Mining Science and Technology, 5 (1987) 187–196
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

A REAL-TIME TRACER GAS ANALYZER — AN INVESTIGATIONAL TOOL FOR MINE VENTILATION STUDIES

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(Received September 25, 1986; accepted December 15, 1986)

ABSTRACT

The usefulness of sulphur hexafluoride as a tracer gas in mining would be greatly improved if it could be measured in situ on a real-time basis. This paper describes the field trials of a prototype instrument designed to fulfill that role. The trials also investigated the validity of theoretical relationships regarding stope residence times in an uranium mine, providing data for further radiation control studies.

Details of two tracer gas techniques used and an assessment of the rapid sequential analyzer's performance are given. Derived results include: air quantity flows, average residence times, single air exchange times and the airpath volume. Where appropriate, these are compared with values obtained using standard anemometry instrumentation.

1. INTRODUCTION

Tracer gas is finding an increasing number of applications in solving ventilation problems of Canadian mines. As described herein, the technique was used in a study to determine stope residence times in an uranium mine; in this case, these times are important to relate radon gas and daughter concentrations.

The Cape Breton Coal Research Laboratory (CBCRL) has used tracer gases extensively to solve mine ventilation and related problems. Historically, sulphur hexafluoride (SF_6) and nitrous oxide (N_2O) have been used as tracer gases in coal mines. CBCRL has also used propane (C_3H_8) as a tracer gas during surface trials to evaluate the ventilation system of a full face tunnel boring machine (TBM) [1].

To date, SF_6 has proven to be the best universal tracer in underground ventilation studies as propane cannot be used in coal mines and nitrogen oxides are already present in the air of mines where diesel equipment and/or blasting are used. Prior to this study, all successful underground investigations had been performed by grab sampling, with later analysis by gas chromatography in a surface laboratory.

CBCRL, recognizing the value of real-time tracer gas analysis, produced a prototype rapid sequential tracer gas analyzer suitable for underground use [2]. To date, the prototype gas analyzer can analyze an air sample every ten seconds, but as yet, the unit is not suitable for the hazardous environment of an underground coal mine. As a result of this study, certification of such a unit is actively being investigated.

A study of residence times in a large open stope of an uranium mine was chosen to prove the value of the instrument and the viability of using SF_6 as a ventilation tool in mining. This was performed in conjunction with personnel from the Elliot Lake Mines Research Laboratory (ELMRL) who are studying radiation control measurement and theoretical prediction. For these studies, accurate measurement of ventilation flow, residence time and age of air are extremely important [3].

2. DESCRIPTION OF TEST SITE AND INSTRUMENTATION

The stopes available for residence time determination were in an old worked-out area of an uranium mine. Of the three made available, stope 8260 was selected.

Stope 8260 is approximately 380 m long, 16.5 m wide and 3.9 m high with a trapezoidal cross-sectional shape. Rock pillars at regular intervals along the stope's centerline support the roof. Little spalling has occurred in the stope and its overall condition was deemed good. The location and condition of the stope ensured minimal fluctuations in and disruption to the airflow.

Figure 1 shows a map of stope 8260's location. This and parallel stopes draw fresh air from an intake drive fed directly by a raise to the surface. Air is discharged into the 7040 return driveage. Access through the stope was impossible, but either end could be reached via 8265 ramp which contained double air lock doors. Airflow through each stope is controlled by wooden regulators built into the inlets. These can be adjusted from closed to a maximum open area of 0.53 m^2. Excepting stopes 8255 and 8260, all the other regulators were made as airtight as possible.

The gas chromatograph/analyzer was located in a protective cage within the outlet of stope 8260, thus allowing it to draw samples from the air which had passed through the stope. The outlet was not suitable for making conventional anemometry measurements, but a continuously recording vane anemometer was located at the intake regulator. Radiation measuring equipment was also installed in the outlet of stope 8260, but the results from these are reported elsewhere [4,5].

