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Dust Supression Results with Mineral Oil Applications for Corn and Milo

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ABSTRACT

The Texas Agricultural Experiment Station, Department of Agricultural Engineering has been involved in research with a goal of reducing the probability of grain dust explosions in grain elevators. One of the most attractive technologies for reducing grain dust explosions is suppressing dust in grain by mineral oil application. This project involved the addition of mineral oil to milo and corn at five different application rates. The mineral oil dust suppression effectiveness was determined for four dust concentration levels. Dust suppression effectiveness was based on the percentage of dust in different size ranges captured for the various mineral oil application rates. Overall, the optimum mineral oil application rates for milo and corn were 100 and 200 ppm, respectively.

INTRODUCTION

Grain dust explosions occur when four ingredients are present simultaneously: 1) fuel, 2) oxygen, 3) ignition source, and 4) containment. If any of these four ingredients can be eliminated, the probability of a dust explosion can be reduced. Oxygen and containment will be present in any grain handling facility. Ignition sources can be controlled to a great extent with a well organized and enforceable safety program, but chances of accidental or inadvertent ignitions still exist.

To fuel a grain dust explosion, grain dust (less than 100 microns in aerodynamic diameter) must be in suspension at or above the minimum explosive concentration (MEC). The MEC for grain dust will vary depending upon moisture content, particle size distribution (PSD), and the ratio of inert and organic dust. A commonly accepted value for the MEC of grain dust is 50 g/m^3 (Palmer, 1973).

There is a misconception that dust control systems at grain elevators are designed to separate and capture all of the dust in grains. In reality these systems are designed to minimize dust entrainment into work areas within the elevator. Wade and Hawk (1980) determined dust concentrations inside the confined volume of bucket elevators while grain was being handled and noted that the operation of dust control systems had no measurable effect on the dust concentrations internal to the elevator legs.

Grain dust is normally present in all grains at varying concentration levels. Grain handling systems typically increase the dust content of grain due to rapid movement which produces broken kernels which are converted into dust. Parnell (1985) reported the dust concentrations of wheat increased from 0.1% to 0.5% by weight between arrival at the elevator and departure from the elevator. Samples obtained at transfer points in grain handling facilities have been shown to contain dust concentrations varying from 0.04% to 0.13% by weight (Schnake, 1981). More typically, dust concentrations in grain will range from 1 to 5 kg/Mg or 0.11% to 0.55% by weight (Schulman, 1983). Bucket elevators typically move from 125 to over 1 000 Mg/h. Due to the volumes of grain being conveyed, large amounts of grain dust have the potential of being entrained in confined spaces. For example, suppose that an elevator leg with an internal volume of 10 m^3 is capable of moving 250 Mg/h of grain with a dust concentration of 2 kg/Mg. Only 500 g of dust at any point in time would be sufficient to provide the MEC for this leg. Hence, only 0.1% of the dust handled per hour would be sufficient to achieve the MEC for a 10-m^3 leg.

Good housekeeping has long been considered the only solution to dust control (Theimer, 1972; Marshall, 1983; NMAB, 1982). Schulman (1983) however, demonstrated that layered dust was not essential to produce a secondary explosion. Dust from the initial explosion may be carried into an otherwise clean area and fuel a secondary explosion. The significance of this phenomenon is the implication that a seemingly clean elevator (except for the confined space of the initial explosion) can have a disastrous series of explosions with fuel provided by the legs, bins, or enclosed conveyors.

Since fuel for a grain dust explosion is dust in suspension at concentrations at or above the MEC, a logical approach to reducing the probability of a dust explosion is to minimize the occurrences of a MEC. This can only be accomplished by the application of engineering methods such as ventilation system design and/or dust suppression.

The Food and Drug Administration (FDA, 1982) has given the approval for the use of a white food-grade mineral oil as a dust control agent for commodity seed (21 CFR 172.878) stored in grain elevators. In 1982, the FDA issued a ruling that allowed white food-grade mineral oil application to wheat. This ruling was later modified to include all commodity seeds. The concentration limits for the mineral oil were set at 0.02%

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(200 ppm) by weight for grain subject to human consumption and 0.06% by weight for grain destined for animal consumption.

