Evaluation of a Proposed and an Existing Dust Ventilation/Collection System in an Underground Mine Crushing Plant

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Abstract: - Computational Fluid Dynamics (CFD) modeling of two alternative dust collection systems in an underground mine-crushing plant was carried out. In the proposed system, dust was collected/absorbed through the holes along the top edge of the Run of Mine (ROM) bin. In the existing conventional approach, the outgoing dust laden air is collected through an exit in the ceiling. The dust collection performances of both systems were summarized. Detail results are presented in the form of velocity vectors and dust concentration iso-surface contours. Dust was found to be well contained within the crusher bin for the proposed system and stands out as a viable option. However, the velocity magnitudes were found to be high in and around the hole exits, which has the potential to lead to undesirable pressure drop and generation of noise.

Key-Words: - Dust, modeling, CFD, multiphase, ventilation.

1. Introduction

Extraction of ore using block caving methods is common in underground mines. The ore extracted from the draw point is hauled to the underground crushing station using load haul dump (LHD) trucks and tipped or dropped into the ROM bin. A typical LHD truck tipping into a ROM bin is shown in Fig.1. Dust is released during the tipping process; the released dust often causes visibility problem to the LHD drivers. The released dust is expected to go out along with the outgoing ventilation air. In the conventional approach, the outgoing dust laden air is collected through an exit in the ceiling of the chamber (tipple) housing the ROM bin. The dispersion of dust is governed by local airflow controlled by the mechanical ventilation system and is made complex by the localized turbulent air motion generated by large volumes of material undergoing drop feed [1 & 2]. The piston effect of the LHDs returning after dropping the ore in the ROM bin causes the dust to be sucked into the tunnel and cause visibility problem. Computational Fluid Dynamics (CFD) simulation has been successfully used in the past [3 & 4] to evaluate the ventilation of underground crushing plants. The study [3] also carried out experimentation to qualitatively validate the CFD results and gain more insight into the physics of the dust dispersion by the drop feed.

This paper undertakes CFD modeling of both the conventional and less conventional dust collection system proposed for a mine, details not disclosed for confidentiality reasons. Dust was collected/absorbed through the holes along the top edge of the proposed

ROM bin. The idea was to contain the dust released from the bin to within the bin. Fig. 2 shows the geometry of the exiting conventional system. Geometry of the proposed tipple with 20 cm holes on the edge of ROM is presented as a typical computational grid in Fig. 3. Merits of the proposed and existing dust collection systems were evaluated and remarks/recommendations were made. Simulations were conducted for three cases: empty, half, and full ore bin scenarios.

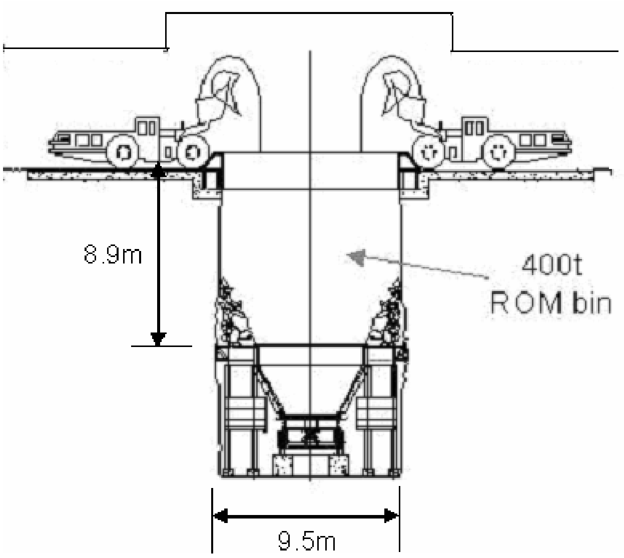

Fig.1 Typical LDH trucks tipping into a ROM bin

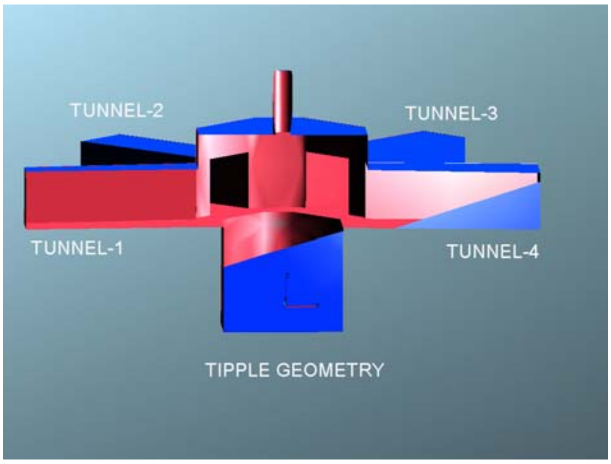

Fig.2 Geometry of the tipple showing the exiting conventional system

The paper presents the flow geometries investigated, computational grid used for modeling the geometries and the computational results obtained under the specified operating conditions. The CFD software FIRE [5] was used for this investigation.

