Evaluation of Air Sufficiency in Underground Mines: A Case of Tanzaniteone Mining Limited

Mtaita Charles Mtoni[1], Dr. Mgaza Somo Muya[2]

[1]Mbeya University of Science and Technology, Department of Civil Engineering, P.O Box 131, Mbeya, Tanzania

[2]Mbeya University of Science and Technology, Department of Built Environment Engineering, P.O Box 131, Mbeya, Tanzania

Abstract: ***Mining Operations in deep underground mine always demand for availability and viability of adequate air supply. Deeper mining and different automated operations intensify the difficulty in upholding the thermo comfort standard in operational areas as well as elimination of noxious gases from drilling and blasting. Design of effective ventilation system is essential in underground mines to ensure adequate air supply. The significance of effective and proficient mine ventilation system in underground mines, is to provide a flow of sufficient quantity of air to the operational areas. This is also done in order to dilute and eliminate airborne toxins and heat, thus providing fresh air that can be comfortably breathed by personnel. Study was conducted at Tanzaniteone Mining Limited (TML) by evaluating air sufficiency within targeted operational areas during working hours. The study reveals that, the thermo comfort standard decreases with the increase of noxious gases resulted from drilling and blasting activities, this is due to inadequate air supply in underground mines. Additionally the study shows that, mine ventilation system is a key factor for personnel's comfort zone in operational area. In order to provide adequate air supply and keep conducive environment for personnel in operational area, it is recommended to monitor ventilation system performance time to time and adjust it to the required level as proposed in this paper.***

Keywords: Air supply, Air sufficient, Ventilation system, Underground mine, Mining operation

1. Introduction

Tanzanite One Mining Limited (TML) found in Mererani area located in northern Tanzania at Simanjiro district in Manyara region about 40km southeast of Arusha town and 24 km southwest of the Kilimanjaro International Airport. The company is dealing with mining, processing (sorting) and selling of tanzanite in the world market. All mining operations at Tanzania One Mining Limited are conducted by underground mining methods.

The mererani tanzanite deposit is located within the Lelatema Mountains in NE Tanzania. The Lelatema Mountains forms a part of the Eastern granulite complex as described by Hepworth 1972, situated in the Mozambique orogenic belt of NE Tanzania. The Mozambique belt is host to a large variety of gemstones deposits. [1]

Underground mining has been noted to have more cost intensive compared to the surface mining operations. This is mainly influenced by the additional costs that underground mining operations incur for air supply in operational areas. [2] One of the additional costs that underground mines incur as compared to surface mine is that for ventilation. Nevertheless supplying of fresh air in underground operational areas, ventilation network system serves other two purposes which are; removing of noxious gaseous and particulate matter also upholding the air temperature of the mine at a comfortable level for personnel. Upholding of air temperature in deep mines has been the most difficult task to the extent that air conditioning is required.

Mine ventilation adopt fluid dynamic principles to the air flow within mine areas and is accountable for provision of flow of sufficient quantity of air to dilute and eliminate airborne toxins, heat, and provide clean air for breathing.

There are mainly two types of ventilation namely; Natural ventilation and mechanical ventilation. In natural ventilation, air flows because of regular variance in pressure within and without the mine. This regular pressure can only be supplied by an energy basis which can generate and sustain sufficient air distribution; it is thermal energy due to temperature change. The thermal energy is added to the air as the air passes through operational areas and mine openings. It is known that, warm air dislocates cold air within the mine due to the change in altitude and in temperature of the operational areas. Normally, the greater these temperature differences are, the larger regular ventilation pressure created and the higher resulting airflow.
It is not obvious to find only natural ventilation is used in mines. This is due to the fact that the pressure differential is normally not enough to produce an adequate and secured flow of air within the operational areas in mine. [3]

Mechanically, mine fans can be used to create the pressure differential by altering the air pressure at specified points in the mine. Whenever the pressure difference is higher, then the air flow becomes faster.

