2012 SME Annual Meeting, Seattle WA

CFD SIMULATION STUDY OF CONTINUOUS MINER SPRAY AND SCRUBBER PERFORMANCE DURING EXTENDED-CUT MINING WITH EXHAUST FACE VENTILATION

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Outline

- Objective
- Background
- CFD Model Development
  - Simulated Domain
  - Particles Simulation Approach
- Simulation Results
- Conclusions

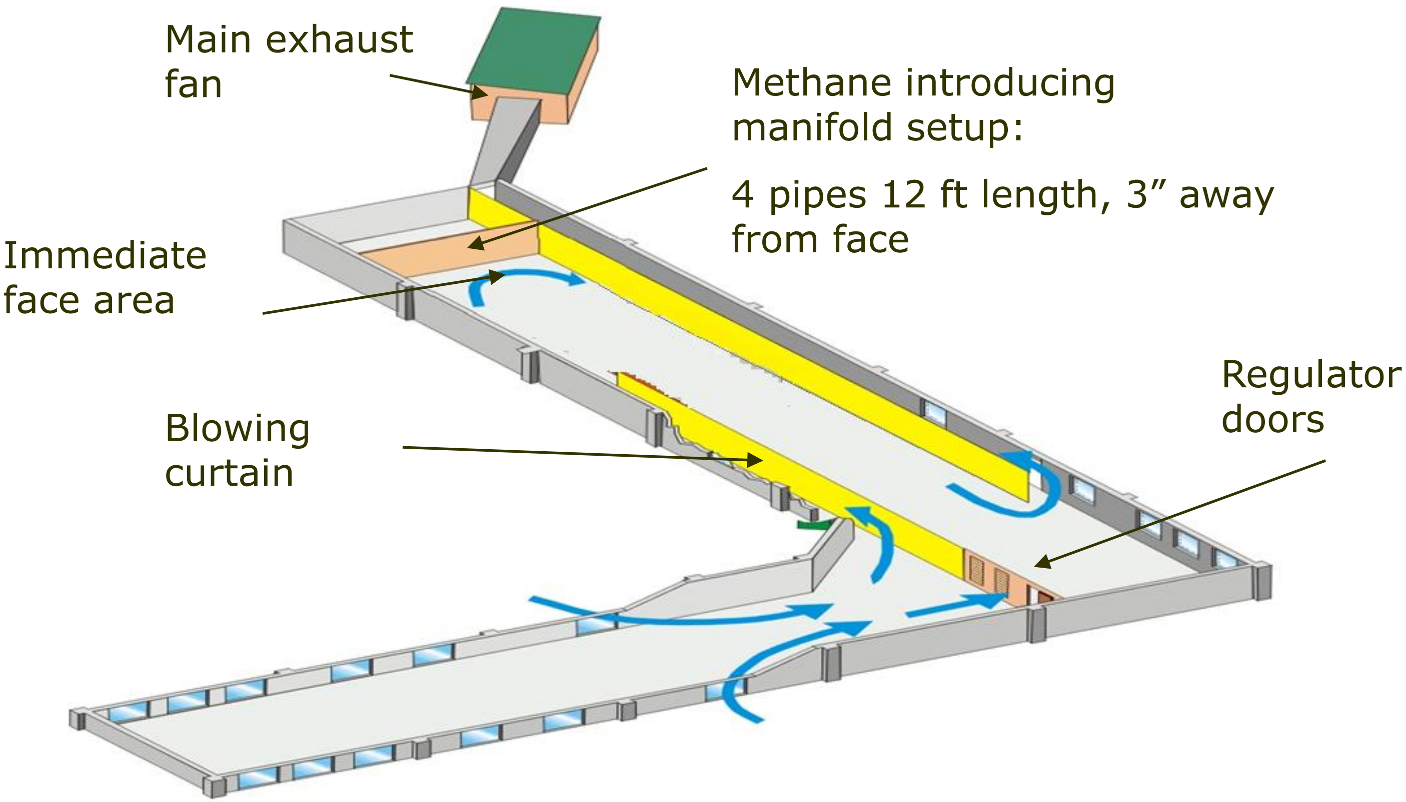
Objective

- Develop CFD model of an exhaust face ventilation for extended cut mining using continuous miner with water spray and scrubber. The commercial CFD software - Cradle® SC/Tetra, Thermofluid Analysis System was selected as a development platform.
- Perform experimental studies for validation of the CFD software - Cradle® SC/Tetra.

Background

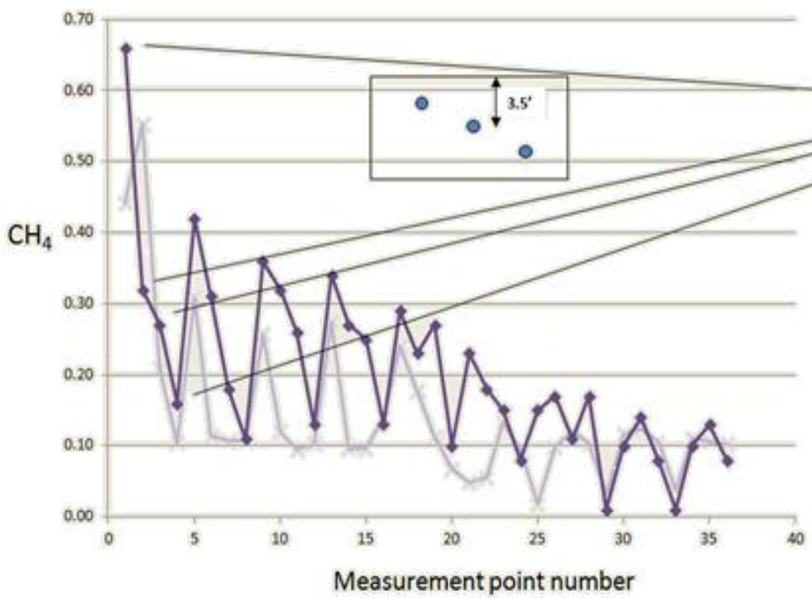
- First validation of SC/Tetra code was performed using experimental data from 1:15 scaled model at the Mine Ventilation Lab at the University of Kentucky.
- Then validation of SC/Tetra CFD code was successfully performed using airflow and methane measurements collected during benchmark experiments conducted in the ventilation gallery at the NIOSH-PRL.