White food-grade mineral oil was defined in 21 CFR 172.878 as "a mixture of liquid hydrocarbons essentially paraffinic and napthenic in nature obtained from petroleum". The food-grade mineral oil must go through several stages of cleaning and must meet specific test requirements and specifications before it is said to be "grain safe" (McIlveen, 1984).

The use of a control agent like mineral oil is a promising alternative to large expensive dust collection systems. Lai and Martin (1982) did a large scale study at the U. S. Grain Marketing Research Laboratory in Manhattan, Kansas for treated and untreated corn, wheat, and soybeans using the suppression additives of water, deodorized soybean oil, and mineral oil. The oil was applied at the first transfer point on both the bottom and top of the grain by an automatic spray unit. They found that an oil additive level between 0.02% and 0.05% by weight was optimal and grain dust entrained in the air could be reduced 71% when an oil additive was used (Lai and Martin, 1982). Dust on the gallery floor was reduced by more than 90% at an application rate of 0.03% by weight of soybean or mineral oil. A hydrocarbon based textile oil added to wheat reduced the dust level up to 59% at an application rate of 700 ppm. But, the application of higher concentrations of oil did not further reduce dust levels. Significant reductions have also been noted with corn and soybean dust (Cocke et al., 1978). No adverse effects were detected after 12 months of storage (Pomeranz, 1981). The functional (milling and breadmaking) properties of wheat were unchanged and no evidence of oxidative or hydrolytic rancidity were found with mineral oil applications to grain (Lai et al., 1981).

Dust suppression using mineral oil offers other advantages to grain storage and processing operators. Using mineral oil at the levels cited earlier can likely reduce the incidence of dust explosions and provide a cleaner working environment. Workers involved in grain elevators reported obvious differences when moving oiled and unoiled grain and were enthusiastic about the use of mineral oil on grain (Goforth et al., 1985). An average worker will inhale about 4 to 10 m^3 of air during an 8-h work shift (Peterson, 1977). If the amount of respirable dust (dust less than 10 microns) can be reduced, the working environment of grain handling facilities will be improved and it will be less likely that employees will develop respirable diseases.

The suppression of smaller size dust particles by oiled grain provides an ideal situation for reducing the incidence of dust explosions and improving the working environment of grain handling facilities. Plemons and Parnell (1981) found that the smaller grain dust fractions remain entrained in the air longer, increasing the probability of a MEC occurring. If the oiled grain can decrease the amount of smaller particles entrained in the air, the probability of reaching the MEC can be reduced.

Objective

The ultimate goal of this research was to reduce the incidence of grain dust explosions. An underlying objective was to enhance the environment of workers by reducing the respirable dust content in the air of the grain handling facilities. The specific objective was to determine the amount of dust retained by corn and milo as a result of treatment with mineral oil levels of 0 ppm, 50 ppm, 100 ppm, 200 ppm, and 400 ppm at grain dust concentrations of approximately 0.0%, 0.10%, 0.25%, and 0.5% by weight.

METHODS AND MATERIALS

Milo and corn were tested to examine the dust suppression characteristics of adding mineral oil to grain. Mineral oil was added to the grain samples at five different levels: 0 ppm, 50 ppm, 100 ppm, 200 ppm, and 400 ppm. Grain dust was subsequently added to the grain at concentrations that corresponded to 0.0%, 0.1%, 0.25%, and 0.5% by weight of the grain. To insure consistency, the grain dust type was the same as that of the source grain, i.e., corn dust was added to corn. The amount of dust adhering to the grain was determined in order to define the relationship between mineral oil levels and dust retention from which the optimal mineral oil application rate for dust retention could be determined.

Sample Preparation

Milo and corn were obtained from local feed distributors. Approximately 68.1 kg of each grain was cleaned using a Sweco Vibro- Separator with a 2 449 - μm screen. The mass concentration (MC) of residual dust in each of the grains were determined. Milo and corn contained 0.11% and 0.20% residual dust, respectively. Each grain type was divided into five 9.08 kg samples representing five treatments.

