SECTION 5

VUMA-network: A SIMULATION TOOL FOR MINE VENTILATION AND COOLING NETWORKS

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ABSTRACT: Occupational safety and health requirements and the need to ensure worker productivity dictate the thermal environment and, thus influence the feasibility of new projects, as well as the continued viability of required existing operations. Determinants of the underground thermal environment are complex and best optimised using interactive system design techniques. Effective environmental control that considers all thermodynamic and operational factors over the life of mine requires continuous re-optimisation and refinement, an iterative and highly complex process.

Effective tools are essential for the practical and efficient design of mine ventilation and cooling systems and to enable both the development and the interactive simulation of mine layouts. To satisfy these requirements the VUMA-network simulation program has been developed as a joint initiative by the South African Council for Scientific and Industrial Research (CSIR) and Bluhm Burton Engineering. [VUMA is an acronym for Ventilation of Underground Mine Atmospheres, and is also a Zulu word for energy]. The program includes user-friendly interfaces and three-dimensional graphics designed to facilitate the construction and analysis of networks, as well as perform "what-if" and optimisation studies. The software is Windows-based and produces full thermodynamic simulations for the operation of underground environmental control systems. In addition, the program can be used to simulate dust and gas distribution, as well as the effect of various control measures. Ventilation for all major underground mining configurations, including coal deposits, massive ore bodies and tabular ore bodies, are provided for.

This paper describes the new interactive network program, focusing on its important features, advantages and newly developed algorithms. It also examines representative case studies and provides application examples, including the effects of various mining methods and layouts, and variations in water cycles and flow rates.

5.1 INTRODUCTION

Through the use of more efficient modern mining equipment, underground mines are extending by several kilometres each year, not only horizontally but also vertically, resulting in increasingly complex ventilation networks. This leads to greater difficulty in predicting the flow of air and its thermodynamic behaviour, thereby complicating efforts to ensure optimal or even acceptable conditions throughout a mine. With modern and accurate simulation tools, a ventilation and cooling system can be designed to optimise thermal conditions in mine workings at the lowest possible cost. The major benefits of favourable environmental conditions are improved worker health, safety, productivity and, ultimately, profitability.

A prime example of new technology developed to assist mine operators in optimising thermal conditions is the mine ventilation and cooling network simulation program, VUMA-network, developed as a joint initiative by the South African Council for Scientific and Industrial Research (CSIR) and Bluhm Burton Engineering. This paper examines the relevance and potential benefits of using VUMA-network to simulate mine ventilation and cooling networks.

5.2 THE NEW MINE VENTILATION AND COOLING NETWORK SIMULATION TOOL

VUMA-network simulation software is specifically designed and developed to assist underground ventilation control engineers and practitioners in planning, designing and operating mine ventilation systems. VUMA-network is an interactive network simulation program that allows for the simultaneous modelling of airflow, air thermodynamic behaviour, as well as gas and dust emissions in an underground mine. The program caters for a wide range of mining methods. A fundamental design criterion of VUMA-network was its incorporation of user-friendly interfaces to allow the rapid construction of simulation networks, thereby enabling “what-if” studies to determine system requirements for optimal designs.

5.2.1 VUMA-network Principles of Operation

The principal design criteria used in the development of VUMA-network were to provide:

- A program specifically designed for use in the mining industry
- User-friendly interfaces with graphic network viewing facilities
- Compatibility with all Windows-based platforms and applications
- Capability to simulate all major mining methods
- Simultaneous and interactive modelling of airflow, contaminant concentration and air thermodynamic properties in a mine ventilation network

These design criteria provided the basis for the following principles of operation:

- Graphic construction of the mine ventilation network using a computer mouse
- Use of network branches, each starting and ending with nodes, to depict network components such as shafts, tunnels, etc.
- Use of input data for individual branches to calculate air pressure drop, and changes in air thermodynamic properties and contaminant levels within each specific component of the network
- Input data consisting of X, Y and Z co-ordinates, barometric pressure (BP), virgin rock temperature (VRT) and air temperatures (BP, VRT and wet-/dry-bulb temperatures are only required for the start-node, as these parameters are automatically calculated for subsequent nodes in the network)

