SME Annual Meeting
Feb. 15 - 18, 2015, Denver, CO

Preprint 15-104

DEVELOPMENT OF A DUST SAMPLE COLLECTION PROTOTYPE FOR USE IN UNDERGROUND COAL MINES

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ABSTRACT

Researchers at the Colorado School of Mines, under a project funded by the Alpha Foundation, have developed a working prototype of a dust sample collection device designed to determine if sufficient rock dust has been placed in an underground coal mine to prevent coal dust explosions. When used in conjunction with the Coal Dust Explosibility Meter (CDEM), the device will provide near instantaneous results on the quality of rock dusting at the tested location. The sampling device applies a pulse of air to a testing surface and collect a representative sample of mine dust based on the pneumatic entrainment process during a mine explosion. The use of both physical testing and Computational Fluid Dynamics (CFD) modeling has allowed researchers to refine the design to accurately represent the particle entrainment and optimize the sample size collected for the CDEM. The prototype is being tested in a mine environment to produce information of usability and practical aspects of mine dust sampling. This paper is a progress report summarizing the current status of sampler development. Researchers expect to have a fully developed and tested sampler in early 2016.

INTRODUCTION

Underground coal mines face the danger of methane and coal dust explosions. The disaster at Upper Big Branch mine (2010) has demonstrated the impact of a violent coal dust explosion that fatally injured 29 miners. Reviewing the history of coal dust explosions, researchers found that that mine operators and mine inspectors do not have a reliable method of collecting dust samples to assure that sufficient amounts of rock dust have been places to inertize the coal dust. This is a problem specifically with small mines that do not have dedicated safety departments to track rock dusting work. The aim of this research is to develop a simple, portable device that can help underground mine examiners collect dust samples from workings and test the explosibility of the sample near instantaneously.

Researchers determined that the current brush-and-pan sampling method required by MSHA (MSHA 2013) is flawed in several aspects: Mechanical sampling with a brush exerts forces on the mine dust that may differ significantly from those present during an explosion. Also, U.S Bureau of Mines research (Nagy 1965) has determined that only the top 0.125 inches of the mine dust layer will be entrained in a coal dust explosion. Using a handheld pan and brush, it is difficult to correctly and repeatably sample a layer of this exact thickness.

The following will describe the CFD modeling and experimental testing for the development of the prototype sampler. Researchers analyze the accuracy and performance of the prototype during the course of the build process.

FIRST DESIGN PROTOTYPE OF THE DUST SAMPLING DEVICE

Initial Nozzle Testing

To develop the initial prototype sampler, researchers tested various nozzle configurations to understand the scour patterns left due when varying testing parameters including nozzle geometry, nozzle angle, pneumatic pressure, duration of air pulse supplied to nozzle, nozzle height above the dust surface, nozzle orientation and sampler dimensions.

First Prototype Design

The first prototype was made using 1/8” thick pieces of ABS plastic, as shown in Figure 1. The nozzle is attached to the front wall of the sampler box and adjustable to the desired angle. A collection plate opposite the nozzles sits on the surface of the dust and is adjustable in length. This setup allowed researchers to change the width of the dust collection opening to optimize the collected sample mass for the CDEM.

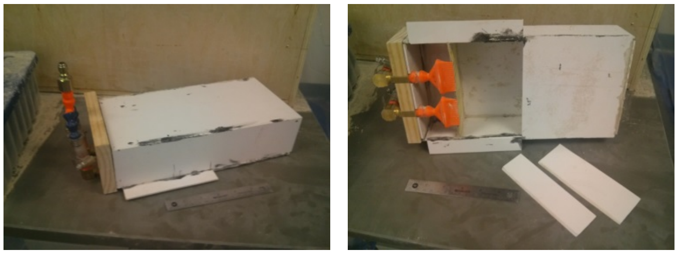

Figure 1. Side view (left) and bottom view (right) of first prototype with hose and nozzle system.

In order to deliver a defined air pulse to the sampler, researchers designed an air containment vessel with a charge-and-release valve configuration as shown in Figure 2. Researchers prime the air vessel to the desired pressure and then release the stored air through the hose and nozzle setup to create airflow into the sampler. This setup has been used with great success to supply a consistent and repeatable volume of pressurized air to the nozzles.

Figure 2. Palm button charge and release valve system.