Each of the samples were prepared using a mixing box constructed of wood and powered by a 93.25 W motor with a speed reducer to produce 6.1 J of torque. The mixing box was painted with a latex paint to prevent absorption of mineral oil into the walls of the box. The mixing box had a volume of 0.038 93 m^3. Due to the small amount of surface area associated with the mixing box, compared to the total grain surface area, the mineral oil losses on the walls were considered negligible.

Mineral Oil Preparation and Addition

The exact amounts of mineral oil referred to above were added to the 9.08 kg grain samples using the following procedure. The mineral oil was measured with a pipet and placed into a flask. It was subsequently diluted with 25 mL of hexane before it was added to the grain. The addition of hexane had a two-fold purpose. First, the hexane facilitated the removal of the small amounts of oil normally left on the flask used to measure mineral oil. Second, the hexane aided in uniform mixing of the mineral oil with grain. Hexane was used as the diluting agent because it readily dissolved the mineral oil and quickly evaporated after mixing. The mineral oil and hexane mixture was added in four equal parts. After the addition of each part, the mixing box was rotated for 5 min at a rate of 40 rpm. The total mixing time was 20 min. At the completion of the mixing process, the lid was opened to allow the hexane to completely evaporate.

Grain Dust Preparation and Addition

Milo and corn screenings were obtained from terminal elevators in Texas. The grain dust was sieved through a 100-μm screen using a Tyler Portable Sieve Shaker and the particle size distribution (PSD) of the dust was determined.

The grain samples which were mixed with mineral oil were separated into 20-454-g samples and placed in plastic containers. Grain dust less than 100 μm was added to the grain samples to obtain approximate dust concentrations of 0.0%, 0.1%, 0.25%, and 0.5% by weight of grain. Each 454-g oiled grain sample and its corresponding dust was subsequently tumbled for 15 min at a rate of 40 rpm.

Tumbler Box Air Wash Procedure

Following the 15-min mixing period, each container was subjected to the tumbler box air wash. The air wash tumbler box was constructed of plexiglas and had a volume of 4.48 L with the sides having 20% open area. Each of the 454-g grain samples were placed in the air wash tumbler box and tumbled for 3 min at 40 rpm. Free dust, dust not adhering to the grain, was removed from the sample by transferring air through the sample at a rate of 18.9 L/s. The free dust removed by the air wash was captured on a 20.32 cm by 25.4 cm preweighed filter. The mass of free dust obtained from a sample was divided by the mass of the sample to obtain a MC of free dust in the sample. A PSD of the free dust captured on the preweighed filter was obtained using the Coulter Counter Model TAII (Coulter Counter, 1980). The MC of the filter dust was multiplied by its corresponding differential PSD to obtain the mass concentration particle size distribution (MCPSD) of the free dust in the grain.

MCPSD Procedure

The MC and PSD of the dust retained by the grain were found using the Coulter Counter Model TAII. The techniques associated with the Coulter Counter and MCPSD procedure are summarized as follows: 1) The grain dust retained by the grain was separated from a grain sample by washing the grain with prefiltered electrolyte. An ultrasonic bath was used to aid in the separation of the particles from the grain; 2) The electrolyte-dust solution was passed through a 100-μm screen and the filtrate saved; 3) The Coulter Counter TAII was calibrated using particles of known size; and 4) The total volume of dust in the filtrate was measured and the MC of the captured dust was calculated.

The final step in the MCPSD procedure was to obtain a PSD of the grain dust filtrate using the Coulter Counter procedure outlined in the owner's manual (Coulter Counter, 1980). A PSD yields a percentage of dust in each of 15 size ranges (channels). The MC of the dust captured on the grain was multiplied by the differential PSD values associated with the dust captured on the grain to produce a MCPSD of dust retained by the grain. This procedure provides a means of measuring the grain dust fractions present in oiled and unoiled grain samples. Parnell et al. (1982) found the procedure to yield repeatable results for the mass of dust present in cotton lint fiber. A more detailed explanation was described by Jones (1986).

