

Simulation of Air and Contaminant Flow in Underground Mine Ventilation Networks

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ABSTRACT

Simulating a ventilation network of an underground mine can help in solving complex ventilation systems with many features, selecting proper fan specifications, location and settings. Early computer systems running simple network simulations were able to provide solutions to the most common and immediate problems regarding underground mine airflow. The more advanced systems available today can perform more sophisticated modeling and simulation of a mine's ventilation network and present their results in a more understandable and easy to communicate form. This paper presents a ventilation network case study from an underground mine. All aspects of mine ventilation network modeling and simulation are discussed as well as the results from the simulation process. The algorithms and techniques used are thoroughly explained. Some useful guidelines for the application of ventilation network software are also provided in the text.

1. INTRODUCTION

1.1 Overview

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. The contaminants may include dust, aerosols, diesel fumes and particulates and fumes from

blasting, as well as gases released from the rock strata. Reduction of oxygen may result from oxidation of reactive sulphides under some circumstances. Oxygen reduction may also take place due to recirculation of ventilating air where diesel engines are operating, and in unventilated areas where "standing" water is present.

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. In present day mining, ventilation systems designed and operated to maintain efficient operations will normally enable a high standard of occupational health and safety to be achieved.

1.2 Principles and Scope

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):

- Solving complex ventilation systems with many features;
- Fan selection and optimal fan location selection;
- Determining optimal fan settings for efficient operation;
- Determining the amount of regulation required to control airflow;

- Selection of locations for doors and regulators;
- Determining the effect of air leakage on the overall system; and,
- Determining possible effects of improvements/changes to airways.

2. UNDERGROUND VENTILATION NETWORK DESIGN

2.1 General

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.

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). There are two forms of Atkinson's Equation based on the system of units used:

$$\text{Imperial} \quad R = \frac{KP(L + L_e)}{5.2A^3},$$

$$\text{SI} \quad R = \frac{KP(L + L_e)}{A^3},$$

where R is the airflow resistance of a particular airway, K is an empirically determined friction factor, L is the length of the airway, L_e is the equivalent length (empirically determined) used to account for shock losses due to changes in the airway shape and/or obstructions in the airway, P is the perimeter of the airway, and A is the airway's cross-sectional area.

VULCAN allows use of the existing mine design eliminating the need to manually input or import design information. The output of the module can be used to change the visual attributes of the network or be directed to reports for further analysis.

2.2 Network Design

The representation of an underground mine design as a ventilation network is usually a fairly straightforward procedure.

New branches can either be digitised, or copied from an existing centreline. Each branch in the ventilation network is defined by two junctions (Start Node and End Node) and by numerical data that indicate the characteristics of the airway. Any number of points can exist between the start and end node allowing more complex branches such as ramps to be directly represented in the network, unlike earlier systems where such complex entities had to be split into smaller straight segments (Figure 1).

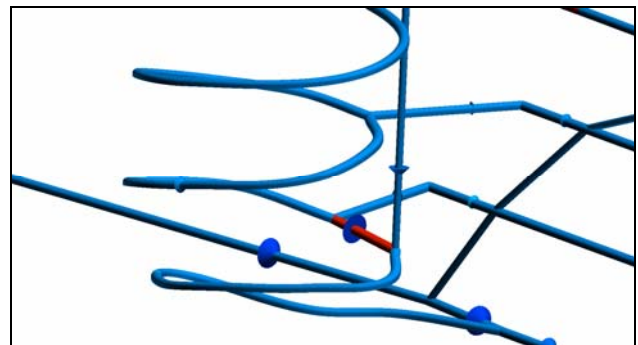


Figure 1: Detail of ventilation network showing straight and non-straight airways (branches).

The resistance can be defined in four different ways using different parameters depending on what is available (Figure 2):

1. *Known*: fixed resistance
2. R/L : resistance per unit length
3. *Atkinson Equation*: resistance from Atkinson's equation (empirical)
4. $R=p/Q^2$: resistance based on Square Law.

The branch static pressure can be either entered if known or calculated using the change in elevation between the start and end nodes of the branch.

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 2,000ft into two or more branches for more accurate calculations (Marks and Deen, 1993). 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.

Branches can be split into smaller branches using a node insertion function. 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.

