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A heat study and the modelling of future climatic conditions at Vale Inco's Coleman/McCreedy East Mine

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ABSTRACT: A study was undertaken to evaluate the thermal environment and determine the contributing heat sources within the existing 153 Orebody of Coleman/McCreedy East Mine which would then enable the prediction of the climatic conditions in the mine's future 170 Orebody. The study entailed continuously monitoring, for a 2-week period, the dry-bulb temperature, humidity and barometric pressure along the existing intake airways from surface down to the 4810 Level and throughout an active mining area on that level. Furthermore, the mining activities and associated equipment that could be responsible for any changes in the temperature and humidity conditions within this mining area were also monitored. These data were then used to develop and validate a climatic simulation of the mine's mechanized cut and fill mining method. This climatic model was then transposed to the future 5700 Level in the deeper 170 Orebody, to determine the environmental conditions within its production workings and along the main haulage route ascending from that area. Based upon the simulations performed it was shown that the level of ventilation planned for the new orebody should be able to maintain adequate environmental conditions. However, this study did emphasize the importance of the appropriate distribution of airflow in workplaces that used auxiliary ventilation in order to sustain a suitable thermal environment.

1 Introduction

In underground mines, heat can be transferred to the ventilating air from a variety of sources. The four major heat sources are the conversion of potential energy into thermal energy as air descends vertical airways (autocompression), mining machinery, strata (geothermal gradient) and pressure generators (i.e. primary/auxiliary fans). In shallow and medium depth mines the level of ventilation needed to remove other contaminants, such as diesel fumes, typically has sufficient capacity to remove the heat that is produced by the mining process. However, with increasing autocompression and strata components, the efficiency with which the ventilation can remove additional heat from the mining process is reduced. Consequently, in deep mines, heat exposure is usually the dominant environmental concern, necessitating increased ventilation rates or the use of some level of refrigeration in order to maintain suitable working conditions within the mining area.

The study undertaken at Vale Inco's Coleman/McCreedy East operation was designed to facilitate the prediction of the environmental conditions that will prevail in its future 170 Orebody, which will extend to 1,738 m (5,700 feet) below surface. These predictions would be based upon observations within the existing 153 Orebody, 1,466 m (4,810 feet) below surface. The mining method employed both in this existing orebody and being considered for the future area was mechanized cut-and-fill (C&F). The results of predictive climatic simulation were then compared against the mine's design criterion, used at the time of this investigation, an average psychrometric wet-bulb (t_{wb}) limit of 25.5 8C (78 8F). This temperature value was exceeded, for short durations during the summer months, in the 153 Orebody.

The objectives of this study were to:

- Perform a climatic survey of the mine's intake system and 4810 Level, within the 153 Orebody, to quantify the changes in dry-bulb temperature, relative humidity and barometric pressure from surface through to the mine's exhaust system.
- Evaluate and model the heat loads added to the air by autocompression, strata, fans and mining equipment as it travels from surface down to the 4810 Level and then through to the exhaust.
- Predict the climatic conditions for the deepest level, the 5700 Level, within the future 170 Orebody assuming a similar mining method.
- Predict the conditions along this future orebody's main haulage ramp, an exhaust airway ascending from the 5700 Level to the 5100 Level.

2 Methodology

2.1 Climatic Survey

A climatic survey was used to gather the data necessary to determine the heat loads added to the mine environment.

For 14 days, during June 2005, the dry-bulb temperature, relative humidity and barometric pressure were monitored throughout the Coleman/McCreedy East Mine's intake air delivery system and 4810 Level with real-time data loggers. These three environmental parameters were then used to calculate the psychrometric wet-bulb temperatures using standard equations.

The placement of the data loggers was based upon the following survey objectives:

- To determine the contributions of autocompression, strata and the primary fans to the temperature conditions within the intake system.
- To assess the contributions of level and auxiliary ventilation fans plus the strata to the temperature conditions to the intake air en route to the discharge of the auxiliary ventilation system within a mining block.
- To establish the heat loads generated by production activities and the resultant conditions both at the workface, and downstream along the exhaust air route through to the 4810 Level return.

2.2 Activity Monitoring

To differentiate between the effects of constant heat sources, such as the strata, and the transient intermittent heat sources, namely, the mobile mining equipment, it was necessary to monitor where and when mining activities were taking place.