- Simulation networks are constructed within a two-dimensional (2-D) graphic editor on a level-by-level basis, with different levels typically interconnected by shafts or declines
- Network is viewed in 2-D format, in either geometric, strike or section view, as well as 3-D graphics
- Input data for each branch is entered in a specific input screen for that branch-type, before a solution is calculated for airflow, air contaminants and air thermodynamic properties
- Where the only requirement is an airflow solution, inputs can be limited to information regarding the geometry and air resistance characteristics of the relevant branches
- Iterative network solution algorithms are used to solve for airflow, and updated heat flow models are used to calculate changes in air thermodynamic properties for each branch
- Extensive help functions are incorporated to assist the user in developing the simulation model
- The network is displayed in three-dimensions by means of a 3-D graphic viewer
- A tabular format output display is available, in addition to the 2-D and 3-D graphic displays

The solver around which VUMA-network is designed is based on theoretical and empirical models developed and verified by engineers and scientists at Bluhm Burton Engineering and CSIR: Miningtek during their extensive involvement in research and consultancy projects over many years.

5.2.2 VUMA-network 2-D Editor

The 2-D editor is used to construct and edit a network, and to enter all relevant data necessary to obtain a solution for the simulation. The left portion of Figure 1 shows a geometric view of a single level, while the right portion provides a section view of two levels in a small network.

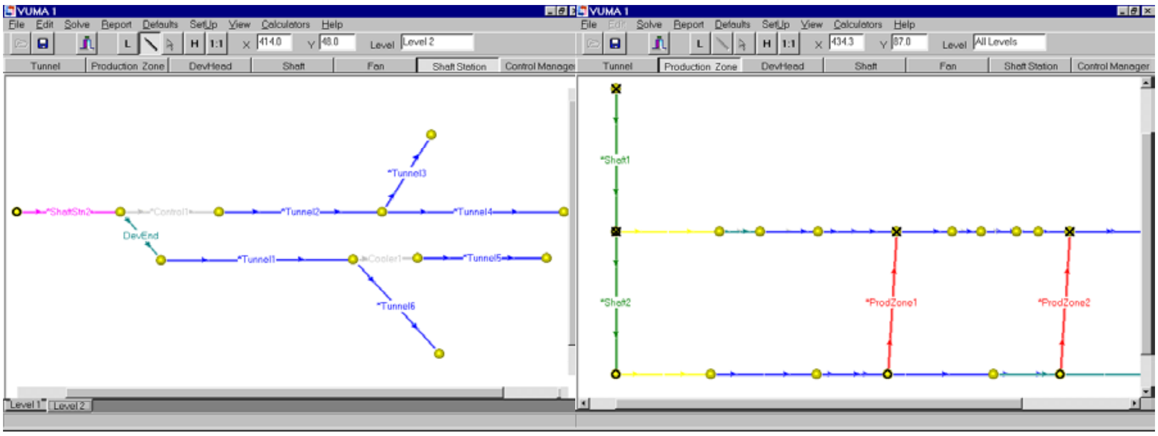

Figure 1VUMA-network 2-D Editor

The figure indicates that branches connecting two levels can only be seen in the section view and, therefore, both views are needed to enter branch data. Once a branch is created it can be moved by dragging either the inlet or outlet node to the desired location in the network. The network can also be zoomed in or out, and a panning facility enables the viewing of large networks that span multiple screens. In addition, a search facility is provided for the direct location of specific branches and nodes.

5.2.3 Libraries

Libraries are "dynamic" catalogues, data tables and other information built into VUMA-network, and designed to transfer information directly to the input forms and solver routines. Basic or typical data is provided in each library, but the user can add to or delete information as required. The libraries include:

- Rock property data
- Catalogues of ventilation fan specifications
- Catalogues of mining equipment specifications

Information contained in the mining equipment catalogue is shown in Figure 2, below.