Researchers tested with a large number of different air nozzles and an air knife to understand the interaction between nozzles and dust. Early results showed that, in order to achieve the 1/8” sample depth while collecting a mass of dust sufficient for a CDEM test, two nozzles would need to be used in a horizontal pairing.

Different nozzle angles and vessel charging pressures were tried to understand the sensitivity of these parameters. To determine the scour depth, researchers used a metal caliper to gauge the maximum depth of the dust imprint against the original depth of the dust layer.

This resulted in efficient and consistent measurements. The results of scour depth and dust mass collected vs. charge pressure are shown in Figures 3, 4 and 5 for different nozzle angles and with other key parameters varied. The data points represent the average values obtained from multiple tests.

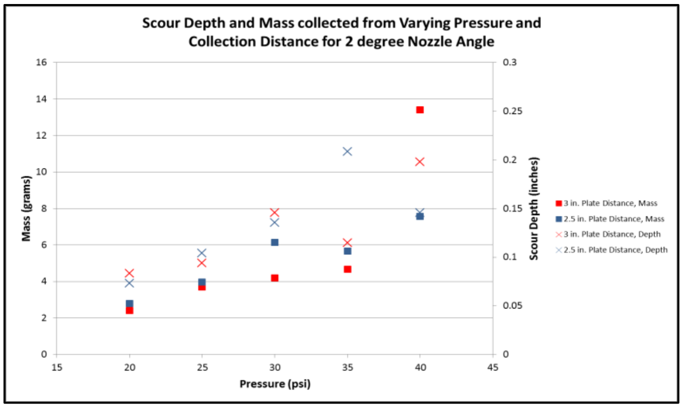

Figure 3. Comparison of 3 inch and 2.5 inch Plate Distances for a 2-degree nozzle angle.

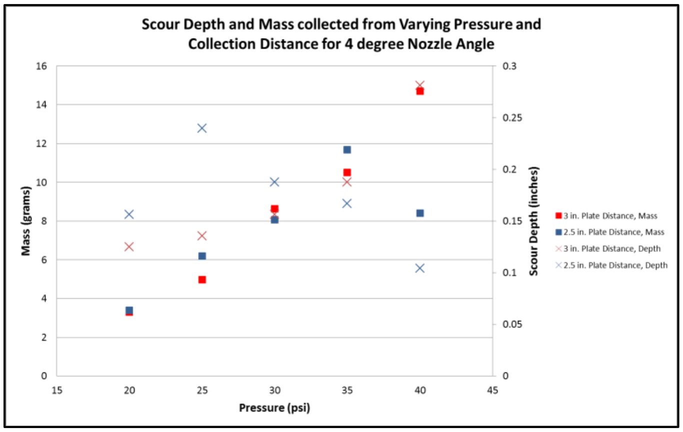

Figure 4. Comparison of 3 inch and 2.5 inch Plate Distances for a 4 degree nozzle angle.

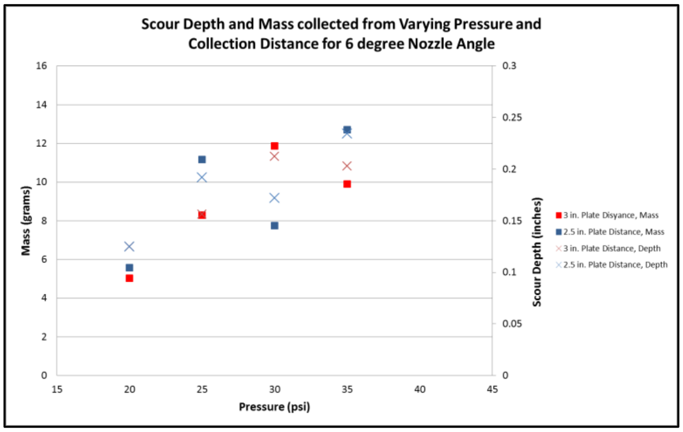

Figure 5. Comparison of 3 inch and 2.5 inch Plate Distances for a 6 degree nozzle angle.