During the active dayshifts of the 14-day climatic survey, two observers manually recorded the operation of any mining equipment, the mine's identification number for that unit and the associated conditions. The mining activities were generalized as either: mucking (ore loading and transportation), bolting and screening for ground support or explosive loading and blasting. The associated conditions of the ventilation arrangements, such as the status of the auxiliary fan and the distribution of the airflow were also recorded.

The activity and condition data were then compiled with the monitored environmental data to identify specifically:

- The non-active conditions resulting from autocompression, strata and primary fan heat inputs.
- When the mining activities or auxiliary ventilation arrangements were affecting the working conditions.

2.3 Supplemental Data

To facilitate the climatic modelling of the conditions in the current and future orebodies, the mine staff supplied additional data as required; this included:

- The power rating of mining equipment, such as ventilation fans and diesel equipment.
- Dimensional data with respect to airway lengths, widths and heights.
- Rock and strata properties, such as thermal conductivity and diffusivity, virgin strata temperatures and geothermal step.

Surface environmental data were also obtained from weather records to establish the starting conditions for air entering the mine.

2.4 Climatic Modelling of the 153 Orebody

The C&F mining method being considered for the 170 Orebody was the same as currently employed within the mine. Therefore, the prediction of climatic conditions within the future orebody would be based upon a simulation model of the process in this pre-existing area of the mine.

The simulation of the environment on the 4810 Level within the 153 Orebody was performed in two steps using the collected data, as follows:

- Initially, a climatic model was developed for the intake air system to replicate the changes occurring from surface down to the 4810 Level. This element would be extended in the next phase to predict the conditions at the intake of the future 5700 Level within the new orebody.
- Secondly, a climatic model was developed of a typical C&F mining method production area to replicate the environmental conditions within the 4810 Level under both active and non-active states. This model would then be used as the basis for predicting conditions within the deeper mining area based upon the new starting conditions determined for that depth.

The output data generated by the climatic simulations of the 153 Orebody model were validated against field data.

2.5 Climatic Prediction of the Conditions within the Future 170 Orebody

The conditions resulting from mining activities in the 170 Orebody were predicted in three steps as follows:

- Firstly, the intake system model was extended to a depth of 1,738 m (5,700 feet) taking into consideration the air route to that depth. Here, it should be noted that the fresh air to the 153 Orebody was delivered through the #1 Intake Shaft from surface to the 3880 Level and then an internal raise to the 4810 Level. The predictive modelling of the 170 Orebody would require the inclusion of an extensive series of lateral transfer drifts, short vertical raises and a set of booster fans to provide air to the intake of the new mining area.
- Secondly, using a simplified model of the C&F mining method, the overall conditions for a mining block in the new mining area were predicted based on the newly determined intake conditions.