2. Computational Method

A typical computational grid arrangement, out of the six used for two separate systems and different bin content scenarios (empty, half empty & full) is shown in Fig. 3. Grid independency tests were performed and a total of close to 500,000 grids were found to give grid independent results. The grid independency was achieved by increasing the number of grids by 25% in each step until a variation of less than 3% was achieved in mean velocities. The grids used were mainly hexahedral (approximately 90%) with few prisms (approximately 10%). Only k-ε model was used to close the turbulence Reynolds stress through turbulent eddy viscosity. Time averaged equations were solved to obtain the values of velocities, pressure, dust concentrations and turbulence parameters. The multi-phase capabilities available in FIRE[5] were used to model the air-dust flow system where separate velocities for each phase (air and dust) were solved along with the phase volume fraction. The conservation equations used for mass, momentum and turbulence parameters were:

Contunity:

$$\frac{\partial(\alpha_i\rho_i)}{\partial t}+\nabla.(\alpha_i\rho_i\mathbf{u}_i)=0\,, \quad (1)$$

Momentum:

$$\begin{aligned}&\frac{\partial(\alpha_i\rho_i\mathbf{u}_i)}{\partial t}+\nabla.(\alpha_i\rho_i\mathbf{u}_i\mathbf{u}_i)-\mu_i\alpha_i\nabla^2\mathbf{u}_i=\\&-\alpha_i\nabla P+\beta_{ij}(\mathbf{u}_j-\mathbf{u}_i)+\alpha_i\rho_i\mathbf{g}\end{aligned} \quad (2)$$

Turbulence kinetic energy:

$$\frac{\partial(\alpha_i\rho_i k)}{\partial t}+\nabla.(\alpha_i\rho_i\mathbf{u}_i k)-\mu_i\alpha_i\nabla^2 k=P_k-\rho\varepsilon \quad (3)$$

Turbulence kinetic energy dissipation rate:

$$\begin{aligned}&\frac{\partial(\alpha_i\rho_i\varepsilon)}{\partial t}+\nabla.(\alpha_i\rho_i\mathbf{u}_i\varepsilon)-\mu_i\alpha_i\nabla^2\varepsilon\\&=C_1P_k\varepsilon/k-C_2\rho\varepsilon^2/k\end{aligned} \quad (4)$$

where α_i is the phase volume fraction, ρ_i is the phase density, t is time, $\mathbf{u}_i$ is the phase velocity vector, P is the pressure, $\mathbf{g}$ is the acceleration due to gravity, β_{ij} is the inter-phase momentum exchange coefficient, k, P_k and ε are turbulence kinetic energy, its generation and destruction rates respectively.

Air was considered as the continuous phase (1st Phase) and dust, with a density of 2000 kg/m^3 and particle size of 5 microns, was considered as the dispersed (2nd phase). Both transient and steady state conditions were modelled. In the transient, or time dependent situation efforts were made to simulate the cyclic loading pattern observed in the real life operation (one LHD feed per min). A 5 m^3 of air-dust mixture (representing the volume of air displaced from the bin by each LHD feed) with a dust loading of 1% was released from the bottom of the bin over a period of 5 sec. (i.e a flow rate of 1 m^3/sec) The cycle was repeated every 60 seconds and a total of 10 cycles (i.e. a total of 600 seconds in real time) was simulated. Under the steady state situation a continuous release of 5 m^3/60 (0.0833 m^3/sec.) of air-dust mixture was maintained from the bottom of the bin. The simulations were carried out under iso-thermal (200º C) conditions. The volume flow rates of air through each tunnel and the air-dust mixture released from the bottom of the bin, for all the three case scenarios investigated, are given in the Table-1.

