Environ 2.5 - A Mine Ventilation and Cooling Network Simulation Tool

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ABSTRACT

As mining operations progress, ore reserves are depleted and alternative are almost invariably found at increasing depth and a host of attendant difficulties in this regard face the mine operator. Most significant among these is the control of the increasingly hostile environment encountered at depth in terms of both ground behaviour and the increasing hot environment.

To enable the practical and economical design of mine ventilation and cooling systems, ventilation practitioners need effective and efficient tools to perform their duty. One such tool is the Environ 2.5, an interactive network simulation program that allows for the simultaneous simulation of airflow and air thermodynamic behaviour in an underground mine. The program can simulate networks consisting of up to 600 components such as shafts, tunnels, regulators, coolers, stopes etc. to determine optimal designs and future requirements.

This paper describes the need for such software, provides a brief overview of the program's functions and operation and highlights the application and benefits of Environ 2.5.

KEYWORDS

Environmental, Conditions, Simulation, Software, Ventilation, Cooling, Network, and Planning.

INTRODUCTION

As mining progresses, ore reserves are depleted, and alternative ore bodies have to be identified. In the case of gold, these ore bodies are usually found at greater depth. The problems and challenges presented by the gradual increase in average working depths are especially significant in the area of mine environmental control. The single dominant challenge in this context is heat, which is aggravated at depth mostly, but not exclusively, due to increased virgin rock temperatures.

The ultimate future of mining at great depth will increasingly depend on the industry's ability to contend, in an acceptable and cost-effective manner, with the environmental control problems related to the provision of satisfactory ventilation and cooling Mine environmental engineers are faced with a major challenge to ensure that the overall design of a deep mine will provide an optimised environmental control system from both a practical and economic point of view. It is also inevitable that the overall design process will be conducted in an iterative manner and the effect of any changes in the original design must be evaluated rapidly.

Environ 2.5, developed by the Council for Scientific and Industrial Research (CSIR) in South Africa has been a useful mine ventilation and cooling network simulation tool, which can assist the environmental engineer to face these challenges. This paper provides a brief overview of the program's functions and operation and highlights the application and benefits of Environ 2.5.

THE NEED FOR NETWORK SIMULATION TOOLS

The Anticipated Challenges of Ultra Deep Level Mining

The term 'Ultra Deep Level Mining' does not necessarily refer to mining beyond a specific depth. However, it is generally accepted that mining at depths greater than 3,000 metres below surface may be classified as ultra deep. Various problems are anticipated in mining at depth of which the most significant are rock mass behaviour and the provision of an acceptable working environment.

Research efforts in South Africa are currently focussed on mining at depths of between 3,000 and 5,000 metres below surface, where the heat flow from the surrounding rock is considered to be the predominant problem. With typical geothermal gradients of between 0.009°C/m and 0.0134~

°C/m, Virgin Rock Temperatures (VRT) in excess of 80°C are anticipated. Planning ventilation and cooling systems for such conditions will require innovative and careful design.

Planning Accuracy a Cost Factor

A 200 kTon/month operation at these depths could require a refrigeration capacity of up to 100 MWR. The capital and operational costs associated with systems of this magnitude could determine the viability of a proposed mining operation. Inaccuracy during the planning of the ventilation and cooling system could either lead to the cancellation of an otherwise viable operation or to significant cost penalties.

Specifically, significant differences between air mass and volume flow will exist at these depths due to the wide range of air temperatures and the high barometric pressures. It is important that airflow and air thermodynamic behaviour be simulated interactively as changes in either of these will have significant influences on each other.

Resource and Time Considerations

Planning and design for environmental systems in ultra deep mines require extensive optimisation, and have to take into account other factors such as the mining and engineering systems and methods used in the overall mine design. Due to the integrated and extended nature of an ultra deep mine, seemingly small planning changes have a significant impact on the environmental system. The effect of these changes need to be evaluated in the context of the final mine design in order to ensure the most practical, safe and cost effective system is chosen.

To predict environmental conditions under such circumstances could be an arduous and costly exercise without the assistance of an interactive network simulation tool such as ENVIRON 2.5. Any network simulation tool used must be accurate and should allow for simulation networks to be altered easily to cater for rapid evaluations of all possible scenarios.