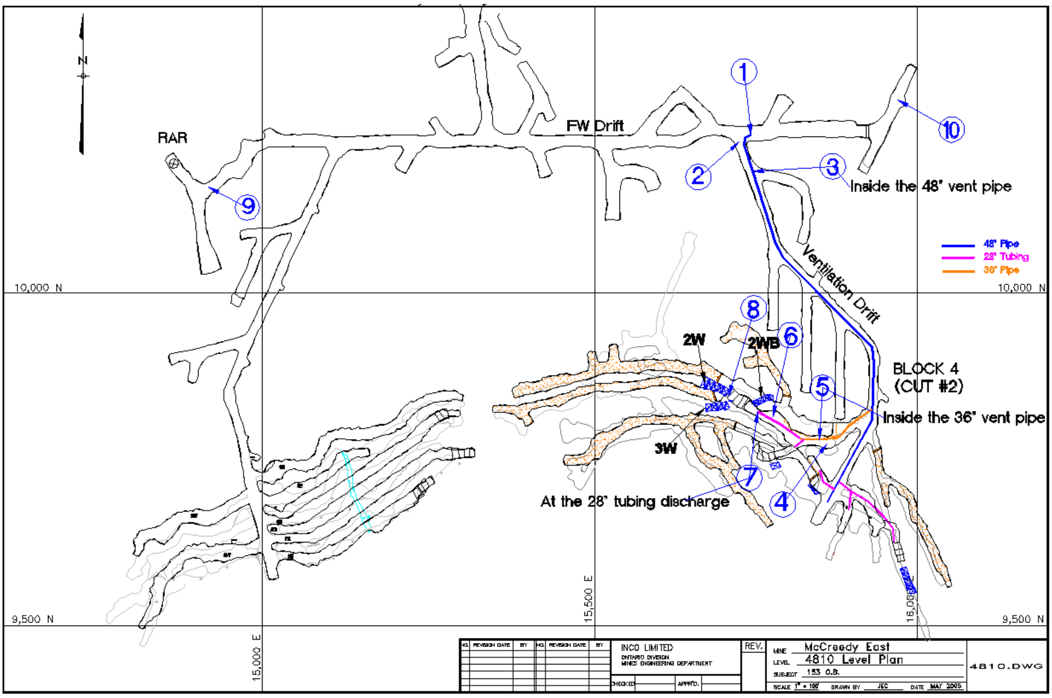

Figure 1: Coleman/McCreedy East Mine's 153 Orebody – 4810 Level plan

- Thirdly, the environmental conditions were predicted along two sections of the main haulage ramp ascending from this deeper orebody. This was to assess the conditions that would be generated along this exhaust air route which also served as an escapeway.

3 Data Collection

3.1 The Ventilation System

At Coleman/McCreedy East Mine, fresh air is delivered by two main surface intake fans to the east side of 153 Orebody's 4810 Level via the #1 Intake Shaft and a short system of raises. As shown in Figure 1, the air is taken from the intake raise and discharged onto the 4810 Level through two booster fans installed in parallel. This air then travels freely along the footwall drift to the return air system located on the opposite (west) side of the level.

Within the level, fresh air was directed from the footwall drift to a mining block and the individual stopes within it through auxiliary ventilation ducting. This forcing system employed a single 112 kW (150 hp) auxiliary fan installed at its intake in the footwall drift. The auxiliary system consisted of a 1.2 m (48") diameter steel duct in the main ventilation drift to the mining block, a 0.9 m (36") diameter steel duct in one access drift splitting the delivery between mining areas within the mining block, and 0.9 m (36") and 0.7 m (28") diameter flexible fabric tubes directing the air towards the individual stopes.

The return air from the stopes travelled back through the access drift to the main ventilation drift and then along the footwall drift to the return air system.

When the auxiliary fan was operating, a consistent air volume was delivered through the 1.2 m and 0.9 m diameter steel ducts. These flows were measured by means of a tracer gas method. The air volumes delivered through the flexible ducts to each individual C&F production stope varied considerably as a function of the ventilation arrangement. The ventilation duct discharges were measured for each production arrangement using an electronic vane anemometer (Testo Inc., Testo 445).

3.2 Environmental Data Collection

Eleven environmental data loggers (ACR Systems Inc. SmartReader Plus Series) were installed along the air route from surface down to and throughout the 4810 Level. The monitoring locations are also shown in Figure 1. These pocket sized units were used to continuously record the dry-bulb temperature, the relative humidity and the barometric pressure 24 hours a day, at 1-minute intervals.

It should be mentioned that it was not possible to continuously monitor psychrometric wet-bulb temperatures directly. This was due to the number of units required and the long-term monitoring limitations of the water reservoirs of direct measuring instruments.

An infrared thermometer (Raytek MX) was used to measure the wall surface temperatures of the drifts and within the stopes, as well as the external surface temperature of the auxiliary ducts.

In the production area, a Kestrel 4000 Pocket Weather Tracker was also used for spot measurements of the underground environmental conditions.

3.3 Mine Activity Tracking

During the 14-day survey, drilling, bolting and screening, explosive loading or blasting and loading or transportation (mucking) of ore/waste activities were monitored when occurring on day-shift. For each day surveyed, data were compiled for the study area, the three individual stopes within it and the mining block as a whole. The details recorded included the type and location of activity, start and finish times, mining equipment used and the duration of scheduled (i.e. lunch) or unscheduled (i.e. equipment breakdowns) production delays. The operational status (off/on) of the auxiliary fan for the area and resultant distribution were also recorded.

Here, due to their different heat contributions, it was important to monitor and identify every specific instance of LHD activity both inside and outside the C&F production area. For example, a 2.5 yd^3 LHD was used to move ore from the face of the production stope to a remuck bay; while a larger 6 yd^3 LHD was used to move ore from the remuck bay to the 4810 Level orepass. The mining equipment observed during the study is listed in Table 1.

