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## **Modeling of Grain Dust Emissions and Depositions during Water Mist Applications.**

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### ABSTRACT

Whenever bulk grain is dropped, mixed or tumbled, dust particles enter the air streams and produce clouds of dust. Grain dust clouds are a nuisance and health risk to workers and a potential fuel source for fires and explosions. Direct applications of oil and water to grain are effective in reducing grain dust emissions. Water misting can be used to confine and suppress dust clouds and emissions, however, its effectiveness and optimum application requirements are unknown.

The purpose of this paper is to model airflow and dust-mist particle movements using a computational fluid dynamics software. Modeling was used to simulate ambient air conditions and induced airflow from a water-mist system at steady-state conditions. Four models were presented which estimate air-flow patterns and dust movement from a grain receiving hopper. The air velocity from the dust source was tried at 1.1 and 2.0 m/s. Once the air velocity profiles were determined, the model used particle tracking to estimate emissions and depositions of particles. The 10-50 microns particles were the source of airborne emissions for this example. The larger particles settled to the floor. The induced air from the fine spray reduced the path height of the escaping particles, but the particles still escaped.

Near the tip of the spray nozzles, the drop velocities and concentration are greater than the dust velocities and concentration. The potential for collisions between drops and particles was investigated and appeared to be low. Several potential scenarios were considered and were based on the drop flux density and sphere of influence.

**KEYWORDS:** grain dust, air flow patterns, misting systems

### INTRODUCTION

Many factors can effect the amount of dust produced during grain handling such as the grain type, type of drying, handling method, etc. Corn tends to produce the most dust among grain. The dust collected by the pneumatic system on the bucket elevator ranged from 0.05% to over 0.2% by weight from corn after drying treatments and repeated handling (Converse and Eckhoff, 1989). Wheat emitted 0.001% to 0.004% dust from grain receiving operations (Noyes and Kenkel, 1994).

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The problems created by grain dust range from minimal to extreme. Grain dust problems include housekeeping which affects insect infestations and grain quality deterioration. Workers exposed to dusty environments can develop respiratory problems. High concentrations of grain dust in confined machinery provide fuel for a potential fire or dust explosion which might be caused by rubbing parts or welding repairs.

Martin (1981) determined particle size distributions, densities, and compositional characteristics of corn, wheat, soybean, and sorghum dust samples. The median particle diameter ranged from 20 to 60 microns. For grain dust collected from a bag-house, 25% of the mass consisted of particles with diameters less than 11.5 microns and 50% had diameters less than 25.5 microns. The densities of grain dust samples ranged from 1.4 to 1.4 and averaged 1.5 grams/cc. The composition of the dust was roughly 65%-85% grain matter and the balance was water and foreign material. Corn dust contained less than 9% ash while one soybean dust sample was up to 40% ash.

Grain dust is controlled by several means. Dust concentrations in air are commonly reduced using pneumatic systems to collect the dust in cyclones and bag-houses. Handling techniques such as unloading from hopper bottom vessels or using choked grain-flow methods produce less dust. The direct addition of small amounts of oil to the grain stream has proven to reduce grain dust emissions significantly. Dust emissions were reduced on the gallery floor of a terminal grain facility by over 90% when 200 ppm of mineral oil was applied directly to the grain in the boot of the elevator (Lai et al, 1984).

As an alternative method for dust control, water-mist systems are being studied. The merits and potential benefits of these systems are being evaluated to help explain their functionality and potential effectiveness in suppressing emitted dust. Any water, which is added to the grain by this system, has to be insignificant, because direct application of water to grain for the purpose of adding weight is illegal (Federal Register, 1994).

## MATERIAL and METHODS

The water-mist system used in this research produced a distribution of fine drops from a high-pressure pump which forced water through a 200 microns (0.008") diameter nozzle. The pump pressure ranged from 1380 to 6900 kPa (200 to 1000 psi). The drop diameters were estimated by collecting samples of the plume on water sensitive paper. At 5500 kPa (800 psi) and 61 cm from the nozzle, 51% of the drops were greater than 100 microns and 21% were less than 50 microns in diameter. At 122 cm from the nozzle, over 60% of the drops were less than 50 microns.

ASAE standards (1992) define a mist as a spray which contains drops with a median drop diameter less than 50 microns. If a single 15 micron particle is injected into still air at 10 m/s, it will travel only 0.70 cm according to Stokes' drag forces. Also, a 10 and a 100 micron drop settled in still air at a rate of 0.3 and 24.8 cm/s, respectively (Hinds, 1982). In order for a 25 micron drop to travel over a meter in length, it needs to be propelled by air currents.

The fine spray in this study induced airflow. The high pressure system supplied the drops near the nozzle with high initial velocities for exchanging momentum with the air. Thus, the spray system behaves as a fan source as well as a source of drops. The induced airflow was observed with several methods. An anemometer measured air velocities around 1 m/s when positioned between two nozzles and outside the spray plume. Secondly, an air pressure front was measured within the spray plume using a pitot tube and a magnehelic pressure gage. With the pump pressure at 5500 kPa, the air pressures in the plume at 15 cm and 61 cm horizontally from the nozzle tip were 75 Pa and 7.5 Pa (0.30" H<sub>2</sub>O and 0.03" H<sub>2</sub>O), respectively. Finally, smoke was injected underneath the spray plume. The smoke did not pass through the spray plume but was redirected (fig 1). If airflow were not present, then a portion of the smoke would pass through the spray.

