MEASUREMENT OF GRAIN DUSTINESS[1]

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ABSTRACT

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Three grains—corn, sorghum, and wheat—were handled in the U.S. Grain Marketing Research Laboratory headhouse while dust and grain samples were collected. The amount of dust separated by the dust control system was considered a relative measure of the grain dustiness. A diverter-type grain sampler collected grain samples during each handling. Each grain sample was bagged separately and moved to the laboratory for individual analysis. Grain samples were washed in isopropyl alcohol to remove residual dust and sieved to remove broken kernels. The residual dust was separated from alcohol by filtering and weighed. Data show that the amount of broken kernels from a sample were not always related to dustiness, while seed residual dustiness was indicative of dust collected during handling.

Dust generated each time grain is handled is a hazard in the grain elevator industry. The Environmental Protection Agency (EPA) (1) has estimated that the grain elevator industry emits 604,000 tons of particulate matter each year, and the EPA is charged by law to prevent any increase in this amount.

Verkade and Chiotti (2) pointed out the increasing frequency and severity of dust explosions. Two other problems of concern are the environmental pollution by dust and the health hazards to workers who inhale grain dust. Health problems have usually resulted from handling moldy or heating grain. Examples of illnesses from such handling are farmer's lung or heating grain syndrome (3). None of the participants at a recent international conference on the health hazards of grain dust, however, considered farmer's lung important. The major problems appear to be chronic bronchitis and asthma-provoking allergies (4).

Regulations that govern permissible levels of grain dust emissions are causing large grain elevators to increase their control measures. Although improved control measures have reduced air pollution, disposal of the additional dust collected from these control systems creates dust-handling problems. Sometimes the dust is returned to the grain, and the hazards created by dust are merely passed on in greater magnitude. If dust is not returned to the grain, an operator must be concerned with shrinkage, plus dust-handling and storage costs.

Little work has been done on measuring the dustiness of grain. Greenaway (5) developed two tests, a fundamental and a rapid empirical test, for measuring dust in corn. Although the fundamental method could be applied to many types of grain samples, the empirical method was applied only to corn. In the fundamental method, suction and manual shaking are used to separate dust from grain. The dust is trapped in distilled water, filtered, dried, and weighed to determine the percentage of dustiness. The dust separation is the same in the rapid empirical test, but conductivity of the water is measured instead of weighing the dust. A linear relationship exists between conductivity and percentage of dustiness. Greenaway showed that the Carter dockage tester,

[1]Mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

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which measures broken kernels, foreign material, chaff, and dust, was unsuitable for separating dust from corn.

Martin and Sauer (6) studied dust separated by conventional dust control systems during full-scale grain handling. Their studies showed that the amount of dust collected varied among types of grain and among types of handling operations. Many grains are coated with an oil or wax that tends to retain small dust particles. Some of these particles are separated, whereas some cling to kernels during handling. Conventional grain cleaning separates only a fraction of these small particles, leaving the bulk of the grain dusty.

The size distribution of dust particles collected with conventional dust control systems usually reveals an abundance of particles that pass through a 120-mesh (125-μm) sieve. The dust so collected is called fine dust. These small particles, comprising 60% of the dust by weight, play an important role in problems related to explosion and pollution.

The objective of this study was to develop and test a method for removing dust from grain samples as an alternative to removing dust by suction and shaking. In this study, fine dust that clings to kernels and fragments of kernels is called residual dust. The residual dust from grain samples was compared with the dust separated from the entire grain lot during full-scale handling.

MATERIALS AND METHODS

Grain Lots

Corn, sorghum, and wheat were selected as grains known to have different dustiness characteristics. Both the corn and sorghum were grown and harvested near Wamego, KS, in 1975. Corn at 25%[2] moisture was harvested with a corn combine, hauled to the U.S. Grain Marketing Research Laboratory (USGMRL), screened with a rotary cleaner to remove excess fine material, and augered into a bin for drying. After the corn was dried with solar-heated air to 13% moisture, it was augered from the bin into a truck and placed in storage in the headhouse. The corn graded No. 1 and had a 60 lb/bu test weight at 13% moisture.

The sorghum was combined at 24% moisture, hauled to the USGMRL, and augered into a bin for drying. After the sorghum was dried to 13.7% moisture with unheated air, it was augered into a truck and placed in storage in the headhouse. The sorghum was removed from storage, placed in another bin, and returned to storage where it remained until the test. The sorghum graded No. 1 and had a 59 lb/bu test weight at 13.7% moisture.

Wheat was obtained from the Commodity Credit Corporation. Its origin was unknown, but it was graded No. 1 hard red winter, with a 62.5 lb/bu test weight at 13.2% moisture.