Table-1 Volume flow rates (boundary conditions)

Inlets	Air Volume flow rates m^3/sec		Dust loading % volume
Tunnel-1	20.1		0.0
Tunnel-2	3.3		0.0
Tunnel-3	10.8		0.0
Tunnel-4	22.6		0.0
Bin (bottom of bin)	**Steady** 0.0833	**Transient (60 sec/cycle)** 1.0 for first 5 sec 0.0 for next 55 sec	1.0

3. Results and Discussions

The overall dust collection performance is summarized in Table-2. The detailed results are presented in the form of velocity vectors on vertical and horizontal planes and dust concentration iso-surface contours in the solution domain. As the time dependent effects were introduced through air-dust mixture released from the bottom of the bin (see Table-1), it was not expected to alter the overall flow dynamics of the domain substantially. However, the dust concentration pattern will be altered. The dust concentration iso-surface contours obtained for transient cases are presented in this paper. The time dependent videos of dust concentration iso-surfaces were also developed but could not be made available with this paper. The velocity vectors obtained for steady state cases are presented in this paper.

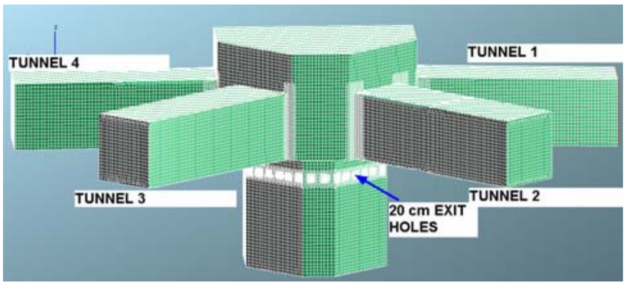

Fig.3 A typical computational grid used, exit through 20 cm holes (empty bin scenario)

Dust collection performance summary (see Table-2) is presented as dust released and dust collected under the steady state conditions. Dust was found to be well contained within the bin (Fig. 7) and stands out as a viable option for dust collection on the basis of the present study.

Table-2 Dust collection summary

Dust collection scenario	Dust released from the bottom of the bin Kg/sec	Dust collected Kg/sec	Remarks
Exit through 20 cm holes in the bin (Empty bin)	1.67	0.84	50% dust is extracted, the rest is contained within the bin
Exit through 20 cm holes in the bin (Half-empty bin)	1.67	1.01	60% dust is extracted, the rest is contained within the bin
Exit through 20 cm holes in the bin (Full bin)	1.67	1.1	65% dust is extracted, the rest is contained within the bin.

Exit through top of tipple (Empty bin)	1.67	0.9	55% dust is extracted, the rest is **NOT contained within the bin**
Exit through top of tipple (Half-empty bin)	1.67	1.08	65% dust is extracted, the rest is **NOT contained within the bin**
Exit through top of tipple (Full bin)	1.67	1.09	65% dust is extracted, the rest is **NOT contained within the bin**

The velocity vectors on a vertical plane through the centre of Tunnels 1 & 4 are shown in Fig. 4. For the proposed system (Fig.4a), the flow bifurcates at the entrance to the tipple, with the majority of the flow bending downwards towards the exit holes and a small portion bending upward forming two vortices near the ceiling. This upward stream has the potential to carry the dust which may come from the tunnel to the two vortices near the ceiling and form dust cloud. The velocity magnitudes in the bin, below the exit-hole level, were very small. For the existing system (Fig.4b), a majority of the flow travels towards the exit duct in the ceiling. The shearing action of the flow coming out from the tunnels appears to enhance the dust-laden flow coming out from the bin which forms the dust cloud, evident in the dust iso-contours (Figs. 7b).

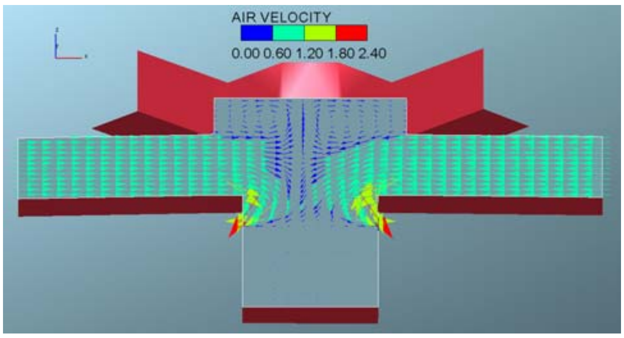

Fig. 4a Velocity vectors on a vertical plane through the centre of Tunnel 1 & 4, exit through 20 cm holes (empty bin scenario)