Effects of Dust Packing Density

Initial tests revealed that the packing density of the dust was inconsistent prior to sampling. Researchers developed a system to prepare an even, consistently packed layer of dust that represents a layer of freshly placed rock dust in the mine. The dust layering system consisted of a mesh screen mounted on a roller system in a box frame. Rock dust is loaded onto the screen and then the box is moved forward and back to pass the rock dust through the screen, replicating the pneumatic spreading of rock dust in an underground coal mine. The system also allowed researchers to vary the thickness of the dust layer. Figure 6 shows the top box and screen assembly.

Figure 6. Box screen-mesh assembly on rails above dust layer

IMPROVED PROTOTYPE DUST SAMPLING DEVICE

In the second prototyping phase, an improved sampler cavity design was developed based on previous test results and CFD modeling of dust movement in the device. Researchers determined that a flatter sampler cavity would better channel the airflow towards the collection area while reducing the amount of dust recirculation in the cavity. Researchers also determined that the previous method of dust collection from the sampler would be unsatisfactory for in-mine sampling. The new prototype had an open back with a plastic sample collection bag attached. Researchers also created inserts to vary the cavity height in the sampler. Figure 7 shows the advanced prototype with the nozzle and sample bag attached.

Figure 7. Views of second prototype with nozzle system.

To determine mass with the new collection method each bag would be weighed prior to being attached to the cavity and after the test was completed. Free dust on the exterior of the collection bag was brushed off to accurately determine the sample mass. Results for the scouring depth and sample mass for the second prototype are displayed in Figures 8 and 9, including error bars indicating the variability of test results.

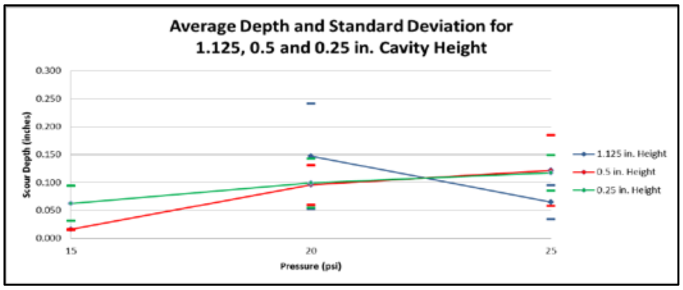

Figure 8. Comparison of height and scour depth vs. pressure.

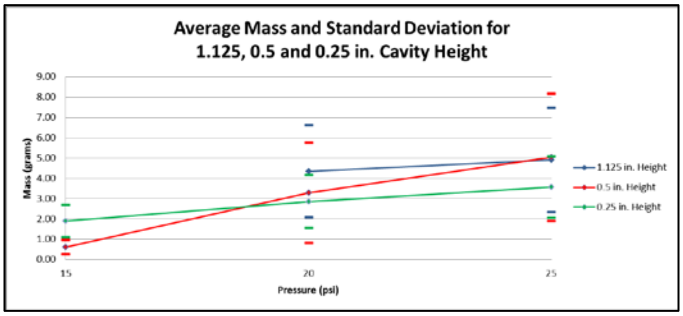

Figure 9. Comparison of height to average and standard deviation of mass against pressure.

Inconsistencies with Nozzle Height above Dust Layer

The data presented in the above figures shows inconsistencies between the test results. Though the averages appear reasonably close to the target, Researchers recorded a number of outlying test results. Researchers found that the vertical distance from the nozzle to the dust surface was primarily responsible for these inconsistencies. A second series of tests at the 1.125 inch cavity height was conducted with researchers carefully placing the sampler so the nozzle ports remained at a consistent height directly above the dust layer. This improved sampling repeatability significantly. A comparison of the initial data and improved test data is provided in Table 1.

Table 1. Comparison of 1st Run and 2nd Run data for 1.125 inch cavity height.

Rock Dust Mass Weighed (grams)				
Pressure (psi)	*Initial Test*		*Improved Test*	
	Average	Standard Deviation	Average	Standard Deviation
20	4.35	2.27	2.35	0.47
25	4.92	2.57	3.08	0.56
Scour Depth Measured (inches)				
Pressure (psi)	*Initial Test*		*Improved Test*	
	Average	Standard Deviation	Average	Standard Deviation
20	0.148	0.094	0.094	0.028
25	0.065	0.030	0.109	0.026

CFD MODELING OF AIR AND DUST MOVEMENT IN SAMPLING DEVICE

Modeling of dust sampling device has been critical in correlating the optimum design with experimental results. The modeling activity involved 3 stages: designing the geometry, developing the mesh generation and defining boundary conditions.