Safety Considerations

It is certain that a mine at great depth will have areas where air temperatures are dangerously high. From a safety perspective, it is essential that mine management are aware of such areas to ensure safety precautions are put in place timeously. Escape and rescue procedures and systems could be design by conducting "what-if" studies with the network simulation software. Such simulations would consider ventilation and or cooling failures and other emergency situations such as underground fires.

ENVIRON 2.5

Short Description of the Software

ENVIRON is an interactive network simulation program that allows for the simultaneous simulation of air flow and air thermodynamic behaviour in an underground mine. It is intended for use by environmental engineers for the analysis of heat loads and mine ventilation systems at all mining depths on both a local and mine wide basis. A mine or section of a mine is represented as a network of components (called branches in the program).

The solution algorithm used by ENVIRON 2.5 is a modified version of the Hardy Cross method. The method requires that all loops in the network are closed. This implies that the exit node from the network, usually the top of the upcast shaft, should always be connected to the inlet node to the network, usually the top of the downcast shaft. The branch between these nodes is typically the main surface fans. The air thermodynamic properties of the outlet node is not taken as the inlet to the downcast shaft when this node is specified as the network's starting node (in other words, the return air from the mine is not fed back into the downcast shaft).

Simulating a Mine Ventilation and Cooling Network

Branches (Components) And Nodes. A mine ventilation network is simulated by representing various components of an underground mine, such as tunnels, shafts, stopes etc., with ENVIRON 2.5 components, called branches. The computer network is constructed in such a way as to represent the actual mine as accurate as possible. Global defaults are set for a specific mine and includes rock properties (density, diffusivity, conductivity) for up to four types of rock, geothermal information (gradient and datum temperature), ambient air conditions and the datum Barometric pressure. This data, together with fan curve data can be saved for each mine or section of a mine and do not require input every time the simulation network is recalled.

Branches in the network are connected via nodes, which represent single, non-dimensional, connecting points and are used mainly to specify elevation. Ambient air conditions are specified (normally the surface intake conditions) at the starting node. Predicted air thermodynamic properties entering and exiting a specific branch are indicated at nodes once a simulation is complete. Figure 1 shows a typical portion of a network. The 'boxes' indicate branches such as Sh (shaft), Ho (hoist), Tu (tunnel), and the numbers indicate nodes.

Available Components. The branches available in ENVI-RON 2.5 are Tunnel, Regulator, Fixed Flow, Fan, Hoist, Shaft, Cooler, Development End, Shaft Station, Stope and Spot Heat. A short description of each of these branches is given below. A (Figure 2) typical data input screen for the first component is also shown, but due to space constraints none of the other input screens are shown.

Tunnel. Tunnels may be rectangular or circular in shape. In many cases the heat flow from the rock is only one factor affecting environmental conditions and linear heat sources are used to account for the effect of drains, pipes or diesel machinery. There is provision for two linear heat and enthalpy/moisture ratios to allow, for instance open drains and chilled water pipes to be simulated. The pressure drop calculation method can be altered between Atkinson's method, Roughness method and Measured. Figure 2 shows the data input screen for a tunnel.
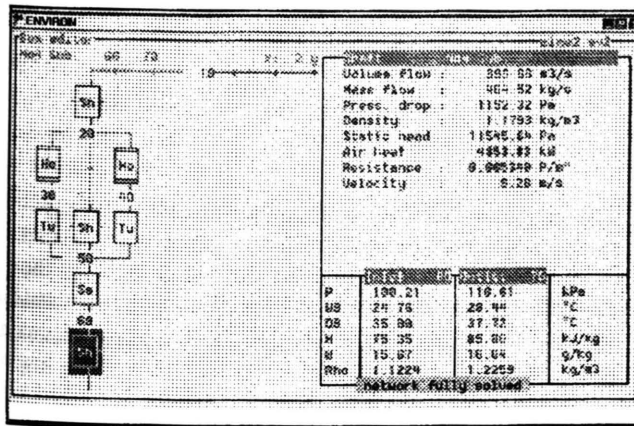

