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Development and integration of ventilation simulation tools for colliery ventilation practice

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ABSTRACT: Effective tools are not only essential for the design of practical and efficient underground mine ventilation systems but must also play an integral part in the operation of the mine. One such tool is VUMA-coal ventilation simulation software. VUMA-coal is Windows-based and has been specially designed for the simulation of underground coal mines and includes user-friendly coal specific interfaces and three-dimensional graphics designed to facilitate in the construction and analysis of networks. VUMA-coal can be utilised during the design phase of new collieries, be used to conduct "what-if" and optimisation studies, and be integrated into the "day-to-day" ventilation related operations. In addition, VUMA-coal can be used to simulate dust and gas distribution in a ventilation network, as well as predict the impact of control measures. This paper describes the interactive VUMA-coal ventilation simulation software and its underlying design features and outlines a case study of how VUMA-coal has been integrated into Anglo Coal's Ventilation and Occupational Hygiene Engineering [VOHE] department as part of the standard planning and evaluation process in their operational mines as well as long term planning and future mining operations.

1 Introduction

The global increases in the demand of resources has lead to bigger mines being developed and continually drives efforts to develop more efficient and rapid mining methods. This leads to large, complex and last changing underground infrastructures that needs to be ventilated. To effectively ventilate these complex mining networks requires a fast and accurate ventilation planning and design process. By replacing manual calculation methods with fast and accurate ventilation simulation software the ventilation planning and design process is significantly improved.

With this in mind, VUMA-network ventilation software was developed. Over the past decade VUMA-network has been used in the analysis of environmental control networks ranging from mining narrow reefs, massive ore bodies and underground collieries. The program may be used equally effectively as a planning tool and as a means of verifying environmental performance parameters of operational mines.

VUMA-network is a Windows based software program for the simulation of steady-state environmental conditions encountered in underground mines. VUMA-network is used to predict airflow and pollutant [dust, gas, radon, smoke, heat] distribution throughout the ventilation circuit. The software includes graphics enhancements that facilitate the creation, editing and management of mine ventilation networks.

Although VUMA-network can be successfully used to model underground collieries, a need for a coal-specific network simulator, which excludes thermodynamic aspects, with specific focus on coal mining practices and terminology was identified. By developing a coal specific version of VUMA-network [VUMA-coal], not only will the simulation software be made more user-friendly to coal mining ventilation practitioners, but a reduction in price of VUMA-coal compared to VUMA-network, due to the removal of the thermodynamic aspects, could be affected making the software more accessible to a larger user group.

To satisfy this need a new product, VUMA-coal was developed based on the tried and tested VUMA-network simulation software and added to the VUMA suite of simulation software.

2 VUMA-Coal Simulation and Operational Process

One of the major benefits of ventilation simulation is the ability to incorporate ventilation into the strategic planning of current and new mining operations. This allows mine management to test various mining scenarios such as number of mining sections, position/distance of working areas from main ventilation intake/return infrastructure, scheduling of main infrastructure, etc.

VUMA-coal was specifically designed and developed to assist underground coal mine managers and ventilation engineers and practitioners to effectively plan, design and operate coal mine ventilation systems.

VUMA-coal is an interactive network simulation program that allows for the simultaneous simulation of airflow, gas and dust emissions in an underground coal mine. VUMA-coal caters for most typical coal mining methods. A fundamental feature of VUMA-coal is the incorporation of user-friendly interfaces that allow for rapid construction of simulation networks. These networks can be used for long term strategic planning, current ventilation system optimization, or to conduct what-if studies to assess the impact of ventilation changes at an operational level.

VUMA-coal is based on the following principles of operation:

