

Narrow vein shrinkage stope ventilation measurement using tracer gas and numerical simulation

G. Arpa, K. Sasaki & Y. Sugai
Kyushu University, Fukuoka, Japan.

ABSTRACT: Ventilation survey using tracer gas measurement is one of the techniques for mine ventilation design, monitoring and investigation of movement of fresh air and contaminants. However, there has been little research into using both tracer gas monitoring and numerical simulation. In this research, tracer gas technique was used for quantitative assessment of airflows through narrow vein shrinkage stopes with various opening shapes and friction factors. SF₆ was used as a tracer gas to monitor airflow through three narrow vein shrinkage stopes in order to obtain diffusion concentration curves against elapsed time. The mine ventilation simulator, MIVENA Ver.6, was used to construct the entire ventilation network of the mine to monitor airflows through the stopes. The diffusion concentration curves against elapsed time were simulated with a numerical model. The result shows that the concentration-time curve is unsymmetrical and is skewed to the front of the flow direction. From the results of history-matching between the measured and the simulated curves, volume flow rates of airways and stopes were evaluated. Importantly, the tailing effect of the concentration-time curve between the measured and simulated is greatly improved by reconstructing an equivalent airflow route to represent unused mine openings, dead end drives and other open spaces. Finally, it can be concluded that openings, dead end drives and other open spaces have no relation on flow rates, but affect the airflow quality provided from the inlet portal as shown by tracer gas diffusion characteristics.

1 Introduction

The use of tracer gas in mine ventilation has been primarily to investigate ventilation network for possible short circuits, leakage, recirculation and survey for airflow rates. There has been very little research on the use of tracer gas to study airflow behavior in mine airway routes. The objective of this research is to conduct tracer gas measurement in a narrow vein shrinkage stope to study the behavior of airflow through airways and stope. The measurements were conducted at the Kainantu Gold mine (in Papua New Guinea).

The main focus in this paper is to obtain a best matching between the measured and the simulated concentration-time curve and to discuss the deficiency with reference to airflow through the airway routes.

2 The Kainantu Mine

2.1 Location and Mining Operation

The Kainantu underground gold mine is located about 230 kilometers North-West of the main city of Lae, Papua New Guinea and is accessible by road to the plant site and then by helicopter flight to the mine site. The Kainantu mine has a narrow vein deposit with extended strike length of more than one kilometer with an undefined depth. The mineralization is hoisted in a mountainous area with sharp fall in elevation at the bottom. Due to the style of deposit, narrow vein shrinkage stope mining method has been used to mine the deposit.

The mine is accessed by two adits, one at 1300 RL and

the second at 800 RL (see Figures 3). The main levels are driven parallel to the deposit at 30 meters interval. As shown in Figure 2, the stopes are 30m by 30m and approximately 1.3m wide. Mining progresses upwards and the ore is handled through a series of ore passes to the lower level 800 portal, and is subsequently hauled to the processing plant (see Figure 3).



Figure 2. Narrow vein shrinkage stope

2.2 Ventilation System.

Kainantu mine uses ascension ventilation system where fresh air is drawn to the lower levels at the 1300 portal inlet and the 800 portal inlet and ascends through the drives, raises, ore passes and stopes. The used air exits

through the 4th outlet at the upper level (see Figure 3). The main operating stopes are ventilated using the through-flow system. Fresh air is moved through the mine by three axial fans all installed in parallel at the 4th outlet.

2.3 Stope Ventilation

All stopes are ventilated by the fresh air flowing up from the lower level. There are two raises constructed at each end of the stope, about 30m apart (stope width). Air enters the raises at the bottom level and flows up the raise and then enters the stope and exits through the other raise, depending on the pressure difference. When stopes are mined out, the raises are closed, thus the movement of airflow was affected. Similarly, when new raises are constructed for stoping, airflow is also affected. Therefore, there is a need to continuously monitor the movement of air especially in the stope where miners are working. This study is conducted to assess the movement of air in the stope.