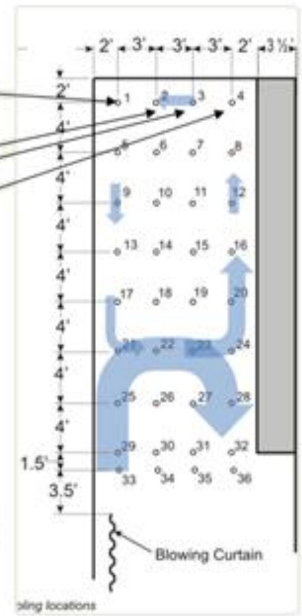
Full scale experimental setup at the NIOSH-PRL For Equipment Free Face Area



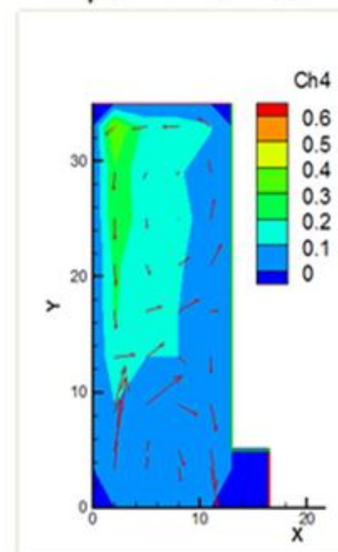
(After Taylor et al., 2005)