Full-Scale Facilities

Figure 1 is a schematic drawing of the grain-handling and dust-control systems at the USGMRL. A grain lot was allowed to fall by gravity through spouts and enter the boot on the descending side of the bucket elevator. It was then elevated 53 m (174 ft) and discharged into another spout. It descended 3 m (10 ft) into and

[2]All the moisture contents are on wet basis.

passed through an automatic divider-type grain sampler, descended 1.5 m (5 ft) to a hopper, and continued 3 m (10 ft) to a distributor that directed the flow to a receiving bin. It then descended another 4.6 m (15 ft) to the point where it entered

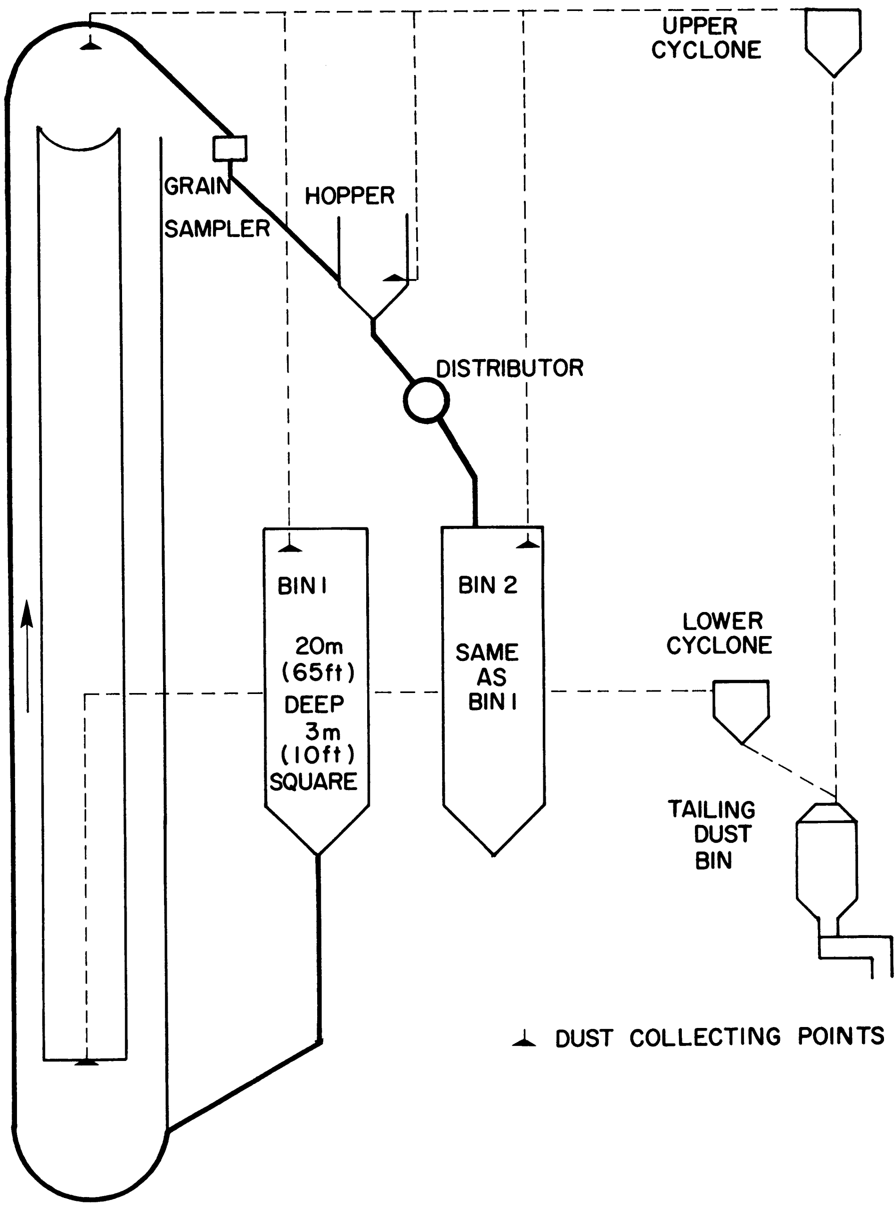

Fig. 1. Grain handling and dust control systems at U.S. Grain Marketing Research Laboratory.

the receiving bin slightly off center. All bins were about 20 m (65 ft) deep and 3 m (10 ft) square, with a hopper bottom that discharged from its center.

The headhouse was equipped with two conventional dust-control systems in which cyclone separators were used to separate dust from the air. One system served the upper and one the lower part of the handling system (Fig. 1). Both cyclone separators discharged dust into a common bin. Ducts in each system connected the many dust-collecting points to the appropriate cyclone. Valves located at dust-collecting points controlled the amount of air flowing into the dust-collection system. The efficient performance of cyclone separators required that most valves be open; however, dust was collected only where grain was flowing. Dust-collecting points were located at the boot and head pulley covers of the bucket elevator. Air that was entrained in the grain entered the elevator boot, and air from an outside vent entered the head cover. A dust-collecting duct that was connected to the hopper drew air from above and entrained the dust suspended within the hopper. Other ducts removed air from the top of the bin overspaces. That air was then replaced by air coming in through outside vents.