- Mine ventilation network is graphically constructed.
- VUMA-coal consists of multiple and single roadway branches, starting and ending with a node. The branches can be used to depict network components such as multiple and single intake and return roadway systems, declines, shafts, etc.
- Only information relating to the geometry, air resistance characteristics and ventilation wall construction of the roadways need be entered.
- Input data for roadways is used to calculate the air pressure drop in roadways, leakage resistance factors for ventilation walls and contaminant sources/sinks in specific branches of a network.
- VUMA-coal also incorporates control manager elements that assist with the design and control of airflow in the model. Typical control managers include ventilation wall leakage paths, workshop commitments, regulators, fixed flows, fans, etc.
- Input data for nodes consists of the X, Y and Z co-ordinates and barometric pressure [BP]. The BP only needs to be set for the start-node as the BP is calculated for other nodes throughout the rest of the network.
- Simulation networks are constructed in a two-dimensional [2-D] graphical editor on a seam-by-seam basis. Different levels are then interconnected, typically by declines and shafts.
- A network is viewed in 2-D format in either geometric, strike, or section view.
- Input data for each roadway or control manager is entered in a relevant input screen for that type of branch or control manager before a solution is obtained for airflow and contaminants properties.
- Iterative network solution algorithms are used to solve for airflow, gas and dust.
- VUMA-coal 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 to conduct fault analysis and visually assess airflow, contaminant and pressure distributions in the network.
- In addition to the 2-D and 3-D graphics output display, results can be exported in spreadsheet format.

3 VUMA-Coal Features

There are four main factors that distinguish VUMA-coal from VUMA-network. The first, as mentioned above, is that VUMA-coal does not support a thermodynamic solution and is limited to a maximum depth of 500 m below surface. For South African collieries in general thermodynamic aspects of ventilation and depths of greater than 500 m is not a concern.

The other three changes include:

- Exclusive use of coal mining terminology;
- Simplified methodology to simulate vent wall leakage; and
- Main development branch input format.

3.1 Terminology

A distinctive differentiating feature between VUMA-network and VUMA-coal is the change in general terminology. By introducing the change in terminology from general hard rock to general colliery terminology made the introduction of VUMA-coal to colliery ventilation engineers and practitioners uncomplicated. By using terminology that is familiar to practitioners VUMA-coal was accepted as a coal mining specific design. The introduction of the terminology also reduced ambiguity and made the construction and interpretation of models easier.

3.2 Primary Vent Leakage Determination

In general airflow requirements for a colliery are determined by methane and/or diesel exhaust dilution requirements, in-section air utilization, required air for commitments other than production [e.g. workshops, battery bays, pump stations etc.], and primary leakage past main intake and return system vent walls.

The accurate prediction of air leakage across ventilation walls, especially in the primary intake and return systems are a critical factor in determining air availability for underground coal mining operations. A unique method was developed to allow VUMA-coal to predict this primary wall leakage. This method is briefly described below.

3.2.2 Primary Vent Leakage Simulation

The above description illustrates the complexities and interrelationships associated with determining the primary leakage in a colliery. These complexities can be handled easily with VUMA-coal which allows primary leakage quantities to be determined by simulating the impact of these influencing factors.

It can be appreciated that not all vent wall leakage paths can be simulated. In order to handle the large amount of potential vent walls for a typical underground colliery, an equivalent length branch is used that is set by the user. With the other geometric input parameters [seam height, bord width and pillar centers] VUMA-coal calculates the overall exposed surface area of the vent walls for that equivalent length branch. Based on a standard vent wall resistance coefficient determined for a specific size [Martinson M.J. 1985] wall, an equivalent pressure related fixed resistance is calculated and a control manager element between the intake and return airways is inserted in the model. Depending on the simulated static pressure differential between the intake and return airway, the control manager "leaks" air from the intake to the return. This leakage is equivalent to the total leakage that can be expected at the highest pressure differential between intake and return airways for the defined equivalent length leakage branch. By constructing the simulation model in this manner the overall leakage of a mine can be accurately modeled. Figure 1 shows how VUMA-coal graphically represents this type of layout.

By varying the equivalent length leakage branch and varying the standard vent wall resistance, existing mines vent system can be accurately calibrated. For new mines current best practice wall resistance values [as a result of experience of typical resistance values of existing mine calibration] are used. Simulation models of typical South African collieries showed that the resistance values for walls of similar quality do not vary significantly from mine to mine [within a mining group].

3.2.3 Results from Primary Vent Leakage Simulation

As mentioned earlier primary vent leakage across a single wall depends on the static pressure differential across the wall. The impact of this is that higher leakage occurs through walls which are close to vent shafts and reduces further away from the vent shafts.

