Characterization of Grain Dust Properties

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ABSTRACT

CHARACTERISTICS of dusts separated by grain elevator dust control systems were nonuniform. Particle size distribution was influenced by capture velocities and air cleaners in dust control systems. Specific densities, ash contents, and heats of combustion were closely related. Dusts contained more fiber and ash than grains. Ash free proximate analysis values of dust were similar to their respective values in grain.

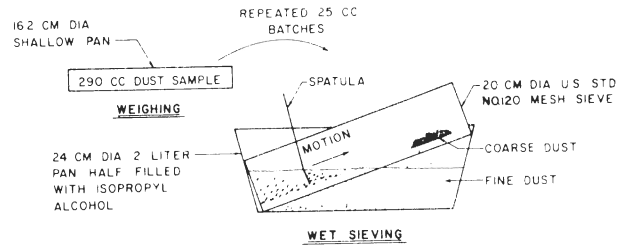

FIG. 1 Apparatus for wet sieving grain dust to separate fine dusts.

INTRODUCTION

Grain dust is always present in grain handling facilities and constitutes fire, explosion, and health hazards. Dust control systems are designed to reduce air pollution and they hopefully also minimize these hazards. The repeated removal of dust can minimize the quantity of dust that is being controlled during the next handling (Martin and Stephens, 1977).

As dust control systems become more sophisticated, the need for good dust management becomes necessary. A logical approach toward good dust management is to treat grain dust as a by-product to be used as feed, fuel, or fertilizer. The first step in detemining the best use for dust is to determine its properties.

Grain dust is composed of solid particles that become airborne during grain handling. Dust control systems capture these airborne particles in moving air streams. Maintaining a capture velocity that is well below the terminal velocity of grain prevents the capture of grain (Comm. on Ind. Ventilation, 1972).

Dust behavior is affected by the size, shape, and density of the particles and is controlled by regulating air movement in the dust-emitting areas (Hesketh, 1977). Capture of dust by a dust control system is essentially an aerodynamic classification process. The physical properties of size, shape, density, and surface area of dust particles are basic parameters that can be measured. Heat-of-combustion values are indicators of potential fuel value or explosibility. Proximate analyses are useful in evaluating nutritional aspects of dust which are determined by its chemical composition. Trace element analyses are important for detecting the presence of undesirable heavy-metal concentrations. Some microbiological characteristics of grain dusts have been studied, and microorganisms are known to concentrate in dusts (Martin and Sauer, 1976).

The objectives of this study were to measure the basic physical and chemical properties which characterize dust from different grains and elevators and to determine those factors that account for most of its variability.

MATERIALS AND METHODS

Dust Samples

We obtained dust from four commercial elevators in central and eastern Kansas. Samples of grain and dust were collected from corn, wheat, grain sorghum, and soybeans. The manager of each elevator was asked to supply about 2 L of the dust discharged from the dust control system on their bucket elevators. All the elevators that were selected had cyclone air cleaners on their bucket elevator dust control systems. One elevator did not handle soybeans, and one elevator included a sample of mixed corn and sorghum dust from a baghouse air cleaner.

Particle Size Analysis

We determined the bulk density of a 290-cc portion of dust and then wet sieved 25 cc portions (Fig. 1), using 1 L of isopropyl alcohol in a 2 L pan and a 20-cm-diameter U. S. standard No. 120-mesh sieve to separate fine dust. A flat-tipped spatula was used to agitate 25-cc portions of wetted dust over the inclined surface of the sieve until all fine dust had been washed through it. We deposited the coarse particles that remained on the portion of sieve surface above the alcohol on a membrane filter with an 0.8-μm opening. Fine particles in the alcohol below the sieve were also separated by a filter with an 0.8-μm opening. Both fine and coarse particles were air dried at room temperature. Isopropyl alcohol used in wet-sieving a sample was distilled at low temperature to separate the

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Article was submitted for publication in October 1979; reviewed and approved for publication by the Electric Power and Processing Division of ASAE in April 1980.

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Acknowledgement: The author is very grateful to Byron S. Miller for his valuable advice and suggestions.