Laboratory Apparatus

The following laboratory apparatus were used for separating dust from grain sampled.

Materials Used in Fluidizing (Fig. 2)

1. 43-mm Diameter piece of 100-mesh screen
2. 500-ml Dispensing burette, about 400 mm long, with an inside diameter of about 43 mm
3. 2-mm Diameter piece of glass tubing, about 450 mm long
4. Two 43-mm plastic disks with several 3-mm holes to distribute airflow
5. Laboratory stand and assorted mounting clamps
6. Regulated air supply and suitable length of plastic tubing

Materials Used in Wet Sieving-Sonifying

1. 92-mm Diameter piece of 100-mesh screen
2. 91-mm Diameter, 130-mm long brass tube
3. Three 900-ml beakers
4. 2-L, 125-w ultrasonic cleaner

A sieve was fabricated by soldering the piece of screen to one end of the brass tube. The equipment was manually assembled for each test by putting the sieve inside a beaker and setting the beaker inside the sonifier.

Materials Used in Filtering

1. Two 300-ml funnels with 47-mm diameter filter holders
2. Two 500-ml suction flasks with suitable stoppers
3. Vacuum source and suitable length of hose
4. 47-mm Diameter in-line filter holder
5. 47-mm Diameter, 0.8-μm membrane filters

Particle Sizing

1. Fine material—Strand shaker (Strand Shaker Co., Minneapolis, MN) with grain-standard sieves: 4.76-mm (12/64-in.) round-hole corn sieve, 1.98-mm

(5/64-in.) triangular-hole sorghum sieve, 1.62 × 9.52-mm (0.064 × 3/8-in.) oblong-hole wheat sieve

2. Coarse dust—Fisher-Wheeler sieve shaker (Fisher Scientific Co., Pittsburgh, PA) and U.S. Standard set of 20-, 35-, 45-, 60-, 80-, and 120-mesh sieves

3. Fine dust—HIAC SS automatic particle counter (High Accuracy Products Co., Claremont, CA) and calibrated latex spheres

Other Analysis. A Model 200 Beckman air pycnometer (Bausch & Lomb, Houston Instrument Div., Austin, TX) was used for measuring average particle density.

Development of Procedures

Separation of Residual Dust. Three experimental methods were tested before selecting a procedure suitable for measuring residual dust. In the first method, 50

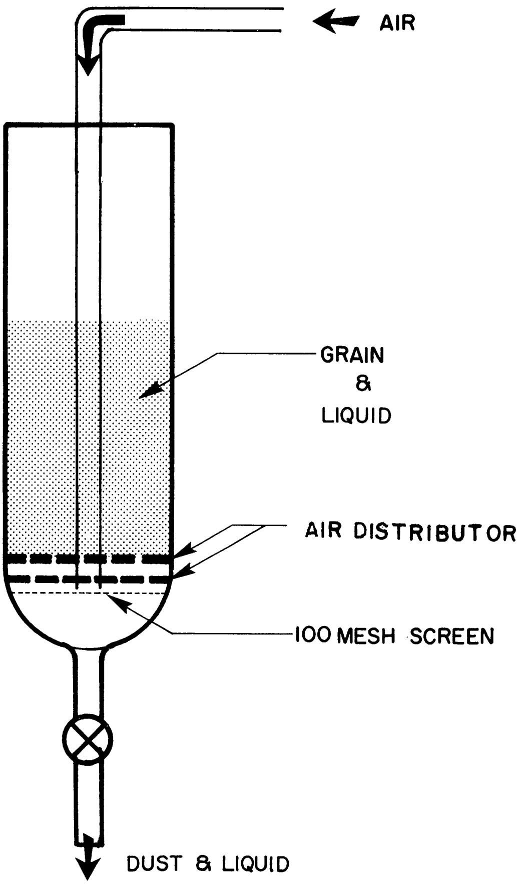

Fig. 2. Grain dust measurement by fluidization.

g of grain were immersed in 200 ml of water in a glass column, and air was injected at the bottom of the column to fluidize the kernels (Fig. 2). After 1 min of kernel fluidizing, the water was drained and filtered through a 47-mm diameter, 0.8-μm membrane filter to separate dust particles. Batch washing was repeated ten times to determine the rate of dust removal.

In the second method, we used a peristaltic pump to circulate liquid continuously through the column used in the first method. While 10 g of grain was being fluidized, water was sucked from the base of the column through a 0.8-μm membrane filter and pumped back to the top of the column. Different fluidizing times were used to assess the rate of dust removal.

In the third method, 50 g of grain were washed ultrasonically in 600 ml of isopropyl alcohol for 1 min, and the alcohol and suspended dust were drained from the grain through a 100-mesh sieve. The dust particles in the alcohol were separated by a 0.8-μm membrane filter until all of the grain sample had been cleaned. The third method gave the most consistent results and was the most efficient method for removing dust.