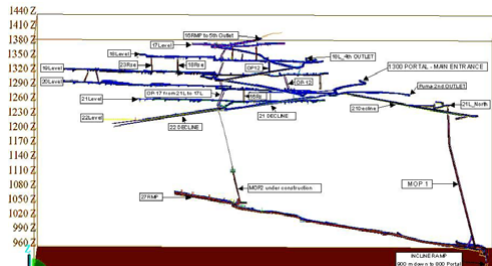


Figure 3 Schematic section of the mine

3 Ventilation Simulation and Measurement

In order to study the ventilation system of the narrow vein underground shrinkage stope, both MIVENA and the tracer gas measurement and simulation were used for the Kainantu Gold Mine. The mine ventilation network simulator, MIVENA Ver. 6 (Sasaki et., 2002) was used to construct the ventilation network of the Kainantu Gold mine. All airway characteristics, major fans and the main inlets and outlet were constructed and simulated for the various operating conditions. Ventilation survey was also conducted.

Secondly, tracer gas, sulfur hexafluoride (SF₆) was used to measure airflow through the working stopes. SF₆ was released at the lower level by pulse injection, and the SF₆ concentration was measured at the upper level raise. The one-dimensional equation for transient turbulent diffusion given by Taylor (1954) for single straight pipes and modified by Sasaki & Dindiwe (2002), equation (1) for multiple flow branches for a mine airway network was used to obtain the best numerical result, matching with the field measurement results.

$$C_i(t) = \int_0^t \frac{C_{i-1}(\tau) Q_i}{2A\{\pi E_x(t-\tau)\}^{1/2}} \exp\left[-\frac{\{X-v(t-\tau)\}^2}{4E_x(t-\tau)}\right] d\tau \quad (1)$$

where:

- C_i = gas concentration at a downstream node
- C_{i-1} = gas concentration at an upstream node
- t = elapsed time from gas injection (s)
- Q_i = air flow rate on an airway (m³/s)
- τ = travel time between two nodes (s)
- A = cross sectional area of an airway (m²)
- E_x = effective turbulent diffusion coefficient in flow direction (m²/s)
- X = distance between two nodes (m)
- v = average gas convection velocity in an airway (m/s)

Finally, the results obtained by MIVENA and tracer gas method were compared to the ventilation survey. In this paper, attention is given to the difference in the tailing effect between measured and simulated concentration-time curve in order to understand the general flow parameters affecting the airflow through the stope, by comparing the measured and the simulated results.

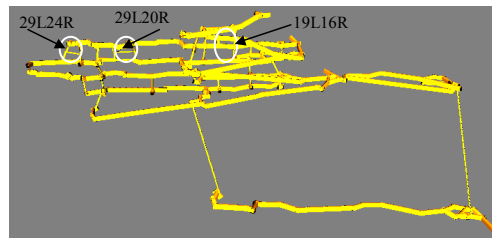


Figure 4 Ventilation network of the mine. (MIVENA)

4 Ventilation Network Analysis

The ventilation network model of the mine was constructed and simulated using MIVENA (see Figure 4). The mine layout and network was constructed by specifying the airway routes ($i-j$) and their parameters. Nodal information was then inputted, followed by main intakes, main fan and auxiliary fans. The network information was then processed using the analysis function to obtain the nodal and airways information and results. In order to simulate for different operating scenario to represent the mining stages, airways and nodal information was updated and simulated to obtain the flow conditions.

5 Tracer Gas Measurements and Simulation

5.1 Measurement

In order to assess airflow through the stopes, sulfur hexafluoride (SF₆) was used as a tracer gas for the measurement. A total of three operating stopes were measured (Stopes; 20L24R, 20L20R, and 19L16R).

