Simulating Airflow Conditions In a South African Coal Mine, Using The VUMA-Network Simulation Software

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ABSTRACT: The international mining industry is experiencing many social and economic pressures to increase levels of safety and productivity. One of the engineering disciplines that can help to improve levels of safety and productivity is that of mine ventilation. In this regard, the accurate design and operation of ventilation systems form an essential part of the ventilation engineer's role to ensure a healthy and safe working environment. To assist the ventilation engineer in fulfilling this role, modern computer tools are required to enable the practical and economical design of effective mine ventilation systems. VUMA-network is a ventilation network simulator that has been jointly developed by the Mining Technology Division (Miningtek) of the Council for Scientific and Industrial Research (CSIR) and Bluhm Burton Engineering Pty. Ltd. in South Africa. VUMA-network is an interactive program that allows the simultaneous modeling of airflow as well as contaminant and thermodynamic behavior in mine ventilation networks. The VUMA-network program can, however, be used to simulate airflow only and in this case the user input requirements are significantly reduced as no heat flow or contaminant input data are required. An example of such an application is in a shallow coalmine where the aim of the simulation is to optimize airflow distribution and to reduce fan power requirements.

To this extend Miningtek has performed a simulation of the ventilation network of a South African coalmine. The initial simulation was aimed at obtaining a good correlation between simulated and measured data. Next a limited number of "what-if" simulations were conducted to determine the possibility of reducing pressure losses and of increasing the ventilation system's efficiency by optimizing the air flow distribution. This paper is aimed at briefly describing the VUMA-network simulation software and then the outcome of the on-mine application project.

1 INTRODUCTION

Mine ventilation planning and design has improved significantly since computer tools are used to replace manual calculation methods. Changes in health and safety regulations in individual countries and mining methods evolving from manual operation to trackless diesel and electric operated equipment require accurate ventilation planning and design. The use of diesel-operated vehicles is significant in South African coalmines and fresh air requirements are becoming exhaustive.

With the use of more efficient and modern mining equipment, mines are extending several kilometers every year, developing complex ventilation networks. This results in increasing difficulty to predict the airflow behavior and to ensure adequate ventilation in all sections of a mine. With modern and accurate simulation tools, a mine ventilation system can be designed to provide the necessary airflow at the lowest cost. The benefits of effective mine ventilation conditions are improved worker health and safety, and ultimately productivity. In most of the literature on South African coalmine ventilation, scant attention is given to ventilation network design. One of the reasons for this might be a lack of confidence in ventilation network simulators available to date. The following sections will attempt to demonstrate the relevance and potential benefit of using VUMA-network to simulate coalmine ventilation systems.

2 VUMA NETWORK SIMULATOR

The simulation software VUMA-network is specifically designed and developed to assist underground ventilation control engineers and practitioners to plan, design and operate mine ventilation systems. VUMA-network is an interactive network simulation program that allows for the simultaneous simulation of airflow, air thermodynamic behavior and gas and dust emissions in an underground mine. The program caters for a wide variety of mining methods. A fundamental criterion of VUMA-network is the incorporation of user-friendly interfaces that allow simulation networks to be constructed quickly and what-if studies to be performed to determine optimal designs and system requirements. The main design criteria used in developing VUMA comprise the following:

- Program specifically designed for use in the mining industry.
- User-friendly interfaces with graphical network viewing capability.
- Compatibility with all Windows platforms.
- Simulation of the majority of mining methods.
- Simultaneous and interactive simulation of airflow, contaminant concentration and air thermodynamic properties in a mine ventilation network.

From the above generic criteria the following principles of operation were derived:

- Mine ventilation network is graphically constructed using a computer mouse.
- VUMA network consists of branches, starting and ending with nodes, and depicting network components such as shafts, tunnels, etc.
- Input data for branches is used to calculate the air pressure drop and air thermodynamic and contaminant level changes in a specific component of a network.
- Input data for nodes consists of the X, Y and Z co-ordinates, Barometric pressure (BP), Virgin Rock Temperature (VRT), and air temperatures. The BP, VRT and wet-bulb and dry-bulb temperatures only need to be set for the start-node as these parameters are calculated for other nodes throughout the rest of the network.
- Simulation networks are constructed in a two-dimensional (2-D) graphical editor on a level-by-level basis. Different levels are then interconnected, typically by shafts or inclines.
- A network is viewed in 2-D format in either geometric, strike, or section view.
- Input data for each branch is entered in a specific input screen for that branch-type before a solution is obtained for airflow, contaminants and air thermodynamic properties.
- If only an airflow solution is required, only information relating to the geometry and air resistance characteristics of the branches need be entered.
- Iterative network solution algorithms are used to solve for airflow, and updated heat flow models are used to calculate the air thermodynamic changes in each branch.
- VUMA contains an extensive help function to assist with the development of a simulation model.
- A three-dimensional (3-D) graphical viewer is used to view the network in 3-D.
- In addition to the 2-D and 3-D graphics output display, results may be obtained via tabular format in which the solver is designed.