Determination of Particle Shape Factor. Shape factor was a dimensionless constant used in calculating the weight of particles measured by the HIAC sensor. The HIAC sensor measured projected areas of individual particles and had a lower limit of 19.6 μm^2, or the area of a circle with a diameter of 5 μm. Shape factor was derived from the relation between particle size, density, and weight, and was predetermined by the procedure described below.

Particles smaller than 5 μm were removed from samples of typical wheat and corn dust by a Bacho air classifier (Harry W. Dietert Co., Detroit, MI). The average particle densities of these prepared dusts were then measured with a Beckman air pycnometer. Next, a known weight of each prepared dust was analyzed by the HIAC, which counted the number of particles in five size ranges. The average shape factor for a given dust was calculated from these data as follows:

$$\text{Average shape factor} = \frac{\text{total sample weight}}{(\text{average density}) \sum n_i d_i^3}$$

where n_i is the number of particles in the range d_i to d_{i+1}; d_i, the calibrated cutoff size for the i-th channel; and i, channel number 1, 2, 3, 4, or 5.

By assuming that the average shape factor was constant for different dust samples, we could use the HIAC analysis and density measurement to calculate size distribution on a mass basis when the total sample weight was known.

Procedures

Full-Scale Test. The air control valves in the upper dust control system of the elevator were set to control the airflow to the cyclone separator at 4.7 m^3/sec (10,000 ft^3/min), and the lower system valves were set to control the airflow to the separator at 7.1 m^3/sec (15,000 ft^3/min). As each grain lot was transferred from its storage bin to a holding bin, grain samples were collected automatically at 1.5-min intervals by the divider sampler.

All dust from the dust bin was collected in barrels for weighing and sampling after each transfer. A 2.3-kg (5.0-lb) dust sample was removed from each barrel by nine full-depth corings and identified by the type of grain from which it came.

Laboratory Analysis. Residual dust was separated from each grain sample by ultrasonic washing and sieving as described in the third method above. The operation was repeated in 50-g batches until all of the grain sample had been cleaned. All of the residual dust from a grain sample was accumulated on one filter. Then the grain and dust were heated in an oven to evaporate all remaining alcohol before their weights were recorded. Next, each grain sample was screened with the appropriate sieve for 20 sec to separate the fine material.

The experimental setup for measuring the grain dust particle size distribution is shown in Fig. 3. We set the HIAC channel cutoff threshold at 5-, 10-, 20-, 38-, and 75-μm, using calibrated latex spheres according to the manufacturer's recommended procedure. Four residual dust specimens were selected at random