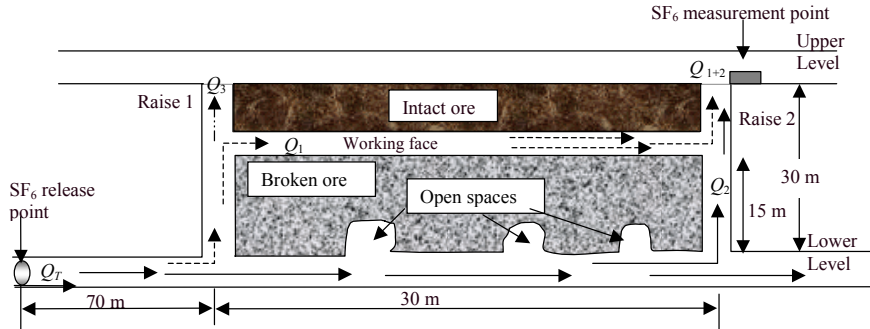


Figure 5 General layout of stopes, 20L24R, 20L20R and 19L16R

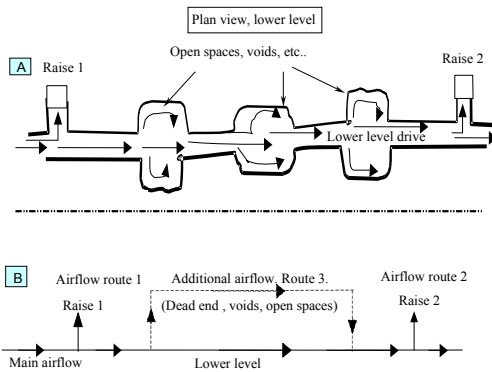


Figure 6. Schematic of airflow routes. A) Plan of lower level. B) Construction of additional airway branch.

SF₆ was released into the airways from balloons of known mass. Mass of SF₆ was obtained by the difference of the mass of balloon and mass of SF₆ plus balloon. The released volume of SF₆ was then calculated from the difference. The tracer gas was released as pulsed injection by breaking SF₆ balloons at the bottom levels about 30 m down stream from the first raise for stope 20L20R, 80m down stream for stope 20L24R and 20m down stream for stope 19L16R. The layout of all the three stopes, are similar to the arrangement as shown in Figure 5.

In these three tests, stope 20L24R has both raises open. Therefore air flows through the main level, some air enters the first raise and then branches at the stope entrance. Air entering the stope (Q_1) ventilates the stope and exits through the 2nd raise, while some air exits through the 1st raise (Q_3) at the upper level. The air traveling in the main lower level (Q_1) splits again at the second raise (Q_2) and rejoins with the air coming through the stope (Q_1) and exits at the upper level (Q_{1+2}). The stopes 20L20R and 19L16R have 2 raises however, the 1st raise has no break through. Therefore all air entering the 1st raise (Q_1) travels through the stope (Q_1) and exits at the 2nd raise (Q_{1+2}) mixing with the air entering the 2nd raise from the main lower level (Q_2) and exits through the second raise (See Figure 5).

SF₆ concentration at down stream, (upper level raise 2) was measured by the tracer gas monitor (Bruel & Kjaer Model 1302 photo-acoustic gas monitor). The monitor has a resolution of 10 ppb, an absolute accuracy of +/-50 ppb and a sampling rate of 40 seconds. Before the measurement, all airflow in the raises and the main drives, cross sectional area and the length were measured.

5.2 Numerical Simulation and Matching

The analyses of concentration-time curve have been done by the numerical simulation model using equation (1) and best matching between simulation and measurement curves were obtained (Figures 7, 8 & 9). The numerical simulation was done for each airflow routes for each stope. The input data, average airflow velocity, u , and the effective diffusion coefficient, E , have been simulated appropriately to match with the measurement curve. In order to simulate for the delayed arrival of air in the dead end and open space, an additional airflow route was constructed for both stopes. Figure 6 shows the schematic arrangement for airflow through the lower level for the three stopes measured.