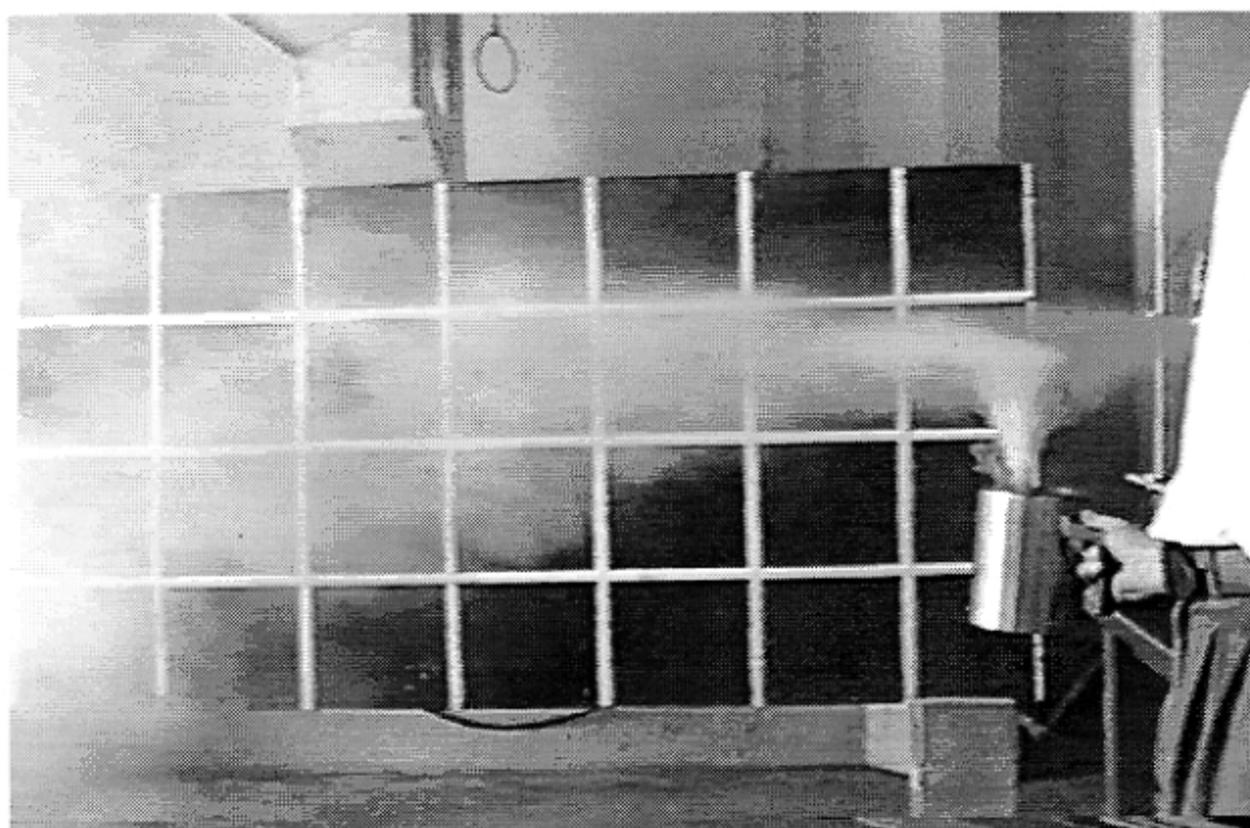


Figure 1. Fine spray plume with smoke added underneath.

### Airflow Modeling

Modeling of grain handling, airflow, and dust emissions was done in several steps. A two dimensional geometry was defined which represented a portion of the receiving area in a grain elevator. The airflow interactions between spray induced air and ambient conditions were modeled with computational fluids dynamic software, CFD (Fluent Inc., 1996). Dust particles were tracked through the geometry of the resulting air velocity profiles.

CFD is a numerical technique developed to study fluid flows and heat transfer (Patankar, 1980). Being a numerical technique, the geometry was subdivided into 4092 discrete

control volumes. The equations for the conservation of mass and momentum of the fluids were applied to each control volume and between control volumes. Conservation of mass or momentum can be physically described as the change in mass or momentum stored in the volume versus the flux entering and exiting the boundaries.

While using the CFD package, the geometry was defined and the grid lines were laid. A view of the geometry and grid is shown in fig. 2. The geometry was two dimensional with a 3.6 m x 3.6 m overall size. The grid was refined in the region of greatest interaction of spray and dusty air. Some grids are as small as 1.3 cm x 2.6 cm while the larger grids are 10 cm x 10 cm. The same geometry was used for all cases described.