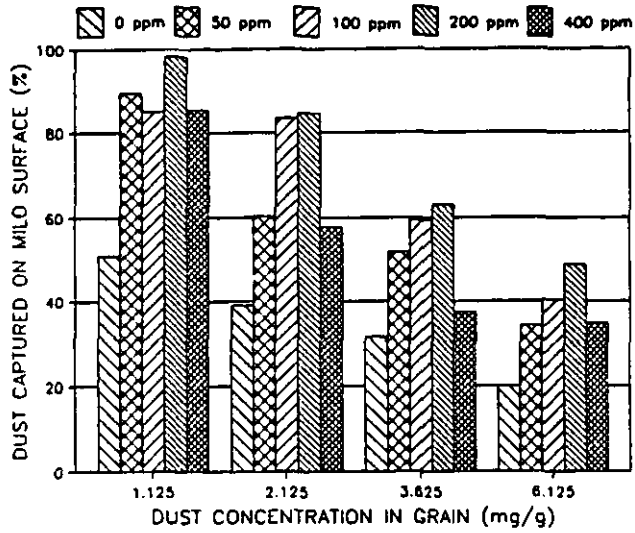

Fig. 1—Percentage of dust captured on milo surface.

RESULTS

The corn and milo used in this experimentation had residual dust levels of 2.0 mg/g and 1.125 mg/g, respectively, following the sieving process with the Sweco Vibro-Separator. The comparison of the milo capture percentages suggested that as the dust concentration in the grain increased, the capture percentages decreased (Fig. 1). For example, at the 200 ppm oil level, the capture percentage decreased from 98.36% for a dust concentration of 1.125 mg/g to 48.8% as the dust concentration increased to 6.125 mg/g. However, the 200 ppm oil level consistently demonstrated the highest capture percentage when compared to other application rates for milo. This suggests that increasing the oil concentration level above 200 ppm for milo will not increase the amount of dust suppressed per unit mass of grain. However, the increase in the quantity of dust captured per unit mass of grain by increasing the mineral oil application rate from 100 to 200 ppm was not significant (Table 1). For example, at the 0.10% dust level, the quantity of dust captured per unit mass of grain only increased from 1.77 to 1.80 mg/g as the mineral oil application rate increased from 100 to 200 ppm, respectively. Therefore, the 100 ppm mineral oil application rate would likely achieve the optimum economical dust suppression benefits for milo.

The dust capture percentage for corn at the various oil levels steadily decreased as the dust concentration levels increased (Fig. 2). In comparing the different oil levels at a particular dust concentration, a trend could be seen where each increase in oil level produced an increase in the dust capture percentage except in the case of the 4.5-mg/g dust concentration level. At the 4.5-mg/g dust concentration, the 200-ppm oil application rate retained a dust concentration of 3.96 mg/g while the 400-ppm oil application rate retained a dust concentration of 3.77 mg/g (Table 2). Even though the 200-ppm oil application rate captured more dust per unit mass of grain than the 400-ppm oil application rate at the 4.5 mg/g dust concentration, the 200-and 400-ppm application rates retained approximately the same amount of dust per unit mass of grain at the 2-, 3-, and 4.5-mg/g dust concentration levels. However at the

TABLE 1. Summary of the mean mc values for milo dust captured on the milo surface

Mineral Oil Application Rate (ppm)	Total Dust Level Percent (%)	Total Dust Level Actual (mg/g)	Mass Concentration* Milo Dust (mg/g)
0	0.00	1.125	0.57
0	0.10	2.125	0.83
0	0.25	3.625	1.15
0	0.50	6.125	1.23
50	0.00	1 125	1.01
50	0.10	2.125	1.28
50	0.25	3.625	1.88
50	0.50	6.125	2.10
100	0.00	1.125	0.96
100	0.10	2.125	1.77
100	0.25	3.625	2.15
100	0.50	6.125	2.47
200	0.00	1.125	1.11
200	0.10	2.125	1.80
200	0.25	3.625	2.29
200	0.50	6.125	2.99
400	0.00	1.125	0.96
400	0.10	2.125	1.23
400	0.20	3.625	1.36
400	0.50	6.125	2.13

* Each value is an average of three repetitions

TABLE 2. Summary of the mean mc values for corn dust captured on the corn surface