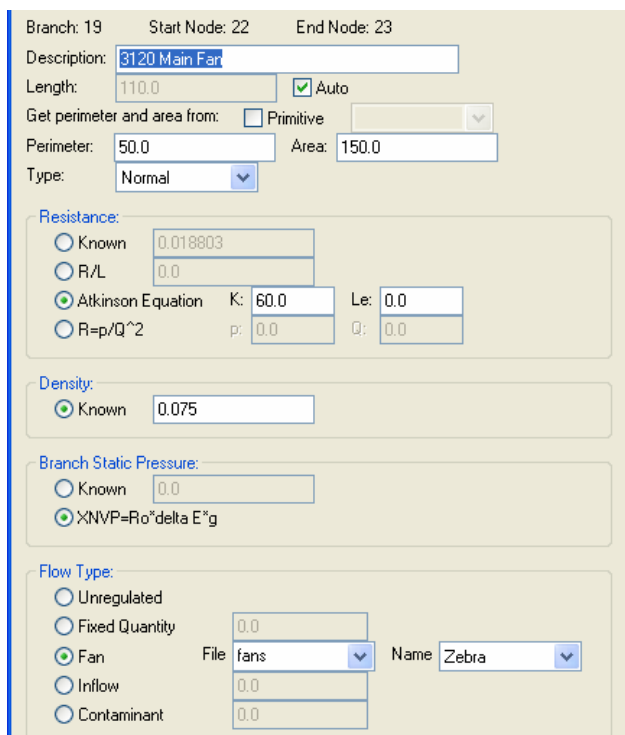


Figure 2: Branch definition panel in VULCAN covering every possible airway configuration.

Different flow types can be assigned to a branch depending on the desired ventilation conditions or current planning. The flow type of a branch can be any of the following:

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. The inflow value needs to be entered as units in flow. 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. If only one branch is connected to this inflow node, then the flow through the branch will be the same as the inflow. However, if there are several parallel branches connected to this node, then the flow through these branches will be determined by other parameters, i.e. resistance etc.

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

Ventilation networks are commonly closed by use of a 'dummy' branch between two shafts representing the atmosphere over the topographical surface. Such a branch is considered to have zero resistance.

2.3 Fans Database

A single fan database can be shared across different ventilation networks. Fans can be added, edited or removed from a fan database. It is possible to add individual fans to an existing fan database, and thus group a number of fans for a particular application, e.g. for a specific mine or area of the mine. An unlimited amount of fans can be added to a ventilation network.

The fan data can be entered via an equation for the curve, points from the curve itself, or as fixed pressure (simulating inflow, natural ventilation or other compressor systems). Figure 3 shows an example of a fan defined using points from the curve. Up to 10 points (with a minimum of 3) can be defined for the fan curve.

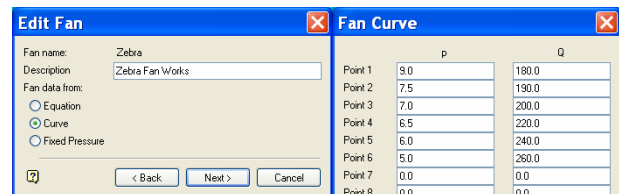


Figure 3: Fan definition panel (left) and fan curve points entry panel (right).

2.4 Simulation Execution & Reporting

Once all the necessary information is provided for each branch, the simulation can be executed. A reference point is used for the simulation. This reference point is considered to be the node at the surface intake.

Simulation normally takes a few seconds to run using modern hardware. Upon successful completion, the user can generate a number of reports on different aspects of the network such as calculated resistances, airflow, velocity, static pressure, pressure loss, etc.

3. CASE STUDY

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 (Figure 4).

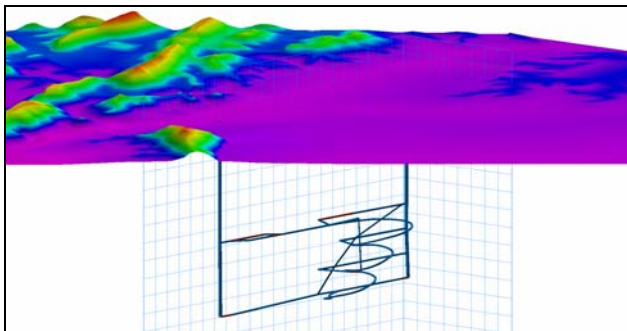


Figure 4: Underground mine model and overlying topography.

The available resistance, airflow and fan information for separate branches is entered to generate the network shown in Figure 5. The network is stored as a design layer in a vector database with special fields for ventilation parameters. 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.

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.

The entire network can be coloured using any of its parameters and a colour legend (Figure 6). Branches can receive up to four annotations. The symbols can be scaled depending on any numerical parameter of the network before or after simulation (Figure 7).

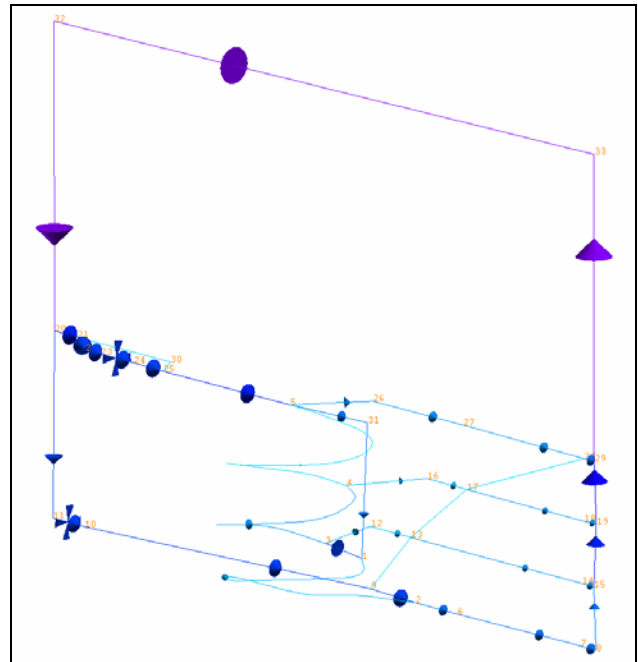


Figure 5: Complete ventilation network with 3D symbols showing airflow direction and fan location.

