Simulation of Air and Contaminant Flow in Underground Mine Ventilation Networks

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Introduction

- Ventilation in an underground mine is of critical importance to the occupational health and safety of underground employees.
- The atmosphere underground is limited and confined, and is thus easily reduced to a sub-standard (or even dangerous) condition if contaminants produced from various operations are not controlled, or safely extracted or diluted to harmless levels.
- Of equal importance to the maintenance of a healthy working environment underground is the need to protect employees against the risk and the consequences of underground fires and unplanned explosions, including sulphide dust ignitions.
- Correct design, implementation and maintenance of mine ventilation is therefore of fundamental importance.
Principles

- The control of primary ventilation flows or circuits in a mine requires careful planning from the design stage and thereafter throughout the operating life of the mine.
- It is strongly recommended that as part of the initial design of any mine or a planned upgrade that computer simulation of the ventilation network be done to assist in (Hartman, 1997):
  1. Solving complex ventilation systems with many features
  2. Fan selection and optimal fan location selection
  3. Determining optimal fan settings for efficient operation
  4. Determining the amount of regulation required to control airflow
  5. Selection of locations for doors and regulators
  6. Determining the effect of air leakage on the overall system and,
  7. Determining possible effects of improvements/changes to airways.
Ventilation Software Packages

• A number of available software packages for ventilation network design and simulation exist today.
• Some of them are standalone packages specifically developed for mine ventilation and others are part of larger systems such as general mine planning packages.
• Such an example is Maptek’s VULCAN 3D Software and its integrated ventilation module.
Underground Ventilation Networks

- VULCAN’s ventilation module allows the user to simulate airflow through the mine based on the Hardy-Cross algorithm of balancing networks.
- This is basically a series of successive approximations based upon two Kirchoff’s laws for electrical circuits and the Atkinson’s Equation (Tien, 1999).
- The module allows the simulation of airflow in underground workings presented as a network consisting of branches.
- The input parameters for the branches can be known values and/or the result of calculations.
- The output of the module can be used to change the visual attributes of the network or be directed to reports for further analysis.
Network Equations

- **Atkisson’s Equation**: There are two forms of Atkinson's Equation based on the system of units used.

- **Kirchoff’s First Law**: The quantity of air leaving a junction must be equal to air entering a junction.

- **Kirchoff’s Second Law**: The sum of pressure drops around any closed path or mesh in a ventilation system must be equal to zero.

\[
R = \frac{K P (L + L_e)}{5.2 A^3}
\]

**SI**

\[
R = \frac{K P (L + L_e)}{A^3}
\]

\[
\Sigma Q = 0
\]

\[
\Sigma H_L = 0
\]
Branch Selection Guidelines
Based on Marks and Deen, 1993

- Selecting the optimum number of branches may be the most delicate part of constructing a network.
- An individual branch should be considered if it carries > 1% of the total mine airflow. Branches with less airflow can be combined into series/parallel sets.
- It is recommended to split single, long, vertical branches of more than 700m into two or more branches for more accurate calculations.
- Individual branches can be placed where a special process is taking place, such as a significant heat addition, air-conditioning, or gas inflow.
- Additional branches may be placed in areas of intense activity or to aid the simulation process.
From Mine Design to Ventilation Network

- Mine design centrelines can be used to form network branches or new objects can be digitised.
- Ventilation parameters for each branch can be set during this process or later.
- Saving the network creates the layer and the network file in the working directory.
Types of Branches

• **Unregulated**: a branch with no known information as to the air flow.

• **Fixed Quantity**: a branch with a fixed quantity of air flowing through it. The entered value works as a target for the network.

• **Fan**: a branch with a fan assigned to it. The appropriate fan file and fan name will need to be nominated.

• **Inflow**: a branch with a known inflow of air. An inflow is used in cases where the ventilation network of interest is a subset of an overall network. This inflow is a nodal characteristic due to the flow of air from the 'master' network into the subset.

• **Contaminant**: This branch type works on the same principal as inflow (except for methane), and needs to be entered as units in flow.
Ways to Define Branch Resistance

- **Known**: a known resistance value.
- **R/L**: known resistance value for a given length. Resistance will equal the branch length times the value entered.
- **Atkinson Equation**: a resistance value calculated by using the Atkinson equation. All necessary parameters need to be entered.
- **R=\frac{p}{Q^2}**: resistance calculated on head loss and flow.
Inserting & Moving Nodes

- Branches can be split into smaller branches.
- Each of the new nodes will inherit the parameters of the original.
- The branch before the inserted node will be assigned the original branch's ID, while the branch after the inserted node will be assigned the next available ID.
Fans & Fan Database

- Different fans and their specifications can be stored in a Fan Database (.vfn).
- The database can be shared across different ventilation networks.
- Fans can be added, edited or removed at any time from the database.
- The fan data can be derived from an *Equation, a Curve or Fixed Pressure*. 

![Image of Fan Database interface]

**Fan Equation**

- $Q$
- $A_0 = 2936.0$
- $A_1 = -0.545$
- $A_2 = 0.2234$
- $A_3 = 0.0$

**Fan Curve**

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<th>p</th>
<th>Q</th>
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</tbody>
</table>

**Fixed Pressure**

- $P$
- $A_0 = 0.0$
- $A_1 = 0.0$
- $A_2 = 0.0$
- $A_3 = 0.0$

![Image of Fan Database interface]
Adjusting the Display Attributes

- Branch colour scheme – a contour legend needs to be set.
- Colour scheme used for annotations
- Number of decimals for numerical annotations
- Option to use the parameter symbol as a prefix to the annotation
Simulation

- Once all the necessary information is provided in the branches, the simulation can be executed.
- A reference point is used for the simulation.
Reporting

A number of csv files can be created containing both input and output information from the network using the Report option.
Case Study - Data

- The example presented in this paper is a simplified version of an underground mine.
- It consists of two main shafts and four working levels linked with a ramp and ore passes.
Case Study - Design

- The available resistance, airflow and fan information for separate branches is entered to generate the network.
- All airways with the exception of the ramp parts are straight segments linking start and end network nodes.
- The ramp is split into multiple point strings, each constituting a single airway between start and end nodes.
Case Study - Design

- Particular branches are set to have **fixed quantity** type of flow as particular airflow is required for them.
- Fixed quantities are used as input data for the simulation process and thus the flow for these branches is not calculated.
- Two branches contain a fan (of the same type). A special symbol is used to identify these branches.
Case Study – Simulation & Reporting

- The simulation process required 200 iterations and produced a successful solution for the network.
- Using the reporting function in VULCAN, a complete report is produced regarding the simulation results.

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<th>Branch ID</th>
<th>Q (cfm)</th>
<th>R (in^3/min/ft^2)</th>
<th>p (in H₂O)</th>
<th>Hr (in H₂O)</th>
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Conclusions

• Ventilation network simulation provides two things: how the airflows are distributed throughout the network and how much pressure it takes to do the job.

• Results from a computer program reveal where resistance bottlenecks are located and which branches might be subject to unacceptably high air velocities.

• These revelations, in turn, indicate how fans should be sized, and where regulators, parallel airways, or boosters might be placed.

• The case study presented in this paper shows the current state of ventilation simulation software and how it is applied for planning and simulation of underground ventilation networks.