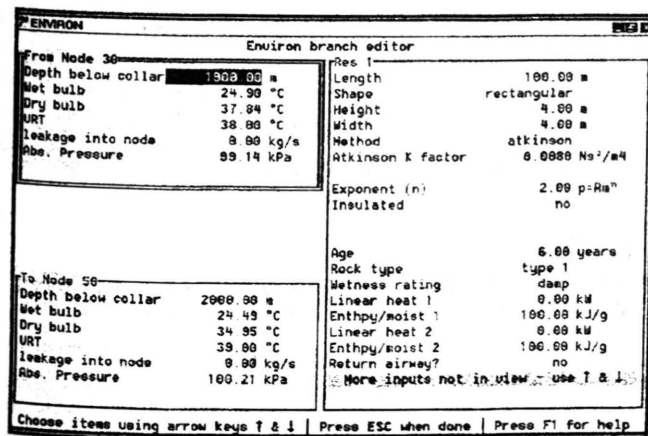*Figure 1. Typical portion of a network.*

Figure 2. Input screen for tunnel branch.

Regulator. Regulators are used to restrict the flow of air to a particular section of a mine. They can be specified in one of three ways:

> Ducts (or fixed regulators);
> Variable regulators;
> Specified resistance.

A fixed regulator may be a duct across two doors or a duct in a wall. The restriction of these regulators cannot be controlled. A variable regulator may be a brattice or a station regulator, the open area of which can be adjusted. Note that even a fully closed regulator is assumed to leak. If a resistance value R of an existing regulator is known, this value can be entered. R is obtained from the equation $P=Rm^n$ where m is the mass flow through the regulator. No heat load on the air is assumed for a regulator.

Fixed Flow. This is a device which is usually used to determine the pressure rise required to specify the size of a fan or regulator. It is used as a design tool in situations where the required pressure drop is not known for the system. After it has produced a specified air flow in an airway, it should be replaced by a fan of the same duty. It can also be used to close the network, for example as the equivalent of the main upcast fan, joining the first and last nodes. Note that this does not imply that this fixed flow branch feeds air into the first branch.

Fan. Fans can be entered in one of two ways. A three point curve can be specified, where the program will then fit a curve through these points, or a fan curve can be specified for an existing or known fan by entering the pressure/volume data. Up to 30 different fan curves can be stored for a specific mine. A fan can be switched on or off and the fan solution algorithm ensures that no heat is added to the air passing through the fan branch when it is switched off.

Hoist. The rated power in kW of the hoist is entered. Of the total electrical energy supplied to the hoist motors, energy equal to that required to hoist the rock is converted to potential energy, and the remainder liberated as heat. Some of this heat is liberated directly from the motors while the remainder is liberated as friction in the shaft and the winding rope system.

The relationship between the heat liberated and the rated power of the hoist depends very much on the way in which the hoist is utilised. Care must be taken when determining the percentage of the rated power dissipated as heat. This is the proportion (in %) of the rated power of the hoist that is dissipated in the ventilation air as heat. This parameter is also used to take account of the utilisation of the hoist. The calculated heat load for the hoist is

considered as an overall, 24 hour average heat load. Because of the intermittent use of hoisting equipment, this parameter usually varies from 15 to 30 %, with an average of about 20 %.

Shaft. Circular or rectangular shafts can be modeled. If a shaft's size changes radically or air is taken off at several levels, separate shaft sections are used with different dimensions and air flows. Heat flow from the rock is only one heat load component and use is made of linear heat sources to account for the effect of electrical cables or chilled water or other pipes. Because the average age of a complete airway must be specified, long shafts are divided into several shorter sections, entering the different ages of each section. This ensures that the varying age along the length of the shaft is taken into account in the heat load calculations.

Cooler. The air cooler models allow the user to select from a number of different cooling methods. In certain cases, such as in stopes, an inlet temperature requirement must be satisfied. Fixing the cooler outlet temperature causes the cooling duty to be calculated. If a specified cooler is to be used, the cooling duty can be set, in which case the outlet temperatures are calculated. If more specific design figures are known, then the user can enter the cooler K factor where Duty = K*(inlet wet-bulb - supply water temperature).

