A CFD Approach for Investigating DPM Concentration over Multiple Work Cycles of an LHD in an Underground Mine

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Outline

• Research Objectives
• Prior Work
• Experiment Overview
• CFD simulation of the DPM concentration distribution over three work cycles of a LHD
• Discussion
Research objectives

• Use CFD to figure out the acceptable airflow requirement to dilute the DPM level under the regulatory limit

• Investigate the DPM concentration behaviour over multiple work-cycles of a LHD in a dead-end heading

Prior Work

• Experiment in an underground mine in the western U.S.
• Methodology of hybrid model established
• Initial findings published in the MPES 2017 conference
Methodology

Start

Survey areas of interest

Check whether DPM, dust, and other gas concentrations are above the regulatory limit

Above?

Yes

No

Check whether the area(s) has any connections to a ventilation raise or an open stope

Connections?

Yes

No

Optimum air quantity (including relevant cost) obtained?

Yes

No

Input for ventilation constraints (DPM, etc.) in production schedule optimization

End

Network simulation and the results are used for schedule optimization

Hybrid model

Change parameters in the models

No

Yes

Method of the Hybrid Model

Start

Survey a ventilation network

Flow properties: velocity, mass fraction, DPM, concentration, etc.

Network solver

CFD solver

Large-area simulation and export boundary conditions to the CFD solver

Small-area (part of the large-area) simulation and import boundary conditions from the network solver

Do the outputs match that from the network solver?

Yes

No

Results compared with that collected in the survey

Difference within tolerance?

Yes

No

Error analysis

End
Simple network model, Simple 3D CFD model, and Hybrid CFD-network model

Plan View of the Experiment Area
Geometry of the Experiment Area

LHD Path
DPM Simulation in Ansys Fluent

Boundary conditions:

<table>
<thead>
<tr>
<th></th>
<th>area (m²)</th>
<th>Velocity inlet (m/s)</th>
<th>DPM mass fraction</th>
<th>DPM (μg/m³)</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation tubing</td>
<td>0.89</td>
<td>35.97</td>
<td>0</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>Main drift</td>
<td>34.08</td>
<td>1.61</td>
<td>0</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>LHD exhaust tailpipes (1 to 18)</td>
<td>0.093</td>
<td>profile (calculated)</td>
<td>profile (calculated)</td>
<td>profile (calculated)</td>
<td>594</td>
</tr>
</tbody>
</table>

\[
DPM \text{ mass fraction} = \frac{DPM \text{ concentration} \left( \frac{\mu g}{m^3} \right)}{\text{air density} \left( \frac{kg}{m^3} \right)} \times \frac{kg}{10^6 \mu g}
\]

Assumptions

- In a work cycle, the DPM concentration from an LHD’s tailpipe is the lowest when it is tramming into a heading with the bucket empty.
- The DPM concentration is the highest while the LHD is mucking in the heading.
- The DPM concentration is between the two concentrations mentioned above while the LHD is tramming out of the heading.
- It takes an LHD much longer to move out of a heading than to move into the heading.
- The DPM concentration levels are stable in each part of an LHD’s work cycle.
- NOTE: The work to-date does not account for any effect of the LHD on the DPM concentration distribution in the heading in a work cycle of the LHD.
DPM Concentration Profile from the LHD Tailpipe

Velocity Profile from the LHD Tailpipe
Partial DPM data collected by the Airtec DPM monitor at location D

DPM Concentration Comparison at Location C in the Experiment and the CFD Model

This work was made possible by the facilities of the Shared Hierarchical Academic Research Computing Network (SHARCNET: www.sharcnet.ca) and Compute/Calcul Canada.
DPM Concentration Comparison at Location D in the Experiment and the CFD Model

DPM Concentration Comparison at Location E in the Experiment and the CFD Model
Error Analysis (CFD and Experiment)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-squared</td>
<td>0.67</td>
<td>0.94</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Main Conclusions

- The approach of using multiple tailpipes to simulate the DPM concentration generated from a work cycle of an LHD is feasible.
- The CFD model is capable of offering detailed contours of airflow and DPM concentration but it is computationally intensive.
- Future work: simulate more work cycles in order to explore the DPM concentration behaviour and determine the optimum airflow quantity that keeps the DPM concentration under the regulatory limit.
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Plan View of the Experiment Area

Location of a Monitor Point
Geometry of the Experiment Area

Dimensions:
Main drift (W x H): 4.3m x 5.5m
Working face (W x H): 4.6m x 5.5m
Tubing diameter: 1.1m