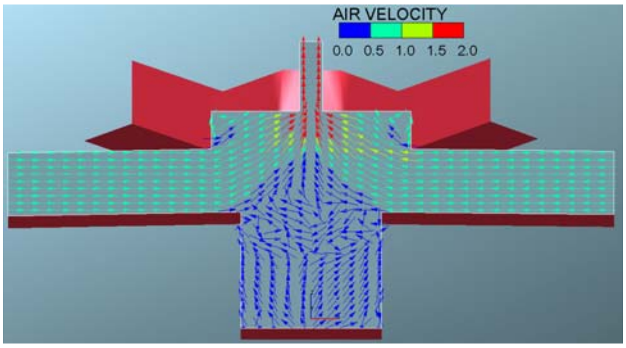

Fig. 4b Velocity vectors on a vertical plane through the centre of Tunnel 1 & 4, Exit through top of tipple (empty bin scenario)

The piston effect of the LHDs, returning after dropping the ore in the ROM bin, can easily suck this dust cloud and cause visibility problem for the driver. The volume flow rate through tunnel-2 is very small (see Table-1). The velocity vectors in Fig. 5a (proposed system) show that the flow does not have enough momentum to penetrate into the tipple and is quickly sucked in towards the exit holes. The volume flow rate through tunnel-3 is medium (see Table-1) but is quickly sucked in towards the exit holes (Fig. 5b).

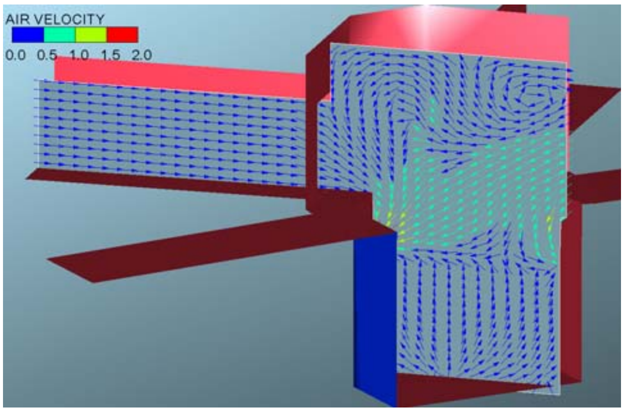

Fig. 5a Velocity vectors on a vertical plane through the centre of Tunnel 2 (empty bin scenario), exit through 20 cm holes (empty bin scenario)

The velocity vectors in tunnel 2 for the existing system (Fig. 5c) show that the flow does not have enough momentum to penetrate into the tipple and is quickly diverted towards the ceiling. It is alarming to see that the dust-laden floe escapes out of the bin and flows towards the tunnel where it encounters the tunnel flow and travels towards the ceiling. This dust-laden flow escaping from the bin and reaching towards the tunnel forms the dust cloud, evident in the dust iso-contours (Figs. 7b). Thus the visibility problem from the piston effect of the LHDs will be worse for tunnel 2. The velocity vectors through tunnel 3 (Fig.5d) does not show the tendency of dust laden flow escaping out of the bin and flowing towards the tunnel. However the flow pattern has similarity to that observed for tunnel 1 & 4 (Fig.4b) and will lead to formation of undesirable dust cloud over the bin.

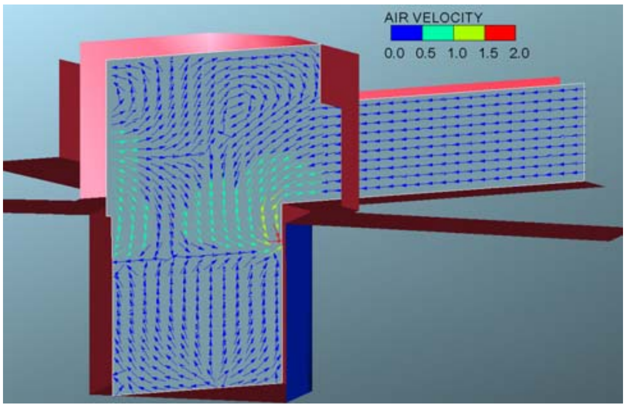

Fig. 5b Velocity vectors on a vertical plane through the centre of Tunnel 3 (empty bin scenario), exit through 20 cm holes (empty bin scenario)

