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Predicting the Re-Entry Time at Chirano Gold Mine Limited Southwestern Ghana using VentSim Simulation Software

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Research Article

Abstract

Re-entry into blast fume affected underground areas is a safety and productivity concern for most mines. Overestimation of the re-entry time may improve clearance of noxious gases but can result in production delays and decrease overall productivity while underestimation of the re-entry time will also lead to safety and health problems. At Chirano Gold Mine Limited (CGML), studies show that, the blastmen use their experience to guess the re-entry time and most often their guesses overestimate or underestimate the re-entry time. This project seeks to eradicate the guess of the re-entry time by conducting explosive simulations using VentSim software to serve as a tool to predict the re-entry time of any development blast. In this work, three different ventilation models were run to evaluate the re-entry time in single and multiple headings. The models were based on the Paboase mine at CGML. The results showed that, the VentSim can serve the purpose of always predicting the re-entry time and by comparing the data collected with the results from the three scenarios, it is very clear that the blastmen in their guess of the re-entry time always overestimate it.

Keywords

Gold Mine; Re-Entry Time; Underground, VentSim software;

Article History

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1. Introduction

In underground mining, in other to make progress to intersect the orebody, several developments must be made. Drilling and blasting are the conventional approach used by most mines to advance their development headings. Blasting is the second phase after drilling has been completed in the fragmentation process and this involves loading explosives into the drilled holes and detonating them to cause an explosion thereby fragmenting the rock (Lopez and Lopez, 1995; Hebda-Sobkowicz *et al* 2019). Carbon II oxide (CO), carbon IV oxide (CO_2), hydrogen sulphide (H_2S), oxides of nitrogen (NO, NO_2, N_2O and N_2O_5), sulphur IVoxide (SO_2) and Azane gas (NH_3) are some of the gases produced after the blast (Zawadzka-Małota, 2015; Tille, 2019). Excess Ammonia Nitrate Fuel Oil (ANFO) prill moisture content has proved to greatly increase the likelihood of post blast fume incidences, namely the formation of oxides of nitrogen (Sapko *et al* 2002). Explosive manufacturers design their product to be fuel rich, and therefore oxygen negative (Henley, 2010; Sapko *et al*, 2002). Most of these gases are colourless, odourless and tasteless and can cause serious health problem or even death if one is exposed to them above some acceptable thresholds (Stewart, 2014). Mine ventilation is the means of removing poisonous gases, diluting or carrying away dust and providing cooling for personnel and machinery underground through displacement of the gases by fresh air from the surface (Agson *et al* 2019). According to (Gillies *et al*, 2004), after-blast re-entry times have been identified as one of the potential safety and health challenges introduced by the advanced mining technology. When there is a blast, the duration miners wait before they re-enter the blasted area to resume working is what is called re-entry time or period (Rispin, 2005). Total adherence to best re-entry period brings balance between the safety of workers and productivity. Obtaining the ideal re-entry time or period is a great concern for most underground mines because when the re-entry time is overestimated, it delays production and when it is underestimated it causes serious health risks on the workers (Jahir, 2016). Therefore, standard re-entry procedures and gas detection and monitoring will remain important parts of safe blast fume management (Jahir, 2016). At Chirano Gold Mine Limited (CGML), monitoring of various gas concentrations is only done when the blastmen have re-entered the blasted area without any prior knowledge of how long the place must take to clear. Currently the re-entry time always predicted by the blastmen at Chirano Gold Mine Limited is within the range of 60 - 90 minutes. The most appropriate way to predict the re-entry time is by adopting the air quality monitoring system whereby sensors underground can be used to monitor the air quality after blast to accurately predict for blastmen the actual time to re-enter the blasted area. However, the mine as at now does not have this technology running. Therefore, prediction of the re-entry time is based on guessing. In view of that, this paper seeks to find solution to the re-entry time challenge at the mine by conducting explosive simulation using the VentSim software which the mine is currently using in monitoring the performance of their ventilation circuit.

1.1 Determination of Blast Re-Entry Time

A few methods are available to estimate concentration and clearance times from underground blasting. In most cases, a variation of a mathematical logarithmic decay series is the basis behind estimations (Stewart, 2014). All methods have significant merits and can closely represent the dilution behavior of blast gases but can be difficult for the site engineer to calibrate to local mine conditions.

Equation 1, (Government Gazette (2021), shows the mathematical formula for calculating re-entry time or period.

$$R = \frac{L \times A \times K}{Q \times \eta \times 60} \quad (1)$$

Where:
R is Re-entry time or period in minutes
A is Area of excavation in m^2
K is Safety factor
Q is Quantity of air in m^3/min
η is Fan efficiency; and
L is Distance from the last return air way (RAW) to the blasted face in m

The re-entry formula is used in almost all mines around the world to estimate their re-entry time theoretically. Using parameters from level access 1600m at Paboase mine at CGML in Figure 1, with the Zitron 2×110 single stage fan of efficiency of 85% supplying 22.2 cubes of air, area ore drive being 5m × 4.8m, area of level access being 5.5m × 6m and safety factor of 5, the re-entry time can be calculated as;

$$R = \frac{(41 + 103) \times [(5 \times 4.8) + (5.5 \times 6)] \times 5}{22 \times 0.85 \times 60} \quad (2)$$