Table 1: Mining equipment used in the 4810 Level stopes during production cycles

Activity/Equipment	Equipment Information
Drilling: Mini-Jumbo	34 kW (45 hp) diesel, 37 kW electrical motor, 2.2 kW compressor motor
Bolting/Screening: Jacklegs	Compressed air system
Mucking Small LHD: moving blasted ore from 3W, 2W & 2WB stope faces to the remuck bay	2.5 yd^3 – 86 kW diesel
Mucking Large LHD: moving ore from the remuck bay to the 4810 level ore pass	8 yd^3 – 250 kW diesel 6 yd^3 – 200 kW diesel
Miscellaneous Vehicles	Utility – 37 kW diesel Small truck – 32 kW diesel Fork lifts: 33 & 37 kW diesel Personnel – 100 kW diesel

4 Data Analysis

The dry-bulb temperature (t_{db}), humidity (%RH) and barometric pressure (kPa) data collected from the monitors along the air route were compiled daily into electronic spreadsheets. Within, these spreadsheets the psychrometric wet-bulb temperature (t_{wb}) was calculated for each individual set of measurements.

The collected activity information, the operational status of the auxiliary fan and the airflows at the active stopes were also compiled within the daily spreadsheets. Once combined, it was possible to identify in temperature and humidity graphs, how and where mining activity had an impact on environmental conditions within the level.

For example, Figure 2 shows the compiled mine activity data for the #4 Mining Block (June 9, 2005) superimposed over the dry-bulb and wet-bulb temperatures and relative humidity data. Typical trends observed from this graph are as follows:

- During mining activities not requiring any diesel or electrical equipment, the background temperatures in the production stopes were typically: 28.5 8C t_{db} and 23.5 8C t_{wb}.
- During the two scheduled production delays when the auxiliary fan was turned off, in the production stopes t_{db} dropped from 28.5 8C to 26.9 8C and then from 30.0 8C to 28.4 8C. In association with this the relative humidity, and hence the wet-bulb temperature, gradually increased. This showed that the auxiliary fan alone was a significant local dry heat source.
- During bolting and screening, the dry-bulb temperatures, relative humidity, and therefore the wet-bulb temperature remained fairly constant: 28.0 8C t_{db}, 58%RH and 22.8 8C t_{wb}.
- Some of the most significant changes occurred during concurrent mining processes. An example of this can be seen between 15:40 to 16:20, when both drilling and mucking activities were taking place in adjacent stopes. At the drilling location, the monitors showed increases of +3.5 8C Δt_{db} and +1.3 8C Δt_{wb}. However, it should be noted that part of this increase was due to an increased amount of fresh air being directed through the auxiliary tubing towards the stope where the diesel equipment operated.

Due to the variability of operational conditions within the production stopes, some filtering of the data was required prior to determining the average conditions. For example, data within the auxiliary ventilated region were omitted when the auxiliary fan was not operational. Scheduled activity delay periods (e.g. lunch) were also ignored when determining the effect of mine activities on the working environment within the stopes. Further breakdown of the data was required when there was more than one activity taking place.

Table 2 shows the averaged environmental data and the derived relative changes in dry-bulb and wet-bulb temperatures between each monitoring location. In