CFD Code Validation Study for Equipment Free Face Area

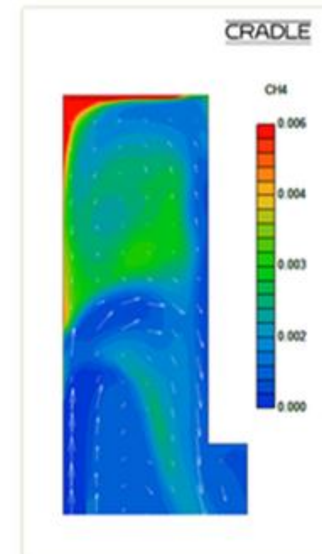




- Experimental results

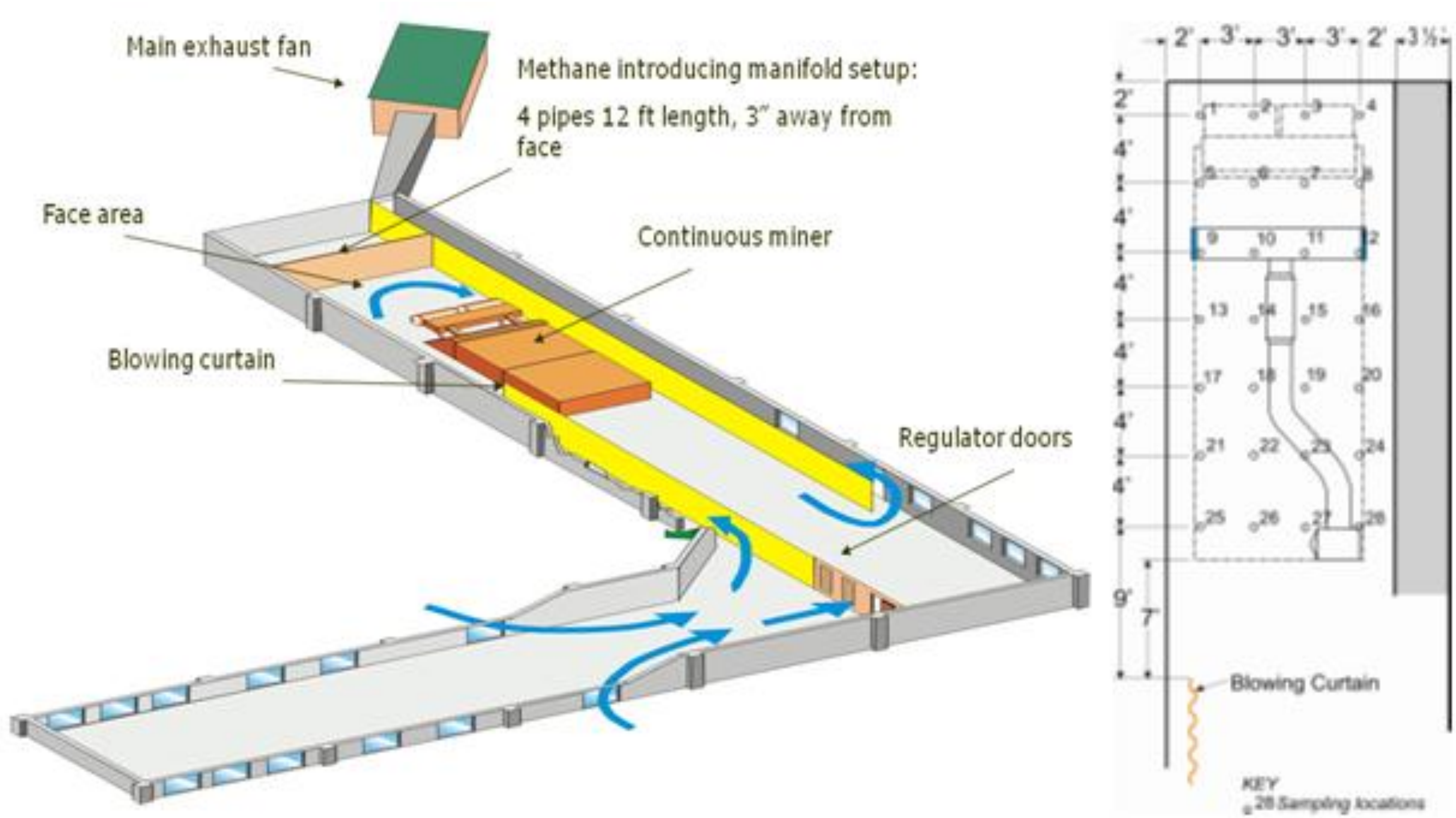


- Simulation results



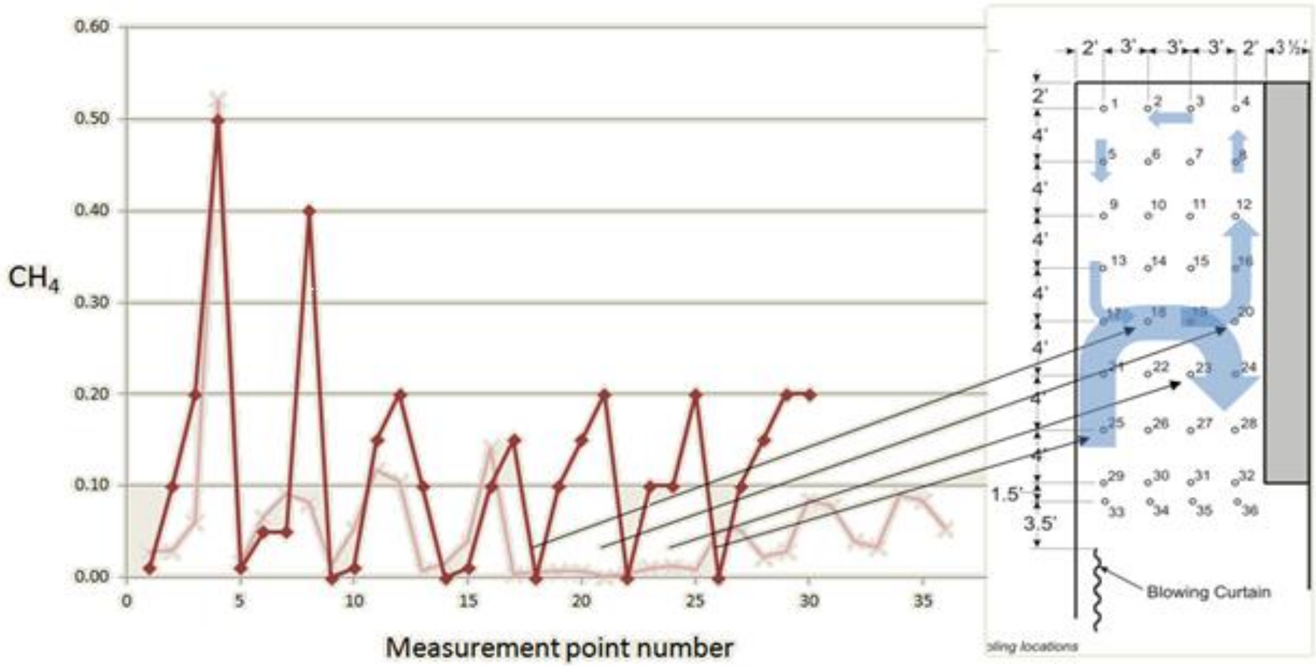
- Experimental data v/s simulation results for the mid-plane
- Correlation coefficient = 0.72

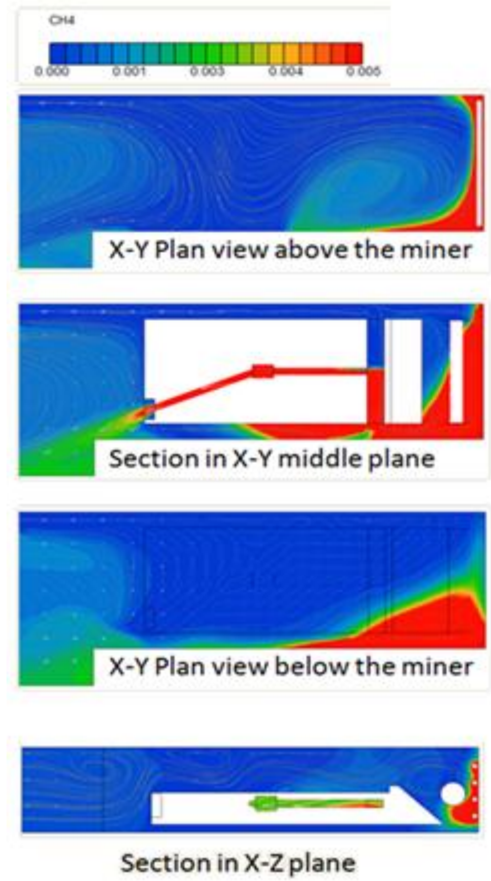
The full scale experimental setup at the NIOSH-PRL with Continuous Miner and Machine Mounted Scrubber



(After Taylor et al., 2008)

CFD Code Validation Study with Continuous Miner and Machine Mounted Scrubber





- Correlation coefficient = 0.65

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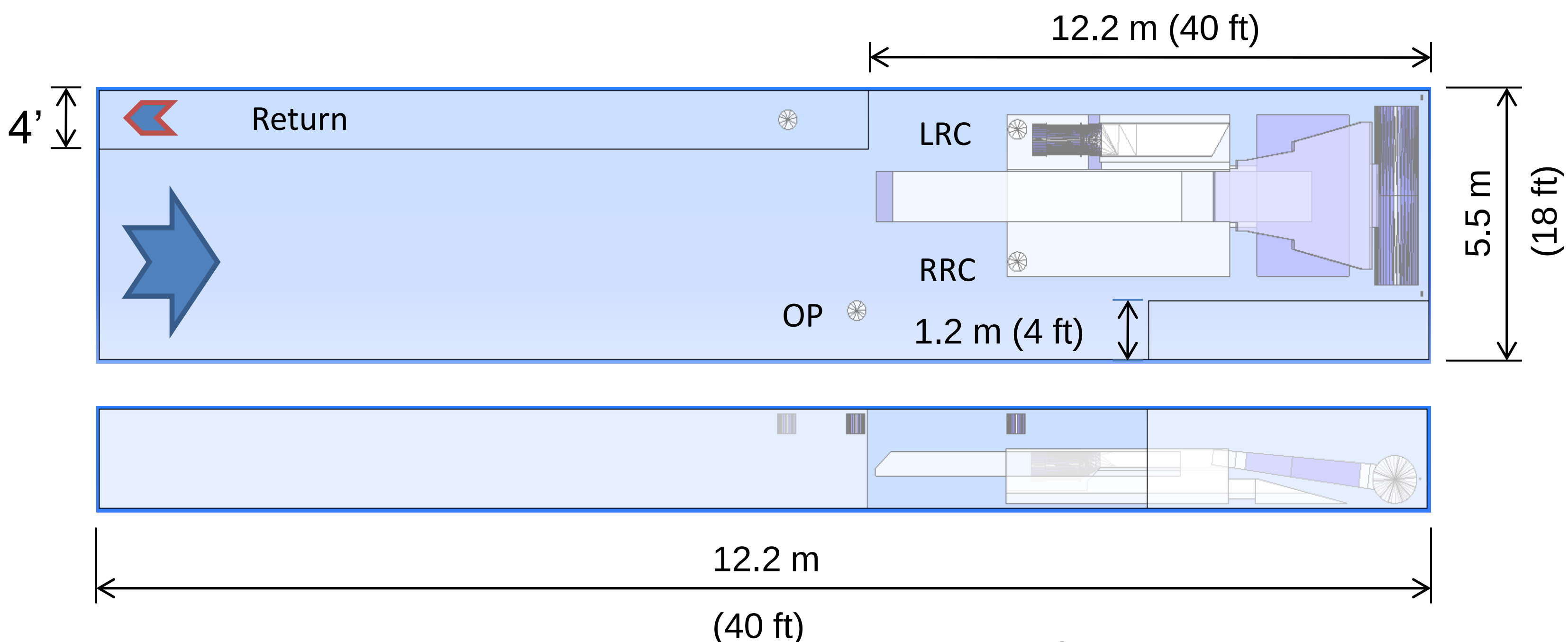
CFD Model Development