This article is reprinted from the TRANSACTIONS of the ASAE (Vol 24, No. 3, pp. 738-742, 1981)
Published by the American Society of Agricultural Engineers, St Joseph, Michigan

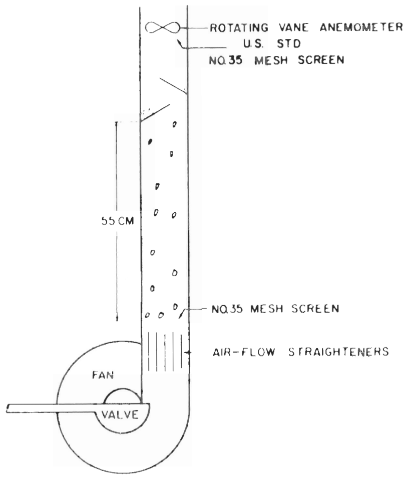

FIG. 2 Apparatus for measuring capture velocity.

solubles.

We separated the trash from coarse particles by sieving with a set of U. S. standard No. 3½-, 5-, 7-, 10-, 14-, and 18-mesh sieves. We used a South Dakota Seed Blower, Burrows Equipment, Evanston, Illinois, to determine the capture velocity of trash. A rotating vane anemometer was placed on top of the vertical column to monitor the controlled setting of the airflow rate (Fig. 2). A thin layer of trash particles from a dust sample was placed on the screen at the base of the column and aspirated for 2 min. Particles that were lifted 55 cm and trapped were considered to have a capture velocity less than the controlled velocity setting, whereas particles not trapped were considered to have a capture velocity greater than that setting.

We measured the weight, thickness, and area of selected trash particles. We counted and weighed 100 randomly selected particles from aerodynamically classified fractions to determine the average weight. We selected five typical individual particles from different aerodynamic classified fractions and used a micrometer to measure their thickness. The total area of the 100 individual particles was measured with a Model 720 Quantimet image analyzing computer (Imanco, 1970).

We determined the size of coarse particles from each dust sample after 20 min of sieving on a Fisher-Wheeler sieve shaker, using a set of U.S. standard No. 25-, 35-, 45-, 60-, 80-, and 120-mesh sieves.

We measured the particle-size distribution of duplicate portions of fine dust by the use of four methods. We used sedimentation method with MSA equipment (Mine Safety Appliance Co., 1973), a resistance gradient technique with a Model TA Coulter Counter (Coulter Counter Electronics, Inc., 1976), a forward light-scattering method with a Leeds and Northrup Microtrac particle size analyzer (Leeds and Northrup, 1977), and a light obscuration method with a Model SSTA HIAC automatic particle counter (High Accuracy Products Corporation, 1972). We selected the forward light scatter and sieve analyses to be used in calculating the composite particle size distribution of each dust sample.

Proximate Analysis

Duplicate portions from each dust sample were analyzed to determine their composition. Moisture, protein, and ash were analyzed by methods 44-46, 46-10, and 08-01, respectively, of the AACC (AACC, 1975). Crude fiber and fat were analyzed by methods 7.050-7.054 and 7.047, respectively, of the AOAC (AOAC, 1975). Starch was assumed to be that percentage unaccounted for by other ingredients. To compare the nutritional qualities of grains and dust samples, the as-measured percentages of protein, crude fiber, fat, and starch were adjusted to values based on 14 percent-moisture (wet basis) and 0 percent ash content.

Trace Elements

Trace elements were analyzed by Realtech Scientific Services, St. Louis, Missouri. They used AOAC (AOAC, 1975) methods 7.070-7.075 for copper, iron, manganese, and zinc; 41.009 for arsenic; 7.077-7.0782 for calcium, 25.044 for lead; and 0.008 for moisture and a method from the Journal of Biological Chemistry (Kuttner & Cohen, 1927; Kuttner & Cohen, 1930) for phosphorus.

Density

We measured the absolute density of dust with a Model 200 Beckman air pycnometer. The densities of fine dust and of dust without trash were measured for each sample. We calculated the densities of coarse dust, using the weight ratio of coarse and fine dust particles. Densities of combustible and noncombustible fractions were calculated from the regression analysis of fine dust and ash.