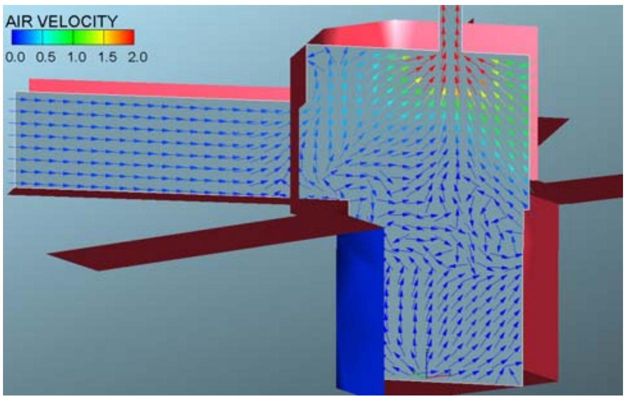

Fig. 5c Velocity vectors on a vertical plane through the centre of Tunnel 2, exit through top of tipple (empty bin scenario)

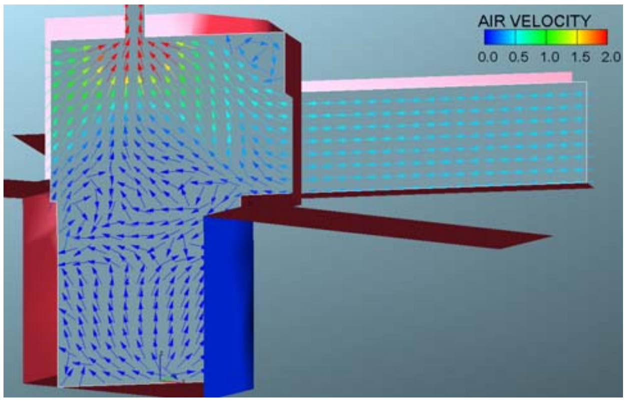

Fig. 5d Velocity vectors on a vertical plane through the centre of Tunnel 3, Exit through top of tipple (empty bin scenario)

Velocity vectors on a horizontal plane through the centre of all tunnels (Fig. 6) show that the higher flow rates through tunnels-1 & 4 leads to greater penetration into the tipple, whereas the least flow rate through tunnel-2 leads to the lowest penetration. The extent of penetration is relatively more for the proposed system (Fig. 6a). The velocity vectors presented for the proposed system (Figs. 4a, 5a, 5b 6a) clearly show that the air flows from the tunnels penetrate well into the tipple to form a curtain of cleaner air before getting sucked into the exit holes. This air curtain acts as a barrier and prevents dust from escaping the bin.

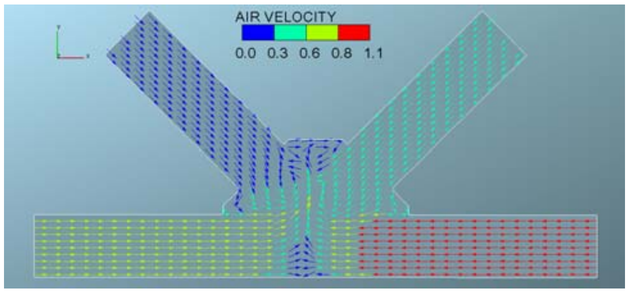

Fig. 6a Velocity vectors on a horizontal plane through the centre of tunnels, exit through 20 cm holes (empty bin scenario)

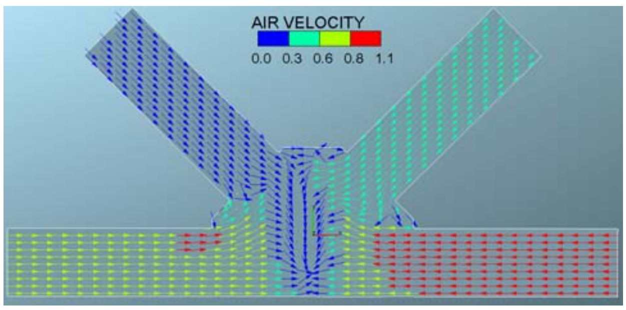

Fig. 6b Velocity vectors on a horizontal plane through the centre of tunnels, exit through top of tipple (empty bin scenario)

Velocity contours (not shown here due to space constraint) on a horizontal plane through 20cm holes in the proposed bin clearly show that the velocity magnitudes are very high in and around the holes and reach a maximum of 102 m/s. This high velocity may lead to high pressure drop and generation of noise. Efforts may me made to reduce these high velocities by using larger hole diameters.