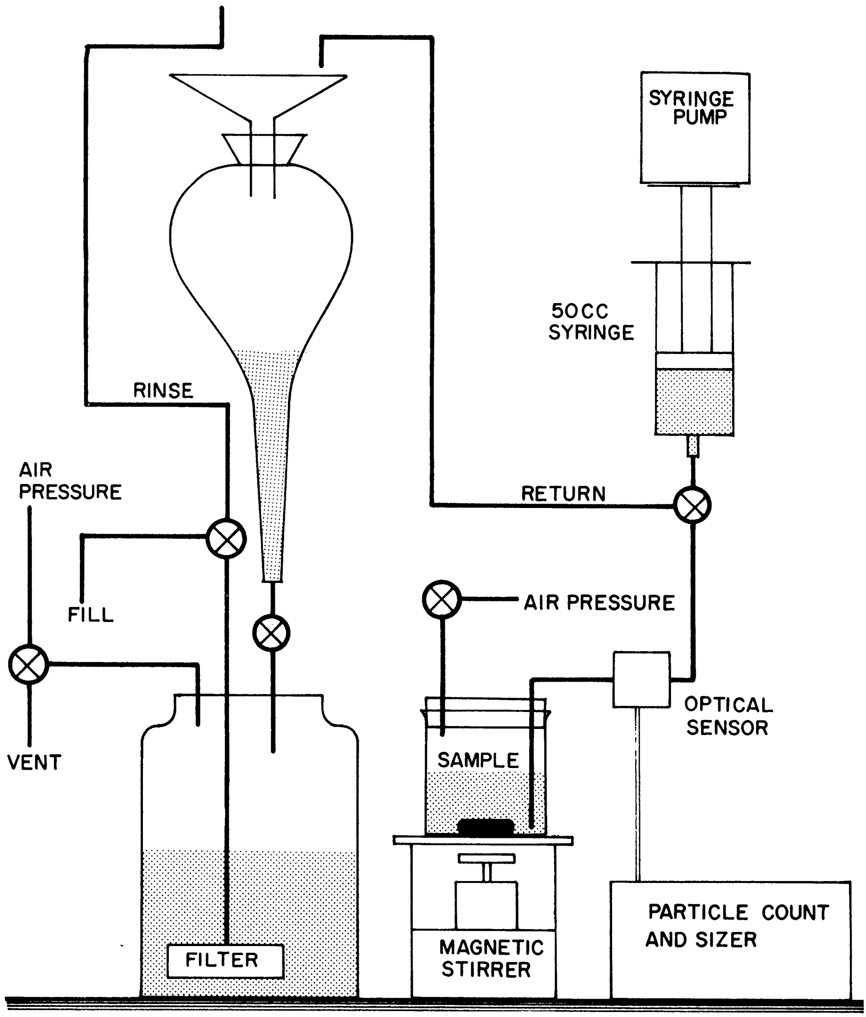

Fig. 3. Experimental apparatus for measuring grain dust particle size distribution.

from each type of grain. About 135 μg of dust was weighed on a small clean disk; then both disk and dust were dropped into a clean flask that contained 135 g of filtered isopropyl alcohol. Next, the dust was dispersed in the alcohol by sonifying the flask and its contents for 1 min. The suspension was passed through the HIAC sensor while a magnetic stirrer kept the particles evenly dispensed in the alcohol (Fig. 3). The weight of the dust sample measured was assumed to be proportional to the weight of the alcohol that flowed through the sensor.

The residual dust specimens that were not used for sizing were combined by grain type to obtain a quantity sufficient for measuring particle density with the air pycnometer. The shape factor of each grain type was assumed to be a constant 0.785 ($\pi/4$) when calculating the percentage of particles in each size range according to the following equation:

$$\frac{100\% \times 0.785 \times \text{density} \times n_i d_i^3}{\text{total weight of sample}} = \% \text{ of size } d_i$$

The weight of particles smaller than 5 μm was determined by subtracting the summation of channel weights from the total weight of the sample.

The distribution of coarse particle sizes in the cyclone tailing dust was determined after sieving 100 g of dust on the Fisher-Wheeler sieve shaker for 20 min. Particles that passed through the 120-mesh sieve were called fine dust.

RESULTS AND DISCUSSION

Results of the full-scale handling are shown in Table I. The difference in grain lot sizes affected the segregation of fine material, and is discussed in more detail below. The quantity of cyclone tailing dust collected varied with grain type, but the amount of dust from the grain sorghum was less than what we normally collected during similar routing handling. Variation in grain sample weight was caused by variations in flow rate during the handling. We do not believe that these differences in flow rate had any effect on the overall results, because belt and conveyor speeds were constant.

A summary of the data from the grain sample analysis is given in Table II. The operational loss was caused mainly by moisture lost during the evaporation of excess alcohol after wet sieving. The average amount of alcohol-soluble material

TABLE I
Data From Full-Scale Handling

	Grain			Grain Samples		
Lot	Total Amount Handled (MT)	Average Flow Rate (MT/hr)	Total Cyclone Tailing Dust (kg)	Total Number Collected	Average Weight (g)	Weight Range (g)
Corn	46.32	59.3	43.77	29	519	416–613
Sorghum	33.55	65.5	20.87	23	615	440–730
Wheat	56.70	87.3	20.27	30	734	616–972

for each grain type ranged between 0.013 and 0.018% per sample and was part of the operational loss. These losses did not affect the percentages of fine material or residual dust. Fine material content was nearly the same for all three grains. These relatively low fine-material levels had a minimum effect on the surface area of grain samples from the different grain lots.

Although the surface areas of the three grain types were not measured in this study, they should at least be discussed. For a given weight of grain, the surface area of wheat was roughly the same as sorghum but greater than corn. Since the residual dustiness levels were higher in corn samples than in either sorghum or wheat samples, the concentration of dust particles on corn surfaces had to be greater than the concentrations on sorghum or wheat surfaces.

Table III compares percentage of grain-lot dustiness with the percentage of grain-sample residual dustiness. Corn emitted or generated more dust during handling and had more residual dust than did sorghum or wheat. The grain sample residual dustiness was the same order of magnitude as the grain lot dustiness. Most of the cyclone tailing dust was composed of particles smaller than 125 μm as determined by the sieving analysis.

The percentage of fine dust collected from the grain during handling was nearly equal to the percentage of residual dustiness for corn and wheat. There was a significant difference, however, in the two dustiness measurements for sorghum. One explanation could be that sorghum surfaces had a greater ability to retain dust than did corn or wheat surfaces. Another possibility is that isopropyl alcohol removed but did not dissolve part of the sorghum surface.

TABLE II
Summary of Data From Grain Sample Analysis

	Residual Dust[a]		Fine Material[b]		Operational Loss[b]	
	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)
Corn	0.082	0.067–.128	1.61	1.06–2.93	1.13	0.67–1.73
Sorghum	0.070	0.059–.081	1.44	0.98–1.77	1.49	0.95–2.51
Wheat	0.025	0.014–.061	1.58	1.20–2.51	1.33	0.82–3.08

[a]Percentage of grain sample as weighed before operation.
[b]Percentage of grain sample as weighed after operation.