For open spray chambers, the Factor of Merit method is used. It is necessary to enter the spray direction (counter- or crossflow), the supply water temperature, the water flow rate and the Factor of Merit for the program to calculate the cooling duty and the outlet air temperatures. In each of the above cases the duty is calculated from the change in enthalpy.

Development End. It is possible to model three types of development end. These are:

Single developments with forcing ventilation;
Single developments with exhausting ventilation;
Twin developments.

The development end is treated as a young tunnel from the point of through ventilation to the face and includes the heat from the broken rock. The rated power of any machinery used in the face area or the associated tunnel is also entered. The model does not take any heat transfer between the air in the tunnel and the air in the duct into account.

The development end is assumed to have zero pressure drop with respect to the rest of the air circuit and thus the air mass flow in the duct system is entered. The model takes into account the mixing of air leaving the development end with any air that bypasses the end.

Shaft Station. In the area surrounding a shaft station, within a radius of about 200m, there are generally many interlinking tunnels and other excavations. There are also numerous installations of heat generating equipment. The major installations could include hoists, refrigeration plant, booster fans and main dewatering pumps. There are also smaller scattered items of machinery, for example transformer stations, battery chargers, lighting, dust filter fans, booster fans for localised ventilation control, pumps, locomotives and workshop equipment. The larger individual items of equipment affect the environment substantially and must be treated as separate branches. The shaft station branch can be seen as a single heat source taking the total heat load from the station area into account, including changes in moisture content.

Stope. The heat flow from the rock in stopes is divided into four components. These are:

Face zone;
Ventilated worked-out area;
Strike gullies;
Dip gully.

The heat flow for each component is calculated separately, while the stope outlet temperature is calculated from the total heat flow and the difference between the dry-bulb and wet-bulb temperatures specified by the user. ENVIRON 2.5 only deals with narrow reef conventional type stoping methods. There are three types of stoping models in ENVIRON 2.5:

Single-sided;
Double-sided;
Dormant.

When dormant stoping is selected, two parameters, ledging advance and dormant period, is entered. Ledging advance is the rate of advance during the ledging stage, and the dormant period is the period (in days) since the last blast, that is the period the stope has lain dormant. In the dormant stage, there is no heat from the service water, but the heat from fissure water is based on the rate of production during the ledging stage.

Spot Heat. The spot heat source branch is used to cater for local heat sources that may affect the moisture content as well as the enthalpy of the air stream. The parameters used to describe the process changes of the air are the total heat (or enthalpy) change and the enthalpy/moisture ratio. The heat load is the actual heat flow to the ventilation air on an overall, 24 hour average basis. It therefore corresponds to the change of enthalpy of the air. The

enthalpy/moisture ratio defines the proportion of the total heat used for heating the air and the proportion used for vaporising moisture.

Some examples of spot heat sources are given below.

Transformer stations: the transformation of electrical energy is a very efficient process. However a small amount of heat is generated which is about 3 % of the power rating of the transformer.

Pumps and refrigeration machines: the heat load on the air in pump stations and refrigeration plant chambers is a result of heat being dissipated by electric motors, machine bearings, circulating fans and other machinery. To evaluate the heat load one could typically use a value of 10 % of the rated power. It should be noted that the user is only concerned with the heat load on the air and not any temperature change of water.

Solution Methods

Four solution options are provided within the program.
Air Flows Only;
Heat Flows Only;
Air and Heat Flows;
Air and Heat Flows with Back Calculation.

Air flows only. If the user wishes to obtain only air flows and pressure drop values in a network, it is not necessary to alter any of the parameters such as age and linear heat loads. These values are only necessary for heat flow calculations. Only the physical details of each branch must be input. The program will use the default thermodynamic values provided for the air density calculations.

Heat flows only. This option allows calculation of heat flows in a single branch, a series of connected branches or a network, using user-defined air flows. The network can either be a closed or open circuit to run the simulation. Note that if the network under analysis is open, other solution options will not work because solving for air flows requires the network to be a closed circuit.

Air and heat flows. Choosing this option results in solving the network for both air and heat flows. The solution is reached in an iterative manner and the effects that air thermodynamic properties and air flow has on each other are thus taken into account.