Mineral Oil Application Rate (ppm)	Total Dust Level Percent (%)	Total Dust Level Actual (mg/g)	Mass Concentration* Milo Dust (mg/g)
0	0.00	2.0	1.29
0	0.10	3.0	1.47
0	0.25	4.5	1.78
0	0.50	7.0	1.44
50	0.00	2.0	1.54
50	0.10	3.0	1.87
50	0.25	4.5	2.34
50	0.50	7.0	2.89
100	0.00	2.0	1.63
100	0.10	3.0	2.01
100	0.25	4.5	2.69
100	0.50	7.0	2.78
200	0.00	2.0	1.92
200	0.10	3.0	2.81
200	0.25	4.5	3.96
200	0.50	7.0	4.12
400	0.00	2.0	1.99
400	0.10	3.0	2.83
400	0.20	4.5	3.77
400	0.50	7.0	5.50

* Each value is an average of three repetitions

7.0-mg/g dust concentration level, the 200-and 400-ppm oil application rates retained a dust concentration of 4.12 and 5.50 mg/g, respectively. Therefore, at the 7.0-mg/g dust concentration level, there is a significant difference between the dust captured per unit mass of grain with a 200-and 400-ppm oil application rate.

In comparing the capture percentages of mineral oil levels on milo and corn, the observation can be made that oiled grain retains more dust when the grain is corn rather than milo. For example, the maximum dust concentration retained on the milo surface was 2.99 mg/g at the 200-ppm oil application rate with a total dust concentration of 6.125 mg/g. The maximum dust concentration retained on the corn surface was 5.5 mg/g at the 400-ppm oil application rate with a total dust concentration of 7.0 mg/g. This data illustrates that the mineral oil captured of 7.0 mg/g. This data illustrates that the mineral oil captured 2.5 mg/g more dust on the corn than on the milo at the highest dust concentration in the grain. Therefore, the quantity of free dust in oil treated milo will generally be greater than the quantity o free dust in oil treated corn (Table 3).

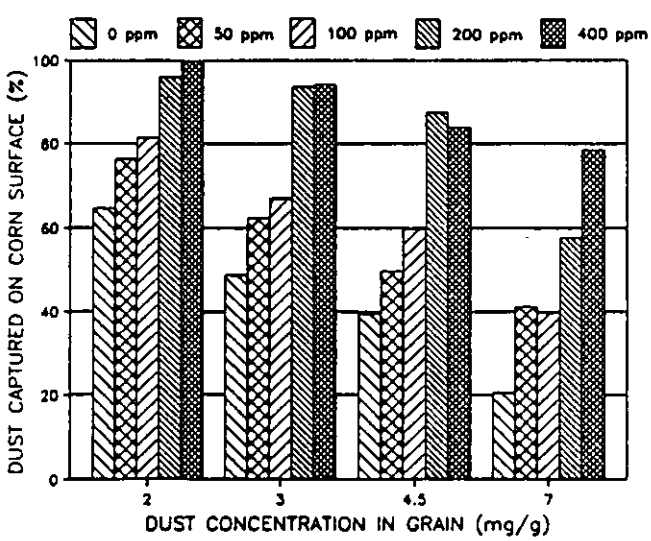

Fig. 2—Percentage of dust captured on corn surface.

TABLE 3. Summary of the mean free dust mc values for corn and milo

Mineral Oil Application Rate (ppm)	Total Dust Level (%)	Mass Concentration* Corn Dust (mg/g)	Mass Concentration* Milo Dust (mg/g)
0	0.00	0.18	0.30
0	0.10	0.65	0.76
0	0.25	1.35	1.61
0	0.50	3.07	3.27
50	0.00	0.15	0.05
50	0.10	0.45	0.40
50	0.25	0.94	1.21
50	0.50	1.98	2.77
100	0.00	0.12	1.04
100	0.10	0.29	0.43
100	0.25	0.73	1.20
100	0.50	1.91	2.82
200	0.00	0.08	0.05
200	0.10	0.20	0.53
200	0.25	0.58	1.33
200	0.50	1.44	2.84
400	0.00	0.19	0.05
400	0.10	0.20	0.37
400	0.20	0.45	0.96
400	0.50	1.04	2.26