TABLE III
Comparison of Cyclone-Tailing and Grain-Sample Residual Dusts

Grain	Grain Lot Dustiness (%)	Grain Lot Fine[a] Dust Content (%)	Fine Dust[a] Collected From Grain Lot (%)	Average Grain Sample Residual Dust (%)
Corn	0.0945	85	0.080	0.082
Sorghum	0.0622	60	0.037	0.070
Wheat	0.0357	78	0.028	0.025

[a]Fine dust is defined as particles that pass through 120-mesh (125-μ) sieve.

An important aspect of this study is the effect of fine material segregation on the relationship between fine material content and sample residual dustiness levels. In previous studies at the USGMRL, Martin and Stephens (7) plotted the percentage of fine material against the percentage of grain flow for grain that was handled repeatedly. Those graphs were distinguished by high levels of fine material that accumulated in the initial and final stages of grain flow. In this study, we have plotted the percentages of residual dust and fine material against the percentage of grain flow. The corn used in this study had a minimum amount of fine material from previous handling. The profile of fine material content shown in Fig. 4 does not show above-average initial levels because of this minimum handling. The level of fine material in the last grain out was above average, however, because segregating factors were developing. The sorghum grain had two transfers at the USGMRL before this test. In Fig. 5, the fine

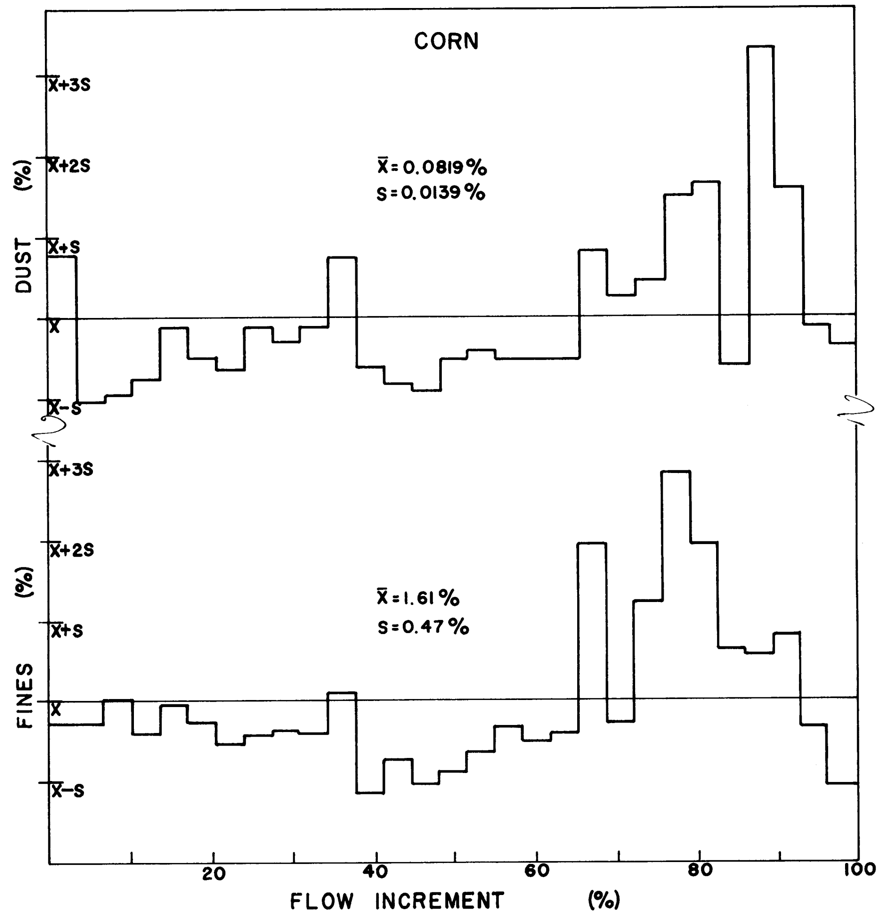

Fig. 4. Profiles of residual dust and fine material in corn flowing from storage bin at U.S. Grain Marketing Research Laboratory.

material profile shows a distinct above-average percentage in the initial flow of sorghum grain, because segregating factors had more opportunity to develop. The fine material profile for wheat (Fig. 6) was smooth and had a distinct peak, because it had many previous transfers.