$$= \frac{29396}{1122} = 26 \text{ min} \quad (3)$$

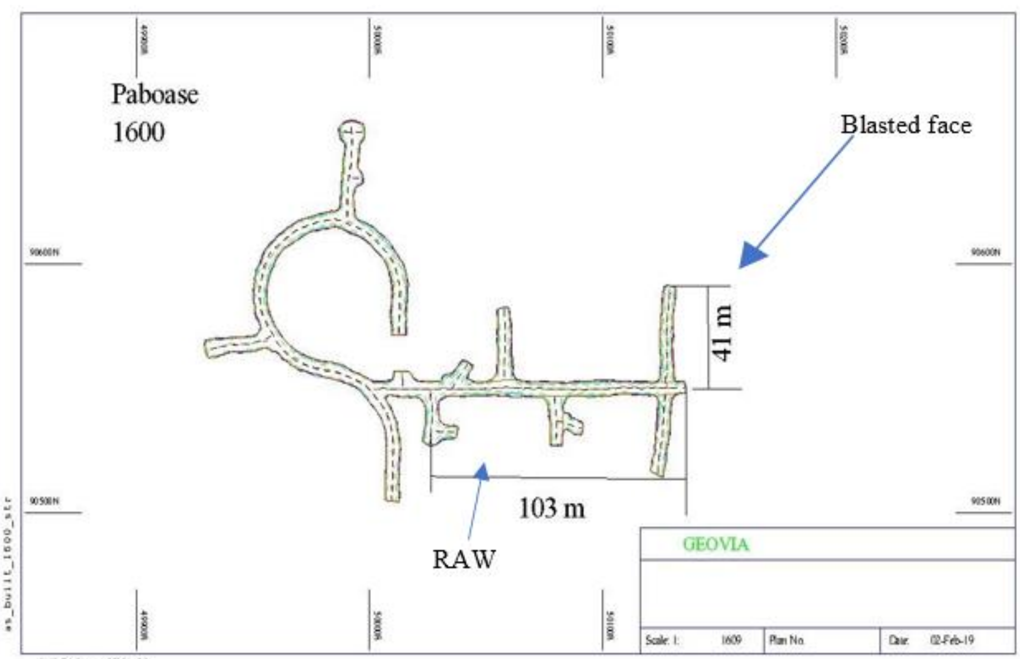

Figure 1: Level Access 1600m – Paboase Mine

2. Materials and Method

The methods used include review of relevant literature, site visit for data collection; Data collected included:

i. Blasting time.
ii. Re-entry and gases concentration after end of night shift blast.
iii. Charge design and quantity of explosives used; and as built string file of levels access 1675m to 1600m,

Questionnaire and interview were administered with the ventilation engineer on site; and simulation was carried out using VentSim software.

2.1 Study Area

Chirano is located in southwestern Ghana, approximately 100km southwest of Kumasi, Ghana's second largest city. Chirano achieved its first gold pour in October 2005, and consist of 13 deposits: Akwaaba, Suraw, Akoti South, Akoti North, Akoti Extended, Paboase, Tano, Obra South, Obra, Sariehu and Mamnao North, Mamnao central and Mamnao South.

Chirano Gold Mine Limited (CGML) is situated in southwestern Ghana, 100km south-west of Kumasi, which is Ghana's second largest city. The town of Bibiani lies 15km north-northeast of the mine area (37km by road). Figure 2 is a district map showing the location of the mine.

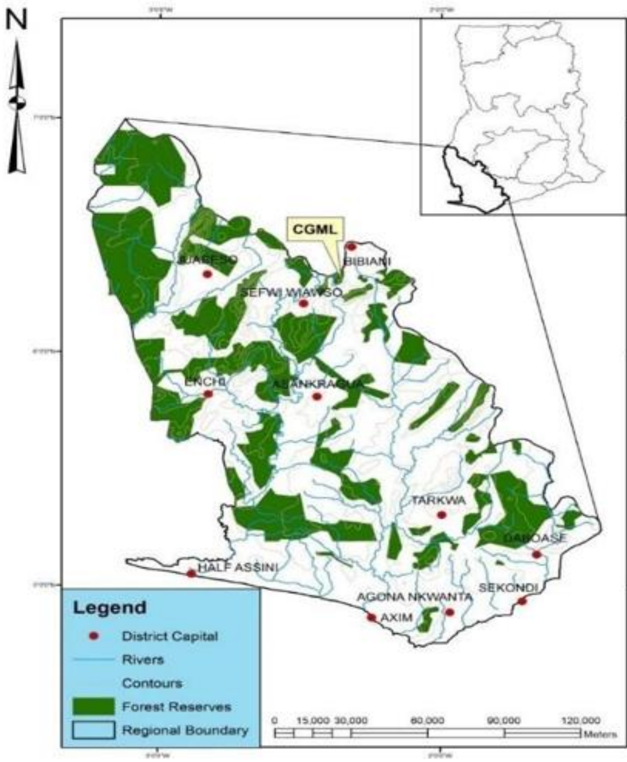

Figure 2: District Map showing the location of CGML (Anon., 2015).

2.2 Mining Method

The mining methods employed at CGML are sublevel caving and open stoping. Sublevel caving method is mainly employed at the Akwaaba Decline and the open stoping method is employed at Paboase Decline. The production holes are drilled in an upward direction from the level below as reef drives into the ore. Due to the nature of the orebody, three production drifts are excavated along the strike at the end of each haulage drift. These divide the orebody into a geometrical pattern. Holes of diameter 102mm are drilled at intervals of about 2.5m in the orebody. From the end of the production drifts near the ore-waste contact, slots are driven up to the next sublevel drift above as a free face. Maxam Ghana Limited has been contracted to supply explosives, blast accessories and to charge the blast holes for CGML. However, CGML performs the initiation of the blast. After blasting, the broken rocks are hauled by LHDs. The LHDs also load and dump the broken rocks at the underground stockpiles and later hauled to either the processing plant or the waste dump by the dump trucks. Figure 3 is a schematic of the various levels at Paboase and Akoti mine.