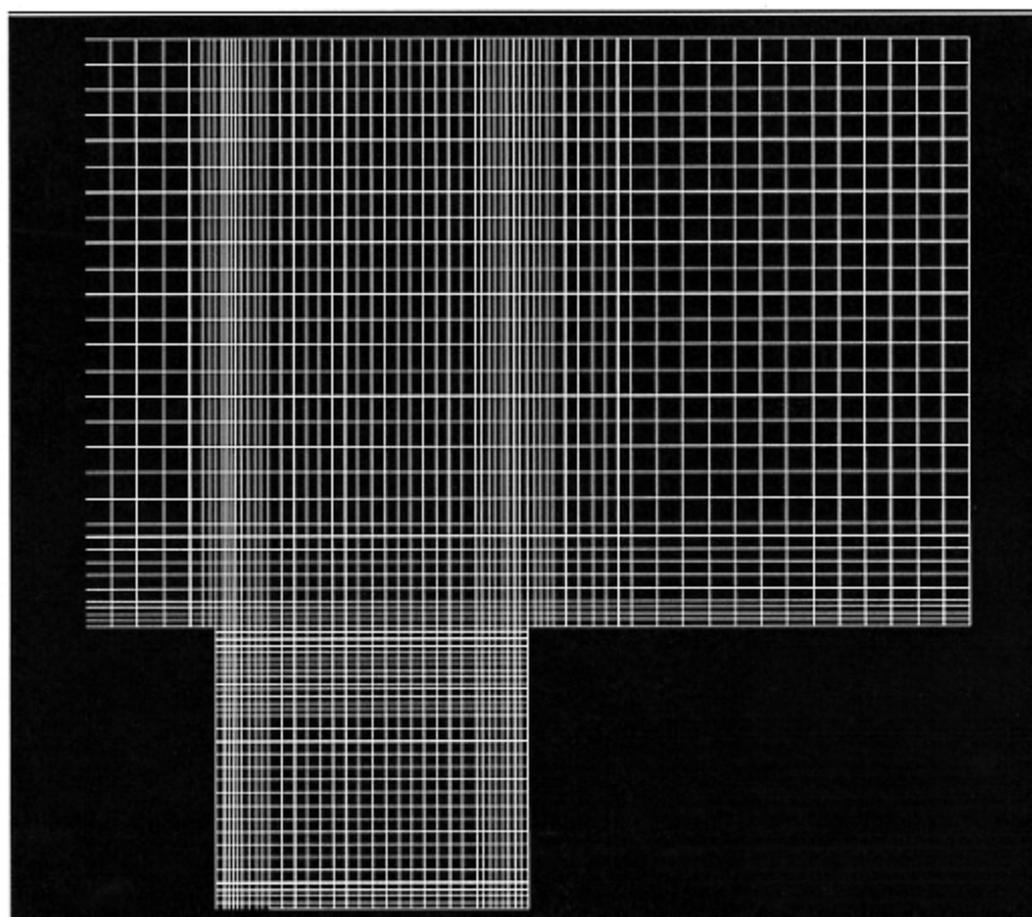


Figure 2. Geometry and grid for modeling.

Four cases were considered. The ambient airflow crossing a receiving pit varies with the prevailing winds and is commonly 0 to 3 m/s. The ambient cross-flow of air in the upper section was set at 0.9 m/s in all cases. Two models represented the control situations or no-spray and two models included the fine-spray induced airflow. Dust and air velocities of 0.5 to 2 m/s were measured at the edge of a receiving pit while grain was being dumped. For all models, the dust source entered through an 20 cm wide opening located at the lower left of the bottom section. Two air velocities, 1.1 and 2.0 m/s, were used for carrying dust.

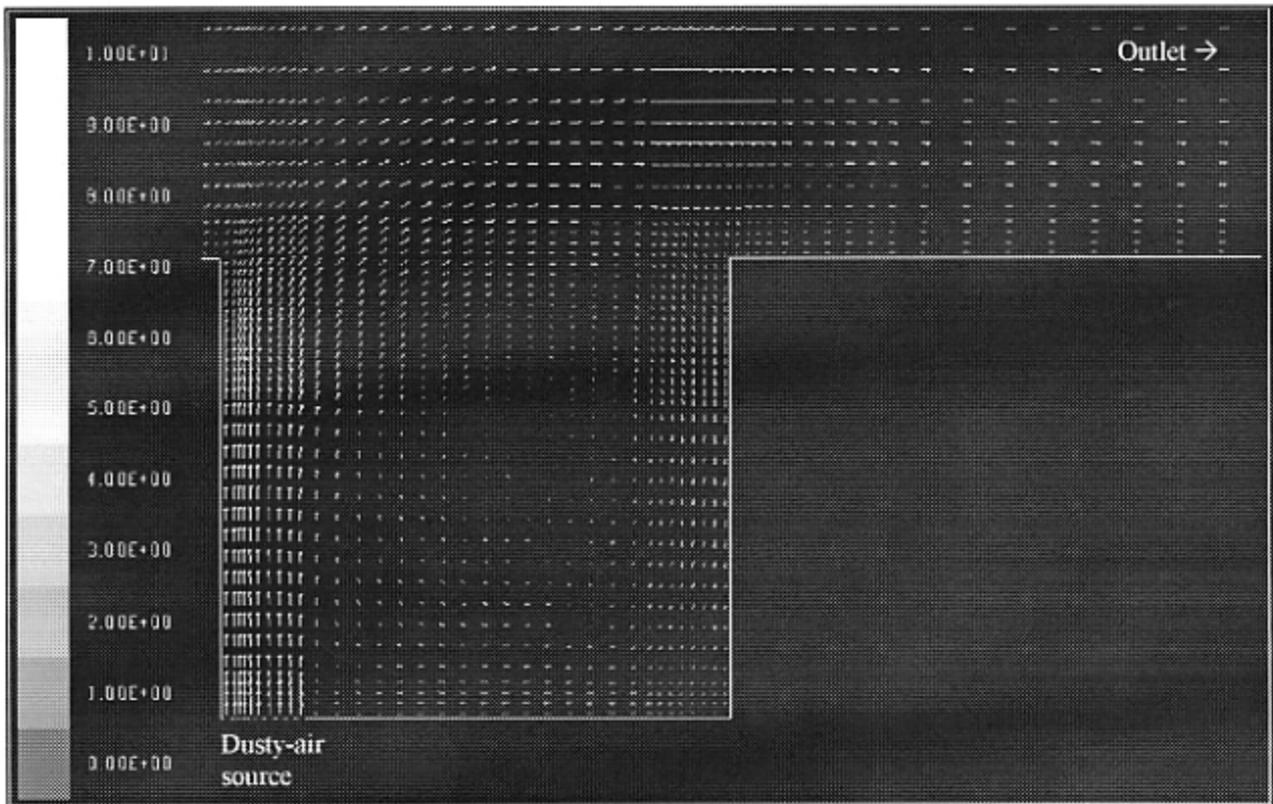


Figure 3. Air Profile for Control Case with 2.0 m/s dusty air. Scale in ft/s.