6 Results and Discussions

The measured concentration-time curve and the best simulated history matching curves were obtained for each stope and their airway routes, as shown in Figures 7, 8, and 9. The Traveling time and shape of the gas concentration time-curve provide very good information on airflow routes, quantity and flow behavior. Stope 20L24R has both raises open, therefore when SF₆ is released, air travels through three different routes. Air traveling through the stope and the second raise can be confirmed by the SF₆ measurement as well as the simulated curve. Stope 20L20R has two raises but only raise one is opened. Therefore when SF₆ is released it travels through two routes. The air traveling into the first raise enters the stope and exits through the second raise in about three minutes and the air entering the second raise arrives after about six minutes later (Figure 7).

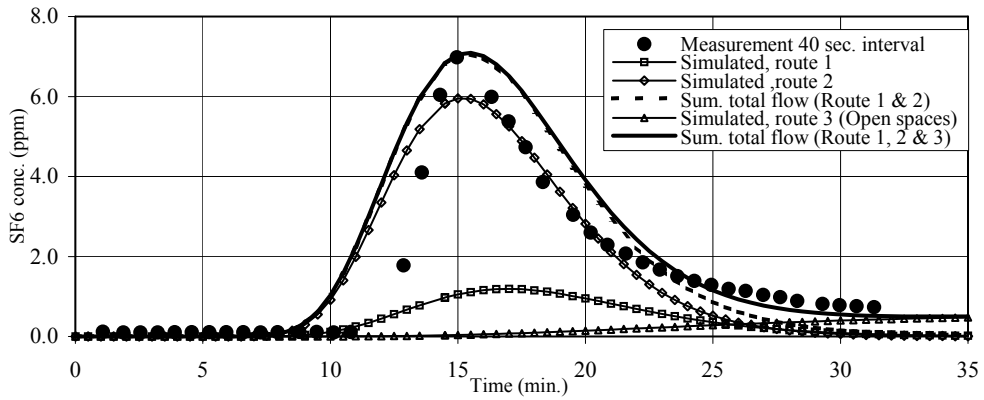


Figure 7 Concentration-time curve for slope 20L24R

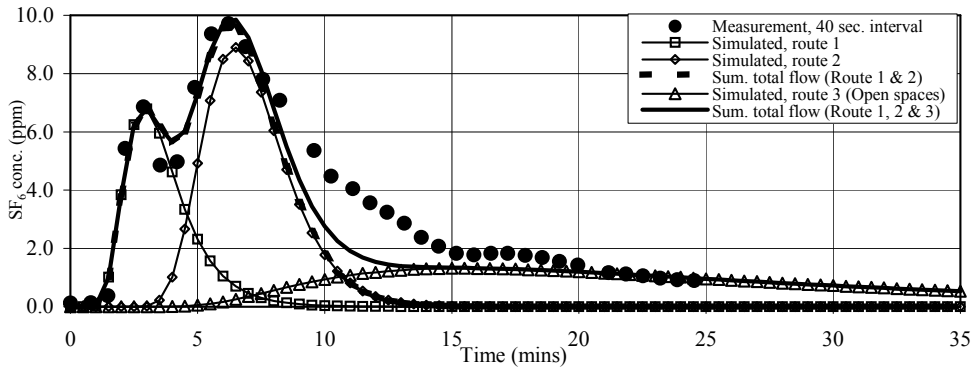


Figure 8 Concentration-time curve for slope 20L20R

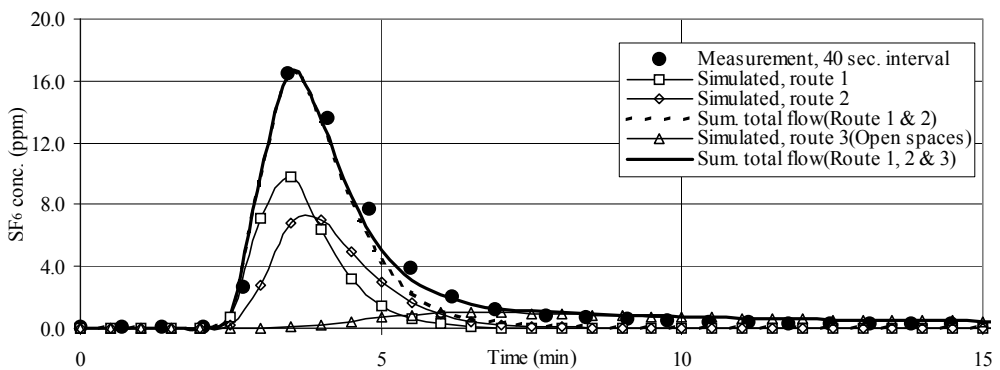


Figure 9 Concentration-time curve for slope 19L16R

This is due to the different cross sectional area of the main drive and the raises. Stope 19L16R has the similar arrangement as stope 20L20R, however arrival times for the two routes are separated by less than one minute (see Figure 9).

The results of the measured and simulated curves for the three stopes show a very clear mismatch towards the tail end of the curves. We called this the tailing effect. The total simulated (sum of route 1 & 2) is less than the measured curve. This is due to the delayed arrival of SF₆ due to recirculation in the open spaces, dead end drives and voids along the airway routes.

In order to model the dead end drives and the empty spaces in stopes, 20L20R, 20L24R, and 19L16R, we reconstructed an additional airflow route to run parallel to the main lower level drive with increased cross-sectional area and extended airway length and assign as route 3 (see Figure 6). Route 1 is the flow through raise 1 and through the stope. Route 2 is the flow through raise 2 and connects with the air flowing through the stope. Route 3 is the additional route constructed to represent the dead ends and the open spaces along the airways. After simulating route 3, the three routes were summed up to obtain the total airflow.