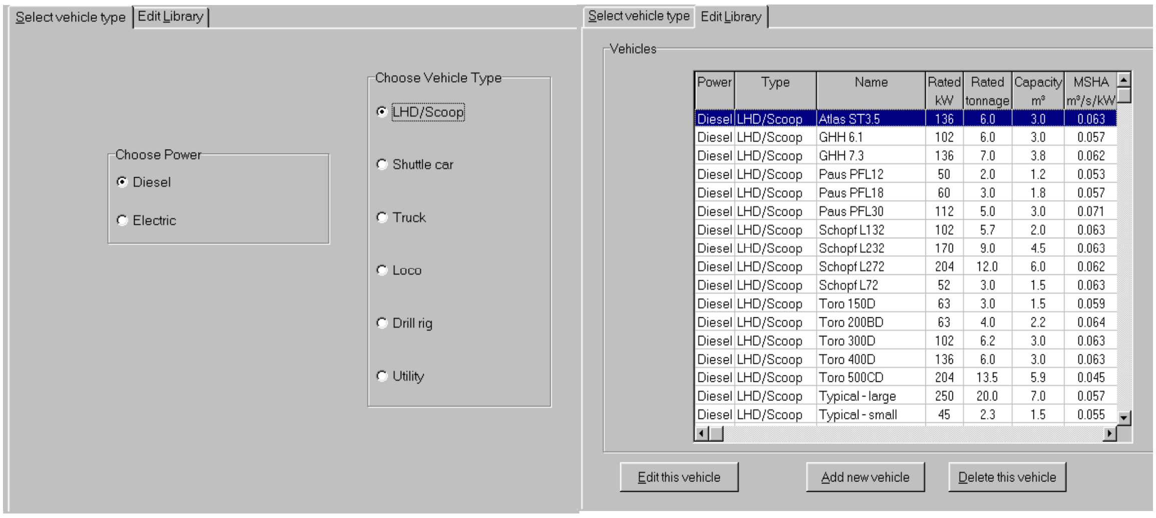

Figure 2 VUMA-network mining equipment catalogue

Rating Categories

The nature of mining is such that it is often impractical to define parameters in a fully quantitative manner. For example, work cycles, load ratings, and/or utilisation descriptions of some elements of mining equipment are often difficult to quantify. In addition, the workloads of dump trucks, loaders, roadheaders, tunnel-boring machines, continuous miners, locomotives, utility vehicles, winches, etc, can all vary significantly from one operation to the next and, accordingly, the program uses rating categories that allow for a consistent qualitative approach tailored for the specific mining operation. Typical vehicle work cycle categories are as follows:

- Very heavy: Machine working at continuous full-load rating on maximum inclines
- Heavy: Machine at heavy-load rating on moderate inclines, with regular use for carrying medium loads
- Typical: Machine working at average-load rating on moderate inclines, with regular use for carrying medium loads
- Moderate: Machine working at moderate-load rating on gentle inclines, with occasional use for carrying light loads

- Light: Machine working at very light load rating on flat ground, with infrequent use for carrying no load

Rating categories are also defined for the factors listed below, with the "Help" function providing guidance in the selection of the most applicable rating category:

- Rock surface wetness
- Heat-moisture ratios
- Duct leakage
- Rock cover [insulation]
- Ventilation bends and junction
- Pipe insulation
- Inclination of development heading

5.2.5 Calculators

There are currently two calculators available in the 2-D editor: a psychrometric calculator and an air cooler calculator. Either or both calculators can be activated at any stage during the construction or editing of a network. The psychrometric calculator allows the user to determine various psychrometric properties [in the range -40 to 80°C and 40 to 180 kPa], and the air cooler calculator allows determinations of cooling duty for various air cooler configurations [direct or indirect contact, horizontal or vertical, spray or packing] under certain airflow and water flow conditions.