- Recently, exhaust face ventilation has become a recommendation as a more effective method for lowering the dust exposure of the operators of remote controlled continuous miners.

- Therefore, a 3D computational fluid dynamics model for simulation of interaction between dust particles and water spray droplets during extended-cut mining was developed at the University of Kentucky.

Simulated Domain

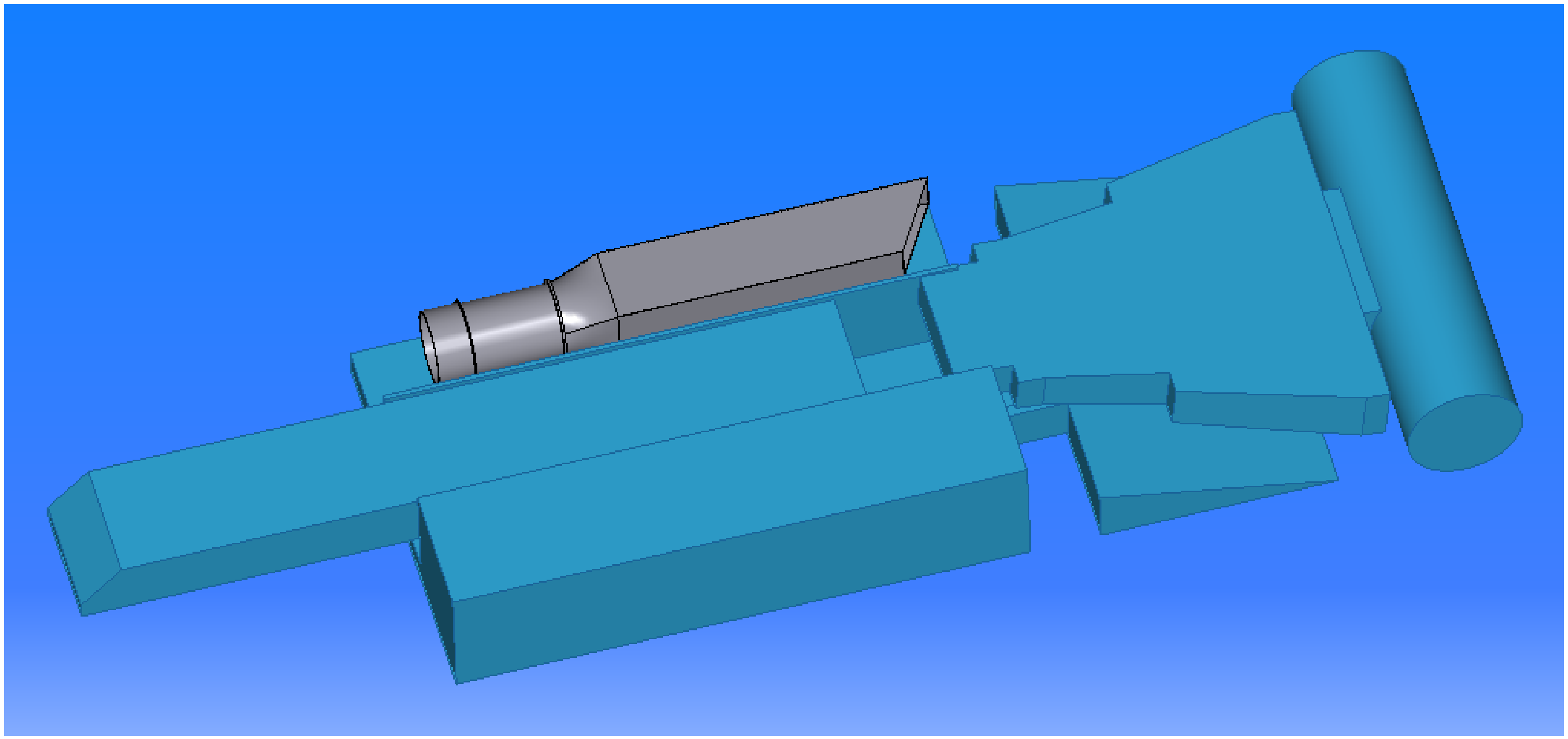
The simulated setup recreates the experimental setup presented in October 2010 by Organiscak and Beck in their paper "Continuous miner spray consideration for optimizing scrubber performance in exhaust ventilation systems," *Mining Engineering*



Continuous miner: Joy 14CM15
Airflow rate = 2.90 m^3/s (6,150 cfm)
Scrubber airflow rate = 2.27 m^3/s (4810 cfm)
Qscr/Qin = 0.8
Coal dust: 25 g/min (0.9 oz/min)

Spray setup:
- 15 boom
- 3 under boom sprays
- 3 sprays on each side of the cutter
- 2 blocking sprays

Continuous Miner Geometry

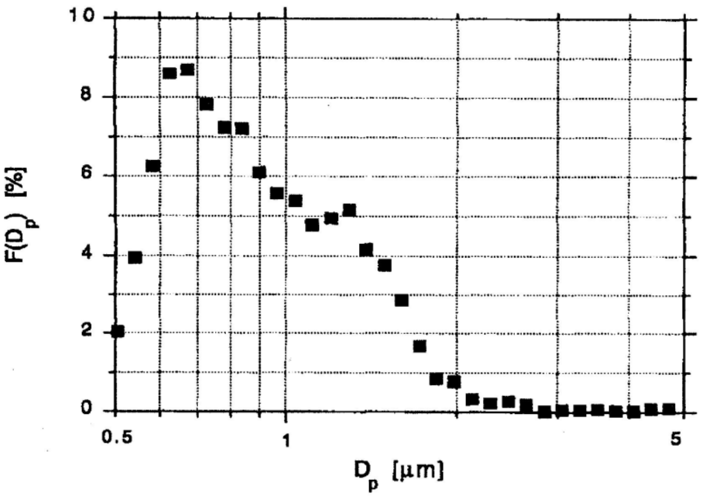


Geometry of the Joy 14CM15 continuous miner, provided by JOY Mining Machinery Inc, was adopted for the performed CFD study.