* Each value is an average of three repetitions

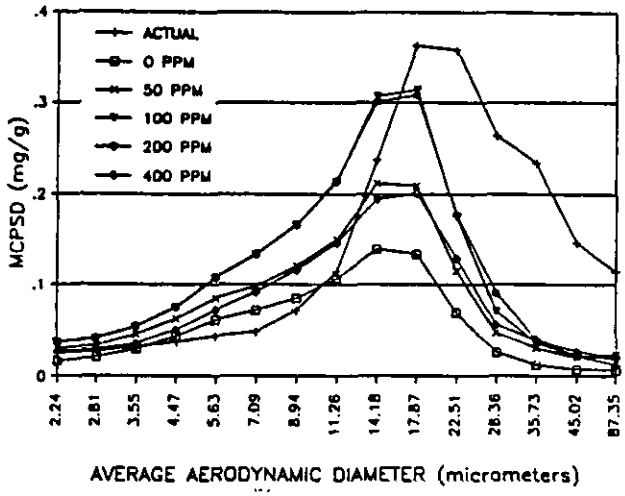

Fig. 3—MCPSD for milo dust (1.125 mg/g residual + 1.00 mg/g added).

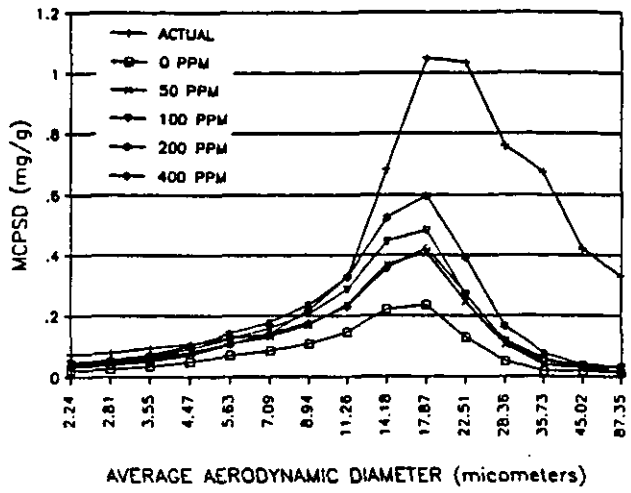

Fig. 5—MCPSD for milo dust (1.125 mg/g residual + 5.00 mg/g added).

The best method for determining the optimum oil application rate is to plot the mass concentration particle size distribution (MCPSD) for each combination of oil application rate, dust concentration and grain (Fig. 3-8). The actual (ACT) dust level illustrates the total dust concentration level in the grain which includes the sum of both the residual dust and the added dust. The ACT curve is the MCPSD of the actual dust in the grain. The ideal capture curve would be a MCPSD that exactly overlays the ACT curve. The area under the ACT curve which is not contained under a particular oil application rate MCPSD defines the amount and particle size distribution of the free dust available to be entrained into the air at that particular oil application rate. For example, the area under the ACT curve not contained under the 100 ppm MCPSD curve characterizes the quantity and particle size distribution of the free dust contained in the grain when oil is applied to the grain at a rate of 100 ppm.

At the 2.125-mg/g dust concentration level in milo, the MCPSD of dust captured by a 100- or 200-ppm application rate were similar (Fig. 3). In addition, the MCPSDs for the 400-ppm and 50-pm application rates were similar. These results suggest that one should not apply more than 100 ppm mineral oil to milo. The 3.625-mg/g dust concentration level yielded similar results to the 2.125-mg/g dust concentration level (Fig. 4). However, at the 6.125-mg/g dust concentration level, the 200-ppm oil application rate exhibited a slight increase in the retained dust concentration (Fig. 5). Even though the 200-ppm oil application rate captured the most dust at the 6.125-mg/g dust concentration level, the 100-ppm oil application rate would likely achieve the optimum economic dust suppression benefits for milo.