5.2.6 VUMA-network Branch-Types

The program includes branch-types that represent all components typically making up an underground mine ventilation circuit. Input fields for branches are divided into Aero, Thermo and Contaminant categories, as described below:

- Aero: Aerodynamics and other parameters influencing air flow in a branch, e.g. shape, physical dimensions (length, cross-section, and perimeter), and surface frictional resistance characteristics
- Thermo: Thermodynamics and other parameters influencing heat flow in a branch, e.g. surrounding rock and equipment/activities within the branch. Factors influencing heat flow from the surrounding rock are the rock properties, age of excavation and VRT. Sources of heat or cooling within a branch include vehicles, equipment, drains, pipes, ducts, etc.
- Contaminant: Parameters describing contaminant sources or sinks in the branch, e.g. filters or scrubbers

As noted earlier, if the user does not require Thermo or Contaminant solutions, it is only necessary to enter the relevant Aero information.

Branch-types provided for in VUMA are listed below, with short description of each given in the sub-sections that follow.

- Tunnel
- Production Zone

- Development Heading
- Shaft
- Fan
- Shaft Station
- Control Manager (all components not included in the above)

5.2.6.1 Tunnel

A tunnel or airway is the most commonly used branch in VUMA. Figure 3 shows an 'Aero' input screen for a tunnel branch.

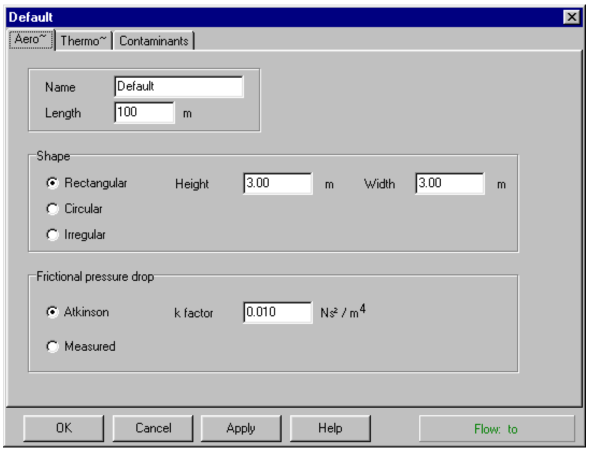

Figure 3 Tunnel input screen

5.2.6.2 Production Zones

New algorithms have recently been developed to simulate air thermodynamic behaviour for a number of mining methods, based on a thorough understanding of heat and mass transfer in underground excavations, and the operational implications of the various mining methods. This knowledge and experience is core to the VUMA team, and is being expanded by verification of the new algorithms against historical data, and further validation during the daily use of VUMA-network in research projects.

The production zone branch caters for the majority of mining types found in underground mining. Each of the mining types can be either a drill and blast operation or continuous mining. Different variations of a broader mining type can also be selected. The following mining types, with their derivatives, are available in VUMA-network:

- Drift [and Fill]
- Benching/cutting [and Fill]
- Open Stoping
- Stope Shrinkage
- Vertical Crater Retreat
- Room and Pillar
- Colliery Longwall
- Narrow Reef Stoping
  - Single-sided Breast
  - Double-sided Breast

- Up-dip
- Down-dip

The input form for production zones includes a graphical representation of the specific zone being considered. Figure 4 shows the input screen and corresponding production zone representation for a narrow-reef stoping configuration.

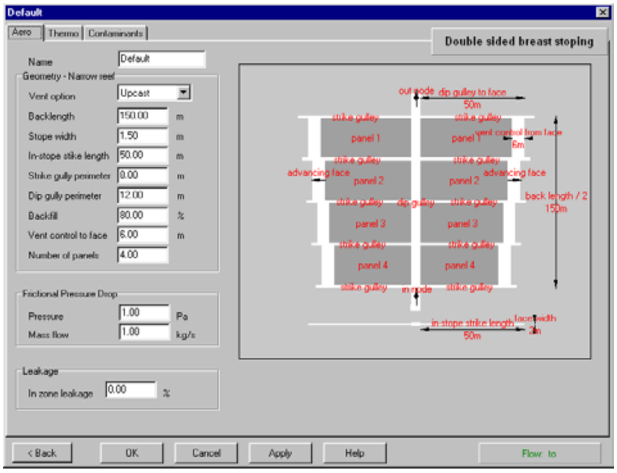

Figure 4 Input form for narrow-reef stoping configuration

5.2.6.3 Development Headings

As with production zones, the user has the option of simulating various heading types, in accordance with the mining methods and/or machinery employed. These include:

- Drill and Blast
- Road Header
- Continuous Miner
- Tunnel-boring Machine

5.2.6.4 Shafts

The input data for a shaft are similar to those for a tunnel.