Briefly, the analyzer comprizes a gas sampling pump which continuously draws air into a sampling loop. Air is injected from this once every ten seconds alternately into two molecular sieve columns. These separate SF_6 from the other gaseous compounds of the sample for subsequent measurement. After elution of the SF_6 the remaining gases are backflushed from the columns. The carrier gas flow through the analyzer has been optimized such that both separation and backflushing cycles total less than twenty seconds allowing an analysis every ten seconds.

The SF_6 is measured by a sensitive electron capture detector that produces an output voltage proportional to the gas concentration; this is logged on site, on a time base, by a strip chart recorder and/or a data logger.

Briefly, the experimental protocol of taking airflow measurements with tracer gas was to

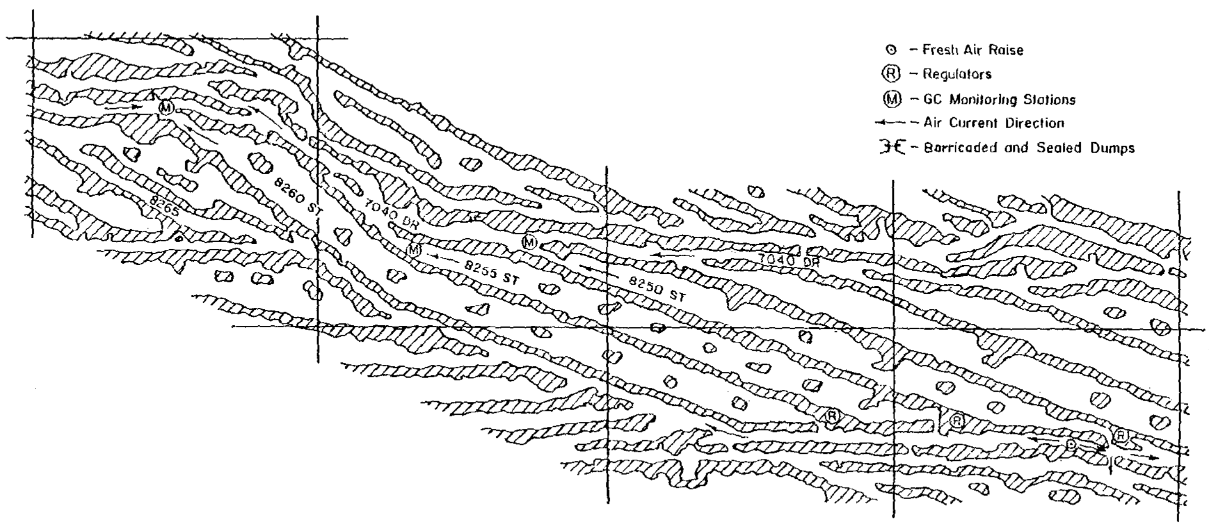

Fig. 1. Plan of the test stope 8260 and surrounding area.