Air supply in underground mines is affected by contaminants which are in the form of aerosols (solid or liquid particulates) from blasting activities, dust and diesel engine exhaust fumes, gasses like carbon dioxide (CO2), Oxides of nitrogen (NOX) and sulfur (SOX). While the main sources of underground heat are auto compression, strata heat, and machinery and the additional sources are human metabolism, oxidation, blasting, rock movement, and pipelines. [4]

The foundation of effective ventilation network system in operational areas is the suitability of the main ventilation system that is the total air movement within the mines which is directed from the major operational areas in underground mines, usually it is done by division of either parallel or series circuit. Components which decide all out essential volume limit necessities incorporate the degree and deepness of the mine, the intricacy, stoping and extraction frameworks, together with the extent of the improvement openings and the gear utilized. The shorter and more straightforward the ventilation circuit through each working region, the better the arrangement of ventilation. [5]

The recommended quantity and quality of air are normally set by legal obligations in a given operational area basing on the safety policy. Satisfying ventilation requirements for equipment may not automatically guarantee the fulfillment of requirements for exposure levels for personnel. Hence, proper planning of the ventilation system is vital, especially if further development is to be undertaken. [2]

Airflow in underground mines is induced by either forcing the external clean air into the operational areas or exhausting used air from the mines. This is normally performed by a set of main fans, generally located on the surface at the entrance of a shaft or decline, or at the outlet point of an exhausting shaft or decline. A forcing system generates fresh air by increasing the total head of the mine air above atmospheric head at the intake so the airflow can overcome all losses it would encounter in the ventilation circuit. An exhausting system overcomes the same losses at the end of the ventilation circuit. [2]

Air supply in underground mines is affected by contaminants which are in the form of aerosols (solid or liquid particulates) from blasting activities, dust and diesel engine exhaust fumes, gasses like carbon dioxide (CO2), Oxides of nitrogen (NOX) and sulfur (SOX). While the main sources of underground heat are auto compression, strata heat, and machinery and the additional sources are human metabolism, oxidation, blasting, rock movement, and pipelines.

The source of operative ventilation arrangement in underground mines is the suitability of the essential ventilation framework that is the absolute move through the mine which is directed from the significant underground operations, typically including parallel or series circuits. Factors which determine total primary volume capacity requirements include the extent and depth of the mine, the complexity, stoping and extraction systems, together with the size of the development openings and the equipment used.

Evaluation of ventilation system is done by examining the existing ventilation system efficiency to see if it is sufficient at a given point and at particular time. The parameters that should be assessed are; area of a mine headings, the quantity of air flowing into the operational area faces and airways, air temperature both dry and wet bulb temperatures and the number of personnel in a particular operational area faces.
The cross sectional area of a heading is studied by considering the length and width of an open access. The mine heading should be ventilated to meet the air requirements depending on the type of operation that is performed. The suggested amount of air necessary to ventilate the narrow headings (stopes) and to overcome the leakages is at least $13.5m^3/s$ [6]

The quantity of airflow is calculated by multiplying the average air velocity by the cross section area of a tubing or curtain. The flow quantities may not be a good estimate for the quantity of air that reaches the operational area because there are leakages as the air is moving through the duct or heading. [7]

Air amount recognized in operational areas for satisfactory air supply is approximately $25m^3/s$ after taking into consideration the acceptable air leakage of 30% [8] and that required to be reserved out of the shaft is approximately $40m^3/s$. Also in order for the operational areas to be regarded thermally comfortable at least 80% of the personnel should feel comfortable [9]. When heat effect grows in mines, the suitable reaction is to maximize the fresh airflow to the operational areas in order to dilute the contaminant (heat). [10] Normally any rise of the rock temperature with deepness is regarded as the geothermal incline and standards vary from below 10ºC/km to above 60°C/km, at deepness above 15m. [11]

The equation for computing air flow quantity is as shown below;

$$\mathbf{Q = A \ X \ V}$$

Where Q is the air quantity, A is the cross sectional area of tubing or curtain and V is the average air velocity.

The quantity of air required is affected by the number of reasons such as surface temperature and humidity, underground rock strata temperatures and moisture contents, blasting and equipment emissions. The overall requirement is that in all operational areas, air stream must be provided in such amounts that will protect security and wellbeing, conform to supported prerequisites and that will also provide a reasonable comfort.