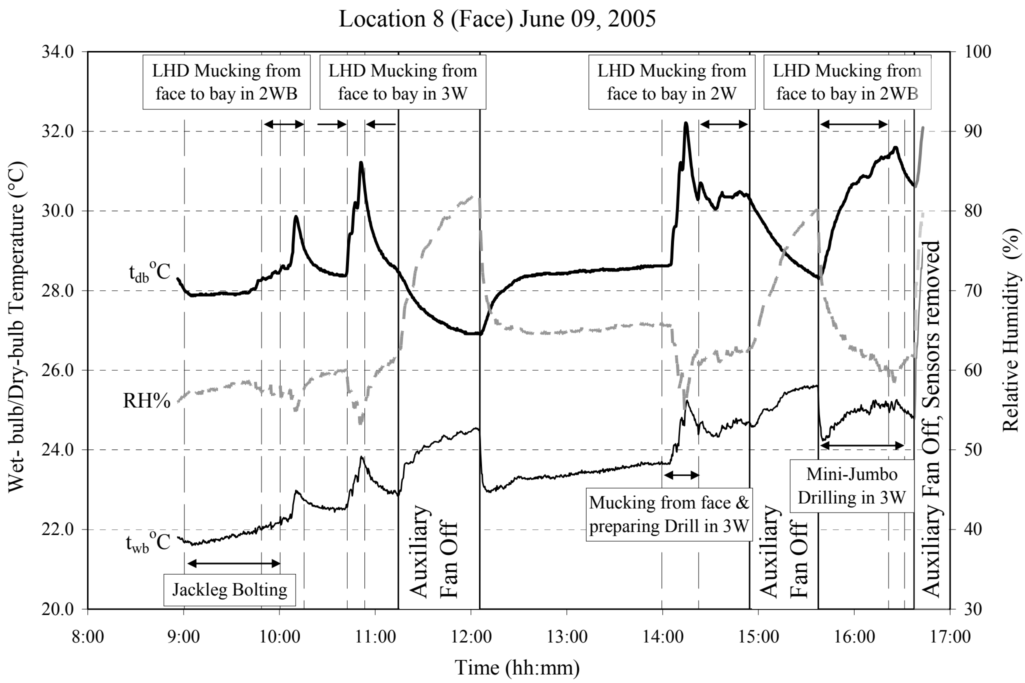

Figure 2: Wet-bulb, dry-bulb and relative humidity in the C&F production stopes

combination, the environmental and mine activity data showed the following:

- The greatest temperature increases occurred between surface and the intake to the 4810 Level, +10.6 8C Δt_{db}, +6.9 8C Δt_{wb}. This is equivalent to changes of 0.7 8C t_{db}/100 m and 0.5 8C t_{wb}/100 m; which indicates that autocompression was the main controlling factor on the intake conditions.
- Across the 4810 Level, the majority of the temperature changes were minor - if not negligible. For example, apparent changes of up to ±0.3 8C between measuring locations could be purely the response difference of two instruments.
- The booster fans delivering fresh air to the 4810 Level added heat to the system. They produced at least a +1.3 8C Δt_{db} increase in the intake air, as still evident at the intake of the auxiliary fan.
- The 112 kW (150 hp) auxiliary fan delivering air to the mining block added heat and produced an immediate +2.5 8C Δt_{db} increase in the intake air across the fan.
- The decreasing t_{db} through the duct shows some of the fan heat added to the intake air was transferred to the auxiliary steel duct prior to its discharge.

Table 2: Average monitored dry-bulb and wet-bulb temperatures form Surface to the 4810 Level

LOCATION	t_{db} 8C	Δt_{db} 8C	t_{wb} 8C	Δt_{wb} 8C
Surface Intake	18.4		15.7	
4810 Level Intake Location 10	29.0	+10.6	22.6	+6.9
48” Aux. Duct Intake Location 1	30.3	+1.3	22.9	+0.3
48” Aux. Duct after Fan Location 3	32.8	+2.5	23.1	+0.2
36” Auxiliary Duct Location 5	32.3	-0.5	22.9	-0.2
Auxiliary Pipe Discharge Location 7	31.9	-0.4	23.4	+0.5
Stope Face (3W/2W/2WB) Location 8	29.4	-2.5	23.8	+0.4
Stope Return Location 6	29.4	0	23.9	+0.1
Access Drift Return Location 4	29.4	0	23.9	0
Ventilation Drift Return Location 2	29.4	-0.3	23.5	-0.4
Footwall Drift to RAR Location 9	29.1	-0.3	24.0	+0.5

- Within the face area the dry-bulb temperature continued to decrease, -2.5 8C Δt_{db}. However, there was a corresponding notable increase in the wet-bulb temperature, which could indicate that some evaporative cooling was taking place within the production stopes.
- The return air temperatures were relatively consistent as the air left the stope area and continued to the exhaust.
- Overall, the results in Table 2 show t_{db} decreases across the level from 30.3 8C to 29.1 8C and a corresponding increase in t_{wb} from 22.9 8C to 24.0 8C. These changes indicate that heat and moisture had been added to the return air.