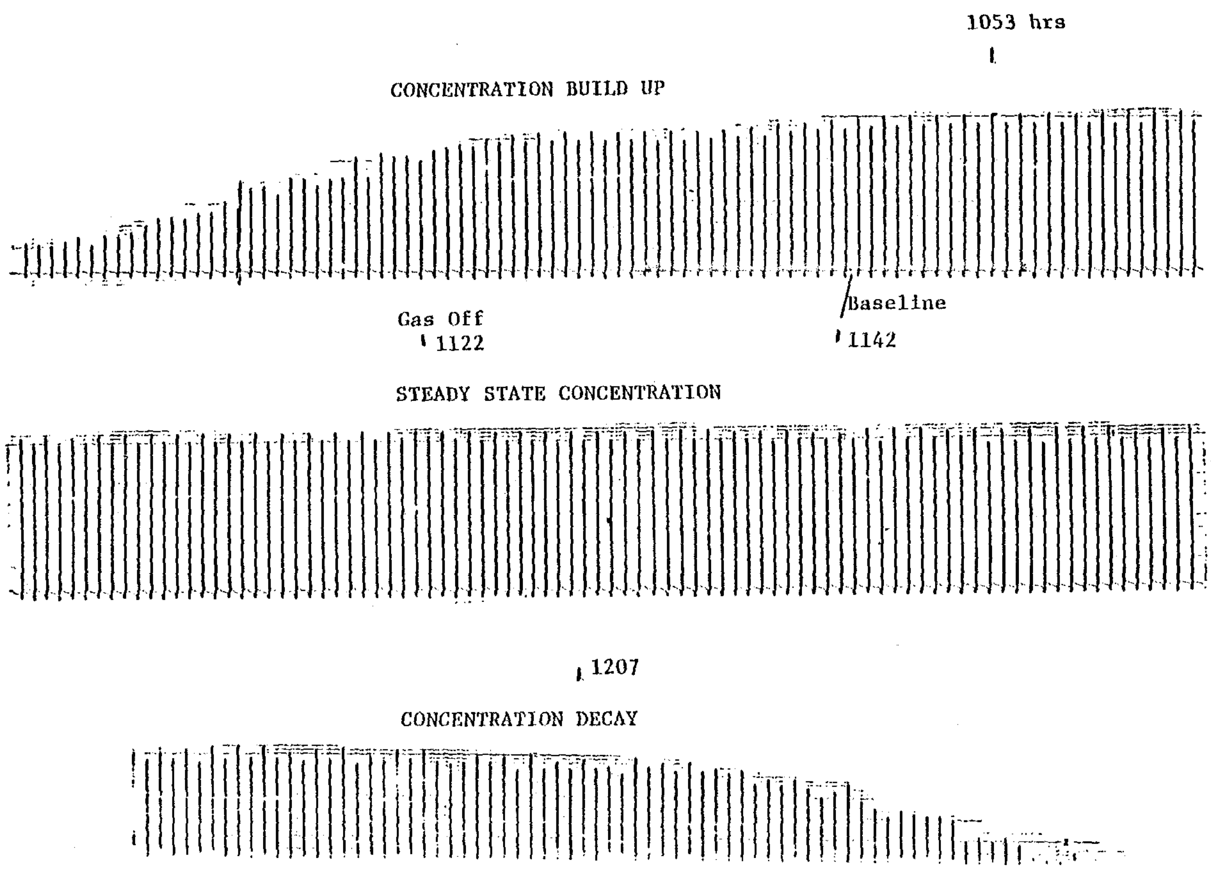

Fig. 2. Chromatogram of the continuous injection into stope 8260.

inject SF_6 into the stope at the regulator and measure resultant concentrations in the airstream at the outlet. Six tests were performed at different regulator settings of which five were of the preferred pulse injecton mode and one by continuous injection.

3. GAS ANALYZER PERFORMANCE

A more detailed description of the gas analyzer and experimental protocol are given elsewhere [3,6]. Briefly, the gas analyzer's performance in the field was excellent. Expected problems with infield calibration and stability failed to materialise and the machine operated continuously without a flaw. The major shortcoming of the analyzer was its lack of portability. Modifications are being made presently to overcome this and make the instrument totally self-contained and portable. Figure 2 shows an example of the type of trace produced by the analyzer; this pertains to the continuous injection described below.

4. TRACER GAS INJECTION RESULTS AND ANALYSIS

4.1 Continuous injection

A steady flow rate of SF_6 was obtained from a lecture bottle of the gas with a limiting orifice connected to the bottle regulator. The injection lasted for more than two hours allowing the airflow to be determined and providing an indication of its stability. The average residence time and stope volume may also be derived.

The volume flow rate of air through the stope may be calculated from the following equation:

$$Q = \frac{\dot{v}}{c} \times 10^9 \qquad (1)$$

where

Q is the airflow through the slope (m^3/s)
$\dot{v}$ is the flow rate of tracer gas (m^3/s)
c is the steady state concentration of tracer gas measured at the outlet of the stope (ppb).

This injection produced two distinct steady state concentrations at the stope outlet which indicate that the airflow through the stope changed (see Fig. 2); this was supported by conventional anemometry measurements. The most probable cause for this change was the opening or closing of a main ventilation door or switching on or off a fan elsewhere in the mine as no alterations were made in the vicinity of the test site.