The solver around which VUMA is designed is the result of the development of both theoretical and empirical models that have been developed and verified by engineers and scientists at both Bluhm Burton Engineering and CSIR: Miningtek over a number of year's involvement in consultancy and research projects. Further details of the VUMA simulator are discussed in detail in the technical paper by Marx et al., (2001).

3 EVALUATION METHOD

Ventilation planning and design is one component of the broader mine planning system. The methodology of mine ventilation planning and design in modern mine theory and practice differs substantially from the traditional hands-on calculation approach, and uses all possibilities offered by computer hardware and software that are available to the mine ventilation engineer. The following methodology was applied in the current study:

- Obtain mine ventilation network layout, and the required physical and operational data.
- Construct the simulation model and complete data input.
- Obtain base case solution and ensure correlation with operational data.
- Evaluate results and optimize airflow distribution through 'what-if'' analysis.
- Determine areas of excessive pressure loss and optimize to reduce overall fan power requirements while maintaining airflow balance.
- Document results, including conclusions and recommendations.

As part of the broader mine planning system, recommendations might include changes to the original layout and physical parameters such as fan specifications and shaft and roadway sizes.

3.1 Operating Mine and Section Details

Bank colliery of Amalgamated Collieries Limited (AMCOAL) was approached to assist Miningtek in this study and they kindly provided the mine layout and required input data for the simulation. Bank Colliery is situated in the Witbank coalfields, 40 kilometers East of Witbank in Mpumalanga, South Africa. The mine consists of four shafts, namely Main, Brown, South and West shafts. At West shaft the No. 5 coal seam is mined while mining of the No. 2 seam takes place at the other three shafts. Mining is done by means of the bord and pillar method using mainly Voest Alpine and Joy mechanical miners, with a few conventional sections (Holdroyd, D., 1997). Table 1 describes the mining operations in the South shaft ventilation network. Figure 1 shows the general layout of a typical road header section in the mine using auxiliary ventilation devices.

Table 1. No. 2 Seam South Shaft Production Data.

Section	Mining Depth (m)	Mining Height (m)	Pillar Center (m)
5-SE28/9	79	4.32	19
9-SE28/6	85	4.98	20
13-SWS1/7/2	74	5.49	20
15-SWS1/6/2	94	5.70	22
SW1	93	5.43	24

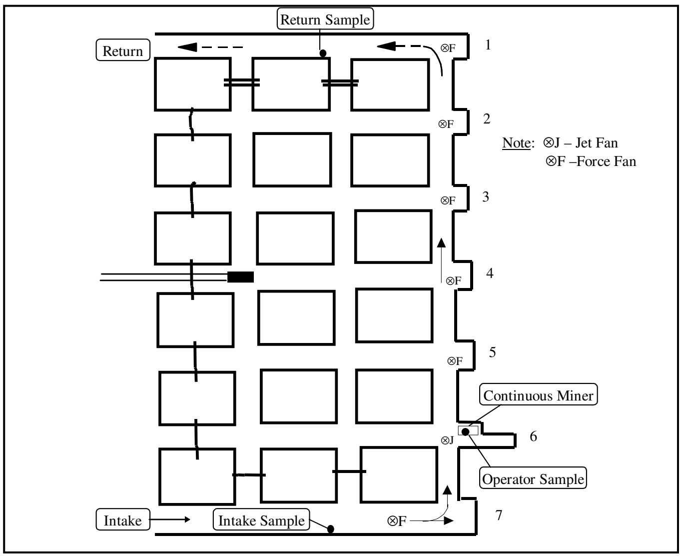

Figure 1. Typical u/g layout of a section at South shaft.

3.2 Network input data

In addition to the physical layout of the mine, the following data was provided by the mine: a

- Roadway height - 5.2 m.
- Roadway width - 6.7 m.
- Downcast shaft near SW1 development with a diameter of 4.1 m and a volume flow of 102.8 m^3/s.
- Rescue borehole with a diameter of 0.9 m and a volume flow of 2.8 m^3/s.
- Downcast near South shaft collar (belt incline) with dimensions of 3.0 m × 6.0 m with a volume flow of 43.2 m^3/s.
- Downcast transport incline shaft with dimensions of 7.0 m × 5.0 m and a volume flow of 157.4 m^3/s.
- Downcast shaft for SE28/6 and SE28/9 with a diameter of 4.1 m and a volume flow of 44.9 m^3/s.
- Up-cast shaft with a diameter of 5.0 m and a volume flow of 215 m^3/s. South shaft fan is installed on this shaft.
- Up-cast shaft to Shaft fan 5 with a diameter of 4.1 m and a volume flow of 136.7 m^3/s. This shaft has an additional 110.0 m^3/s entering from the 5-seam workings.
- Various other measured airflow quantities at specific locations in the mine were indicated on the mine plan.