Even though the effects of mining activity appeared to be small in the averaged data; the following specific instances note where temperatures were considerably higher:

- During drilling, the 37 kW Mini-Jumbo could create up to +3.2 8C Δt_{db} increases depending on the amount of fresh air delivered to the stope.
- During mucking (from the face to the remuck bay) with the 2.5 yd^3 (86 kW) diesel LHD, the increases ranged from +1.3 8C to +9.4 8C Δt_{db} and from +0.6 8C to +3.5 8C Δt_{wb}. Once again, the magnitude of the increase was influenced by the arrangements of auxiliary ventilation.
- In the production stopes, concurrent processes created some of the highest temperatures. In the immediate vicinity of the mining equipment, temperature spikes ranged from 29.2 8C to 38.6 8C t_{db}, and from 24.9 8C to 26.3 8C t_{wb}. These were usually short-lived (e.g. 20-30 minutes).
- Consequently, due to either concurrent activity and/or local ventilation arrangements there were some short periods when temperatures were above the average design criteria 25.5 8C t_{wb}.

Overall, the environmental monitoring data showed that the dry-bulb temperature and relative humidity (and hence the wet-bulb temperature) changed quickly with the onset of mining activity in the C&F stopes of the #4 Mining Block. Similarly, with the completion of the mining activity, any elevated dry-bulb and wet-bulb temperatures quickly returned to the stope background values. These changes were purely local as temperatures remained constant at the exhaust of the mining block.

An important finding of the environmental monitoring was that the resulting working conditions, specific to an individual workplace, were a function of the amount of fresh air being delivered through the auxiliary ducting system to each stope. Despite daily anemometry measurements showing the overall volume of air delivered to the mining block as being sufficient to control temperatures, it was observed that the auxiliary system was not always adjusted promptly in response to the variable air volume requirements of the individual production stopes.

5 Climatic Modelling

The climatic models of the current 153 Orebody and future 170 Orebody were developed using the Climsim™ software package. The models were based upon the mine layouts and the following geothermal rock properties supplied by the mine:

- Geothermal step derived from supplied virgin strata temperatures: 63 m/8C
- Conductivity: 5.6 W/m8C
- Diffusivity: 2.5 x 10^{-6} m^2/s

5.1 Model Development – Intake Air Delivery System & 153 Orebody Mining Block

A climatic model was developed by combining various airway segments. These segments simulated the temperature changes from surface down to the 4810 Level, across the level to the auxiliary fan system serving the mining block, through the auxiliary ventilation system, the production stopes and then continuing across the level to the exhaust. The following is an example of the ventilation parameters and heat sources used to create the climatic simulation in the C&F area with concurrent mining activity:

- Volume of air delivered by the auxiliary fan through the 1.2 m diameter steel duct: 27.5 m^3/s.
- Combined air volume directed to the production stopes through the flexible fabric ducts: 11.5 m^3/s.
- Initial temperatures of the air from the previous simulation segment: 30.3 8C t_{db} and 22.9 8C t_{wb}.
- Depth: 1,466 m; Barometric Pressure: 118 kPa.
- Auxiliary fan power: 112 kW; fan pressure generation: 2,488 Pa.
- Mini-Jumbo power characteristics: $P_{electrical}$: 37 kW, P_{diesel}: 34 kW, $P_{compressor}$: 2.2 kW.
- 2.5 yd^3 diesel LHD power characteristic: P_{diesel}: 86 kW.

The output from this climatic simulation is shown in Table 3. On comparing the simulation output against the averaged measured data presented in Table 2, it can be seen that the only major difference is the dry-bulb temperature at the face. The simulation predicted 33.0 8C t_{db}; this is 3.6 8C higher than the average t_{db} measured from the monitored activities. However, it should be noted that this specific simulation was set to represent concurrent activities with the airflow distribution being focused on the diesel LHD. As previously stated, such activity and airflow arrangement also produced some of the highest measured conditions.

The simulations also indicate that with sufficient airflow for the activities taking place, the temperatures should be within the 25.5 8C t_{wb} design criteria.

The simulations of the 4810 Level also highlighted the difficulty of replicating the individual conditions in each stope within the mining block when the location and type of activity changes constantly; and when the ventilation distribution is continually being adjusted but not necessarily matching the changes in mining activity.