5.2.6.5 Fans

Fan branches require the input of a fan curve with six or more data points for pressure and airflow quantity. A fan catalogue is used to define or select fan curves for specific appliances, from which the solution engine determines effects on airflow and heat increase.

5.2.6.6 Shaft Stations

Due to the complexity of a shaft station area and the numerous excavations associated with it, a shaft station branch is used to simplify total airflow, contaminant load and heat flow effects on the network. The total length of excavations and major contaminant sources, as well as heat loads such as pump chambers and workshops are all simulated in a single branch. This reduces the effort required to construct the network, and greatly simplifies the network without compromising the simulation's accuracy.

5.2.6.7 Control Manager

A control manager branch is used to simulate a host of air control (Aero), heat/cooling load (Thermo) and contaminant-related components. Aero options that can be selected from the VUMA Control Manager list are:

- Leakage Paths
  - Specified Flow
  - Percentage of Flow
  - Fixed Resistance
  - Measured Flow & Pressure
- Regulators
  - User-defined Resistance
  - Fixed Flow
  - Fixed Pressure Difference
  - Measured Flow & Pressure
  - One-way Flow (Door)
  - Duct Piece through Wall
  - Reduced Tunnel Area
  - Bends
  - Air Crossings
  - Abrupt Contraction Losses
  - Abrupt Enlargement Losses

Thermo options for a control manager branch are as follows:

- Coolers
  - Fixed Duty
  - Fixed Outlet Condition
- Heaters
  - User Defined
  - General Equipment
  - Pump Station
  - Refrigeration Station
  - Hoists & Winders
  - Crushers
  - Auxiliary Fans
- Substations

Contaminant-related options for a control manager branch are as follows:

- Gas
  - Source
  - Sink [scrubber or filter]
- Dust
  - Source
  - Sink [scrubber or filter]

The input form for a dust scrubber is shown in Figure 5, below.

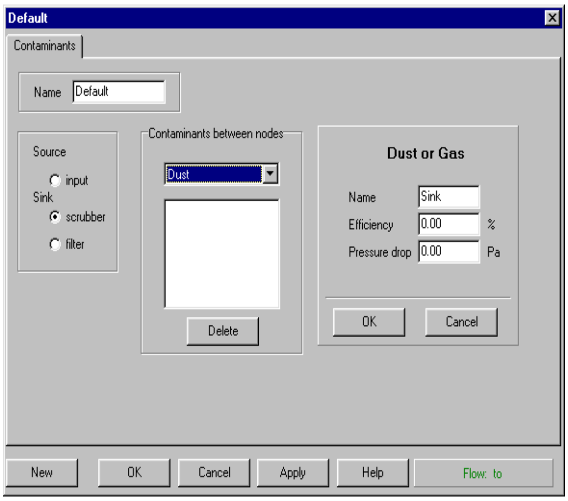

Figure 5 Input form for a dust scrubber

The regulator fixed flow branch may be used in place of a fan when building a new network. The resulting branch pressure increase and volume flow will be used to determine the required operating point for the fan.

5.2.6.8 Reporter

The report facility is used to view input and output data in tabular format. Data are sorted either by nodes and branches, or by branch type, and reports can be printed directly or exported to a spreadsheet application such as Excel for further data processing or analysis.

5.2.6.9 Solver

Once a network is completed and all input data entered, one of four solution methods can be selected:

- Aero: Network airflow will be simulated.
- Aero & Thermo: Airflow and Heat flow will be simulated
- Aero & Contaminants: Airflow and Contaminant concentrations will be simulated
- Full Solution: Aero, Thermo and Contaminant concentrations will be simulated

Where a solution is not obtained, the program will highlight all branches and/or nodes with errors or inconsistencies to be rectified by the user.