4 THE SIMULATION MODEL

The following figures are graphical representations of the simulation model that was developed in VUMA-network. Figure 2 shows a geometric view of the underground ventilation network and Figure 3 shows a three-dimensional view of the network.

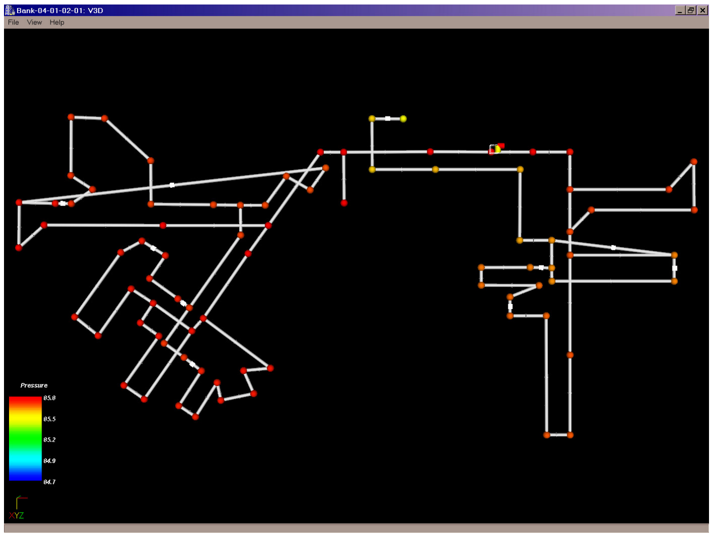
Figure 2. Geometric view of the South shaft ventilation network.

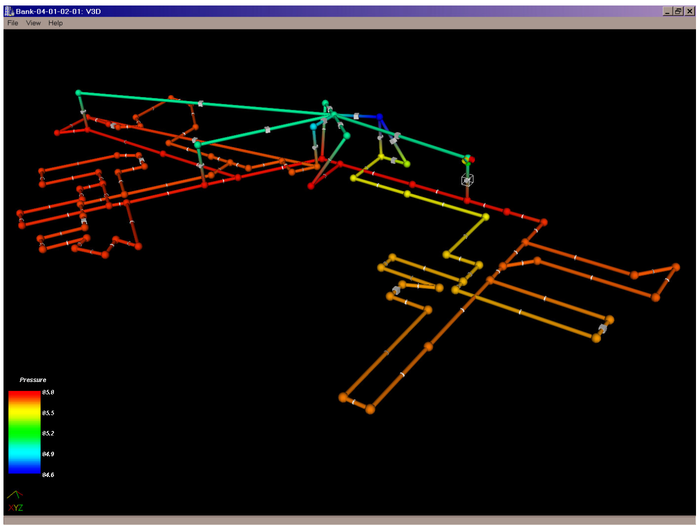
Figure 3. Three-dimensional view of the South shaft ventilation network.

5 BASE CASE SIMULATION

The following table shows the correlation obtained between the base case simulation and the operational data obtained from Bank Colliery for the main intake and return system of the mine:

Table 2. Intake/return airflow balance.

Position	Measured m^3/s	Simulated m^3/s
SW1 Downcast	102.8	105.6
Belt Incline Downcast	43.2	44.9
Transport Incline Downcast	157.4	147.8
SE28/ Downcast	44.9	46.1
Rescue Borehole Upcast	2.8	5.1
Up-cast - South Shaft Fan	215.0	214.2
Up-cast – Fan 5	136.7	136.8

The correlation between the simulation results and the operational data for underground measuring points were also acceptable although the differences were bigger than for the main intake and return system. The results were found to be adequate to continue the study and therefore to attempt improving the airflow distribution and reducing overall fan power requirements. The following figure shows the mass flow distribution for the base case model with the four production zones circled and numbered:

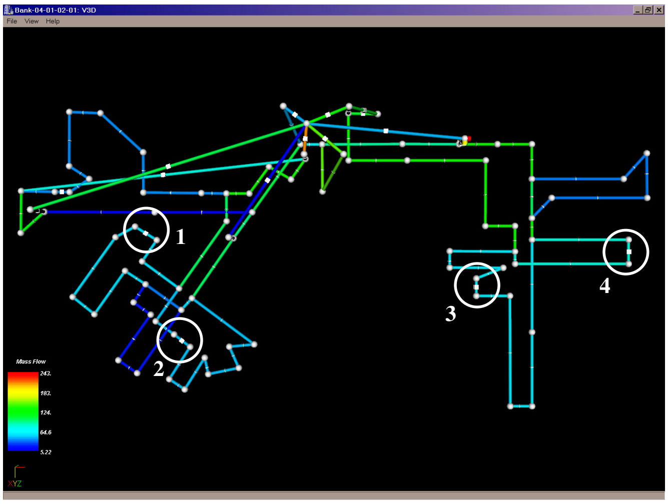

Figure 4 Mass flow distribution for base case model.