The correlation coefficients of percentages of fine material and percentages of residual dust were 0.653 for corn, 0.330 for milo, and 0.375 for wheat. Only the correlation between the fine-material content of corn and the residual dustiness levels of corn was significant at the 99% level of probability. All three profiles of residual dustiness levels show the USGMRL U shape segregation characteristic of high levels in the initial and final stages of flow (Fig. 4–6). The residual dustiness profile in corn was a developing U shape and correlated with the fine material profile. In sorghum, the U-shaped grain dustiness profile was developed, but was not sufficiently in phase with the U-shaped fine material profile to cause significant correlation. The residual dustiness profile in wheat

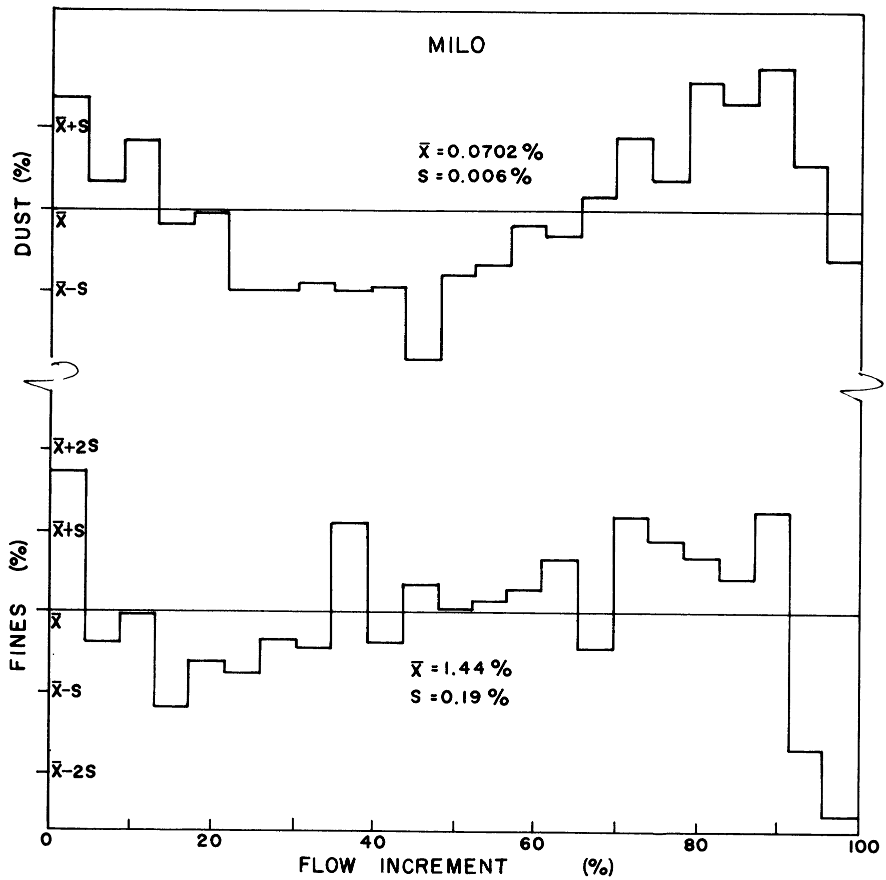

Fig. 5. Profiles of residual dust and fine material in sorghum flowing from storage bin at U.S. Grain Marketing Research Laboratory.

had a distinct U shape, but the fine material profile shape was quite different.

The profile data in Fig. 4–6 illustrate that some relatively dusty grain samples are relatively free of fine material, and vice versa. Dust particles are smaller than are the broken kernel fragments of which fine material is composed and apparently segregate in a different manner.

The densities of dust are shown in Table IV. The densities of residual and cyclone tailing dust were similar. The density of sorghum residual dust was the lowest, suggesting that some of the waxy surface may have been removed by the isopropyl alcohol.

The particle-size distribution curves for the residual and coarse dusts of corn, sorghum, and wheat are shown in Fig. 7. Each fine dust distribution curve is the average of four residual dust samples that were selected for HIAC analysis. The shapes of the distribution curves for corn and wheat residual dust size were similar. Average mass median diameter of residual dust particles was 13 μm for wheat, and 14 μm for sorghum. About 34% of the sorghum residual dust, 33% of