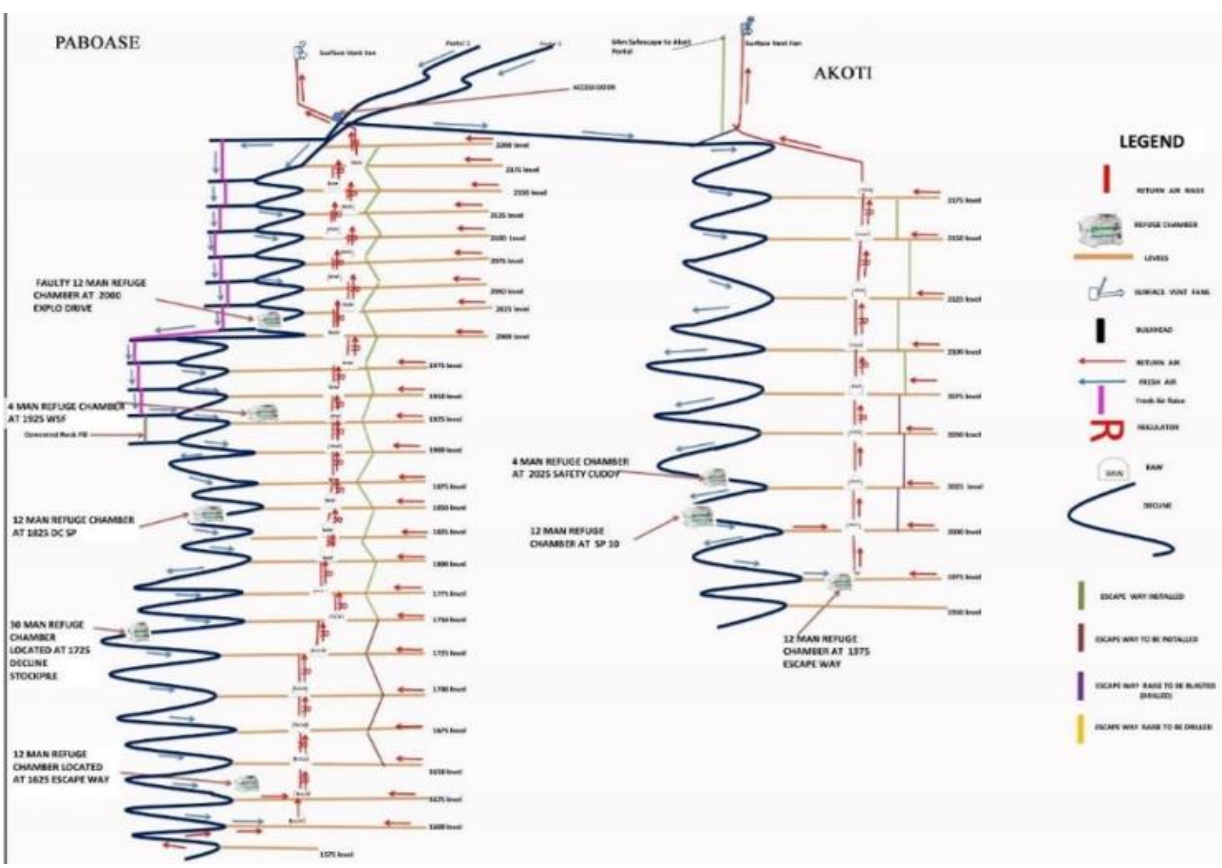

Figure 3: A schematic of the Paboase and Akoti mine

2.3 Re-Entry Procedures at CGML

The time required to remove the blasting gas, dusts and maintaining acceptable temperature after a primary or secondary blast in a mine is called re-entry time.

The purpose of this procedure is to ensure that persons involved in re-entry activities are not exposed to potentially harmful fumes following blasting underground. Fumes from blasting have been known to cause serious injuries and in some cases death. The following are the safety equipment and tools required for re-entry: gas monitor, personal protective equipment, scaling bar, re-entry checklist, shift status report, signage and barricades.

Re-entry must involve three people. Two persons are responsible for conducting the re-entry procedure while the third person remains at the tag board as a sentry. To be deemed competent to carry out re-entry duties, you must have a valid Blast Certificate issued by Minerals Commission, completed all standard operating procedure (SOP's) and authorized by the Underground Manager for this task. For training purposes, it is acceptable for a person not yet deemed competent to be involved in re-entry activities, when this occurs the individual must always be supervised.

2.4 Ventilation Modelling

For all underground mines, planning the ventilation network before mining must be done throughout the mine life without any ventilation problems. Occupational exposure limits to harmful gases, dust and temperature and requirements for fresh air and exhaust air must be greatly considered for safe working environment. To achieve this, the ventilation network is modelled with ventilation simulation software that uses mathematical algorithms to model the fresh air and exhaust air, as well as simulations for blasts, underground fires, possible escape routes and many more. At Chirano Gold Mine Limited (C GML), the software used for this purpose is the VentSim. Figure 4 shows a development model with ventilation simulation of levels 1675m to 1600m of the Paboase mine at Chirano Gold Mine Limited (CGML).