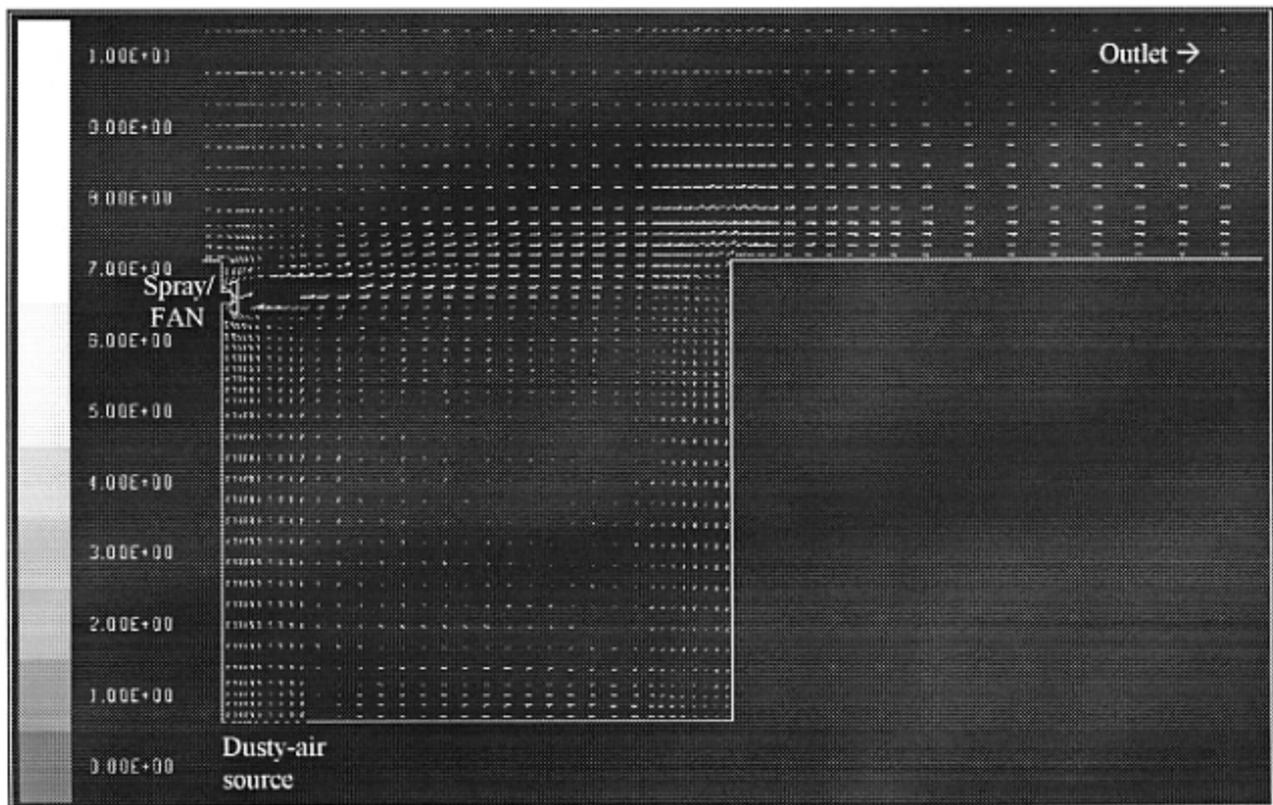


Figure 4. Air Profile for Spray Case with 1.1 m/s dusty air. Scale in ft/s.

The fine spray was modeled as a fan and as a separate dispersed phase. The fan pressure was set at 35 Pa and the exiting velocity was set at 7.6 m/s. These were similar to observed values. The fan was located at the middle-left edge of the geometry (fig. 4). The fan width was 10cm.

Particle trajectories are based on the balance of forces in the x and y axis. The main force on the particle was Stoke' drag. Stokes' drag is proportional to air viscosity, the relative particle-air velocity, and the particle's diameter. Gravitational force is included in the y-axis components of forces. The resulting particle trajectories vary because of the size of each particle and its initial location in the air velocity profile.

## MODELING RESULTS

The air profiles are given for the control case with 2.0 m/s dusty air and for the spray case interacting with 1.1 m/s dusty air (fig 3 & 4). In the airflow pattern of the control (fig. 3), the predominant jet was from the dust source and this jet followed the lower left wall vertically to the upper section. In the upper section, the ambient air interacted and combined with the incoming air. The resulting mixture curved towards the outlet or the right edge of the geometry.

For the airflow profile with the spray induced air (fig. 4), the predominant air jet was from the spray nozzle and it was directed horizontally to the right. The maximum air velocity from the spray was 4.9 m/s near the nozzle and decreased to 2.1 m/s near the upper right corner of the lower section.

The particle tracking plots show the tracks for 10 and 50 micron dust particles that were initiated at 3 locations near the air source. The tracks that started near the wall resulted in higher escape heights. For tracks away from the wall, the particle entered slower air streams. The trajectories are based on mean air velocities. If air turbulence were included, the paths would be more varied with some of the 10 micron particle settling out.

These models predicted that the 10 micron particles tended to remain airborne after leaving the lower section while 50 micron particles settled to the floor or even back into the lower section. For the control plot with 1.1 m/s air, the 50 micron particles settled early. For the control plot with 2.0 m/s air, the particle tracks were higher and more widely dispersed, figs. 5 & 6.

During the spray simulation, fig. 7 & 8, the escape heights of the particles were reduced approximately 50% compared to the control. The 10 and 50 micron particles still escaped the lower section and the settling point was further down wind. The spray with the 1.1 m/s source resulted in the narrowest band of particle tracks and greatest potential for drop and particle interaction.