The experimental design was replicated in CFD using Ansys Fluent® as shown in Figure 10. The green layer represents the dust phase of the model while the pink section represents the sampler cavity.

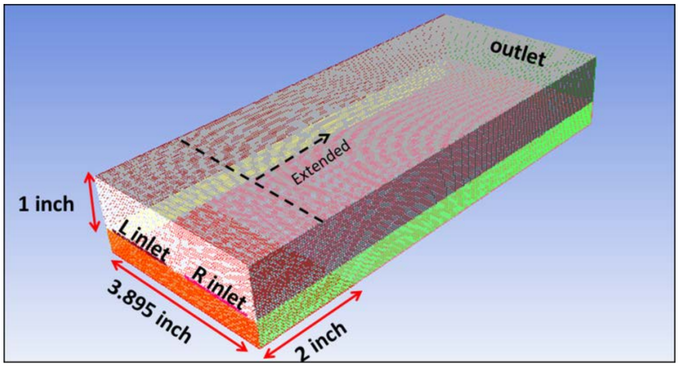

Figure 10. CFD - Geometry design showing sections of red (air phase) and green (dust phase).

The quality of the CFD mesh has a significant impact on solvability and modeling results. The current mesh uses a cell size of 0.035 mm (x direction), 0.046 mm (y direction) and 0.042 mm in the z-direction. Mesh refinement and inflation were used near the interface between the dust and air phases. The mesh elements had the highest possible with no skewness as all cells were cuboid shaped. Reduction of the mesh size demonstrated mesh independence of the model.

The solver used for the analysis is the k-epsilon type with standard wall functions. Eulerian models with two phases (gas and solid) were used to replicate the expected interactions of the air and dust. Figure 11 shows a side view of the sampler and CFD dust entrainment model.

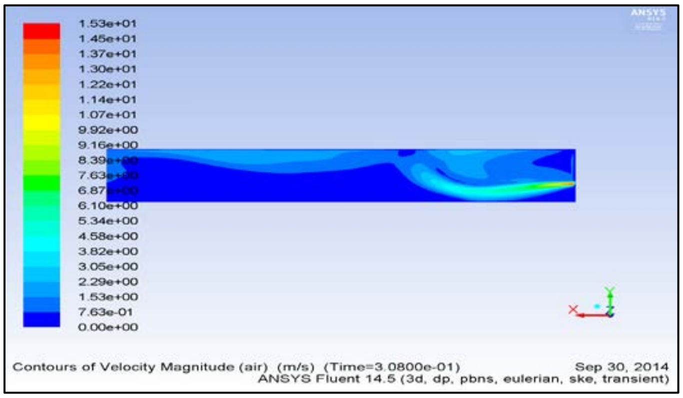

Figure 11. Side view of CFD dust sampler model showing air injection movement through dust.

CFD MODELING RESULTS

Researchers have confirmed laboratory testing results in the CFD model and are now using CFD modeling to further refine the second prototype. CFD modeling has indicated that using a staggered system of nozzles will increase the sample mass and improve the flow conditions inside the sampler. Researchers expect that this improvement, along with a wider lip to consistently place the nozzles above the dust surface, will result in further improvement in sample size and scouring accuracy.

CONCLUSIONS

Researchers at the Colorado School of Mines have developed a working prototype mine dust sampling instrument that will help mine operators and inspectors draw meaningful samples of mine dust, which can then be tested with a Coal Dust Explosibility Meter to verify that adequate amounts of rock dust have been placed in the mine to protect against coal dust explosions. Having the ability for a near instant measurements with a set of simple and relatively inexpensive sampling instruments is especially important for small mine operators who do not have a dedicated staff of mine safety and explosion control examiners. A final prototype is expected to be available in 2015. Following in-mine testing, verification and approval by MSHA, researchers expect to engage with manufacturers to produce and market the sampler.

REFERENCES

MSHA [2013]: Coal Mine Safety and Health General Inspection Procedures Handbook, Mine Safety and Health Administration, Handbook Number: PH13-V-1, February 2013, 276 p.

Nagy et al. [1965]: Float Coal Hazard in Mines: A Progress Report, U.S. Bureau of Mines RI No. 6581, Pittsburgh, 1965, 2 p.