Table 3: Model simulated dry and wet bulb temperatures for the existing #4 Mining Block – 4810 Level

LOCATIONS – 4810L	t_{db} 8C	Δt_{db} 8C	t_{wb} 8C	Δt_{wb} 8C
48"Auxiliary Duct Intake Location 1	30.3		22.9	
48"Aux. Duct after Fan Location 3	32.9	+2.6	23.9	+1.0
Auxiliary Pipe Discharge Location 7	31.9	-1.0	23.5	-0.4
Stope Face (3W/2W/2WB) Location 8	33.0	+1.1	24.2	+0.7
Stope Return Location 6	30.0	-3.0	24.3	+0.1
Access Drift Return Location 4	29.9	-0.1	24.3	0
Ventilation Drift Return Location 2	29.5	-0.4	24.1	-0.2
Footwall Drift to RAR Location 9	29.1	-0.4	24.0	-0.1

Consequently, for subsequent predictive models, it was decided that a "block" model combining all three production stopes should be used.

5.2 Model Extrapolation – Future 170 Orebody Mining Block

The simulation of the climatic conditions within the future 170 Orebody required prediction of the conditions at the bottom of the extended intake air system, and then, through the 5700 Level. The latter level simulation was straightforward, considering that it was a direct replication of the 4810 Level model.

However, obtaining the dry-bulb/wet-bulb temperatures and barometric pressure starting values for the intake to the 5700 Level model required additional climatic simulation. Extending the "Surface to 4810 Level" model to the deeper planned level required the addition of numerous new horizontal and vertical airways and any potential fans. Upon their inclusion, the climatic simulations indicated the temperatures at the entry to the 5700 Level would be 35.3 8C t_{db} and 24.4 8C t_{wb}. These values, along with the simulation predictions of the conditions throughout the level under the worst operational scenario (e.g. concurrent operations) are included in Table 4.

Comparing Tables 3 & 4 for 4810 and 5700 Levels shows the intake temperatures at 5700 Level to have increased significantly with +6.3 8C Δt_{db} and +1.8 8C Δt_{wb}. As a result of the additional autocompression and potential booster fan heat input, the intake t_{db} now exceeds the virgin strata temperature of 30.8 8C for the 5700 Level. Consequently a portion of this heat can be lost from the air to the strata.

The climatic simulation of the 170 Orebody's 5700 Level predicted the highest temperature conditions within the production area to occur at the combined return from the mining stopes, namely 33.6 8C t_{db} and

Table 4: Predicted dry and wet bulb temperatures for a future mining block on the 5700 Level

LOCATIONS – 5700L	t_{db} 8C	Δt_{db} 8C	t_{wb} 8C	Δt_{wb} 8C
48"Auxilairy Duct Intake Location 1	35.3		24.4	
48"Aux. Duct after Fan Location 3	37.8	+2.5	25.4	+1.0
Auxiliary Pipe Discharge Location 7	36.2	-1.4	25.0	-0.4
Stope Return Location 6	33.6	-3.9	25.7	0.0
Access Drift Return Location 4	33.4	-0.2	25.7	0.0
Ventilation Drift Return Location 2	33.1	-0.3	25.6	-0.1
Footwall Drift to RAR Location 9	32.8	-0.3	25.6	0.0

25.7 8C t_{wb}. Again comparing Tables 3 & 4 shows the mining block exhaust temperatures on the 5700 Level to be greater than those on the 4810 Level. However with the relative changes being only +3.6 8C Δt_{db} and +1.4 8C Δt_{wb}, they are not as significant as the increases at the intake to the level. This smaller change is a result of the t_{db} continuing to be above the virgin strata temperature throughout the 5700 Level.

Overall, the simulation of the conditions to be expected on the 5700 Level showed that with sufficient airflow for the activities taking place, the temperatures should be within the 25.5 8C t_{wb} design criteria.

5.3 Model Development – Main Haulage Ramp

The climatic conditions that could develop from diesel based ore haulage in the main ramp return air route ascending from the 170 Orebody were also evaluated. Simulations were performed on climatic models of two sections of the ramp under what was considered the worst-case operational conditions. The ramp sections were, from the 5700 Level to the 5475 Level and then from the 5475 Level to the 5100 Level.

The following provides an example of the data used for the 5700 Level to 5475 Level ramp section:

- Volume of air flowing through this section of the ramp: 71 m^3/s.
- Intake conditions from previous segment: 32.8 8C t_{db}, 25.6 8C t_{wb}.
- Two 2.5 yd^3 diesel LHDs, Combined Power: 173 kW.
- One 6 yd^3 diesel LHD, Power: 231 kW.
- Two diesel trucks, Combined Power: 447 kW.
- Total diesel power: 851 kW.