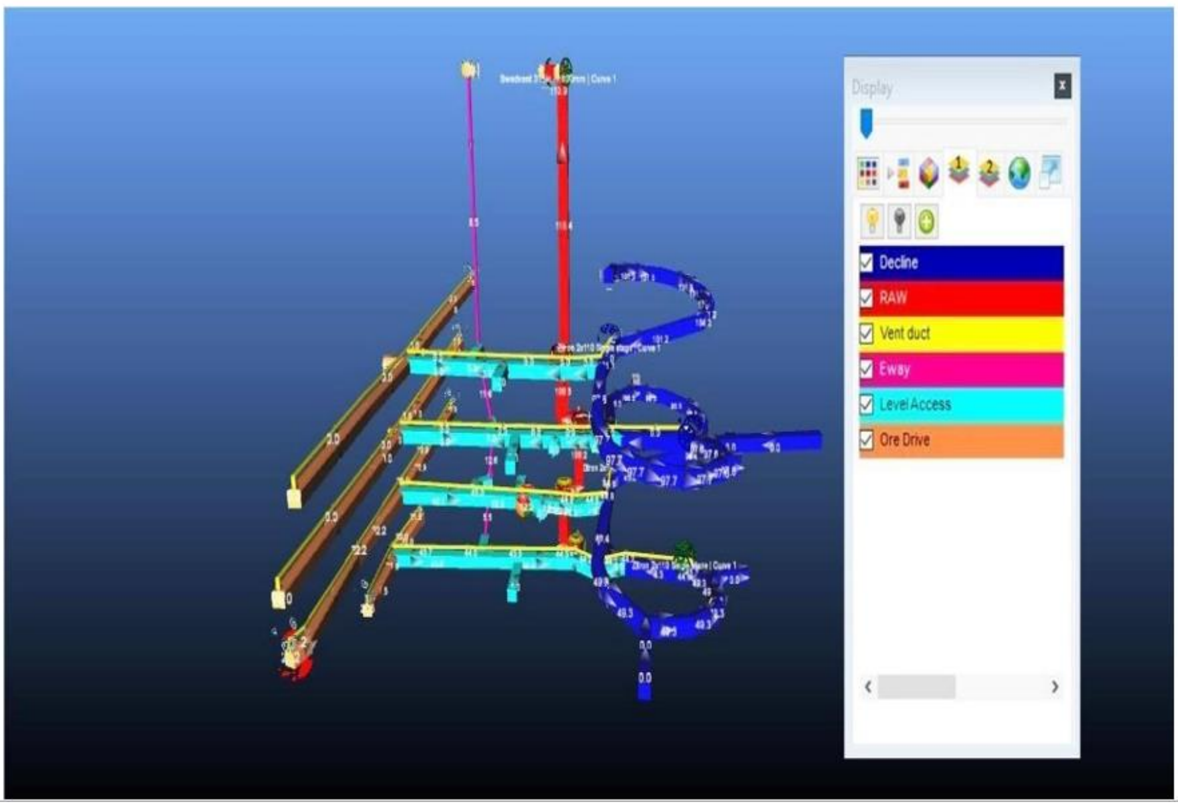

Figure 4: Ventilation Modelling of Underground Development at the Paboase Mine

2.5 Ventilation models

In this research, three different ventilation models were simulated to help in prediction of the re-entry time. They are: one ore drive with single heading blast, one ore drive with double heading blast and two ore drives with double heading blast each. Figure 5,6 and 7 show images of the three models.