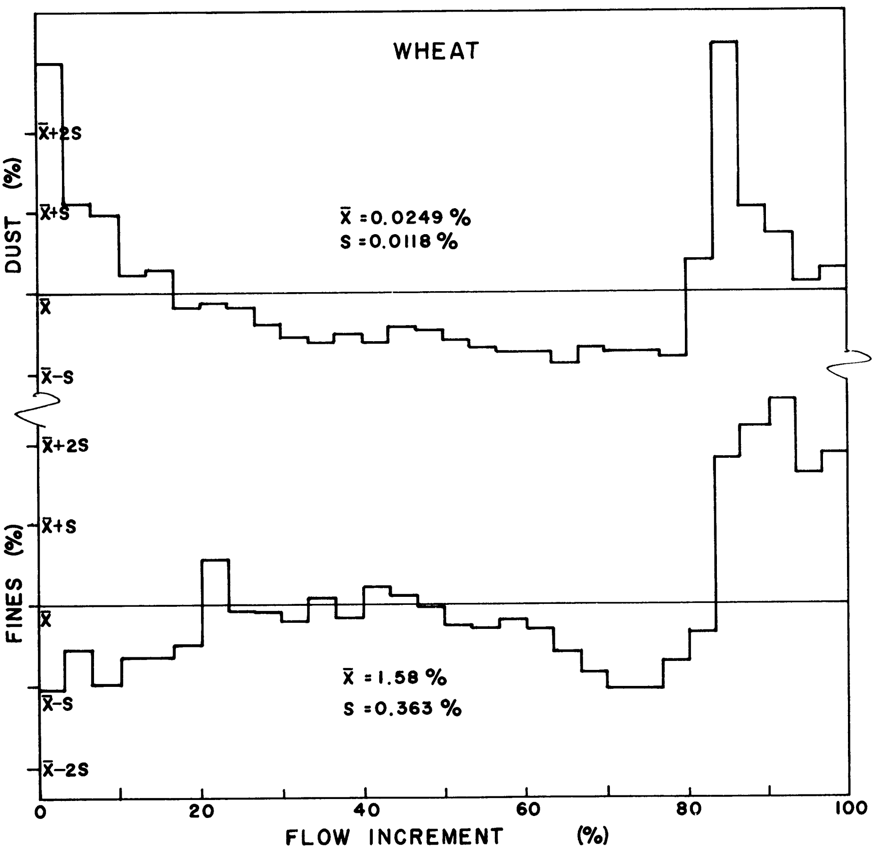

Fig. 6. Profiles of residual dust and fine material in wheat flowing from storage bin at U.S. Grain Marketing Research Laboratory.

the corn residual dust, and 45% of the wheat residual dust particles were less than 10 μm in diameter. Particles of sizes less than 10 μm have been found to be deposited in the human respiratory system (8).

CONCLUSIONS

Rapid separation of dust from grain can be obtained by the wet sieving-sonifying method developed in this study. Because filtering of dust from isopropyl alcohol is slow, a rapid method of measuring dust in suspension is

TABLE VI
Density of Grain and Grain Dust

	Corn (g/cc)	Sorghum (g/cc)	Wheat (g/cc)
Whole kernel	1.29	1.32	1.42
Cyclone tailing dust	1.47	1.45	1.49
Residual dust	1.50	1.39	1.49

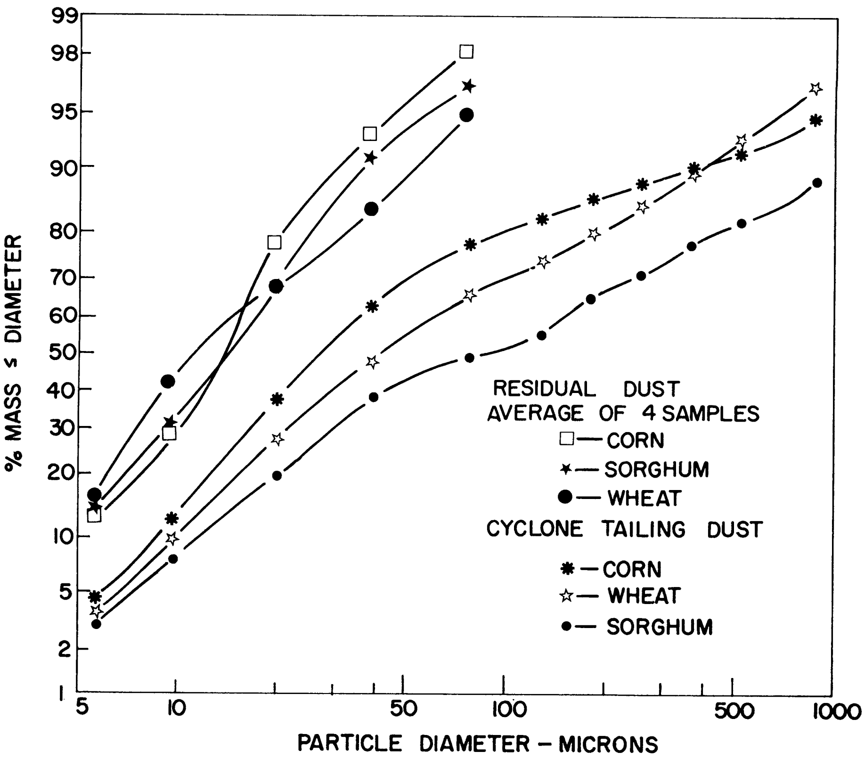

Fig. 7. Particle size distribution of residual and coarse dust from corn, sorghum, and wheat.

needed. Sample residual dustiness, measured by the method developed in this study, is closely related to the amount of dust collected during handling. Segregation of fine material has a pronounced effect on the relationship between fine-material content and residual dustiness levels.

Acknowledgment

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