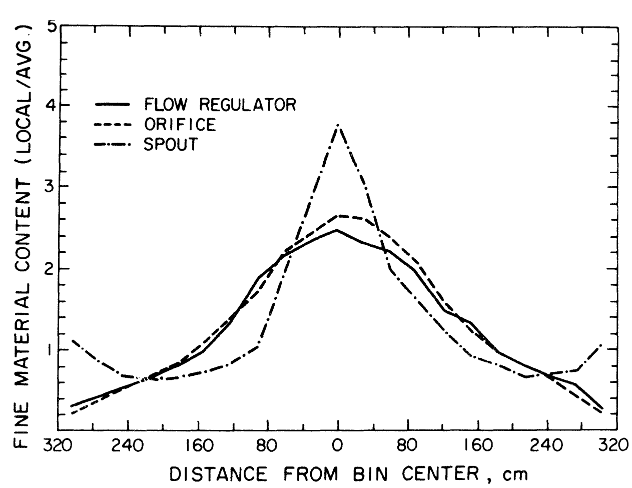

Fig. 4—Radial distribution of fine material in corn transferred to the bin by different flow control devices.

orifice provided about the same level of uniformity of fine material in the grain mass. Segregation of fine material in grain causes an uneven distribution of airflow within the grain mass and results in nonuniform drying and hot spots. Segregation of fine material in a grain mass also increases the chances of insect invasion and fungal development during storage (Christensen and Kaufmann, 1969).

When no flow control device was used, fine material concentrated around the bin center within a radius of 80 cm. Fine material contents in this region ranged from 1.5 to 3.8 times the mean fine material content of 5.75%. When the flow regulator or orifice was used, concentration of fine material around the bin center was reduced; however, fine material contents of grain in the region around the bin center within a radius of 120 cm were still 1.5 to 2.6 times higher than the mean fine material content. Fine material distribution pattern for corn transferred by the orifice was similar to that of corn transferred by the flow regulator.

With the flow control devices, the concentration of fine material around the bin center was reduced and the distribution of fine material was improved. A possible explanation for this improvement in fine material distribution is as follows:

When grain is choke-fed through a flow control device, the velocity of grain leaving the device is relatively low and most fine materials are retained in the grain stream during the fall. After the grain reaches the center of the grain pile, both grain kernels and fine material flow toward the bin wall together. In the conventional spout flow, the velocity of grain leaving the spout is relatively high. Grain kernels separate from the fine material during the fall and spread between the bin center and bin wall, while most fine material falls vertically into the bin center. Furthermore, as grain flows from bin center toward the bin wall, a sieving action takes place due to the impact of grain falling on the surface of the grain pile. This sieving action allows most whole kernels to flow toward the bin wall and leaves most of the fine material around the bin center.

Grain Damage

The increase in fine material content (Table 1) is the difference in fine material content before and after a given test. This increase is mainly caused by breakage of grain during handling. For the three methods tested, the total fine material in the sample increased within the range of 0.22 to 0.34 percentage point. These differences were not significant among the three methods.

Bulk Density

Surface contour around the center of the grain pile was steeper for corn transferred through the flow regulator or orifice than for corn transferred by a vertical spout (Fig. 5). In situ bulk density of corn (Table 1) transferred by a vertical spout was 2 to 3% higher than that of corn transferred by the flow regulator or orifice. The velocity of grain reaching the grain pile was much higher for corn transferred by the spout than for corn transferred by a flow control device. High velocity impact might have been the reason causing a slightly higher bulk density. In situ bulk density of corn transferred by the flow regulator or orifice was very close to its test weight.

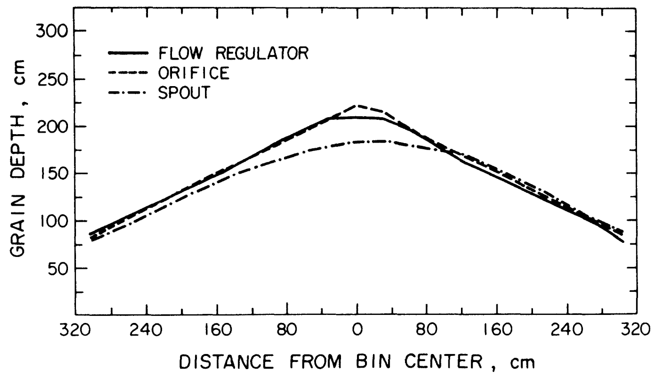

Fig. 5—Radial distribution of corn transferred to the bin by different flow control devices.

Bulk properties of grain in the bin transferred by an orifice were similar to that of grain transferred by the flow regulator. Orifice and flow regulator provided about the same effectiveness in controlling dust emission during loading. An advantage of the flow regulator over an orifice is that it is capable of handling fluctuating flow rates of grain up to its capacity. When an orifice is used, the flow rate of grain in the handling systems has to be fairly constant and be near the capacity of the orifice. In most grain handling applications, use of an orifice for dust control is not practical due to the variation of flow rate in the handling system.

SUMMARY AND CONCLUSIONS

A grain flow regulator was designed, constructed, and tested. It was installed above the grain bin for control of dust emission during bin loading. The apparatus consisted of a hopper with a grain level sensor, proportioning controller, and a swinging gate which was powered by a positioning motor. The proportioning controller provided automatic adjustment of the flow rate of grain through the gate and maintained a constant level of grain in the hopper. Grain flow from the gate into the bin was choke-flow which is similar in appearance to liquid laminar flow. For comparison, an orifice installed at the end of the spout was tested as a second means of obtaining choke-flow of grain into the bin.

1. Dust concentration of air in the bin was reduced by 80% when the flow regulator or orifice was used.
2. Distribution of fine material in grain which passed through the flow regulator or orifice was more uniform than that for grain transferred with a conventional spout.
3. Grain damage caused by the flow regulator or the orifice was not significantly different from that observed when no flow control device was used.
4. The orifice and the flow regulator provided about the same effectiveness in controlling dust emission during loading.
5. The advantage of the flow regulator over an orifice is that is it capable of handling fluctuating flow rates of grain up to its capacity.

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