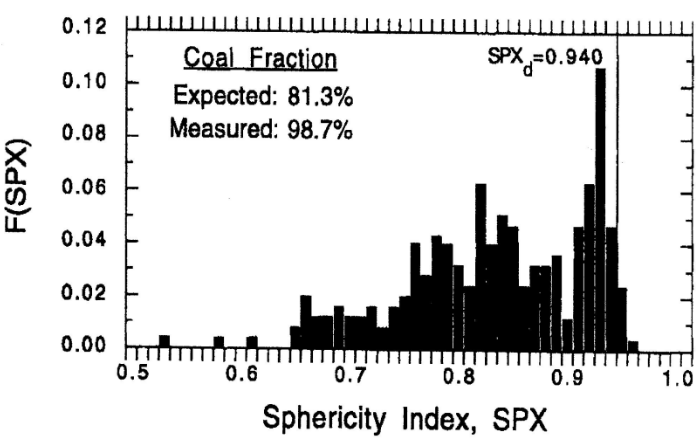
Particles simulation approach

- The dust particles and the water spray droplets are simulated using a particle tracking approach, where the trajectories of the particles or clusters of particles are tracked through the domain using Lagrangian equations of conservation.

About the coal dust particles



The representative size distribution of the respirable bituminous coal dust (Dick et.al., 1996) shows a bimodal distribution (0.6-1.2mm) with a significant fraction below 1mm.



In a study dedicated to the distinction of coal dust particles from liquid droplets, (Dick et.al., 1996) measured a high sphericity index (greater than 90%) of the low coal fraction using an optical detector DAWN-A.

Physical properties of the simulated dust particles

Property	**Value**
Particle material	Bituminous Coal
Shape	Spherical
Density	830* kg/m^3
Particle diameter	0.6 mm
Specific heat	0.00138 J/kg.K
Initial temperature	20 ^oC
Viscosity	0.0005 Pa.s
Surface tension coefficient	0.02 N/m

* Bulk Density and Specific Gravity Chart , ASI Instruments Inc - Solid Level Measurement, Houston, TX.

About the water spray droplets

- The simplest approach to define a representative droplet diameter is the commonly used Sauter Mean Diameter (SMD).

- SMD measured within various spray patterns range between 50 mm and 300 mm and depends on the water pressure, spray nozzle, and method used to create the droplets (Pollock and Organiscak, 2004).

- Studies of spray droplets shape (Husted, 2007) using Dantec Classic Phase Doppler Analyzer has shown that spray droplets could be treated as reasonably spherical.

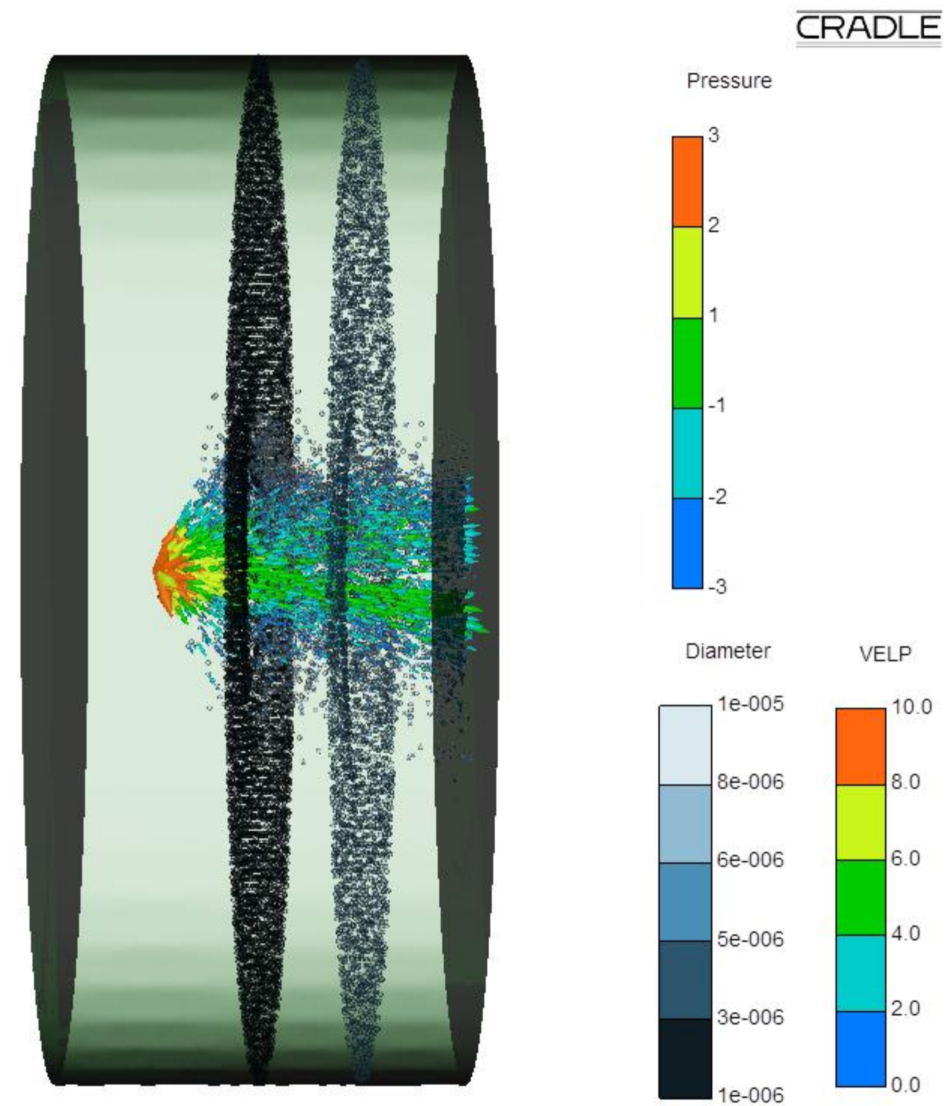
Characteristics of the simulated spray

Property	Value
Spray pattern	Full-cone
Performance of a spray nozzle	3 l/min
Spray angle	77^o
Droplet diameter	100 mm
Initial centerline droplet velocity	10 m/s

Corresponds to hi-pressure (1,103 kPa) FC water nozzle.