2. Methodology

In order to encounter the objective of this study, exhaustive evaluation was conducted to identify air sufficiency and improvement of air supply in underground mine at Tanzaniteone Mine Limited (TML).

Data were collected by means of observations and direct field measurements using the following equipment and materials; measuring tape, whirling hygrometer, pitot tube anemometer & manometer, vernier distometer, field note book, pen and scientific calculator.

2.1. Air Quantity Reaching the Operational Areas

In order to find the quantity of air reaching working places for eliminating noxious gases, upholding underground air temperature at comfortable level and sufficient supplying of fresh air in working places; direct field measurements were done at different working places and data were collected as shown in the table 1;

Table 1: The quantity of air reaching the operational areas at

TML

LOCATION	AIR FLOW VELOCITY (m/s)	AREA (m2)	Q (m^3/s)	NUMBER OF WORKERS	Q/person
Underground station	0.9	6.4	5.76	6	0.96
Face 77 (drive)	0.31	5.2	1.61	18	0.09
Face 78(winze)	0.22	4.73	1.14	20	0.06
Face 77(sub drive)	0.24	4.9	1.18	20	0.059
L80	0.18	4.5	0.81	22	0.04
Cutting point	0.43	5.0	2.2	15	0.15

2.2. Evaluation of air quantity entering and that leaving the main shaft

In order to obtain air quantity entering and leaving the main shaft, ventilation survey was conducted and measurements were taken in each level at TML. Data were collected and recorded as shown in the table 2;

Table 2: Ventilation survey conducted in the main shaft

LEVEL	WB (0C)	DB (0C)	AIRFLOW VELOCITY (m/s)	AREA (m^2)	QUANTITY (m^3/s)
Shaft down casting	19	23	3.6	5.5	**19.8**
Shaft down casting above L67	26	27.5	2.3	7.4	17.02
Shaft down casting below L67	26	27	2.4	7.5	18
L73 down casting	29	29.5	2.4	5.9	14.16
Up casting vent shaft	28	28	2.5	2.6	6.5
Up casting above sub shaft L67	29	29.5	2	8.3	16.6
Up casting below sub shaft L67	30	30	2.2	7.3	16.06
L95 Up casting	30	30	3.7	10.4	38.48
Vent shaft L7	26.5	27	2.4	4.1	**9.84**

2.3. Air Leakages and Shock Losses along the Ventilation System

Air leakage and shock losses along the ventilation system were identified through observation. This is extreme problem when there are many mine heading interconnections or worn out ventilation ducts. Since air always travels through short paths, many interconnections in the ventilation network can lead to air short circuiting to the desired ventilation route through the leakages paths.

Air flow rate through the leakage paths is normally controlled by installing an auxiliary exhausting fan which can pull air to the desired air direction. It can also be controlled by sealing the stoppings and closing the ventilation doors. Ventilation ducts should also be repaired to avoid air leakages.

Shock losses occur in mine ventilation when the air changes its direction of flow or changing in the area of the duct or airway. This can happen when air travels through a bend, junction or an obstruction. Figures 1; shows how air undergoes leakage and shock losses along the ventilation duct.

Figure 1: Air leakages and shock losses as observed at TML.

2.4. Pressure drop and Airflow Velocity

The velocity of airflow was measured by using a pitot - cylinder anemometer and manometer by placing the tube in such a way that the flow of fluid is pointed directly. This cylinder contained fluid, a compression can be estimated when the moving fluid is conveyed to rest (stagnates) as there is no outlet to enable stream to proceed with this compression is the stagnation pressure of the fluid, otherwise called the all-out compression or the pitot pressure.

The deliberate stagnation compression can't itself be utilized to decide the fluid stream speed, thus the device used Bernoulli's equation to determine air flow velocity from dynamic pressure and thereafter it was shown by the device through the screen. Since the air velocity was changing continuously the most recurring velocity was recorded.