Heat of Combustion

The heat of combustion was measured by the U. S. Bureau of Mines.

Surface Area

The surface area of two selected samples was determined by Particle Data Corp., Elmhurst, Illinois, by use of the three-point BET method. We calculated the specific envelope surface (for spheres) from second (area) moment size distribution data as determined by the light obscuration method.

RESULTS

Capture Velocity and Dimension Characteristics

Particles too large to pass through a U. S. standard No. 18-mesh sieve (1.00 mm openings) were present in each dust control system effluent and were characterized as trash. A few trash particles were too large to pass through a U. S. standard No. 3½-mesh (5.66 mm opening) sieve. Trash was composed of "beeswing" from corn cobs, hulls of sorghum, wheat, and soybean kernels and of plant material carried over from harvesting. Table 1 shows capture velocities and typical dimensions and weights of small "beeswing" as they were separated by the airflow in a South Dakota Seed Blower. The capture velocity of "beeswing" ranged upward from 0.4 m/s.

TABLE 1. CAPTURE VELOCITY AND PHYSCIAL CHARACTERISTICS OF "BEESWING" FOUND IN CORN DUST.

Capture velocity, m/s	Weight,* μg	Area,* mm^2	Thickness,† μm
0.533	21.1	1.74	15
0.731	53.1	2.24	23
0.975	112.5	3.06	46

*Average of 100 particles.
†Average of five particles.

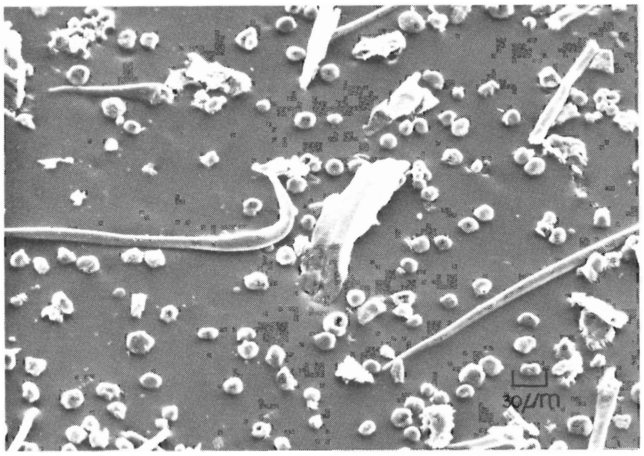

FIG. 3 Scanning electron micrograph of wheat dust.

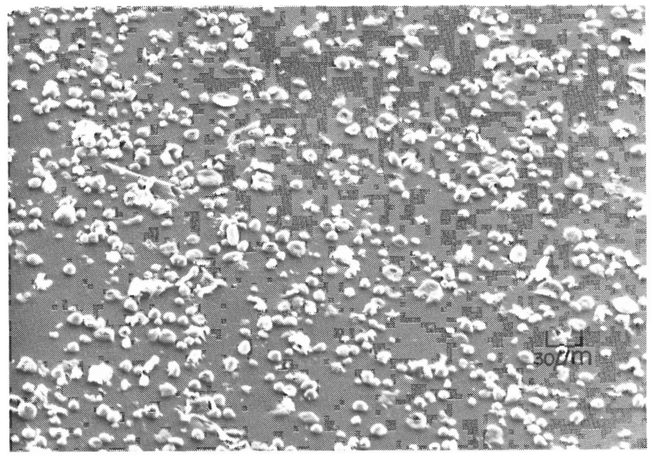

FIG. 4 Scanning electron micrograph of corn dust.

Hulls and other trash had capture velocities ranging upward from 1.27 m/s. The capture velocity for the largest trash was greater than 3.0 m/s. Since most grains contain some trash, capture velocities greater than 1.3 m/s produce trashy effluent. Many small trash particles, especially "beeswing," would classify aerodynamically the same as spherical, coarse dust particles having a diameter of less than 1 mm. Coarse dust particles consist of irregularly shaped grain and small trash fragments.