5.2.6.10 3-D Viewer

The 3-D viewer has two main functions, firstly to graphically display an entire network in 3-D format and, secondly, to graphically display simulation results. View options include Plan view, Section/Strike view, Geometric view, and Diagrammatic view. The geometric view is based on real co-ordinates, whereas the Diagrammatic view uses artificial spacing increments for better distinction of individual levels.

Solved networks are graphically displayed, with colour coding of nodes and/or branches in accordance with a colour bar graph that indicates the range of values for the particular parameter being displayed. Figure 6 shows the 3-D view of a solved network, with the colour-coded bar graph on the left depicting the range of the selected parameter, in this case barometric pressure. Various branch-types and levels can be switched on and off, and the network display can be zoomed in or out, rotated and panned.

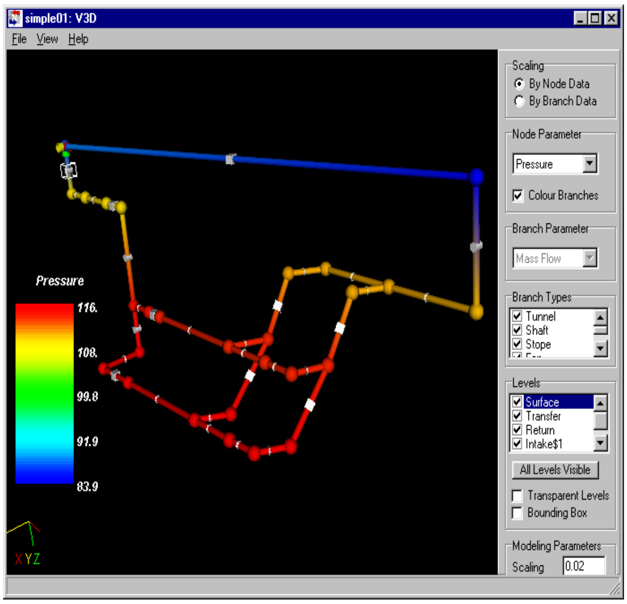

Figure 6 3-D view of solved network

5.3 APPLICATIONS OF VUMA-NETWORK

5.3.1 Effects of different mining methods and layouts

The South African mining industry's DeepMine Collaborative Research Programme commissioned CSIR: Miningtek, and Bluhm Burton Engineering (BBE) as an expert team to perform an analysis of environmental system designs for four different mining layouts. The layouts were prepared by planning engineers and reflect the four possible mining methods that could be implemented to exploit a narrow tabular ore body at depths of 3 500 to 5 000 m below surface in the Witwatersrand basin. The team was first required to determine the suitability of each layout and, secondly, to establish which would be most likely to suit the demands and conditions anticipated at the depths being contemplated.

The four different mining methods resulted in four distinct ventilation and cooling systems, as each method was unique in terms of parameters such as number of levels, production per zone, development schedules, production zone configuration, mining sequence etc. Figure 8 represents a production zone for the Longwall mining method, and also indicates the high level of detail used in the study.

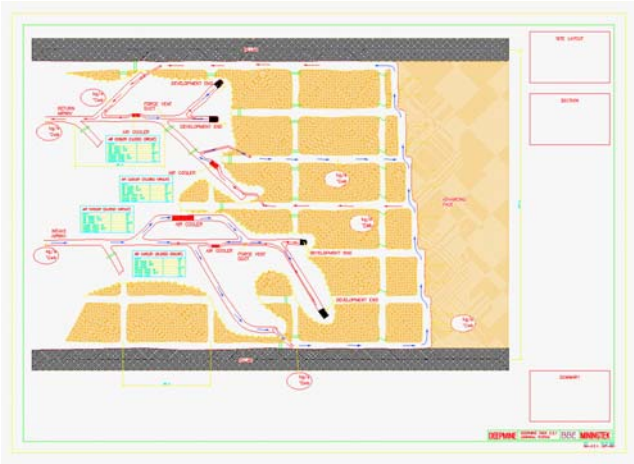

Figure 8 Longwall mining method

Typical results from using VUMA-network to compare mining scenarios before mining commences are graphically represented in Figure 9, which illustrates an analysis of heat loads and cooling sources for the different mining methods noted as LSP, SGM, SDD, and CSDP.