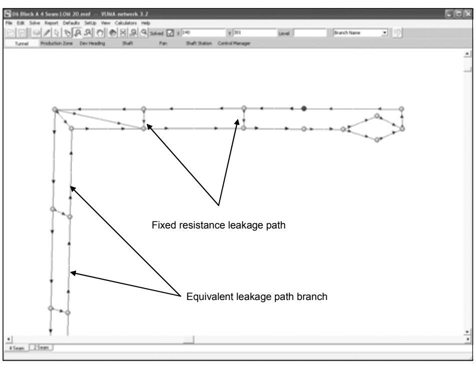

Figure 1. Graphical representation of VUMA-coal leakage paths

The number of vent walls [leakage paths] increases as mining advances away from vent shafts with a resulting increase in overall leakage. However, the overall vent system static pressure also increases with distance. These two factors because the relationship between leakage and distance from vent shafts to be non-linear but follow an almost quadratic relationship.

Figure 2 illustrates the increase in ratio of total air required to air required at the section, with increased in mining distance. The graph is based on two mines that are similar in quality and number of walls per unit length with different system pressures.

Figure 2 further illustrates that with increasing the number of sections in a mine, the overall required air quantity and system pressure increases requiring different design air ratios. It is clear that a mine with lower system pressure would reach a greater distance than a mine with higher pressure difference for the same airflow quantity. Therefore, it is obvious that two collieries with the same wall standard/quality can have significantly different leakage characteristics depending on the mine system pressure.

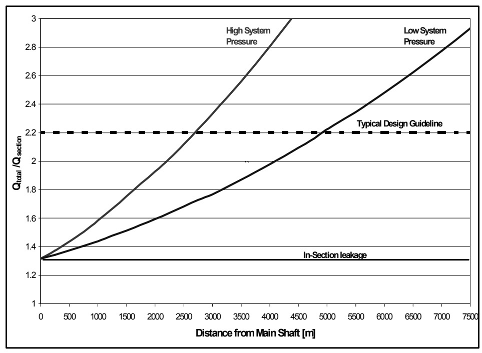

Figure 2. Air requirements as mining distance increase

3.3 Main Development Branch Input Format

Bord-and-pillar mining layouts, either for production or development, are a common feature of underground coal mines. This has the impact that main intakes and returns consists of multiple roadways. In VUMA-coal this scenario is simulated with an equivalent cross-sectional area and perimeter branch type.

A further input required is fixed resistance leakage paths at predetermined equivalent length leakage branches [Section 3.2]. In VUMA-network this input is done manually which is a cumbersome and time consuming exercise that requires concentration.

In order to streamline the input of main development branches with multiple roadways and fixed resistance leakage paths, an input branch was developed specifically for VUMA-coal to simplify this process and by doing so eliminating potential errors. The input branch developed is the Main Development input branch. The input screen for this branch is shown in Figure 3.

4 Mine Ventilation System Design and Simulation Process

4.1 Current Situation

The increasing size and dynamics of modern underground coal mines makes it progressively more difficulty to predict the airflow behaviour and to ensure adequate ventilation in all sections of a mine. With modern and accurate simulation tools such as VUMA-coal, a mine ventilation system can be designed to provide the necessary airflow at the lowest capital and operating cost while ensuring effective mine ventilation conditions and the associated benefits of worker safety and health.

In most of the literature on South African coalmine ventilation, little 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 aim to demonstrate the relevance and potential benefit of using VUMA-coal to simulate coalmine ventilation systems, with a specific example from Anglo Coal.Typical Methodology for Design and Simulation Process.

4.2 Typical Methodology for Design and Simulation Process

The methodology of mine ventilation planning and design in modern mine theory and practice differs substantially from the traditional hands-on calculation approach. It uses all possibilities offered by computer hardware and software that are available to the mine ventilation engineer. The following methodology is typically applied in simulating planned networks:

- Obtain mine ventilation network layout, and the required physical and operational data [mining dimensions, production schedules, etc.].
- Obtain mine vent standards and confirm design criteria and constraints.
- Construct an operational simulation model in VUMA-coal and complete data input.
- Obtain base case solution and calibrate to ensure correlation with operational data.
- Determine critical "snap-shots" over Life-of-Mine [LoM] where significant changes to the system occur or where certain horizons are reached.
- Determine airflow profiles over LoM.
- Construct "snap-shot" simulation models based on operational models.
- Solve airflow networks, evaluate results and optimize airflow distribution through "what-if" analysis.
- Solve contaminant distribution and re-optimize airflow distribution.
- Liaise with mine planning team and iterate to obtain optimum mine planning and design.
- Document inputs and results, and formulate conclusions and recommendations.