Air and heat flows with back calculation. The objective of the back calculation option is to determine the amount of cooling required in a mine air circuit to ensure that no wet-bulb temperature exceeds a user-specified maximum. In using the option, a defined strategy must exist for the preferred location of coolers. This strategy could relate to having:

Large primary coolers located near shafts;
Smaller coolers located at stope entrances;
Numerous scattered coolers.

The coolers defined for the back calculation solution are located at the inlet of tunnel, shaft, stope, development end and hoist branches. A branch cooler is an integral part of the branch and should not be confused with the independent air cooler branches. It is not necessary for the branch coolers to be located only in the branch where the maximum reject temperature is exceeded, and they may be located anywhere upstream. However, a long tunnel could be divided into several shorter sections so that the cooler is located as close as possible to the point where the maximum reject temperature is exceeded. If a branch cooler is located some distance away from the branch in which the maximum reject temperature is exceeded it is possible that some branches close to the cooler will be over-cooled. This can occur while the maximum reject temperature may still be exceeded.

The program will only introduce any cooling which may be required at those branch cooler locations specified by the user. The program is currently set to iterate until all branch outlet wet-bulb temperatures are less than the user specified maximum reject temperature. There is a tolerance of ± 0.5 °C in this setting. Branches in which the maximum reject temperature is exceeded after solving are highlighted in the branch list in the tab editor.

If a cooler location chosen by the user is not directly upstream of a heat source (for example, a stope or tunnel) which causes the maximum reject temperature to be exceeded, that cooler will not have any effect on the reject temperature. It will therefore not be used by the program. If the heat sources in the circuit are such that the specified coolers do not prevent the maximum reject temperature being exceeded the user could:

increase the size of the cooler (by allowing a lower air exit temperature from the cooler);
increase the number of branch coolers in the circuit;
or re-position the branch coolers.

The time taken to produce a solution is greatly increased when using the back calculation option. This time depends on the number of branches in the network and the number of branch coolers. Once a back calculation solution has provided a general indication of the location of required coolers, the branch coolers are switched off and replaced by air cooler branches located upstream of the branches which contained the branch coolers. Any future solutions are carried out using the normal solution options.

Reporting

A number of different types of report can be generated by the program. These can be viewed on screen, printed or written to a text file or a Lotus 1-2-3 compatible spread-sheet file. The types of report available include tables of input data and results, network diagrams, node results, default settings and summary reports. Only summary reports and tables of inputs and results can be written to spreadsheet files. The spread-sheet file has the extension .WK1, and can be loaded into all common spreadsheet programs. Results can than be manipulated to produce additional information and representation of results in graph form is possible. The following figure, Figure 3, is an example of a Quattro Pro spread sheet containing ENVIRON 2.5 results.

Figure 3. ENVIRON 2.5 results in Quattro Pro.

APPLICATIONS OF ENVIRON 2.5

Planning and Design of New Systems

The ventilation and cooling requirements of a new mine can be determined by modeling the proposed mine layout. Although this is crucial in determining infrastructure requirements, it is also very important to determine if the proposed mining and engineering systems are optimal from an environmental system's point of view.

A detailed design of the mine's ventilation and cooling system, using a simulation tool such as ENVIRON 2.5, will enable the specification of refrigeration capacities, up- and downcast shaft size requirements, siting of regulators and coolers, etc. It will also assist design engineers to determine benefits from certain strategies such as chilled service water, backfilling, recirculation and tunnel insulation.

Applications in Existing Mines

Simulation software can be used on existing mines for a number of purposes. The mine's ventilation and cooling strategy can be optimised by assessing the existing network and then refining it. It can also be used to assess the effects of proposed changes to the ventilation and cooling systems beforehand, and significant savings can result as the trial-and-error phase is eliminated. Once an existing mine's simulation network exists, trouble shooting can be done quickly and effectively. Finally, the advantages or disadvantages of different strategies such as chilled service water, recirculation, backfilling and insulation of tunnels can be assessed.

CONCLUSIONS

A holistic approach to mine design necessitates quick and accurate results from the environmental practitioner. Above all, environmental planning must be capable of adapting to changing mining layouts. Such adaptability can only be achieved by using software simulation tools, and it is inconceivable that in the midst of the information revolution environmental practitioners can perform their duties without reliable computer tools.

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