3. Analysis and Discussion

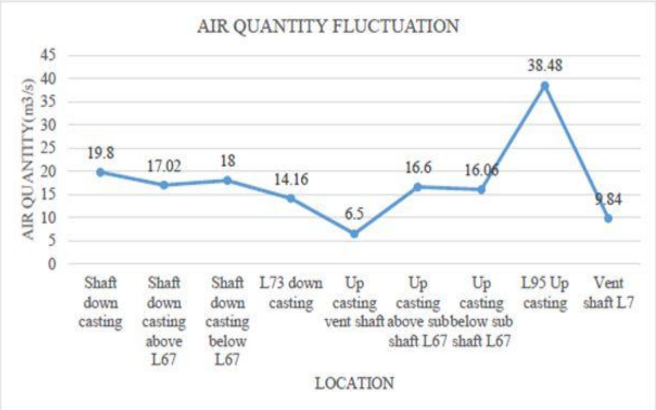
3.1 Analysis and Discussion on Air Quantity Reaching the Operational Areas

According to WHO, the quantity of air required per person is $0.1m^3/s$. Therefore from table 1 Face 77 (drive), Face 78(winze), Face 77(sub drive) and L80 received seemed to have less air quantity than the requirements per person. The air quantity that will meet air requirements for only workers in underground working areas (113 workers per shift) is 11.3m3/s.

Graph 1: Showing the assessment between the available air quantity per person and the recommended air requirement per person according to WHO in mine working areas.

3.2 Analysis and Discussion on air quantity entering and that leaving the main shaft

After calculations it shows that, down casting (intake fresh air) at shaft down casting is 19.8 m3/s and up casting (return spoiled air) at vent shaft L7 is 9.84m3/s. Air down casting is done through the shaft itself then Intake 18Kw fan at the shaft bottom ventilate the bottom of the mine. The intake fan is boosted with 15Kw at L77 sub drive to ventilate the bottom level supported with 11Kw at L78 and 4Kw fan at L80N. The return air is pulled out with 11Kw fan at L77 drive directed to the vent shaft via ore pass to the 22Kw exhaust fan on surface.



Graph 2: Air quantity fluctuation along the shaft

From the analysis, there is a variance of 9.96m3/s between the air quantity entering the shaft and that leaving through the vent shaft. This indicates that there is higher recycling of return air within the shaft due to existence of air leakages and disappearing of air to the open nearby excavations. This is also caused by the existence of exhaust fan (out take) 22Kw on the surface which is not sufficient for up casting the return air (dirty air) from underground. From table 2, it can be observed that there is a need of an exhaust fan capable of up casting approximately 40m3/s of return air.

3.3. Analysis and Discussion on Air Leakages and Shock Losses along the Ventilation System

The analysis has shown that, existence of leakages contribute highly to the tendency of inadequate air supply for removing of noxious gaseous and particulate matters, and maintaining the air temperature of the mine at a comfortable level for the personnel and therefore rechecking and fixing leakages to improve mine ventilation system is required to be done time to time.

From the data collected, air quantity needed in operational areas for adequate air supply is about 25m3/s after taking into consideration the acceptable air leakage of 30% and that needed to be taken out of the shaft is about 40m3/s.

3.4. Analysis and Discussion on Pressure drop and Airflow Velocity

The pressure loss in airways is caused by obstruction the frictional losses and shock losses.

Pressure loss of each branch of ventilation networks is calculated by:

$$\Delta P = RQ^2$$

Where ΔP=Static pressure drop or loss (Pa)
R is airway resistance and Q is air quantity passing through airway
Also Q= AxV
A= $4m^2$
Airflow velocity recommended for the working faces (V) =4m/s
Q= 4x4=$16m^3/s$
Static pressure drops of the intake airway;
$\Delta P=2.34*16^2=599.04$Pa
Static pressure drops of the return airway;
$\Delta P=3.792*16^2=970.75$Pa

In order to calculate the total pressure loss, it is essential to calculate the dynamic pressure loss in the main entrance and exit airway (ventilation shaft). Because of forcing system of air distribution in such a way that total input air enters the system by the main entrance and exits the system through the vent shaft.