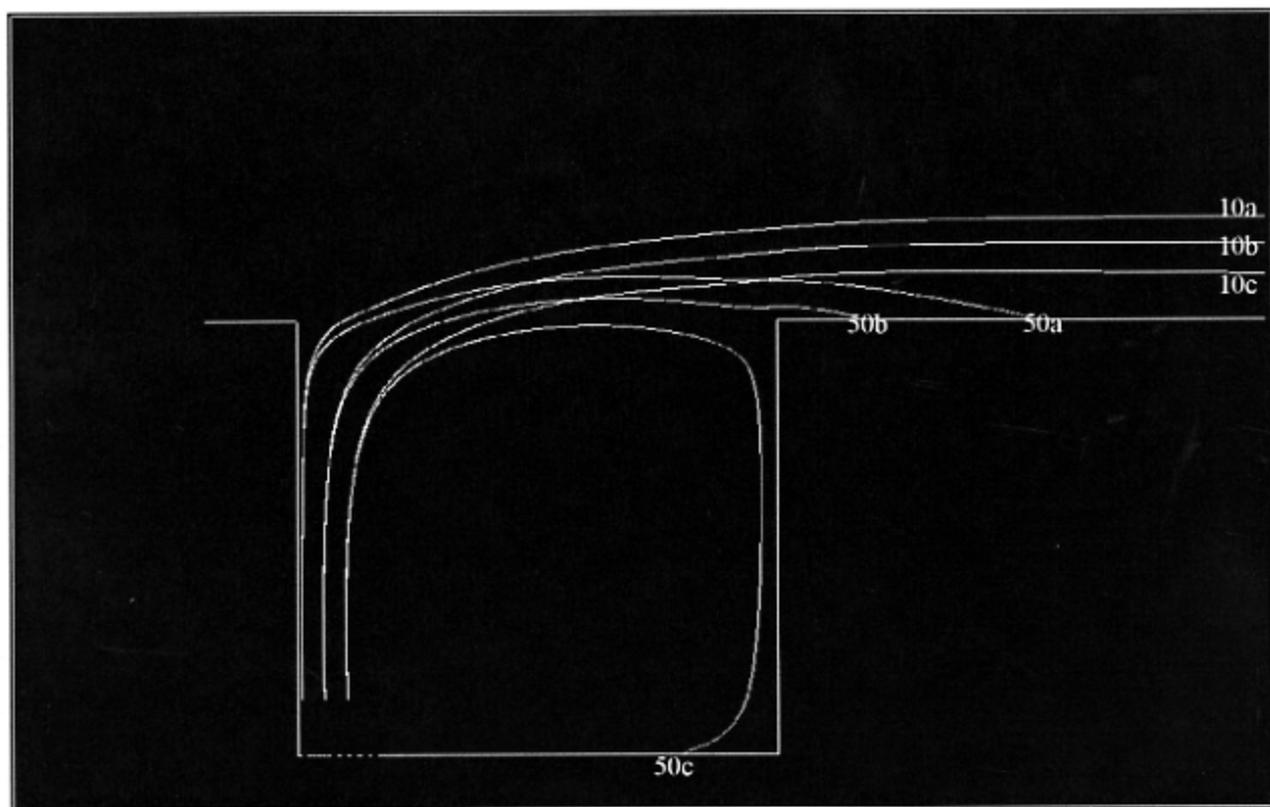


Figure 5. 10 & 50  $\mu\text{m}$  Particle Tracks for control at 1.1 m/s.

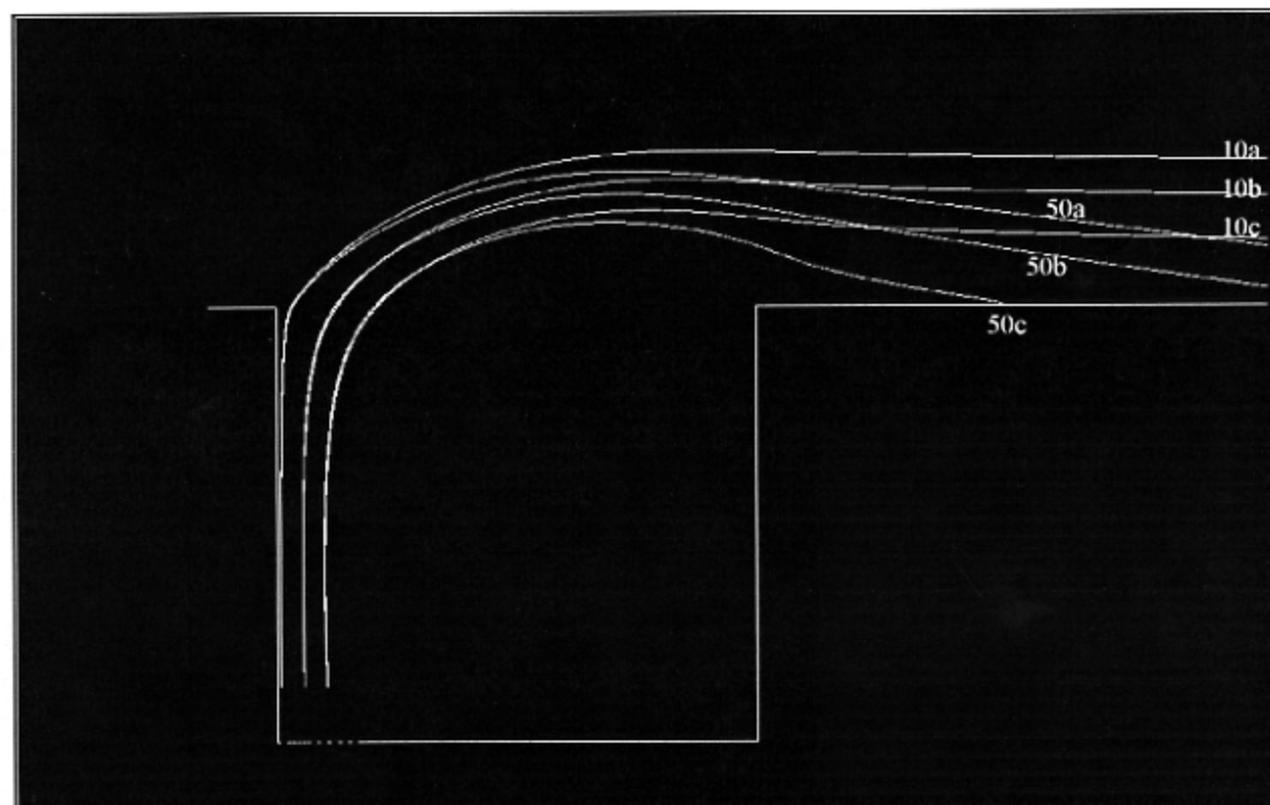


Figure 6. 10 & 50  $\mu\text{m}$  Particle Tracks for control at 2.0 m/s.