The three airflow routes were then simulated to improve the tailing effect. The results show an improvement of the tailing effect and the total simulated curve is almost similar to the measured curve (see Figures 7, 8 and 9). Therefore, openings, dead end drives and other open spaces along the airway route have no relation on flow rates, but they affect the airflow quality relative to traveling time.

7 Conclusion

The assessment of airflow through the mine, and the ventilation of the three selected shrinkage stopes have been established by the tracer gas measurement and numerical simulations, ventilation survey and MIVENA. Particularly, the airflow rates of the stopes were evaluated with matching the measured concentration-time curves with numerical ones by a numerical diffusion model in considering diffusion in open and empty spaces.

Furthermore, it can be confirmed that the skewing of the concentration-time curve to the front is due to short airway length. Most importantly, improvements of the simulations have been made against the tailing effect shown in tracer gas measurements by reconstructing an equivalent branch to represent the delayed arrival of air due to the open spaces along the airways. The additional branch in the numerical model has a much longer length and an increased cross-sectional area with low air flow velocity. Therefore it can be concluded that openings, dead end drives and other open spaces have no relation on flow rates, but affect the airflow quality by longer traveling time and including mine pollutants existing in the spaces.

Acknowledgement

Acknowledgement is extended to Highlands Pacific Ltd for their permission and kind support and hospitality to conduct the field measurement for this research. Financial support from the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) is highly acknowledged.

Reference

- Sasaki, K., Dindiwe, C., 2002. An integrated mine ventilation simulator "MIVENA Ver. 6" with application Proceedings of the 9th US /North American Mine Ventilation Symposium, 2002. pp 243-251
- Taylor, G.I, 1954. The dispersion of matter in turbulent flow through a pipe, *Proceedings of Royal Society*, pp.446-468
- Widodo, N.P., Sasaki, K., Gautama, R.S. and Risono, 2007. Mine ventilation measurements with tracer gas method and evaluations of turbulent diffusion coefficient, *Int. J. of Mining, Reclamation and Environment*, Taylor and Francis, iFirst article, pp. 1-10.