For a continuous injection, the averge residence time of air in the stope can be found from the time taken from the start of the release of SF_6 to reach half the steady state concentration [7]. The average residence time is denoted as t_{50}. Similarily, t_{50} can also be determined on the decay from steady state after the cessation of a SF_6 continuous injection [7].

The stope volume can be calculated from the following relationship:

$$\text{Stope volume} = t_{50} \cdot Q \qquad (2)$$

Further determination of maximum and minimum longitudinal velocities and single air exchange times can be obscured in a continuous injection as it is not always possible to pinpoint the actual times a steady state concentration is achieved and ceased.

4.2 Pulse injection

The pulse injections provided more precise information about the airflow, residence and clearance times, and maximum and minimum longitudinal velocities. They were also easier and quicker to perform than a continuous injection. All five pulse injections were released from plastic syringes filled with a known volume of tracer gas. These were also released into the stope inlet.

For a pulse injection the volume flow rate

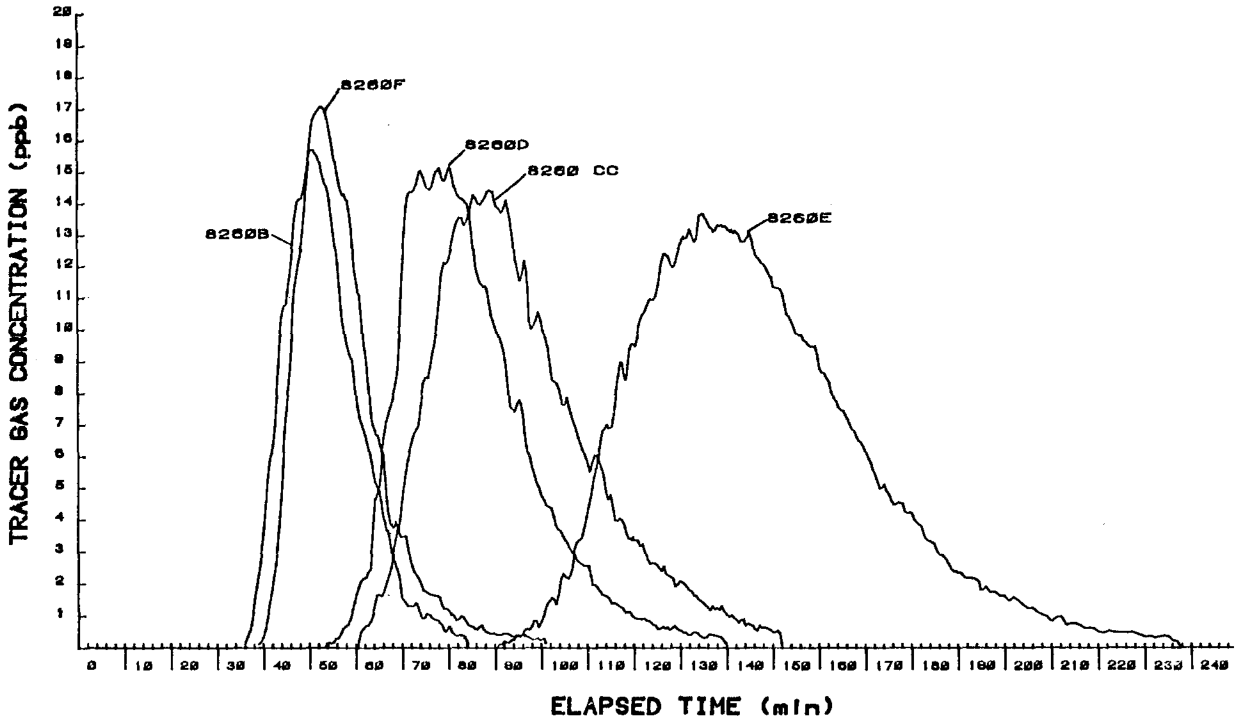

Fig. 3. Concentration/time curves for all pulse injections.