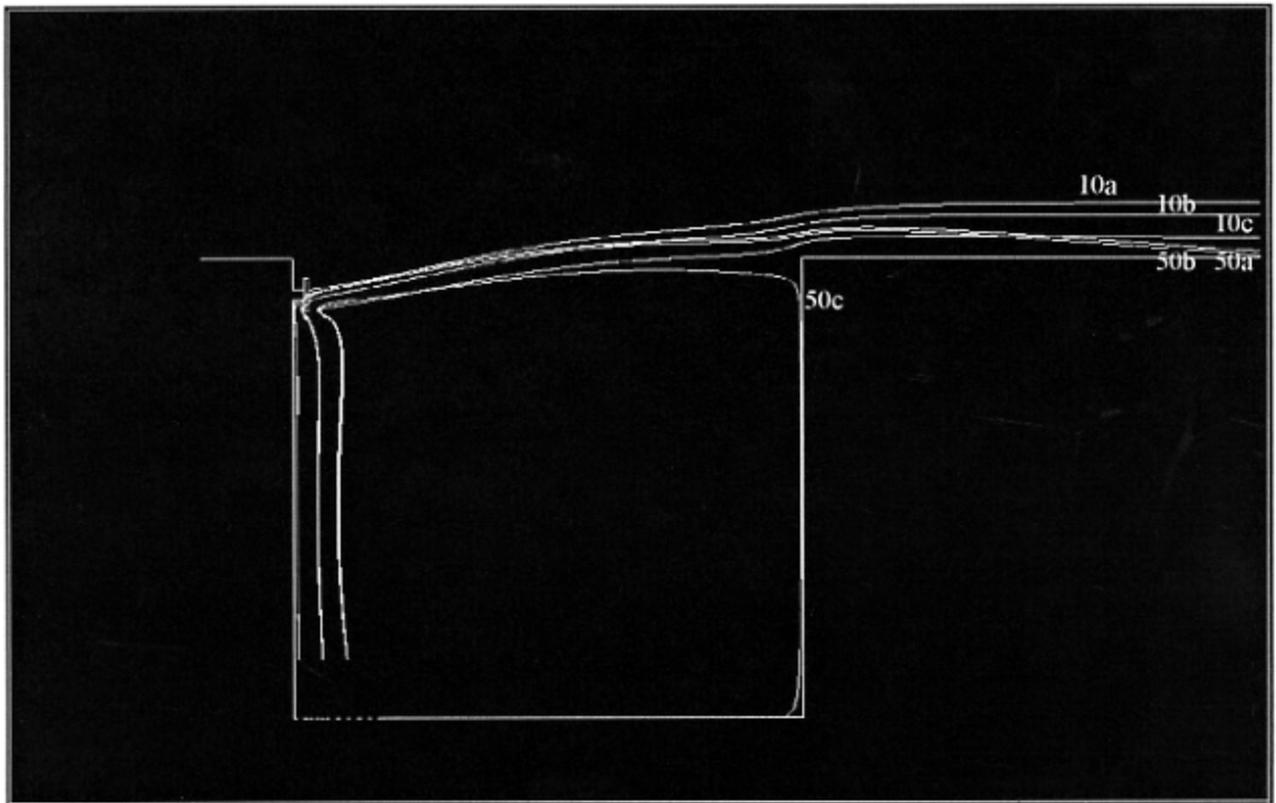


Figure 7. 10 & 50 um Particle Tracks for Spray model at 1.1 m/s.