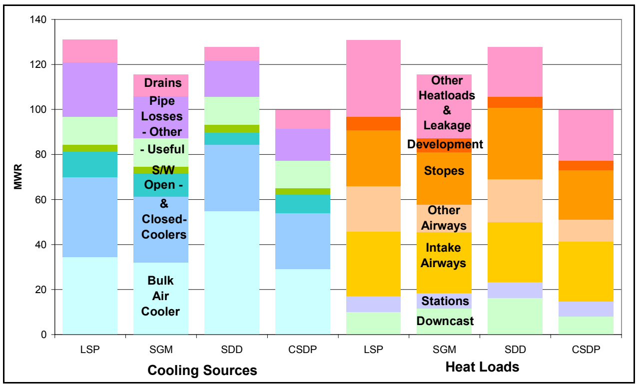

Figure 9 Analysis of heat loads and cooling sources

5.3.2 Effects of water usage

As part of the same study described in Section 3.1, the effects of chilled water usage on ventilation and cooling at a micro (production zone) level were assessed. Figure 10 compares the effect of various chilled water usage rates for the different mining methods, using a 24-hour average period or blast-per-day cycle in production zones, another example of how the VUMA-network simulation software can be applied to a scenario analysis.

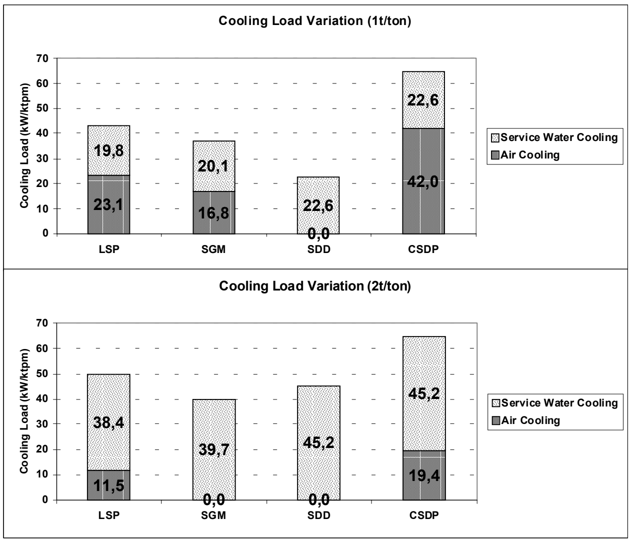

Figure 10 Effects of chilled water usage

5.4 EXAMPLES OF CASE STUDIES

5.4.1 Simulation of coal mine ventilation network

Miningtek used VUMA-network to perform a simulation of a South African coalmine's ventilation network. The initial simulation was intended to evaluate correlations between simulated and measured data. Next, a number of "what-if" simulations were conducted to determine the scope and potential benefits of reducing pressure losses and increasing ventilation efficiency through the optimisation of airflow distribution.

The results of the study led to the following conclusions:

- VUMA-network is capable of simulating a coalmine ventilation system to a high level of accuracy
- The benefit of using a simulation tool such as VUMA-network is that the results can be viewed graphically, in the case of this study, to readily identify areas of high pressure loss and low airflow
- The effect of various changes to the existing ventilation network can be assessed quickly and easily
- Real benefits can be derived from the use of VUMA-network to optimise airflow distribution and fan power requirements: the strategic placement of regulators (as indicated in Figure 11, below) and altering the number of roadways per airway resulted in a significant improvement in airflow distribution, and a 15 per cent reduction in fan power requirements.