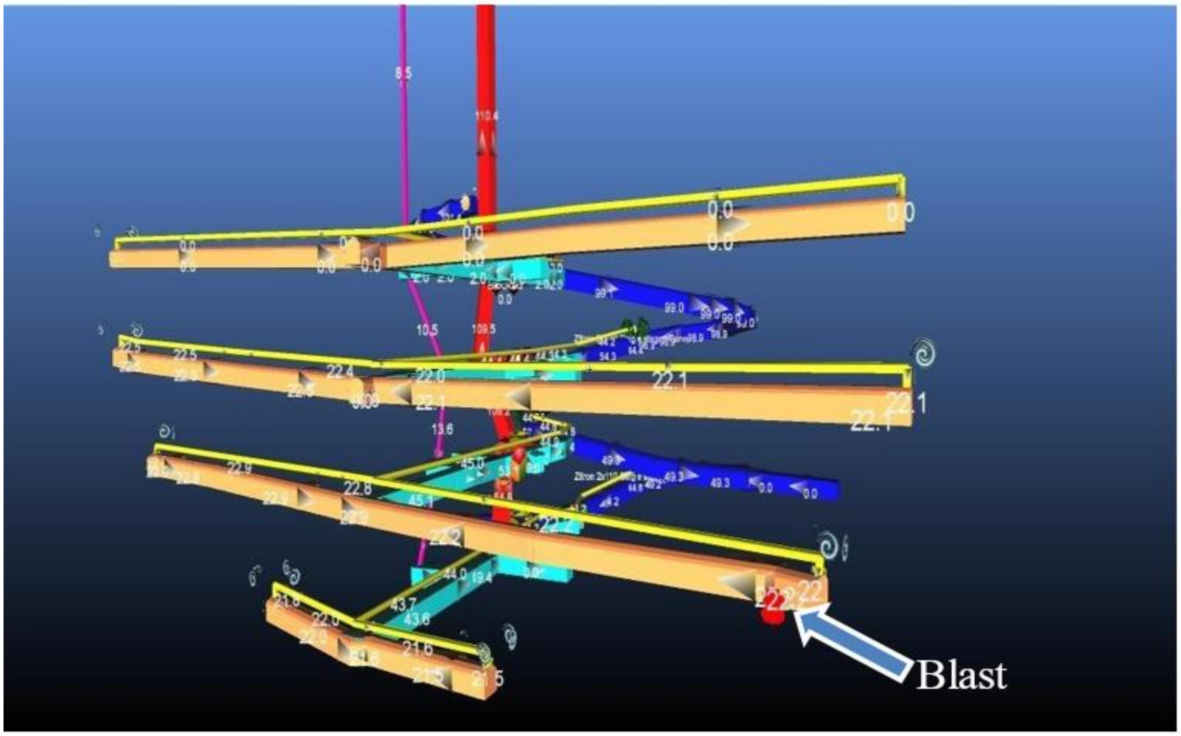

Figure. 5: One Ore Drive with Single Heading Blast

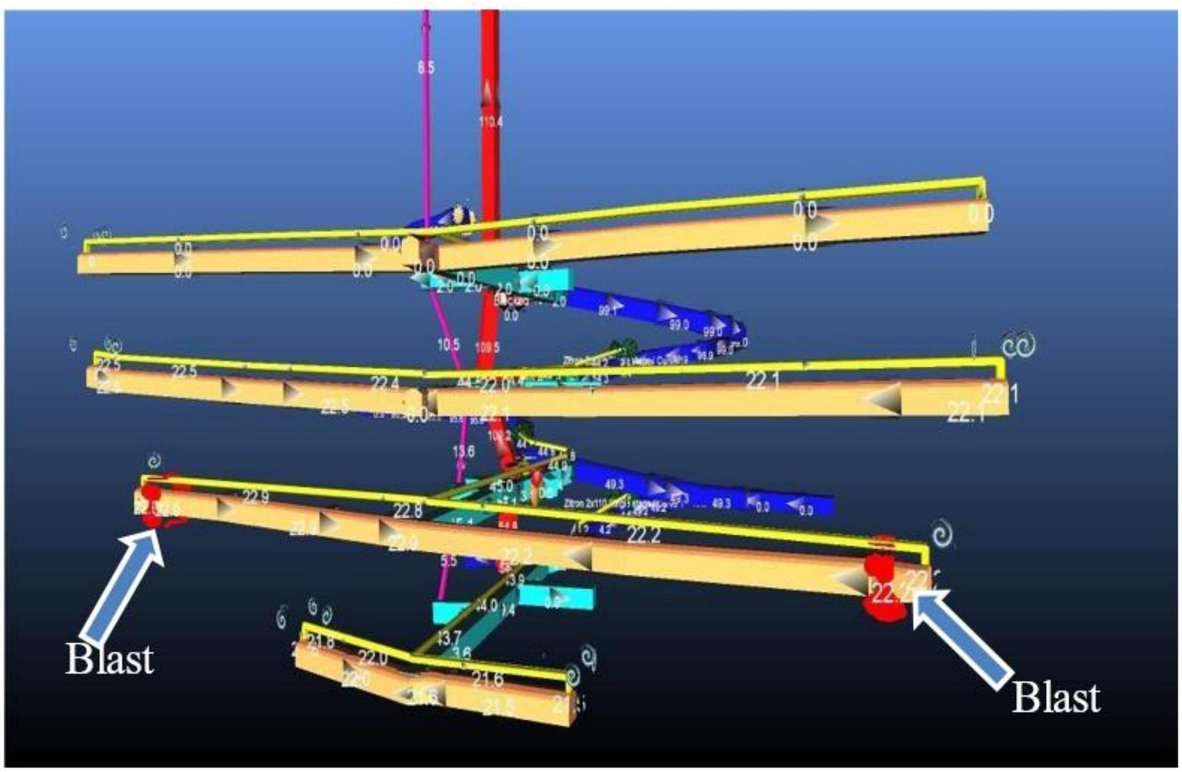

Figure 6: One Ore Drive with Double Heading Blast

These models are all with the inherited parameters of the underground conditions of Chirano Gold Mine Limited (CGML) to ensure that, the system is efficiently calibrated for accurate results. However, all the secondary fans are assumed to run on stage 1 and the ventilation ducts is assumed sufficient, well connected and not damaged, resulting in less air leaks.

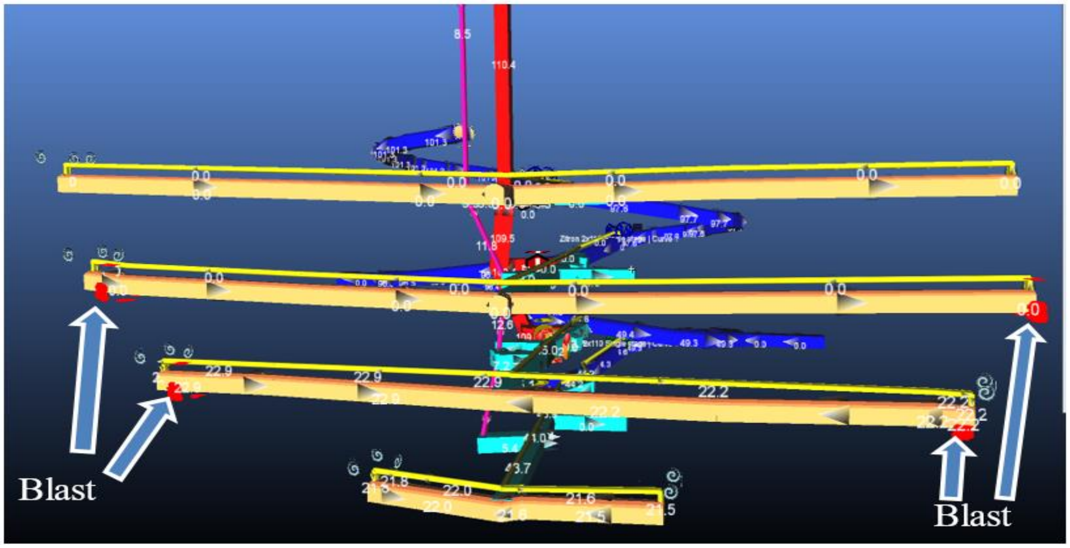

Figure 7: Two Ore Drives with Double Heading Blast Each

2.6 Ventilation Model Requirements

The requirements needed to accurately model the blast fume scenario are: an accurate mine plan design, known drive and raise dimensions, ventilation fan requirements (both primary and secondary), ventilation ducting size, explosive characteristics and total amount of explosives fired per heading.

2.7 VentSim Input Parameters

Within VentSim, a blast is simulated by placing a contaminant in the airways. These contaminants are placed at the end of drives, which in this work, the contaminants are placed at end of the ore drives instead of the decline. For most underground mines, CO is the most dangerous gas because of its ability to easily bind to the haemoglobin in the blood preventing the transportation of oxygen, which can lead to sudden death of a person. In view of this, re-entry time is governed by the concentration of CO in the working area even though other gases might be present.

The Occupational Exposure Limit (OEL) for CO is set at 30ppm, which is a level below which no adverse health issues will arise if a worker is exposed. Re-entry time is governed by a 30-ppm trigger because if the area is less than 30ppm CO, then it is impossible for an employee to be exposed to CO 30ppm for 8 hours which can affect the health of the worker. The contaminant model parameters required are contaminant unit which must be in ppm, contaminant density, yield factor (Yield ratio) and quantity of explosives used.

3. Results and Discussion

Table 1 shows the noxious gas composition at Chirano Gold Mine Limited (CGML).

Table 1 ANFO Explosive Noxious Gas Composition

Noxious Gas	Gas Yield (1/kg ANFO)	Concentration (ppm)	Gas Density (kg/m^3)
NO_2	1.8	1667	2.62
CO	16	14815	1.15

Figure 8 and Table 2 Show the drill pattern and its quantity of explosives used for ore drive development at CGML respectively.

Table 2 Development Profile for Ore Drive at Chirano Gold Mine Limited

Development Profiles (5.0mx4.8m)		Explosives		4.9m steel (Effective: 4.6m)		4.9m steel (Effective: 4.6m)	
	No. of holes	Detonator	Boosters	ANFO, kg	Emulsion, kg	ANFO, kg	Emulsion, kg
Reamer holes	6	-	-	-	-	-	-
Cut holes	9	9	9	46.26	54	38.97	45
Easer holes	24	24	24	123.36	144	103.92	120
Knee holes	6	6	6	30.84	36	25.98	30
Lifter holes	7	7	7	-	42	-	35
Perimeter holes	15	15	15	77.1	90	64.95	75
Total blast holes	61						
		61	61	278	366	234	305
		Charge density (t/m^3)		0.85	1.0	0.85	1.0
		Bags of ANFO (25kg)		12	0	10	0
		Splitex catridges (7 pc/lifter)		A49	0	49	0
		Unchanged collar (m)		0.8	0.8	0.8	0.8