Distance from tailpipe 1 to face: 7.6m
Distance from end of tubing to face: 25.5m

The tailpipes are 3m apart from each other.
DPM Simulation in Ansys Fluent

Boundary conditions:

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<td>0.084</td>
<td>0</td>
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\[
DPM \text{ mass fraction} = \frac{DPM \text{ concentration (} \frac{\mu g}{m^3} \text{)}}{\text{air density (} \frac{kg}{m^3} \text{)}} \times \frac{kg}{10^9 \mu g}
\]

Possible DPM Profile From an LHD Tailpipe
DPM Concentration Profile from the LHD Tailpipe

Velocity Profile from the LHD Tailpipe
DPM Concentration Comparison at the Monitor Points

Distance from the face:
- 5 m
- 8 m
- 11 m
- 14 m

Ventilation tubing inlet velocity:
- 10.00 m/s
- 15.00 m/s
- 20.00 m/s
- 25.00 m/s
- 35.00 m/s
- 35.97 m/s

DPM Concentration Comparison at Monitor Point (5 m away from the face)

This work was made possible by the facilities of the Shared Hierarchical Academic Research Computing Network (SHARCNET: www.sharcnet.ca) and Compute/Calcul Canada.
DPM Concentration Comparison at Monitor Point (8 m away from the face)

DPM Concentration Comparison at Monitor Point (11 m away from the face)
DPM Concentration Comparison at Monitor Point (14 m away from the face)

![Graph showing DPM concentration comparison at different ventilation tubing inlet velocities.]

DPM Concentration Comparison at the Monitor Planes

Distance from the face:  
- 5 m  
- 8 m  
- 11 m  
- 14 m

Ventilation tubing inlet velocity:  
- 10.00 m/s  
- 15.00 m/s  
- 20.00 m/s  
- 25.00 m/s  
- 35.00 m/s  
- 35.97 m/s
DPM Concentration Comparison at Monitor Plane (5 m away from the face)

DPM Concentration Comparison at Monitor Plane (8 m away from the face)
DPM Concentration Comparison at Monitor Plane (11 m away from the face)

DPM Concentration Comparison at Monitor Plane (14 m away from the face)
DPM Concentration Comparison at the Monitor Points

Ventilation tubing inlet velocity:
- 10.00 m/s
- 15.00 m/s
- 20.00 m/s
- 25.00 m/s
- 35.00 m/s
- 35.97 m/s

Distance from the face:
- 5 m
- 8 m
- 11 m
- 14 m

DPM Concentration Comparison at the Monitor Points (Ventilation Tubing Inlet Velocity = 10 m/s)
DPM Concentration Comparison at the Monitor Points (Ventilation Tubing Inlet Velocity = 15 m/s)

DPM Concentration Comparison at the Monitor Points (Ventilation Tubing Inlet Velocity = 20 m/s)
DPM Concentration Comparison at the Monitor Points (Ventilation Tubing Inlet Velocity = 25 m/s)

DPM Concentration Comparison at the Monitor Points (Ventilation Tubing Inlet Velocity = 30 m/s)
DPM Concentration Comparison at the Monitor Points (Ventilation Tubing Inlet Velocity = 35.97 m/s)

DPM Concentration Comparison at the Monitor Planes

Ventilation tubing inlet velocity:
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DPM Concentration Comparison at the Monitor Planes (Ventilation Tubing Inlet Velocity = 30 m/s)

DPM Concentration Comparison at the Monitor Planes (Ventilation Tubing Inlet Velocity = 35.97 m/s)
Conclusions and Future Work

- The lower the ventilation tubing inlet velocity, the higher the DPM concentration will get.
- When the ventilation tubing velocity is greater than 10 m/s, the highest DPM concentration does not increase significantly after the second work cycle of the LHD.
- The DPM concentration does not accumulate after each work cycle of the LHD; specifically, the lowest DPM concentration near the face does not increase.
- When the ventilation tubing inlet velocity is 10 m/s, the further the monitor is from the face (within 14 m), the higher the DPM concentration will be.
- When the ventilation tubing inlet velocity greater than 15 m/s, the DPM concentration profile along the heading does not vary over the work cycles of the LHD.

Future work:
- Results will be compared with experimental data
- Mesh independence study
- Sensitivity study on the spacing between the tailpipes
- Test the effects from different locations of the ventilation tubing in the heading
- Apply the findings to the Schedule Optimization Tool (SOT)

Thank you

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