Dust iso-contours or iso-surface (100 mg/m^3) are presented in Fig. 7. It may be mentioned here that the dust concentration inside the iso-surface envelope is greater than 100 mg/m^3. It is encouraging to see that the dust is well contained within the bin for the proposed system (Fig. 7a) and is unlikely to contribute to the visibility problem. However, the dust generated by the movement of LHD in the tunnels is ignored in this study. The dust generated by the LHD movement has the potential of creating visibility problem. This can be investigated as an extension of this study. Dust iso-contours for the existing system, presented in Fig. 7b, clearly show the formation of dust cloud engulfing most of the tipple volume. The piston effect of the LHDs, will easily suck the dust cloud into the tunnel and cause visibility problem to the driver. The dust generated by LHD movement will aggravate the situation. The results for half-empty and full bin scenarios (not presented in this paper) show very similar behavior to that observed for empty bin scenario presented above.

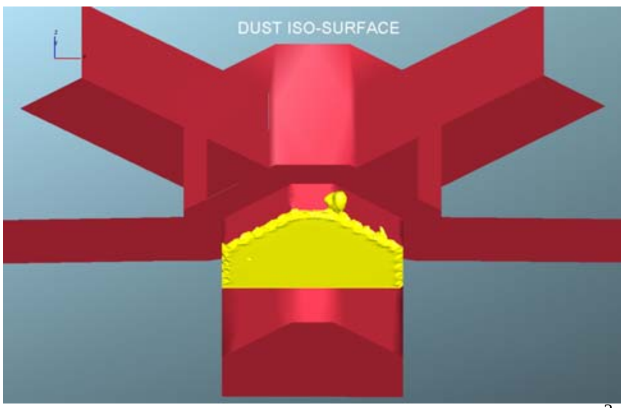

Fig. 7a Dust iso-contours or iso-surface (100mg/m^3) (A snap shot of transient/time dependent case), exit through 20 cm holes (empty bin scenario)

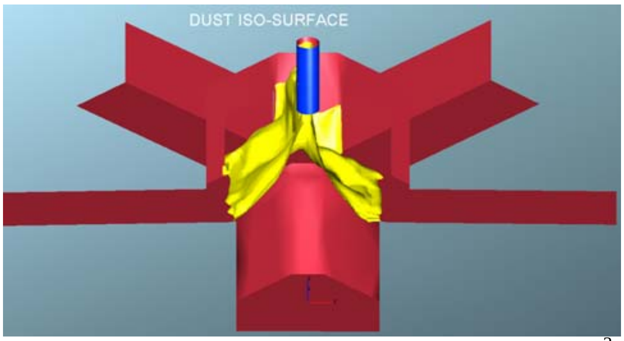

Fig. 7b Dust iso-contours or iso-surface (100mg/m^3) (A snap shot of transient/time dependent case), exit through top of tipple (empty bin scenario)

4. Conclusion

A conventional system where dust is collected through an exit in the ceiling was compared with a proposed system where dust is collected through holes along the edge of ROM bin. Dust was well contained within the ROM bin for the proposed system and appears to be a viable option. Location of the flow exit in the conventional system leads to a flow dynamics which forms dust cloud above the ROM bin.

References:

[1] Johansen, S.T., & Laux, H., Simulation of granular flows, Proceedings of RELPOWFLO III, *The international symposium on the reliable flow of particulate solids*, Telemark College, Porsgrunn, Norway, 11-13 August 1999

[2] Rahaman, F., & Naser, J., An unequal granular temperature kinetic theory: Description of granular flow with multiple particle classes, *Powder Technology*, Vol. 138, pp 82-92, 2003

[3] Silvester, S.A., Lowndes, I.S., Kingman, S.W., The ventilation of an underground crushing plant, *Mining Technology*, Dec. 2004, Vol.113

[4] Silvester, S.A., Lowndes, I.S., Kingman, S.W., Arroussi, A., Improved dust capture methods for crushing plant, *Applied mathematical modelling*, 2007, Vol.31 pp. 311-331

[5] FIRE, *user guide*, www.avl.com