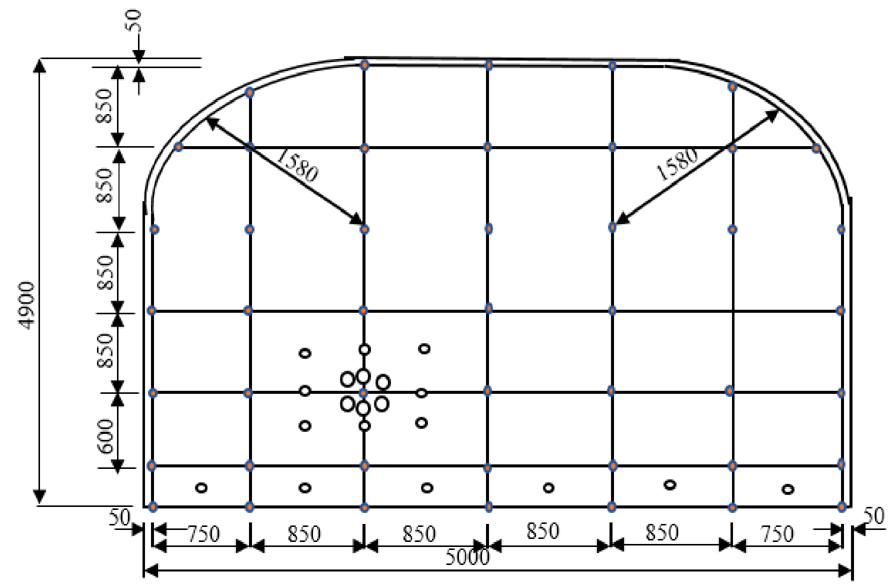

Figure 8: Drill Pattern Ore Drive at Chirano Gold Mine Limited

3.1 Yield Factor

The Yield factor or ratio is the kilograms of CO gas produced per kilogram of explosives used in the detonation process (CO kg/kg$_{exp}$). From Table 1, the gas (CO) yield is 16 kg and the total explosives in kg used for effective cut a development ore drive from Figure 8 is 278 kg. Hence the yield factor will be calculated as:

$$\frac{\text{CO produced from 1 kg of ANFO}}{\text{Total kg of ANFO used in detonation}} \quad (1)$$

$$\frac{16\ \text{kg}}{278\ \text{kg}} = 0.058 \quad (2)$$

3.2 Models Simulation and Results

The input parameters were fed to the software and the results from the three different ventilation models are as follows:

3.2.1 Scenario one

One ore drive at level 1625m with single heading blast. Figure 9 shows the explosive simulation executed in scenario one while graphical representation between the concentration of CO gas against time after the simulation.

Figure 9: Single Heading Blast Simulation

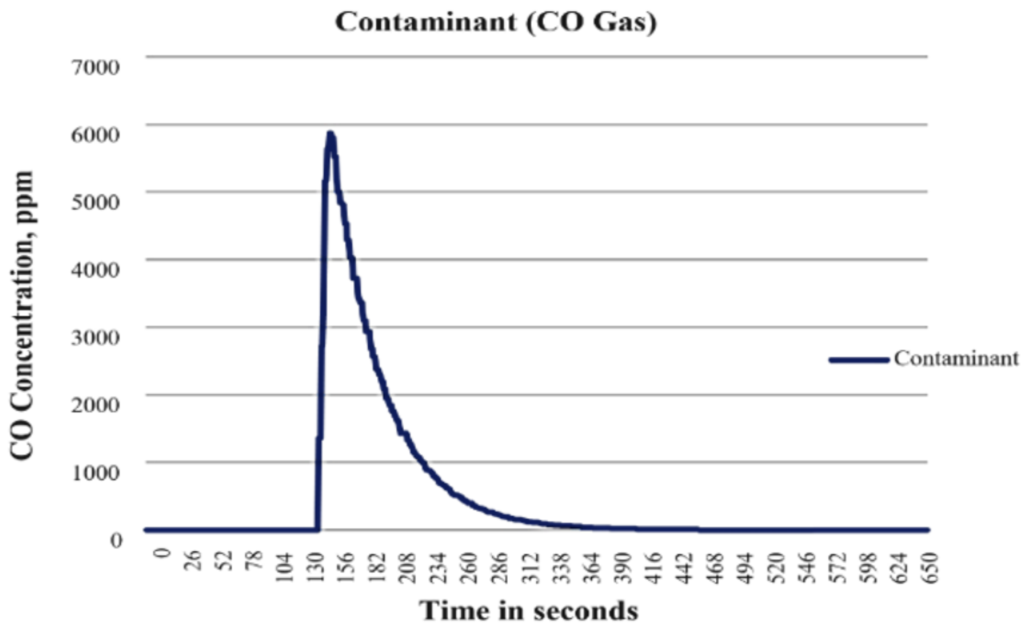

Figure 10: CO Concentration in ppm against time (seconds) (Scenario)

3.2.2 Scenario two

One ore drive at level 1625m with double heading blast. Figure 11 shows the explosive simulation executed in scenario two while Figure 12 shows the graphical representation between the concentrations of CO gas against time after the simulation.