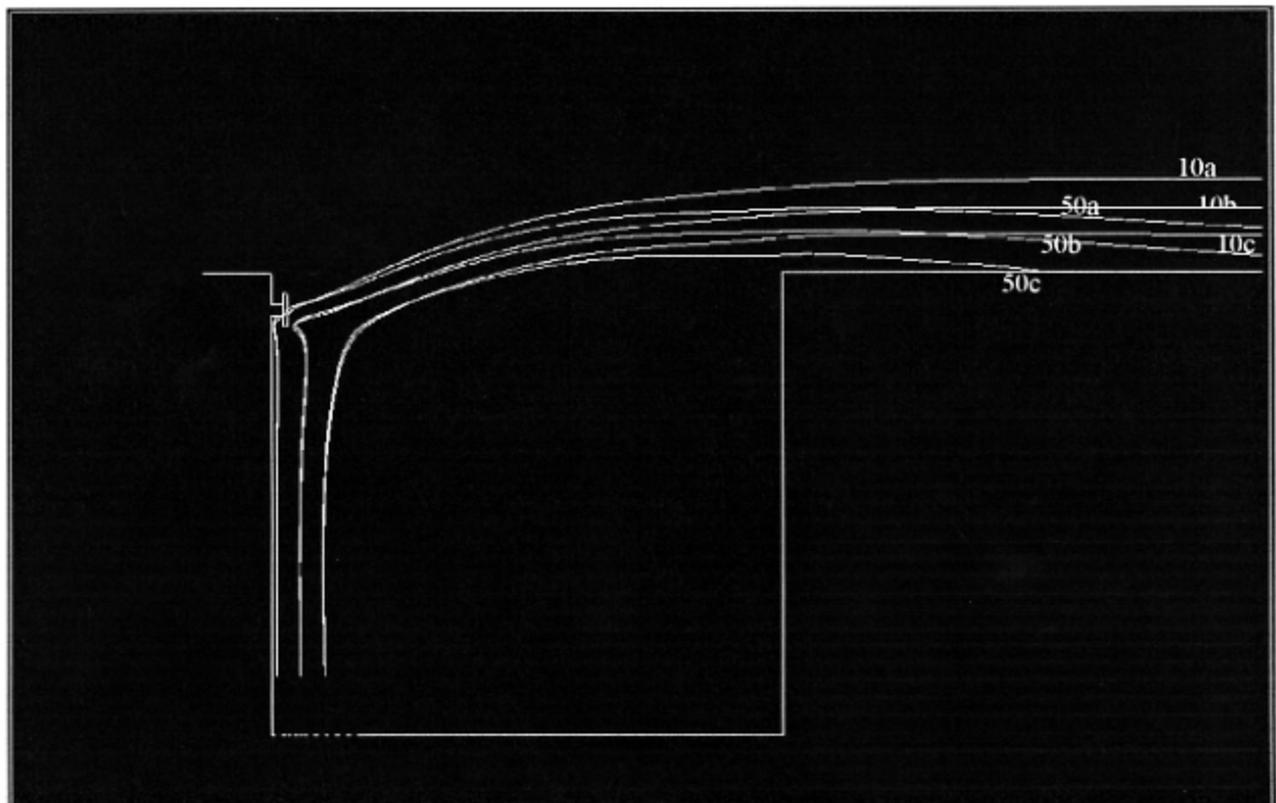


Figure 8. 10 & 50 um Particle Tracks for Spray model at 2.0 m/s.

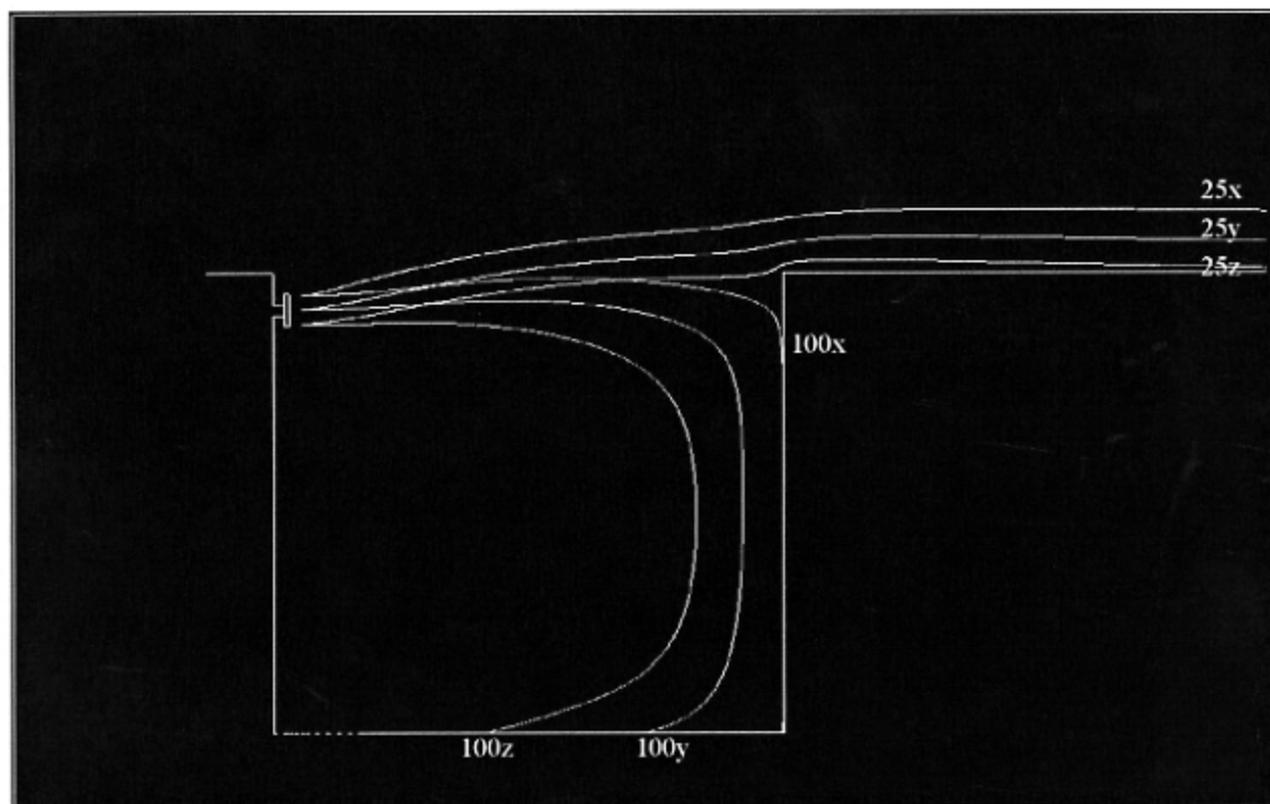


Figure 9. 25 & 100 um Drop Tracks for Spray model at 1.1 m/s.

Figure 9 is a plot of water drop trajectories. The drop sizes were 25 and 100 micron and they were initiated from 3 locations within the spray plume. The drops were given an initial velocity of 9.1 m/s which was greater than the local air velocity. The 100 micron drops settled back into the lower section while all the 25 micron drops followed the air streams out of the geometry. Thus, the emissions resulted in both drops and particles, although, the drops should eventually evaporate.