The 200-and 400-ppm mineral oil application rates on corn exhibit similar MCPSD curves at a dust concentration of 3.0 mg/g, with the 400-ppm oil application rate having a slightly greater capture area (Fig. 6). At the 4.5-mg/g dust concentration level, the 200-ppm oil application MCPSD curve was above the 400-ppm oil application MCPSD curve (Fig. 7). At the 7.0-mg/g dust concentration level, the 400-ppm mineral oil application rate captured the greatest percentage of the actual dust in the grain (Fig. 8). The 200-and 400-ppm oil application rates exhibit similar dust suppression capabilities until the dust concentration

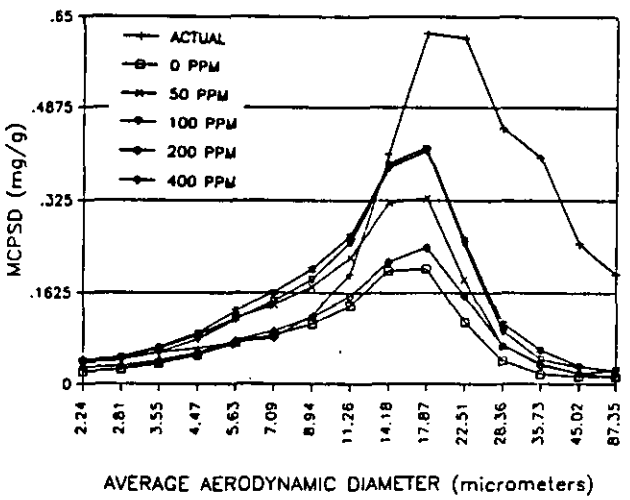

Fig. 4—MCPSD for milo dust (1.125 mg/g residual + 2.5 mg/g added).

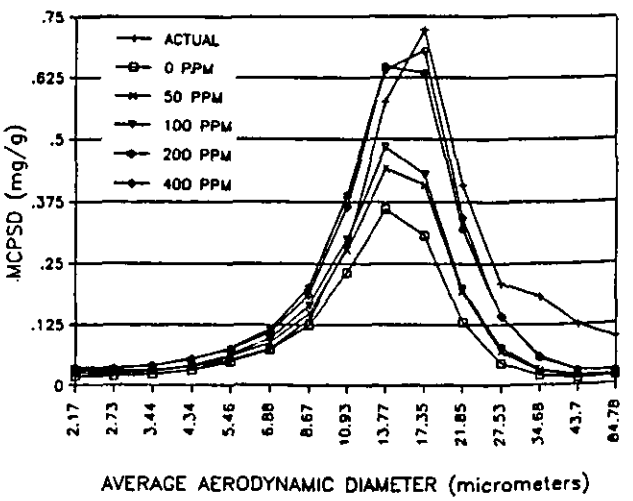

Fig. 6—MCPSD for corn dust (2.00 mg/g residual + 1.00 mg/g added).

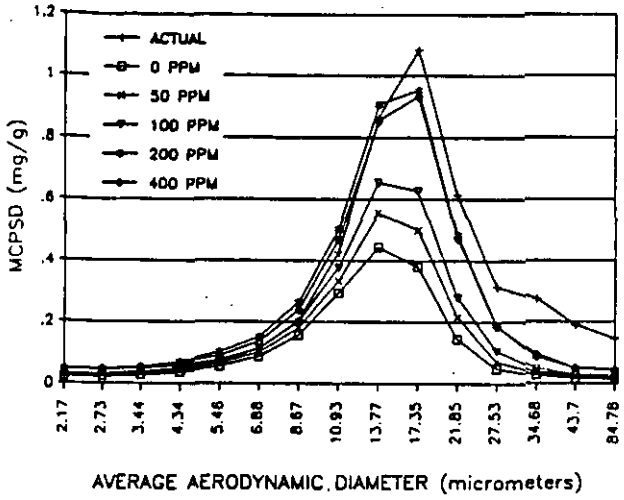

Fig. 7—MCPSD for corn dust (2.00 mg/g residual + 2.5 mg/g added).

reaches 7.0 mg/g. At the 7.0-mg/g dust concentration level, the 400-ppm oil application rate demonstrates the maximum dust suppression capability. Even though, the 400-ppm oil application rate exhibits the maximum dust suppression capability at the 7.0-mg/g dust concentration level, the 200-and 400-ppm oil application rates exhibit almost identical dust suppression capabilities at the other dust concentration levels. Therefore, the 200-ppm oil application rate would likely provide the optimum economic dust suppression benefits for corn.