Dynamic pressure loss is given by;

$$\Delta Pv = \gamma \frac{v^2}{2g}$$

Where, γ=*Air unit weight*
V= air velocity
g=gravitational force (m/s^2)
Dynamic pressure drops of the intake airway;
$\Delta Pv=1.2*4^2/2*9.8=0.98$Pa

Dynamic pressure drops of the return airway;
$\Delta Pv=1.2*4^2/2*9.8=0.98$Pa

Thus, the total pressure drop for both intake and return airways is given by;
$\Delta Pt=\Delta P+\Delta Pv$
Total pressure drop for intake airway;
ΔPt=599.04Pa+0.98Pa= 600.02Pa

Total pressure drop for return airway;
ΔPt=970.75Pa+0.98Pa= 971.73Pa
From the analysis, both main intake fan and main return fans are not sufficient for ensuring adequate air supply in underground working areas as well as up casting of return air to the surface.

In general, the main intake fan to be selected must be capable of delivering 25m3/s at a minimum pressure of 600.02Pa and also the main return fan must be capable of delivering 40m3/s at minimum pressure of 971.73Pa.

Based on the operating point of mine, the required power of the fan can be calculated as follows

$$N = \frac{nQr\Delta Pt}{Qr\Delta Pt\eta 1\eta 2 * 1000}$$

Where Q_r, is total air quantity required (m^3 /s). Δ is total head loss (Pa), $\eta 1$ fan efficiency, $\eta 2$: electromotor efficiency and N required fan power.

According to ASHRAE, 2004 in order to meet the ventilation requirements in underground mines; the fan efficiency must be at least 65% and electromotor efficiency must be at least 70%.

Hence the fans required powers are;

a) Intake main fan;

$$N = \frac{25 * 600.02}{0.65 * 0.70 * 1000} = 33Kw$$

b) Return main fan;

$$N = \frac{40 * 971.73}{0.65 * 0.70 * 1000} = 85Kw$$

Also, since the current ventilation system for air up casting has only one supporting fan of 11Kw at L77 drive, it is advised to install one supporting fan above the cutting point where there is interconnection of a number of mine headings so that it can help to direct the air towards the surface.

4. Conclusion

In this paper, evaluation of air sufficiency in underground mines was conducted and observed that ventilation system at TML plays a key role for ensuring adequate air supply in working areas. Also it was observed that, ventilation system consists of poor infrastructure such as worn out ventilation ducts (too much air leakage as air travel to the operational areas). In addition, insufficient infrastructure was observed such as fans in which the existing intake main fan’s energy operates approximately below half of the required whereas exhaust return main fan’s energy operates approximately below quarter of the required. This contributed to poor air supply, elimination of noxious gases and regulation of heat in underground mines.

In order to meet the air supply requirements, it is recommended to introduce additional support fan, or new ventilation system that can suffice the requirement of underground mines.

References

[1] The geology of the Neoproterozoic “eastern granulites” Muhongo et al., 1994.
[2] Wiley, S. C. (2015). Optimization of the quantity of heated/refrigerated air required for ventilating underground mines with ventilation- on -request systems. Montana tech library of the University of Montana.
[3] Northern mine rescue association, (2005). Mine ventilation.
[4] Hartman, H. L. (1997). Mine ventilation and conditioning 3rd Edition. Hoboken: John Wiley & sons, Inc.
[5] Mcpherson, M. (1988). An analysis of the resistance and airflow characteristics of mine shaft. Brisbane, Australia: 4th international mine ventilation congress.
[6] G.Arpa, K. Y. (2008). Narrow Vein Shrinkage Stoping Ventilation Measurement Using Tracer gas and Numerical Simulation. Fukuoka, Japan: Kyushu University.
[7] Thimons, E. (1999). Evaluating the Ventilation of 40-Foot two Extended Cut. NOISH Report of Investigation. 37 \
[8] MOSHAB. (1997). Underground ventilation. Western Australia: Department of industry and resources.
[9] FANGER, P. 0. (1973). Assessment of man's thermal comfort in practice. British Journal of Industrial Medicine,, 313-324.
[10] Brake, D. J. (2001). The application of refrigeration in mechanized mines. The AusIMM Proceedings, Vol 306, pg 9.
[11] Hall, C. J. (1981). Mine Ventilation Engineering. New York: Society of Mining Engineers of the American institute of mining, metallurgical and petroleum engineer, Inc.