### Collision Modeling

A second portion of the modeling involved a user-defined subroutine to estimate the collision potential between drops and particles within a micro-volume. The micro-volume was 860um x 860um x 860um. This was the void space for a single particle assuming the dust concentration was 10 grams/m<sup>3</sup> and all the particles were 20 um in diameter.

A spray flow of 1.4 g/s of water, producing only 25 micron drops, would make 172,000,000 drops/sec. At 7.6 cm (3") from the nozzle, the plume's cross sectional area was 64 cm<sup>2</sup> and the drop flux was 2,674,000 drops/sec/cm<sup>2</sup>. The drop flux across a micro-volume was 19,700 drops/sec.

The particle was assumed to be traveling 1 m/s vertically upward while the drops were traveling 5 m/s horizontally. The time for the particle to transverse 860 microns vertically through the micro-volume was 0.00086 sec. During this time interval, 17 drops crossed the micro-volume.

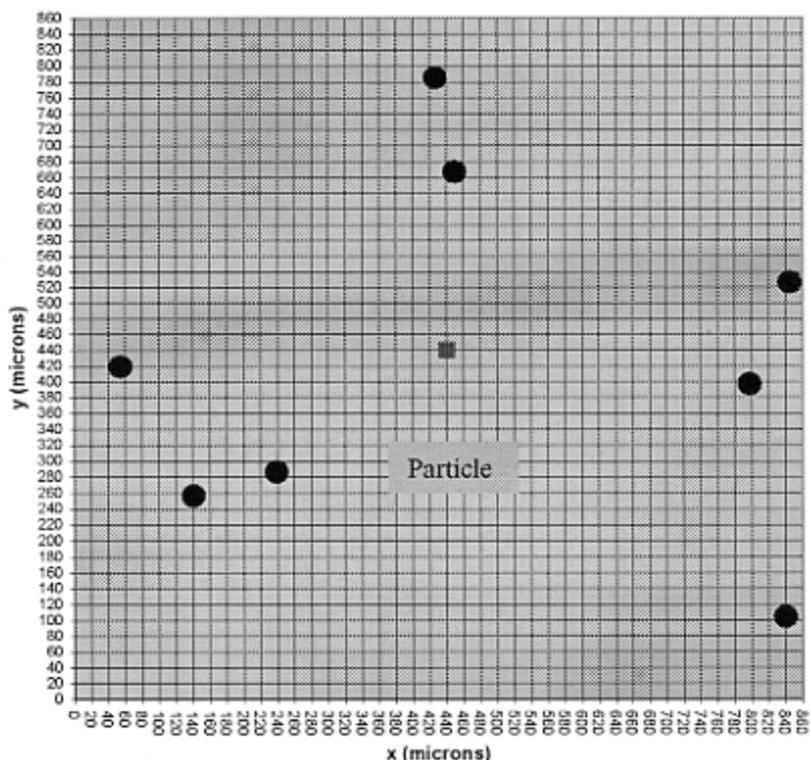


Figure 10. Relative size and concentration of 1 particle & 8 drops.

A software routine was prepared to estimate collision events between a particle and drop. The routine used the 3-dimensions of the micro-volume and random positions of the drops and particle. The particle's position was advanced vertically while the drops were advanced horizontally. A collision event was counted when the particle and the drop positions were overlapping. Seventeen collision events occurred while testing 250 micro-volumes. The relative size of the micro-volume, a 20 micron dust particle, and 25um drops in figure 10.

Electro-static charge could increase the drop's sphere of influence and the drop would only need to be close to the particle for the two would agglomerate. The software was adjusted to allow the drop to be one diameter away from the particle and still count as a collision. With the extended influence, the software generated 54 collision after testing 250 control volumes.

The probability of collision should be studied further. The chance of collision would vary along the particle potential trajectory as the relative velocities and fluxes change. The chances could be accumulated to give an overall estimate of collisions. Turbulence was not considered in the collision model, but it would increase the particle path and mixing thus increasing the potential for collision.

## CONCLUSIONS:

The fine spray induced significant airflow. The airflow from the spray interacted with the air carrying the dust. The airflow profiles for no-spray and spray situations were estimated by subdividing the 2-dimensional, test geometry into a grid of 4092 volumes and solving finite difference equations with computational fluid dynamics software.

Particle trajectories were determined within the airflow profiles. The trajectory models considered 10 and 50 micron grain dust particles. The induced airflow alone did not keep these particles from escaping the geometry. The induced airflow lowered the escape height and concentrated the dust into a narrower band. The initial location of the particle influenced the path of the trajectory. As particles started further from the wall, the flight path was lowered and the particles settled sooner. The emissions from the geometry were a combination of dust particles and fine drops.

The velocities of the drops near the tip of the nozzle were much higher than the air-stream and dust particle velocity. A subroutine was prepared for estimating the potential for collisions within an 860um x 860um x 860um cubic volume. A single particle advanced vertically while 17 drops crossed horizontally. The model estimated 17 collision while testing 250 micro-volumes. If the sphere of influence of the drops was increased by one-drop diameter, then the model estimated 54 collision events from 250 micro-volumes.

These models represent potential air, dust, and spray interaction in a test geometry. They are methods of estimating and illustrating airflow interaction and particle tracking. The current results indicate minimal control of the 10 micron dust particles for the given geometry and airflow. If the airflow for the grain dust was reduced or the drop flux of the spray increased then the dust control may be more positive. The models need further development and improvements as validation tests are performed. Considerations of electrostatic forces, air turbulence, and drop evaporation have been minimal, but they could have significant effect.

When applying these techniques to grain handling situations, the airflow, dust, mist, and geometry need to be accurately represented. Geometry, grain dust concentration, and airflow vary widely with the grain handling. The test geometry was similar to a receiving operation. The spray mist provided an air curtain for confining the dust. The drops provided the potential for agglomeration and deposition.

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