Simulation Results

Simulation of Particles Interaction

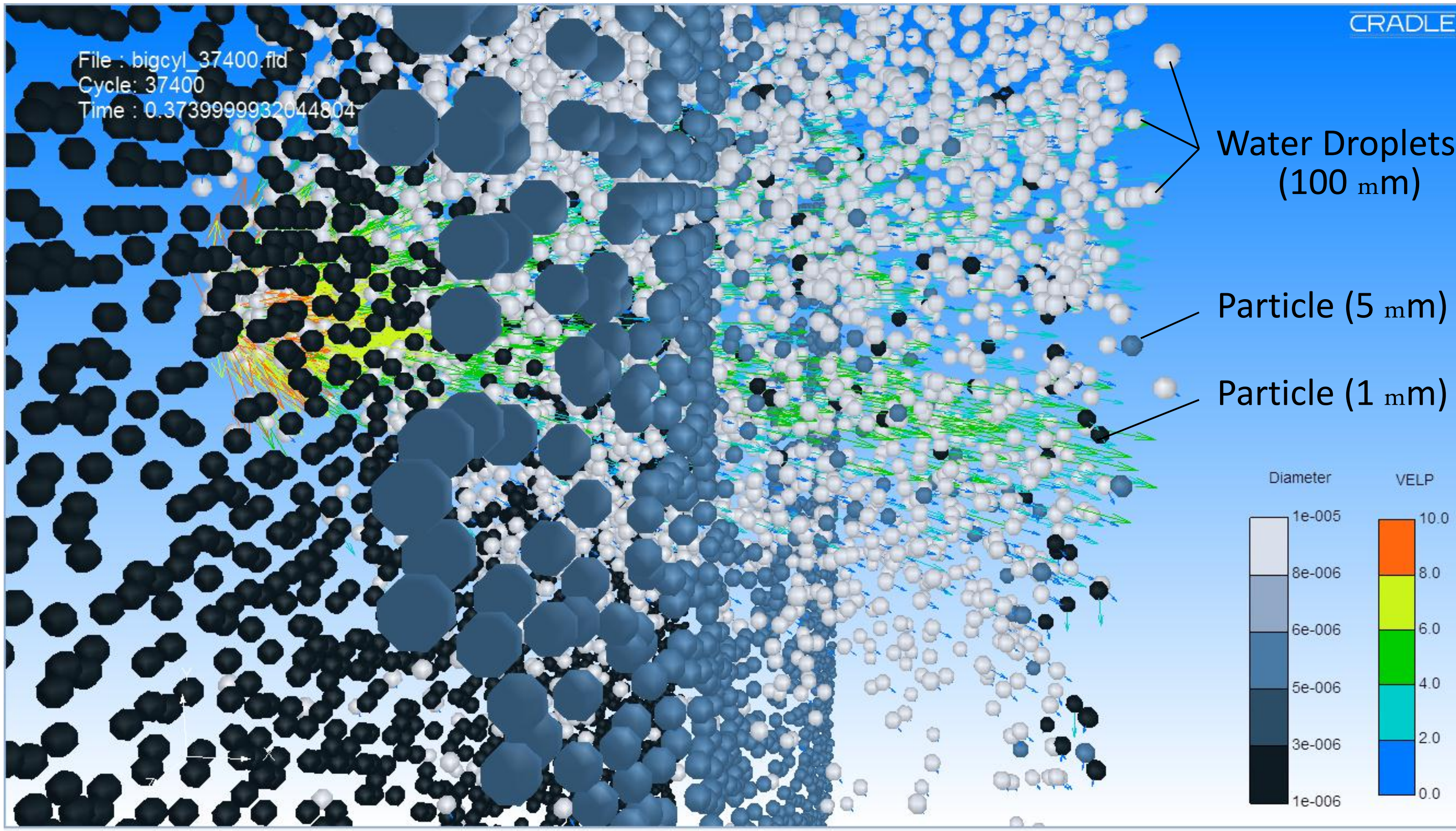


Trial simulation of a single nozzle water spray (77^o FC) and respirable dust particles (1 mm and 5 mm) in a cylinder

Simulated effects

- Gravity
- Collision
- Breakup
- Coalescence
- Adhesion to the walls
- Drag force

Simulation of Particles Interaction
Closer View



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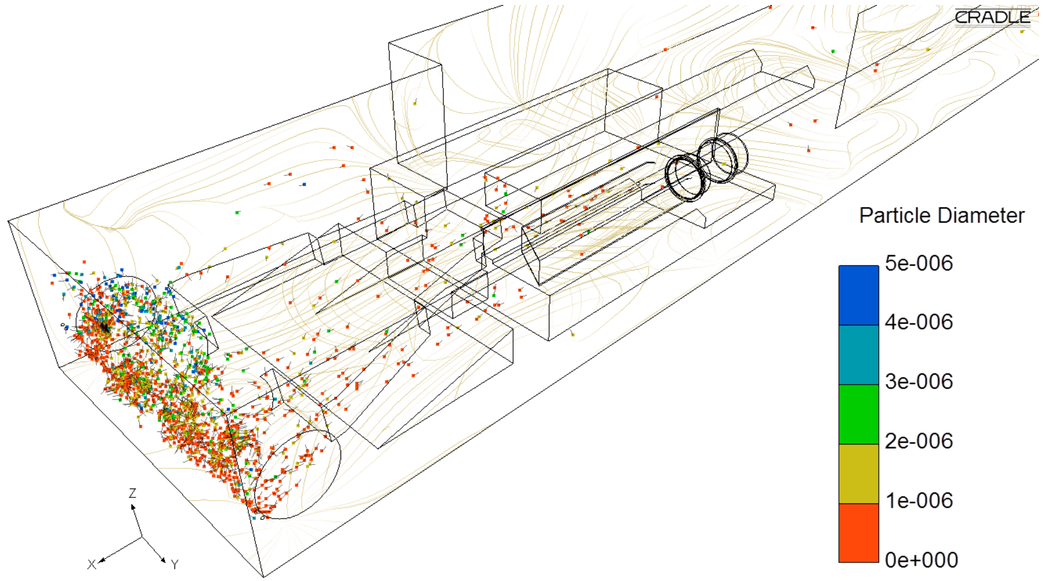
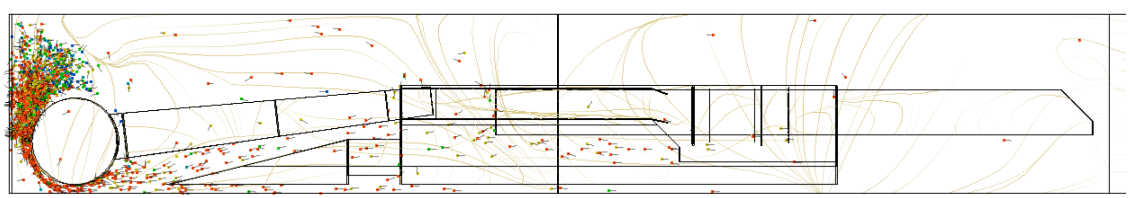
Dust Only Simulation