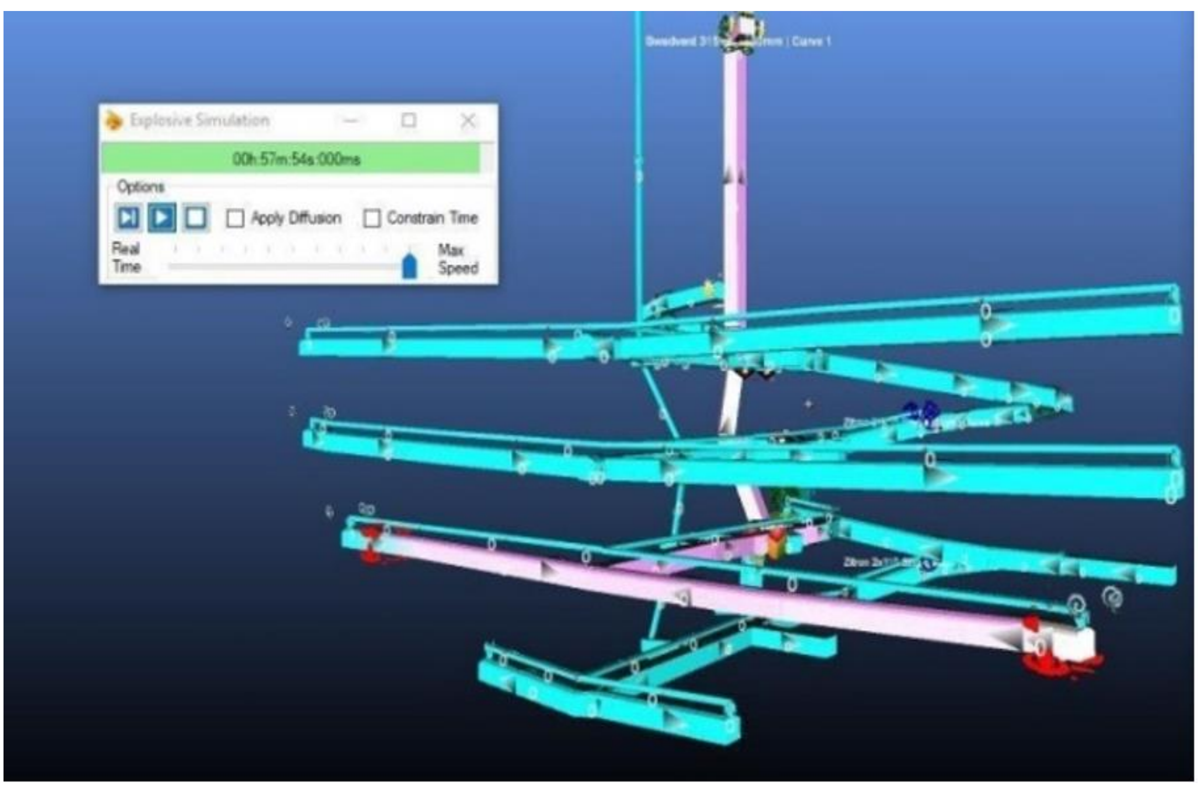

Figure 11: Double Heading Blast Simulation

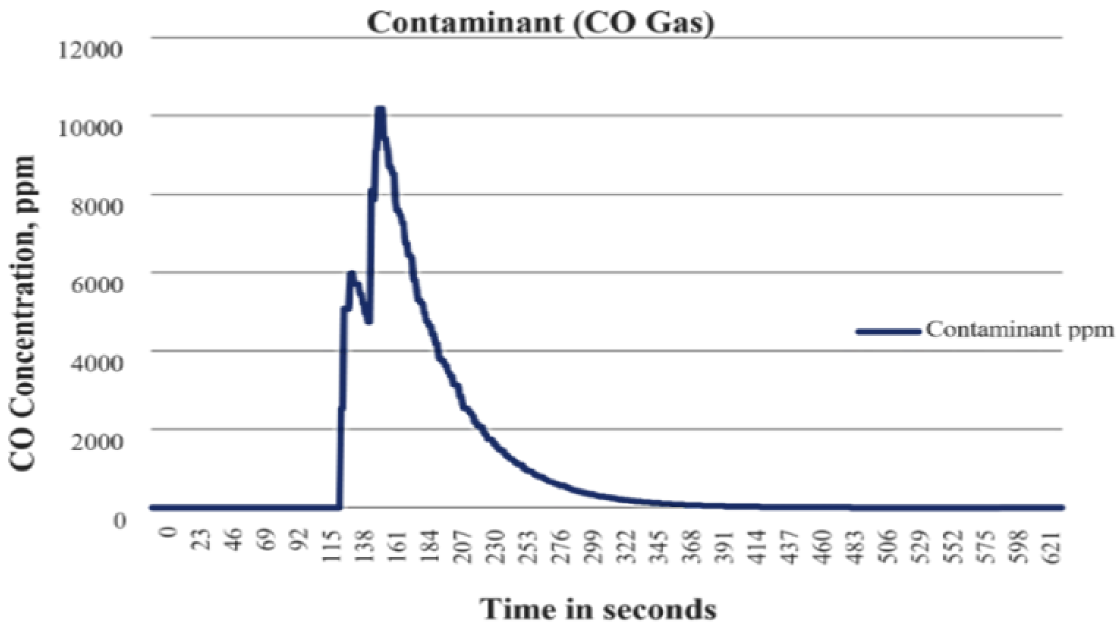

Figure 12: A Graph of CO concentration in ppm against Time in seconds (Scenario 2)

3.2.3 Scenario one

Two ore drives at level 1625m and 1650m with single heading blast Each. Figure 13 shows the explosive simulation executed in scenario three while Figure 14 shows the graphical representation between the concentration of CO gas against time after the simulation.