Ventilation planning and design is one component of the broader mine planning system, and recommendations could include changes to the original layout and physical parameters such as fan specifications, shaft location and timing, roadway sizes, etc.

4.3 Case Study

The following case study illustrates the benefit of VUMA-coal modeling as part of ventilation planning for collieries.

Greenside colliery in the Witbank region is expanding its operations to the north of their current main upcast and downcast infrastructure. The mine already re-located three out of four sections to the north and is planning to move a fourth section north from its current location in the south. The northern mining boundary is significantly further away from the ventilation infrastructure than the southern boundary.

In order to maintain a last through road velocity of 1.5 m/s in all sections will require an additional 45 m^3/s airflow in the north when four sections are situated in this area. Currently the mine has no additional air available to be redirected to the north and strategies will have to be put in place to provide the required 45 m^3/s. One such strategy is to seal off worked out areas to "save" air, which can then be supplied to the north. The following air quantities are currently supplied to areas in the south that could potentially be sealed:

Table 1: VUMA-coal simulation results

Area 1	15	m^3/s
Area 2	20	m^3/s
Area 3	25	m^3/s
Section to be moved	50	m^3/s
Total:	110	m^3/s

Table 2 below gives the results of VUMA-coal simulations where each area in the model has been progressively sealed. The table shows the cumulative impact of each of the sealing strategies on the additional available air quantity in the north, total upcast quantity and total leakage.

Table 2: VUMA-coal simulation results for sealing strategy

Sealing strategy	Cumulative Air Available for North [m^3/s]	Total Upcast Volume [m^3/s]	Cumulative Leakage [m^3/s]
Base	0	515	125
Area 1	15	510	125
Area 2	25	505	135
Area 3	30	495	142
Move Section	45	475	150

The results show that with more areas sealed in the south, more air is forced towards the northern boundary and the mine system pressure increases. The simulations clearly show how the increase in pressure results in a simultaneous reduction of upcast quantity [fan duty] and increase in overall system leakage.

After completing the sealing work and moving the section, of the 'saved' 110 m^3/s in the south only 45 m^3/s was effectively available in the north. The airflow loss can be accounted for as follows:

- 40 m^3/s reduction in total upcast quantity due to increased fan pressure [515 m^3/s down to 475 m^3/s]
- 25 m^3/s increase in leakage due to higher system pressure [125 m3/s increased to 150 m^3/s]

Only 41% of the "perceived saved air" will reach the new section in the north. Simulations indicate that it will be