Figs. 3 and 4 are scanning electron micrographs of aerodynamically classified fine wheat and corn dust particles, respectively. Trichome, spherical, and thin particles can be seen in wheat dust (Fig. 3) whereas corn dust is mostly spherical particles (Fig. 4). Trichomes are hairlike outgrowth on plants and are found on soybean pods, on the brush end of wheat kernels, and on grain sorghum hulls. Trichomes vary from 0.05 mm to 0.20 mm in length and 0.01 to 0.03 mm in diameter. When trichomes of more than 10 percent by weight were present in dust, they formed balls and could not be sieved without the use of sieve brushes. Trichomes behave aerodynamically as spherical fine dust particles with dimensions smaller than 0.1 mm. Fine sorghum and soybean dust also contained trichomes, but spherical particles dominated.

Particle Size Distribution

The arrows in Fig. 5 show the range of cyclone separator effluent particle size distributions. Also, the single baghouse dust is compared to the average of all cyclone effluent particle size distributions. The very fine fraction (smaller than 10 μ in diameter) represented about 20 percent of the dust from a baghouse, compared to about 9 percent of the dust from a cyclone.

Fig. 6 presents data on the particle size distribution of fine soybean dust measured by four methods. About 1 g of sample was used in the light-scattering method and less than 10 mg of sample in the other methods. This soybean dust contained about 15 percent trichomes by weight. The average size as determined by the light obscuration method was larger than that determined by the other methods. The particle size distribution as determined by the resistance gradient and the forward light-scattering methods coincided at the 50 percent point but had different slopes. The sedimentation method measured trichomes as being slightly smaller particles than did the other methods.

Density

The range and average specific densities of grain dust and grain dust fractions are shown in Table 2. High den-

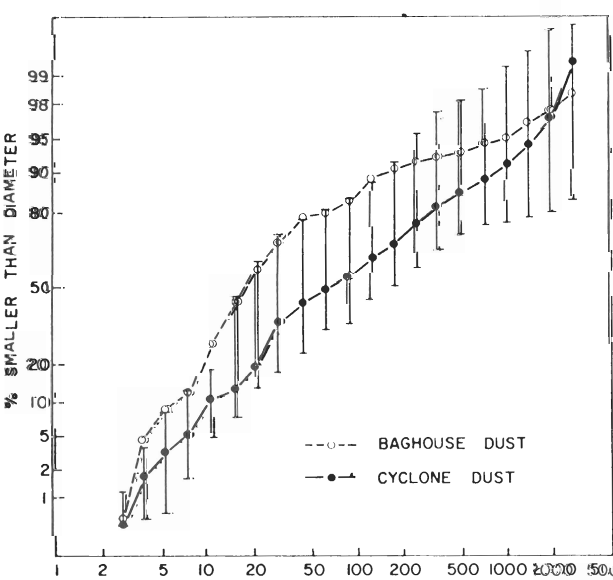

FIG. 5 Particle size distribution of effluent from baghouse and cyclone separators.

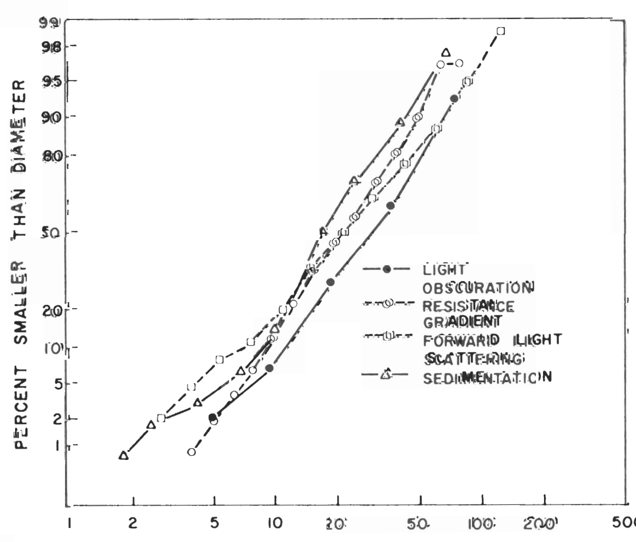

FIG. 6 Comparison of data obtained by four methods of particle size distribution measurement.