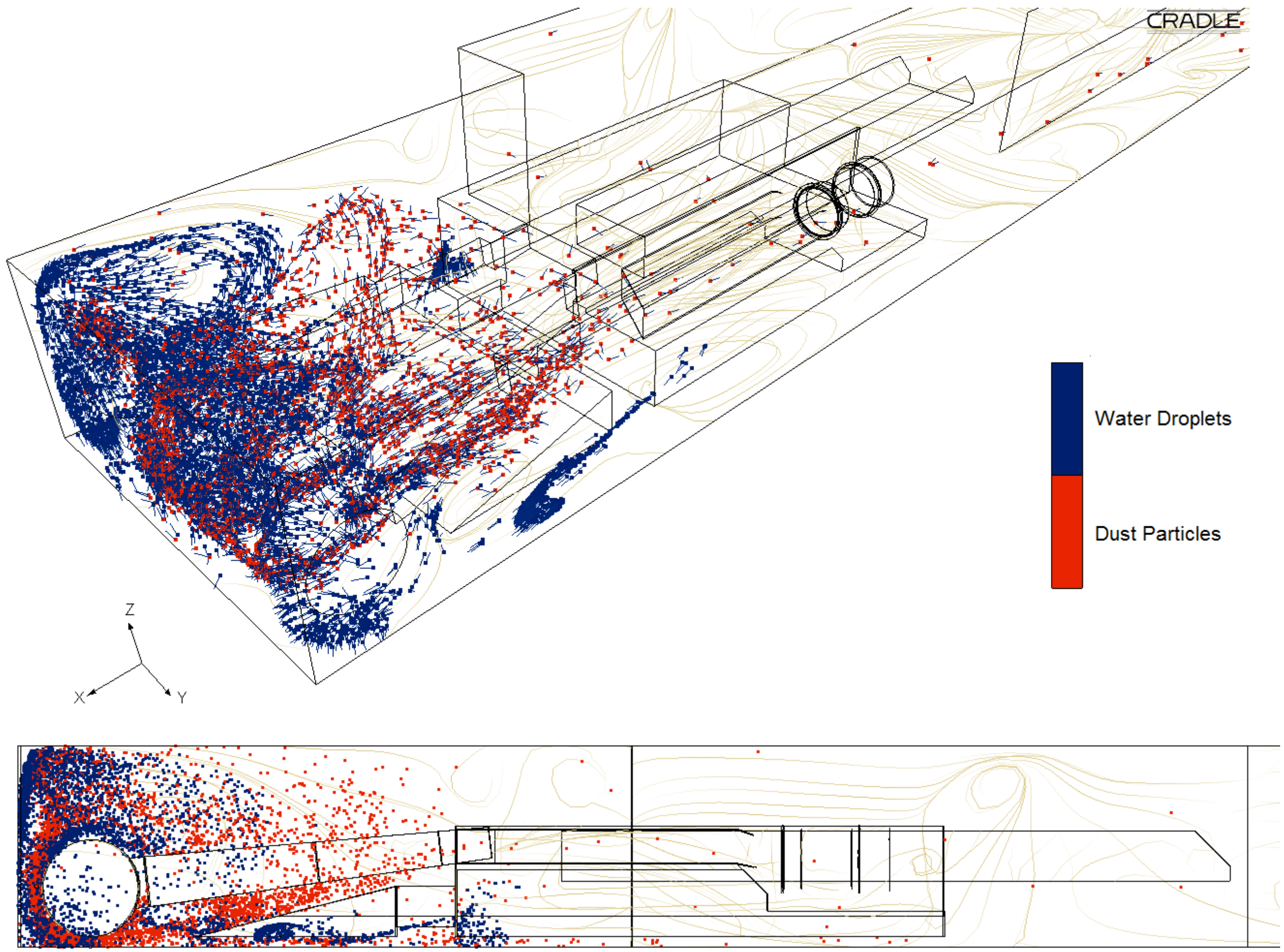
A transient simulation was performed with duration of 600 s





Coal dust particles were generated along the front side of the cutting drum simulating seven equidistant sprays with rate of 0.42 g/s.