6 AIRFLOW DISTRIBUTION OPTIMIZATION

Table 3 below shows the simulated airflow quantities for the four production zones:

Table 3. Production zone airflow distribution.

Number	Production Zone	Airflow m^3/s
1	SWS1/6/2	56.6
2	SWS1/7/2	40.3
3	SE28/6	46.4
4	SE28/9	37.2

Two regulators were included in the simulation model as indicated in Figure 5 to improve the airflow distribution to the production zones.

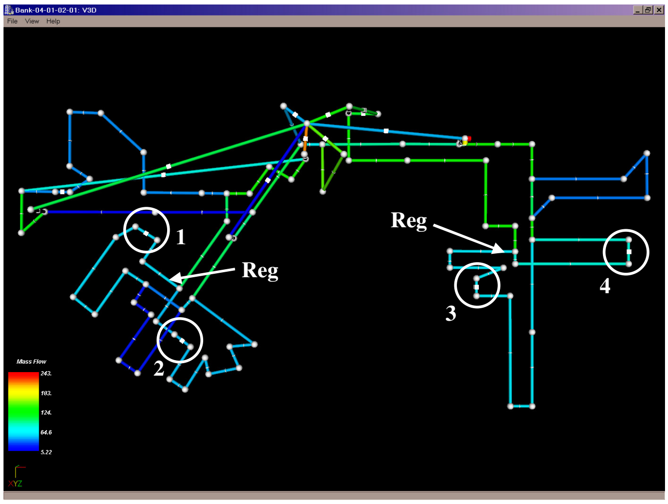

Figure 5 Position of regulators.

These regulators are of the variable airway size type, 4.0 m x 5.0 m in dimension. The regulator near production zone 1 was finally set at 60% open and the regulator near production zone 3 was finally set to 65% open. This resulted in the following air distribution, Table 4:

Table 4. Production zone airflow distribution after regulation.

Number	Production Zone	Airflow m^3/s
1	SWS1/6/2	45.7
2	SWS1/7/2	46.6
3	SE28/6	40.8
4	SE28/9	40.2

Due to the fact that production zones 1 and 2 have a completely separate return system from production zones 3 and 4, it would be more difficult to improve the distribution between the two areas. Although regulators can be used, this will probably require some adjustment of the main fans. It was felt, however, that the distribution in Table 4 was sufficient for this study and adequate airflow velocities were present in all the production zones.

7 REDUCTION OF SYSTEM PRESSURE LOSS

Three areas of excessively high pressure loss were identified from the simulation results. These are:

a. The belt decline.
b. The connection between the transport decline and the main intake system.

c. A 950 m portion (single road airway) of the return system from production zones 3 and 4.

It was possible to reduce the pressure loss in b and c by removing some brattices and air stoppings and thus increasing the airway size in both instances. In the case of the belt decline the physical dimension will have to be changed and it was decided that this would only be practical if it was a real problem area.

The result of these changes was a reduction in fan pressure of 10.6% and 19.7% for the two main fans, assuming the airflow volumes remained constant. These changes had a significant effect on the distribution of airflow between intake and return shafts and inclines, but the distribution to the production zones was not affected at all. By reducing the pressure loss in the transport incline system, the intake volume to the belt incline reduced significantly and thus the contribution to the mine's overall pressure loss.

8 CONCLUSIONS

From the results of the study explained in the previous sections, the following conclusions can be drawn:

- VUMA-network is capable of simulating a coalmine ventilation system to a high degree of accuracy.
- The benefit of using a simulation tool such as VUMA-network is that the results can be viewed graphically and in this study areas of high pressure loss or low flow were identified quickly and easily.
- The effect of various changes to the existing ventilation network could be easily assessed.
- Real benefits could be derived in areas of airflow distribution and fan power requirements by using VUMA-network.

Finally, it is concluded that the planning of changes and optimization of mine ventilation networks will be very cost effective compared to a trial-and-error approach, which is the alternative to using a network simulation tool.

9 ACKNOWLEDGEMENTS

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