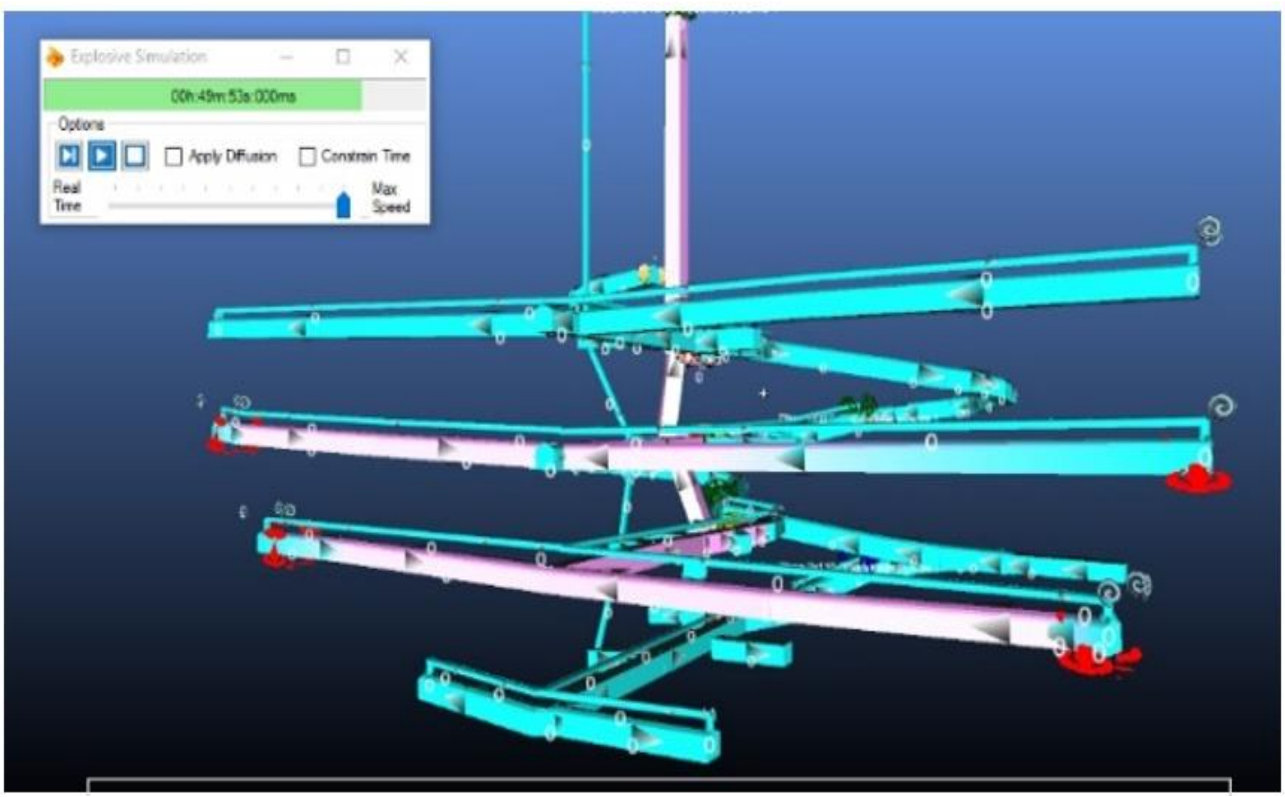

Figure 13: Ore Drives with Single Heading Blast Simulation

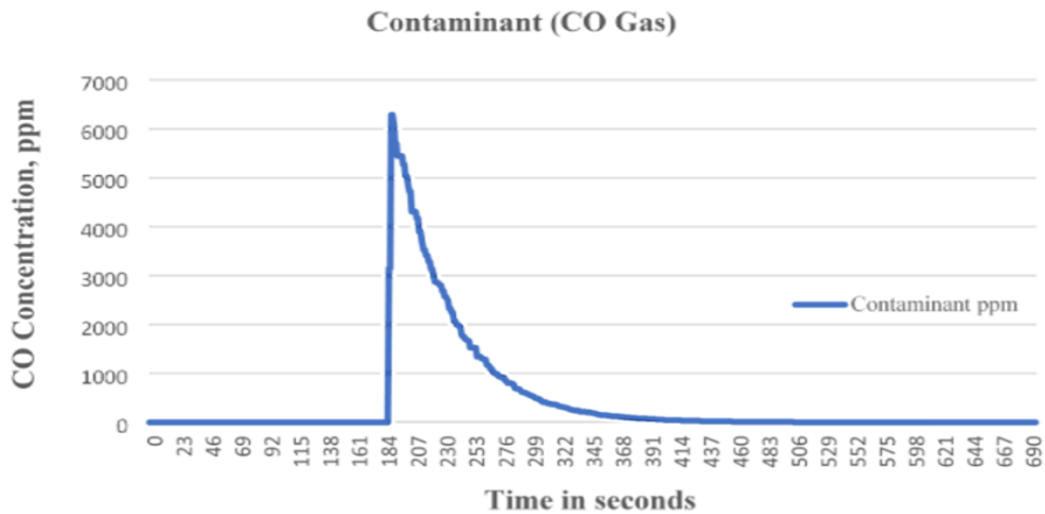

Figure 14: A Graph of CO concentration in ppm against Time in seconds (Scenario 3)

Table. 3 illustrates the table generated in excel from the simulation in scenario 1-3 showing the timeline as CO concentration decreases. Its emphasis is on when the CO gas reaches it 30 ppm and the corresponding time in second in the first column being converted into minutes in the third column.

Table 3 30 ppm of CO Gas (Scenarios 1-3)

30 ppm of CO Gas (Scenario 1)			30 ppm of CO Gas (Scenario 2)			30 ppm of CO Gas (Scenario 3)		
Time (seconds)	CO concentration (ppm)	Time (minutes)	Time (seconds)	CO concentration (ppm)	Time (minutes)	Time (seconds)	CO concentration (ppm)	Time (minutes)
390	34		411	33		505	33	
391	34		412	33		506	32	
392	33		413	33		507	32	
393	33		414	33		508	32	
394	31		415	30	6.92	509	31	
395	31		416	30		510	30	8.5
396	30	6.6				511	30	
397	30					512	30	
						513	30	

3.3 Results Analysis

For the purpose of safety and protection of the health of the miners working in blasted areas in the next shifts, re-entry time is governed by a factor of safety from the Minerals Commission to help protect the lives of miners in the long term. The safety factor is 5. Hence to obtain the re-entry time, five is multiplied by the time CO gas reaches 30ppm from the simulation. Hence the re-entry is tabulated with the safety factor in consideration in the Table 4.

Table 4 Re-entry Time from the three Scenarios

Scenario	*CO Concentration (ppm)*	*Re-entry Time From the VentSim (minutes)*	*Re-entry Time with Safety Factor (minutes)*
Scenario 1	*30*	*6.6*	*33.0*
Scenario 2	*30*	*6.9*	*34.5*
Scenario 3	*30*	*8.5*	*42.5*

4. Conclusion

Ventsim Design is a complete integrated mine and tunnel ventilation software package for the design and testing of ventilation circuits including airflow, pressure, heat, gases, power, fire and many other types of ventilation information. This paper revealed that VentSim Software can be successfully used in predicting the re-entry at the mine through monitoring of the CO concentration level after blast. The results from the simulation showed that the worst-case scenario was scenario 3, which shows that highest re-entry time of any development blast at Chirano Gold Mine (CGML) is approximately 43 minutes. The outcome also revealed that blastmen always underestimate the re-entry time. This could pose danger to the mine working entering the blast when the CO concentration is still higher than the acceptable threshold limit. It should be noted that this software is only used for estimation of entry time at Chirano Gold Mine (CGML), further research should be conducted to compare its applicability in other mines.

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