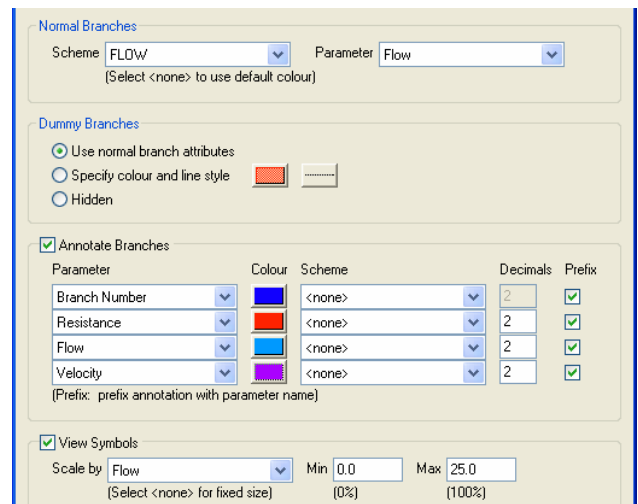


Figure 6: Network display attributes configuration panel in VULCAN.

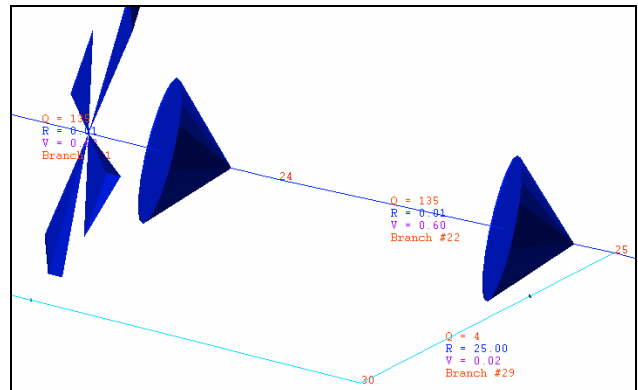


Figure 7: Ventilation network detail showing flow and fan symbols as well as other selected numerical information.

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. Some of these results are listed in Table 1.

Table 1: Part of the ventilation network simulation results showing calculated flow (Q), resistance (R), pressure loss (p) and boost (Hr).

Branch ID	Q (cfm)	R (in*min ² /ft ⁶)	p (in H ₂ O)	Hr (in H ₂ O)
1	35.145	0.076	94.108	0.000
2	60.319	0.064	233.245	0.000
3	10.280	0.096	10.184	0.000
4	75.000	0.008	47.521	0.000
5	75.000	0.024	137.478	0.000
6	75.000	0.003	19.173	4907.552
7	110.145	0.010	120.417	0.000
8	111.003	0.052	637.626	0.000
9	111.003	0.006	72.866	0.000
10	49.826	0.011	27.915	0.000
11	49.826	0.008	20.521	0.000
12	50.000	0.035	86.763	0.000
13	50.000	0.003	6.550	5019.757
14	50.039	0.011	28.306	0.000
15	50.039	0.008	20.241	0.000
16	50.000	0.024	60.019	0.000
17	50.000	0.002	5.504	5158.764
18	138.997	0.021	406.589	0.000
19	134.954	0.007	135.413	0.000
20	134.954	0.003	54.342	0.000
21	134.954	0.007	121.763	0.000
22	134.954	0.008	142.579	0.000
23	138.997	0.032	613.616	0.000
24	74.278	0.011	61.265	0.000
25	74.278	0.018	99.936	0.000
26	74.278	0.025	138.160	0.000
27	75.000	0.002	11.282	5235.145
28	4.043	0.023	0.383	0.000
29	4.043	25.000	408.737	0.000
30	110.145	0.009	104.483	0.000
31	175.000	0.004	130.377	0.000
32	125.000	0.004	66.560	0.000
33	75.000	0.004	23.962	0.000
34	111.003	0.021	260.251	0.000
35	75.000	0.015	86.537	562.863
36	0.722	500.000	261.000	0.000
37	0.683	500.000	233.357	0.000
38	0.857	500.000	367.443	0.000
39	75.000	0.023	128.414	0.000
40	250.000	0.035	2187.410	0.000
41	250.000	0.021	1301.045	0.000
42	250.000	0.000	0.000	0.000

The results produced by ventilation network simulation can be used to identify problematic

areas where, for example, air velocity is too high, pressure loss is too high, or if the entire network is operationally feasible as a ventilation system.

4. 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.

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