TABLE 2. SPECIFIC DENSITIES OF GRAIN DUST AND GRAIN DUST FRACTIONS.

Dust Fraction	Specific Density Maximum g/cc	Minimum g/cc	Average g/cc
Whole dust	1.71	1.38	1.49
Fine dust	1.81	1.48	1.55
Coarse dust*	1.43	1.17	1.32
Noncombustible fraction†	2.41	2.26	2.33
Combustible fraction†	1.45	1.39	1.41

*Calculated from the weight ratios and density differences of whole and fine dust.
†Calculated from the regression equations of ash content and fine dust density.

TABLE 3. HEAT OF COMBUSTION OF DUST AND PERCENTAGE OF COMBUSTIBLES IN DUST CONTROL SYSTEM EFFLUENT

Dust source	Heat of combustion, cal g/g	Combustibles,* %
Mixed	4029	84.0
Corn†	3860	81.6
Wheat†	3663	75.0
Sorghum†	3552	71.3
Soybeans‡	3049	63.2

*Combustibles = 100% — % ash — % moisture.
†Average of four samples.
‡Average of three sammples.

sities are related to high ash content whereas low densities are related to high organic content and high heats of combustion. Whole dust, fine dust, and noncombustible fraction (ash) from soybeans had the highest specific densities. The highest specific densities for coarse dust and combustible fraction were from corn. All of the minimum densities were from sorghum dust. Fine dust and noncombustible fraction densities of corn dust were the same as those of sorghum dust.

Surface Area

The specific envelope surface of dust spheres as calculated from the second (area) moment distribution data ranged from 0.6 to 0.9 m^2/g and agreed with the surface area range of 0.634 to 0.890 m^2/g as determined by the three-point BET method. These surface area data agreed because most dust particles were solid and larger than 3μ in diameter.

Heat of Combustion

The heat of combustion for different dust samples from dust control system effluent ranged from a maximum of 4029 cal gm/gm for mixed dust to a minimum of 2423 cal gm/gm for soybean dust. Heat of combustion values were proportional to the amount of combustibles

TABLE 5. PROXIMATE ANALYSIS OF DUSTS AND GRAIN ON A 0% ASH, 14%, MOISTURE BASIS.

	Protein, %	Fat, %	Fiber, %	Starch, %
Wheat dust*	10.9	2.5	16.4	54.5
Wheat grain	14.0	2.0	3.0	68.0
Corn dust*	8.2	2.5	7.4	67.0
Corn grain	8.8	4.6	2.5	70.0
Sorghum dust*	7.1	5.1	14.3	55.6
Sorghum grain	9.0	3.0	2.0	72.0
Soybean dust†	9.2	3.1	13.7	52.6
Soybean grain	34.3	17.8	4.9	29.0

*Average of four samples.
†Average of three samples.

in each type of dust and are shown in Table 3. The relation between heat of combustion values and percentage of combustibles was due to the wide range in ash content.

Proximate Analysis

The range of the results of proximate analysis as they were measured are shown in Table 4. Ash contents varied more than any other values and probably indicated the amount of dirt carried over during grain harvesting. Table 5 compares the nutritional aspects of grain and dust. The fat content of sorghum dust was higher than that of all other samples, including sorghum grain samples. All values for the fiber content of dust were higher than those for their respective grains due to the presence of small trash particles. The protein content of all dust samples was near that of their respective grains. Generally, the composition of dust was equivalent to the composition of "dirty" or "trashy" grain.

Trace Element Analysis

The results of the trace element analyses are shown in Table 6. Cobalt, iodine, and mercury were not detected in any of the samples. Less than 2 ppm of arsenic was detected in the dusts, but none was detected in the grain. Less than 10 ppm of lead was detected in dust, and less than 1 ppm was detected in some grain samples. The maximum allowable levels of arsenic and lead are 50 and 20 ppm, respectively (Pfost, 1970). Calcium, zinc, and manganese contents were higher in dust than in grain. Iron content was 20 to 40 times greater in dust than in grain, perhaps due to the wearing of iron from the surfaces of machinery that handles grain. Phosphorus content was higher in grains than in their respective dusts. The amount of copper was about the same in grains as in their respective dusts.