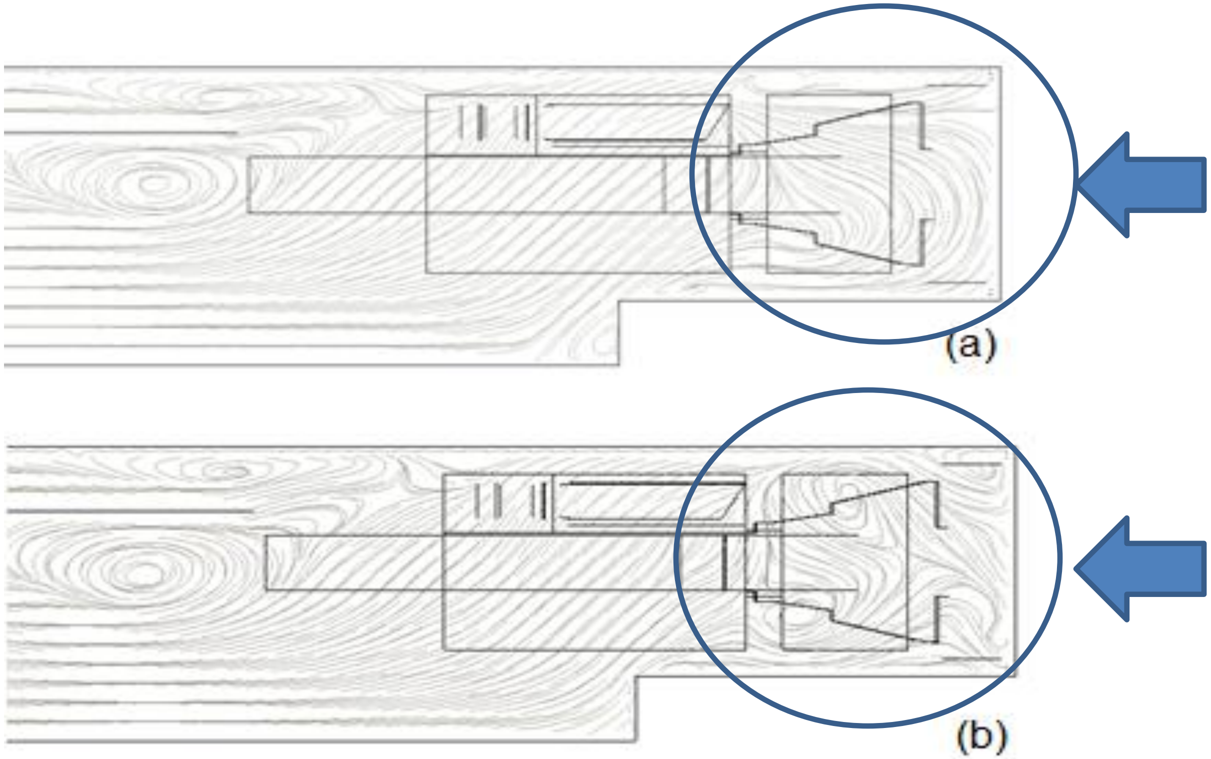
Water Spray and Dust Simulation Study



An instant view of 600 s transient simulation

Effect of the Cutting Drum Rotation

Motion of the cutting drum was simulated and its effect on the airflow is shown below.

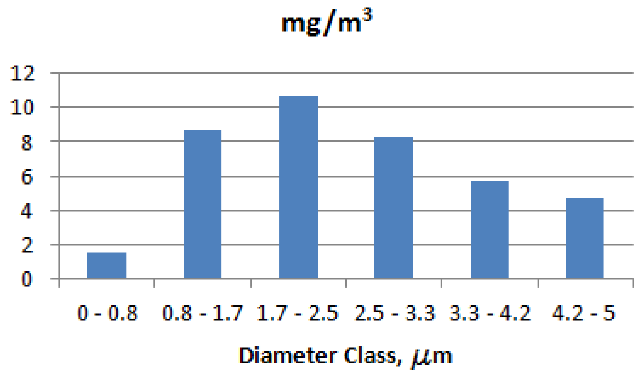


a) drum is not rotating

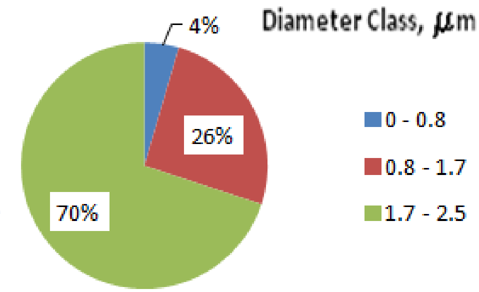
b) drum is rotating

Airflow patterns above the miners

Mass Fraction Distribution Analysis

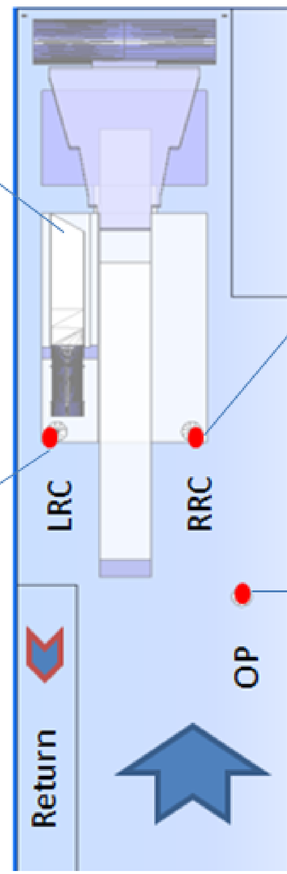


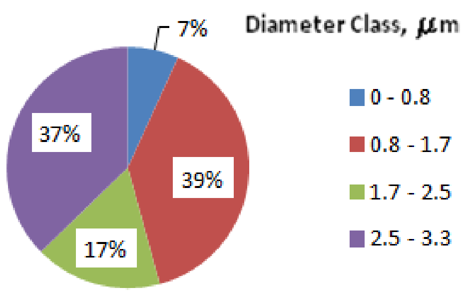
Scrubber mass fraction distribution



0.1 mg/m³

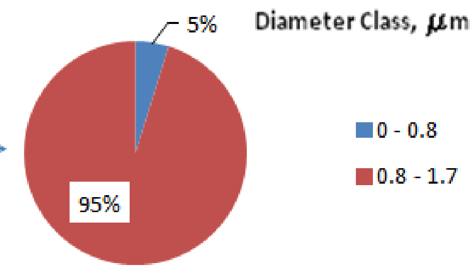
Mass fraction distribution at the right rear corner (RRC) of the miner





0.6 mg/m³

Mass fraction distribution at the left rear corner (LRC) of the miner



0.1 mg/m³

Mass fraction distribution at the Operator position (OP)

Conclusions

- The proposed model offers insight into the behavior of the ventilation at the face area when scrubber and water sprays are applied and is the next step to the development of the industry oriented Face Ventilation Simulator.
- The proposed model helps for elucidation of the mutual influence of the machine mounted scrubber and water spray on the dust suppression at the face area.
- There is, however, a need to validate this numerical model.
- Validation can be done through the full scale experiment in a facility like the NIOSH PRL, JOY Mining Machinery laboratory, or joint efforts of NIOSH, JOY and the Mining Department at the University of Kentucky.

Acknowledgment

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Thank You!