With these inputs, the climatic simulations predicted the following conditions: 36.8 8C t_{db} and 27.2 8C t_{wb}. This shows the wet-bulb temperature to be in excess of the mine's design criteria if all the haulage equipment operated for a significant period. These predicted conditions in the lower ramp were the highest temperatures from the climatic simulations.

The predicted conditions for the upper section of ramp had lower temperatures, despite the use of more diesel equipment, due to a higher air volume.

5.4 Climatic Simulation Summary – 170 Orebody & Haulage Ramp

- The temperature conditions predicted for the intake air to the future 5700 Level would be: 35.3 8C t_{db} and 24.4 8C t_{wb}. The changes between surface and the 5700 Level, +16.9 8C Δt_{db} and +8.7 8C Δt_{wb}, are mainly due to the heat generated by autocompression and the fans.
- Within a C&F mining block similar to that on the 4810 Level, the conditions at the auxiliary duct discharge within the stope area on the 5700 Level would be: 36.2 8C t_{db} and 25.0 8C t_{wb}.
- During concurrent activity (e.g. mucking and drilling), with 11.5 m^3/s of fresh air directed to the production stopes through an auxiliary arrangement similar to the 153 Orebody, the conditions in the common return from the individual stope areas on the 5700 Level will be: 33.6 8C t_{db} and 25.7 8C t_{wb}.
- Along the return airways (from the C&F production stopes to the RAR), the predicted conditions decrease to 32.8 8C t_{db} and 25.6 8C t_{wb} at the return air raise.
- Across the 5700 Level, the simulated dry-bulb temperatures are in excess of the predicted virgin rock temperature for that depth, namely VRT_{5700L} = 30.8 8C.
- Throughout the 5700 Level, heat generated by autocompression and fans in the intake delivery system, and machinery within the level is being rejected to the surrounding cooler rock surface.
- For the 5700L – 5475L section of the haulage ramp, under the worst-case-scenario of significant continuous equipment operation the conditions are predicted to reach 36.8 8C t_{db} and 27.2 8C t_{wb}.

6 Conclusions

A climatic simulation model of a C&F mining area within the 4810 Level of the 153 Orebody was successfully developed from environmental monitoring, activity tracking and other data.

The environmental monitoring data showed concurrent mucking and drilling activities to be the worst-case operating scenario, contributing the greatest amount of heat and generating some of the highest observed temperatures. However, this concurrent activity situation was generally short-lived and infrequent.

The monitoring study also showed that some of the most severe conditions occurred within the individual stopes when the auxiliary ventilation was not adequately adjusted to meet the changes in production activity. For example, under such a situation conditions at the stope face could be up to +9.4 8C Δt_{db} and +3.5 8C Δt_{wb} higher than at the ventilation duct discharge.

Due to the activities and airflow distributions within three stopes operating in parallel constantly changing, it would have been difficult to simulate accurately the specific conditions which could occur in each individual stope. Consequently, it was necessary to treat the three stopes as a single element.

The climatic conditions on the 5700 Level within the future 170 Orebody were simulated using the mining process model developed for the 4810 Level with new intake conditions derived for that deeper location. Here, for the observed worst-case operational scenario, the simulations predicted that conditions could reach 33.6 8C t_{db} and 25.7 8C t_{wb} in the combined return from three C&F production stopes.

The climatic simulation of the future 170 Orebody, with the simplified working area, have shown that 25.5 8C t_{wb} should not be exceeded throughout any level. However, as shown in the original monitoring of the 4810 Level, this temperature could be exceeded within the individual stopes depending on the location of mining activity and associated distribution of the auxiliary airflow. Overall, the simulation modelling has shown that the only area where this condition may only be exceeded for a significant period of time is in the haulage ramp. In the ramp section ascending from the 5700 Level to the 5475 Level, 25.5 8C t_{wb} would be exceeded if all potential equipment was operating simultaneously.

Finally, this study has shown that providing an appropriate auxiliary ventilation distribution for the location of the mechanical heat sources plays the greatest role in maintaining adequate environmental conditions within Coleman/McCreedy East's 170 Orebody C&F mining areas. Furthermore, it is evident from the simulations that unless either the air volume to any level is increased, or its temperature are decreased, to unrealistic values, neither would be able to compensate for a lack of appropriate auxiliary ventilation.

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