CONCLUSIONS

As a product, the effluent from grain dust control

TABLE 4. PROXIMATE ANALYSIS OF DUST CONTROL SYSTEM EFFLUENT FROM COMMERCIAL GRAIN ELEVATORS.

Dust-source grain	Moisture content, %	Protein, %	Ash, %	Fat, %	Crude fiber, %	Starch, %
Wheat*	6.5—12.8	7.9—12.2	7.9—28.5	1.6—2.8	15.0—17.2	39.8—55.8
Corn*	11.7—13.5	6.1— 8.7	4.1— 9.1	1.2—3.6	5.0—10.0	60.9—67.6
Sorghum*	8.0—12.0	5.3— 7.8	8.2—32.2	4.0—4.6	8.2—17.3	38.0—61.5
Soybeans†	9.2—11.8	5.9—13.0	12.1—40.5	1.9—2.3	8.8—11.8	33.6—57.7
Mixed‡	9.5	6.5	8.0	4.0	6.8	65.3

*Ranges of four samples.
†Ranges of three samples.
‡Source, corn and sorghum dust from baghouse, one sample.

TABLE 6. TRACE ELEMENTS IN DUST CONTROL SYSTEM EFFLUENT AND GRAIN, 14% MOISTURE BASIS.

	Corn		Wheat		Sorghum		Soybeans	
Element†	grain, ppm	dust, ppm	grain, ppm	dust, ppm	grain, ppm	dust, ppm	grain, ppm	dust, ppm
Phosphorus	2674.0	1015.0 —1543.0	3240.0	2391.0 —2452.0	2639.0	1322.0 —2234.0	5449.0	1360.0 —1581.0
Calcium	81.0	813.0 —1813.0	382.0	2112.0 —3185.0	199.0	1475.0 —2959.0	2465.0	2690.0 —4607.0
Iron	32.0	679.0 — 867.0	64.0	1219.0 —3159.0	58.0	1132.0 —2174.0	110.0	2720.0 —7365.0
Manganese	6.2	24.0 — 58.0	32.0	93.0 — 96.0	13.0	45.0 — 58.0	26.0	73.0 — 195.0
Zinc	19.0	28.0 — 60.0	22.0	89.0 — 91.0	20.0	54.0 — 65.0	45.0	42.0 — 65.0
Copper	3.0	2.0 — 2.0	3.9	3.7 — 3.8	3.1	5.2 — 5.4	13.0	5.8 — 9.9
Arsenic	NM*	0.22— 0.24	NM	0.37— 0.38	NM	0.27— 0.39	NM	0.50— 1.4
Lead	NM	1.9 — 2.0	NM	5.5 — 10.0	0.15	2.4 — 2.8	NM	2.3 — 4.7

*NM = None measurable.
†Cobalt, iodine, and mercury were not detected in any samples.

systems was made nonuniform because of variations in trash and ash contents. Trash in the effluent could be reduced by keeping the capture velocities in dust control systems below 1.3 m/s. The capture velocity is determined by design and operating criteria of dust control systems. Both trash and ash contents reflect harvest conditions. The design and operation of harvesting machinery would affect the amount of trash and dirt brought in from the field with the grain.

The grain dust (including trash) had about 75 percent as much protein as the grain it came from. The low feed value of dust was primarily due to its high ash content. If dirt were not present, the protein content would be 5-10 percent higher.

The trace element (mineral) content was generally higher in dust than in grain. This could be important if the elements were in a form that is available to livestock.

Energy contents (heat of combustion) of the dusts were lower than those for conventional fossil fuels. However, the energy content of dusts with low ash contents were comparable to that of wood. Because dust consists of finely divided particles, it is in a form that is desirable for fast energy release.

The qualities of grain dust are sufficiently valuable to justify a more detailed study.

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