The mass median diameter (MMD) of the dust retained on the surface of corn and milo was smaller than the MMD of the dust added to the grain. This was illustrated by comparing the ACT curve to the MCPSD curves. The ACT curve had a larger mass median diameter than the MCPSD curves (Fig. 3). This suggests that the amount of smaller dust particles remaining as free dust was significantly reduced. The corn data revealed that 35.6% of the dust-retained on the surface was less than 10 μm, and the amount of dust less than 10 μm remaining as free dust was 28.9%. This demonstrates a significant decrease in the amount of dust less than 10 μm. Similar results were illustrated with milo where 46.8% of the dust retained on the grain was less than 10 μm compared to 33.7% as free dust.

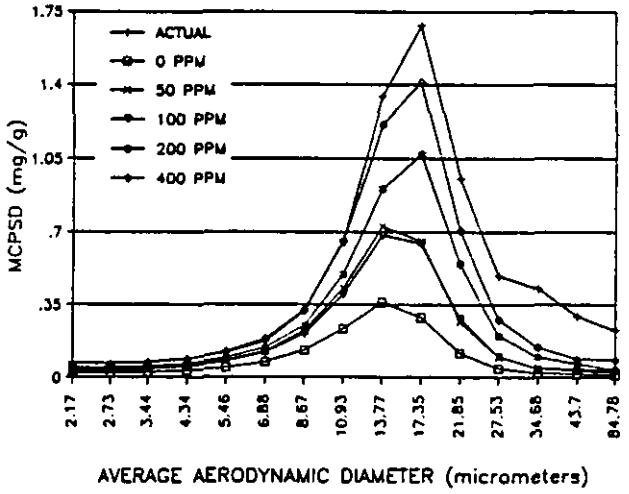

Fig. 8—MCPSD for corn dust (2.00 mg/g residual + 5.00 mg/g added).

CONCLUSIONS

Research into the dust retention capabilities of corn and milo treated with mineral oil has provided new information about the dust retained on the surface of these grains. The dust retained on the grain and the free dust remaining in the corn and milo were determined in order to evaluate the effectiveness of different mineral oil application rates. The particle size distributions of free dust and dust captured (suppressed) on the grain surface were evaluated. MCPSD curves were developed from the test results to determine the benefits of adding different application rates of mineral oil.

The significant findings of this research are summarized as follows:

1. Results of the test performed on corn suggest that increased oil application rates above the FDA approved 200-ppm level will decrease the free dust for corn with high dust concentrations (7 mg/g). However at dust concentrations equal to or less than 4.5 mg/g, a 200-ppm application rate is as effective as the 400-ppm rate.

2. The results of the tests performed on milo indicated that an application rate of 100 ppm was the most economical application rate. A small but insignificant increase in dust retained on the grain surface can be acheived by increasing the application rate to 200 ppm. In addition, application rates exceeding 200 ppm have detrimental effects on the dust suppression system for this grain. The 400-ppm application rate had an MCPSD very similar to the 50-ppm rate.

3. Further evaluation of the results from corn and milo illustrated that the corn surface retained approximately 83.8% of the available dust in the grain samples, whereas milo retained 73.7%. It was noted that corn retained more of its available dust than milo.

4. A large percentage of the smaller dust fraction was retained on the surface of the oiled grain. This result suggests that there would be less respirable dust entrained in the air at grain transfer points with mineral oil applications to grain. Hence, the amount of respirable dust which workers are subjected to will decrease, providing a safer working environment for employees and reducing the probability of workers developing respiratory problems.

5. The results of the tests performed on corn and milo indicate a reduction in the amount of smaller particles in the free dust. This suggests that the smaller particles, which are more explosive, are being retained on the grain surface. The decrease in the small dust particles that can potentially be entrained in the air will likely reduce the probability of dust explosions.

6. A significant result of this research effort was the development of a procedure and technology that can be used to precisely measure the effectiveness of dust suppression with mineral oil.

7. The concept of applying mineral oil to grain to suppress dust at grain transfer points offers the most economical and attractive approach to preventing grain dust explosions.

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