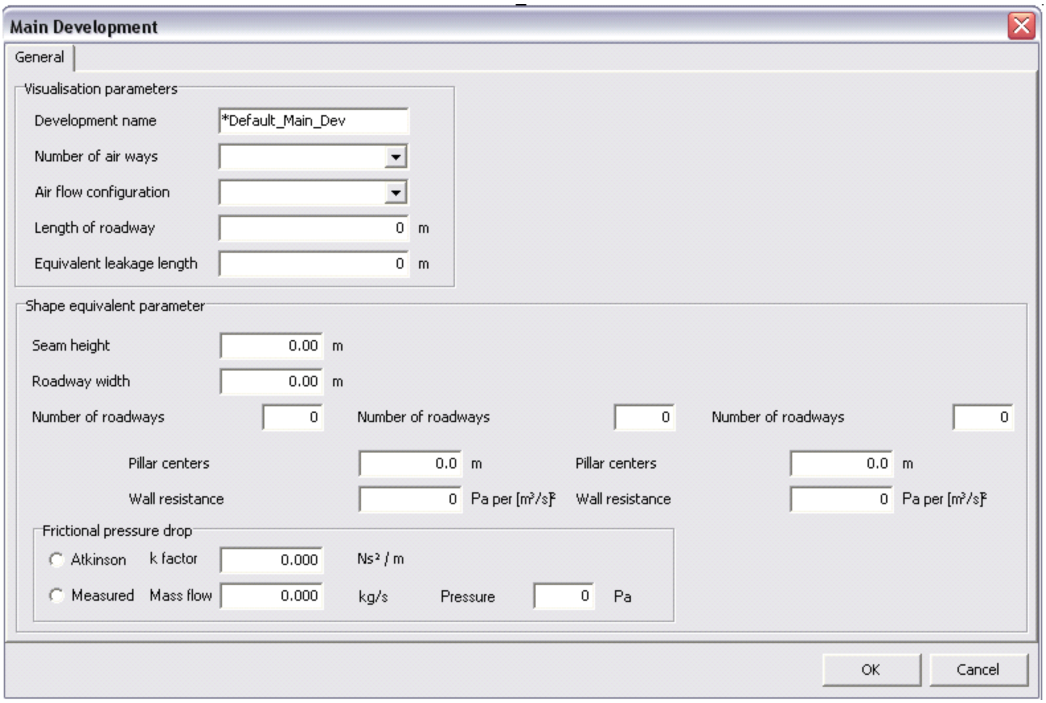

Figure 3. VUMA-coal Main Development branch input screen

possible to move the section to the north and supply the required 45 m^3/s once the sealing work is completed.

A further issue that had to be considered was how far the section can advance away from the main infrastructure before the available air will be insufficient to maintain the minimum last through road. VUMA-coal simulations showed that the section can only advance another 1 000 m before it would run out of air. At this point new ventilation infrastructure would be required which can be sized using VUMA-coal simulation software. From information from the mine, the section started to run out of air at the 1 000 m mark as predicted by VUMA-coal.

5 Simulation as Part of the Planning Process

The interaction between VUMA-coal's ventilation simulation software with its primary design features forms part of Anglo Coal's Ventilation and Occupational Hygiene Engineering [VOHE] departments that have a standard planning and evaluation process.

This process is used across the group and assists in standardization in planning, reporting and evaluation of the VOHE business unit functions. The planning and evaluation process is further supplemented by planning and evaluation documentation including methodologies, reporting templates, graphs, tables and spreadsheets.

The VOHE planning and evaluation system ensures a standard planning process and document that covers short term and LoM, as well as a standard evaluation process and document to compare key VOHE parameters as a measure of performance. VUMA-coal has been integrated into the full VOHE process and forms part of the long term planning and evaluation process as well as the day-to-day operational aspects.

Detail VUMA-coal models are constructed and calibrated for all the Anglo Coal underground collieries once a year. These calibrated base models are used in the LoM planning process of the various shafts to conduct "what if" studies related to current and required new infrastructure.

The calibrated models are also used by the mine ventilation department to quickly and accurately clarify day-to-day ventilation issues that may arise during the year.

Anglo Coal has achieved significant benefits from the process and some of the highlights are quantified and/or qualified below:

- Long term planning simulations showed that a number of previously considered Raise Bored Holes [RBH] and associated fan stations will ultimately not be required. A rough estimate of the Capital Expenditure [CAPEX] saving related to this RBH and fan station capital is $ 155 million [2006].
- Ventilation system "snap shots" simulations for LoM allowed scheduling of ventilation infrastructure according to LoM production planning. This resulted in significant capital expenditure to be delayed by a number of years.
- Ventilation simulations of proposed mining scenarios indicated new ventilation infrastructure requirements [and scheduling] to ensure planned production is achieved. Production would have suffered if the correct infrastructure was not in place on time.
- VUMA-coal models specified all future fan station aerodynamic design criteria.
- The work produced VOHE planning documents that will allow continuity in future as LoM OPEX and CAPEX are scheduled.

6 Conclusion

The VUMA-coal simulation program is an essential tool to assist colliery ventilation engineers, practitioners to assist and mine planners and management to design optimal and cost effective underground coal mines by effectively and confidently incorporating ventilation aspects as part of the decision making process. This will enhance the holistic approach required for modern mine planning and design, and the ever-increasing demands for quick, accurate and reliable answers. VUMA-coal can be used to develop effective solutions for complex and interactive ventilation networks.

Effective integration of simulation software into the operational and long term planning of a coal mining group has been achieved. Anglo Coal is maximizing the benefits from applying simulation software in operational mines, long term planning and future mines.

The continued profitability of existing operations and the viability of future mining prospects will be determined by operators' ability to provide a safe and healthy working environment cost effectively. The use of precise and reliable simulation and planning tools for the design of underground ventilation systems will become more of a necessity rather than a luxury in future.

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