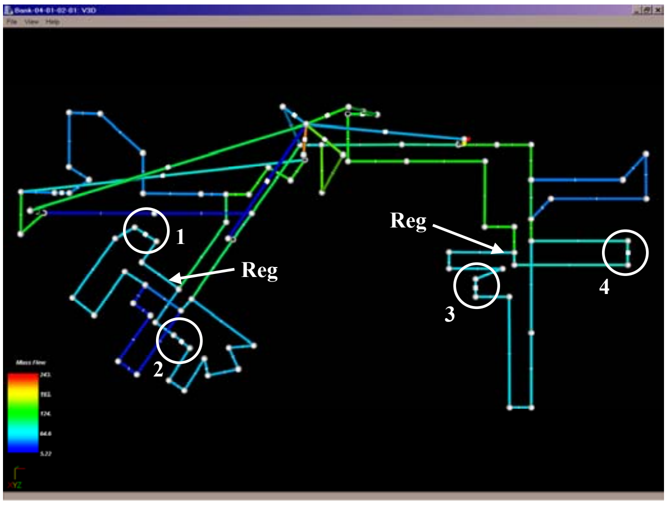

Figure 11 Position of regulators

Finally, it was concluded that the use of simulation software to plan changes and optimise mine ventilation systems is far more cost-effective than a trial-and-error approach, the only alternative to use of a network simulation tool.

5.4.2 Simulation of gold mine ventilation network

Miningtek also used VUMA-network to perform a simulation of a South African gold mine's ventilation network. The objective was to determine ventilation and cooling requirements for a sub-vertical shaft section, based on mine planning for the year 2015. The work focused on modelling relevant portions of the shaft complex, including planned extensions, using VUMA-network. A diagrammatic three-dimensional view of the network is shown in Figure 12.

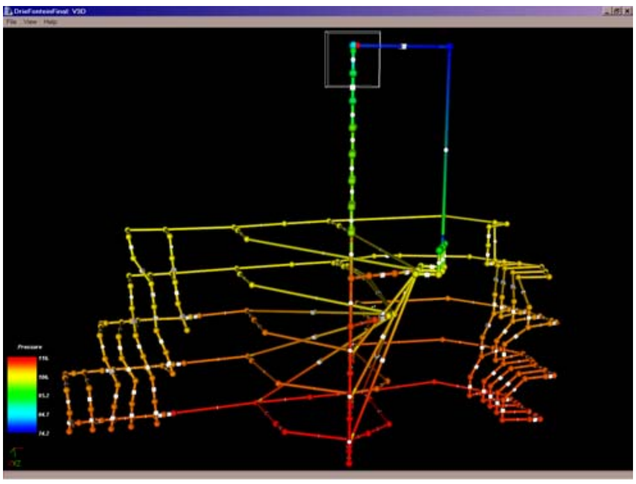

Figure 12 Three-dimensional view of sub-shaft section

The VUMA-network simulation clearly indicated that resistance in the network was seriously imbalanced between the two mining zones, leading to greater fan power requirements, more leakage and increased cooling requirements to ensure acceptable thermal conditions. Recommendations were made for additional airways to solve the problem, indicating once again that a simulation tool such as VUMA-network can be used for the proactive identification and resolution of potential problems during the design and planning phase of a mining operation.

5.5 CONCLUSION

The VUMA-network simulation program is an essential tool to assist ventilation control engineers and mine planners in designing and verifying operational parameters for underground ventilation systems. The holistic approach required for modern mine planning and design, and the ever-increasing demands for quick, accurate and reliable answers can all be met through the use of VUMA-network to develop effective solutions for complex and interactive ventilation and cooling networks. The constraints of finer technical tolerances and the narrower financial margins caused by increasingly expensive capital equipment tend to limit the viability of existing and future mining ventures, making it imperative for decision makers to employ the most advanced design tools for accurate system planning.

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 that is conducive to productivity, at a cost that is not disproportionate with anticipated returns. The use of precise and reliable simulation and planning tools for the design of underground ventilation systems can help to ensure that these requirements are met.

5.6 ACKNOWLEDGEMENTS

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