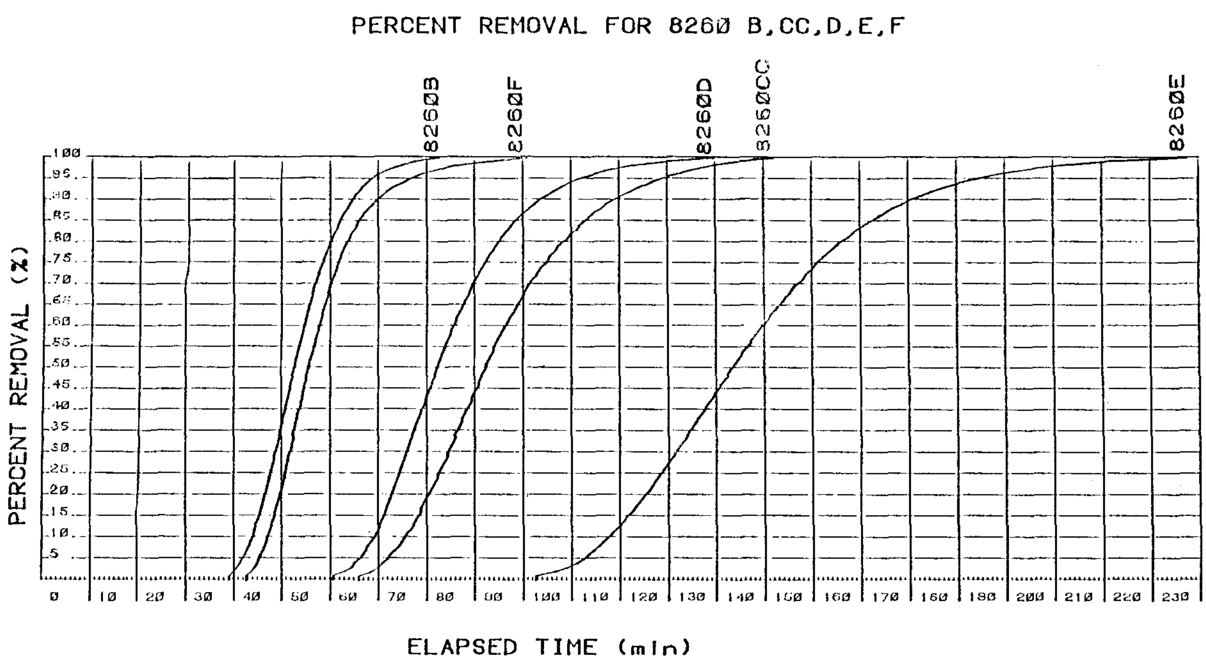

Fig. 4. Comparison of percentage removal curve for pulse injections.

TABLE 1

Derived results from continuous and pulse injections into stope 8260

Test	Open area of regulator m^2	Type of injection and volume, v or $\dot{v}$	Steady state concentration c ppb	Area under injection curve, c_τ ppb.s	Airflow Q m^3/s	Average residence time, t_{50} min	Stope volume m^3	Maximum longitudinal velocity m/s	Minimum longitudinal velocity m/s	Single air exchange min	Anemometer airflow m^3/s
1.1	0.525	Continuous 4.59 cc/min	10.6	N/A	7.22	61	26425	0.13	N/A **	N/A **	
1.2 *	0.525	Continuous 4.59 cc/min	9.2	N/A	8.32	55	27456	N/A **	N/A **	N/A **	
B	0.525	Pulse 150 cc	N/A	17863	8.40	53	26703	0.17	0.08	83	6.39
F	0.394	Pulse 160 cc	N/A	19544	7.68	56	25788	0.16	0.06	101	5.41
D	0.262	Pulse 150 cc	N/A	23004	5.37	82	26353	0.12	0.06	140	3.02
CC	0.132	Pulse 100 cc	N/A	32218	4.66	92	25700	0.10	0.04	152	1.57
E	0.034	Pulse 150 cc	N/A	46554	3.22	142	27651	0.07	0.03	237	0.45
Average							26582				

* Two distinct flow rates were present during the continuous injection.

** The results did not allow accurate determination of these values.

of air in the stope is calculated from the following relationship:

$$Q = \frac{v}{c_T} \times 10^9 \quad (3)$$

where
v is the volume of tracer gas released (m^3)
c_T is the area under the concentration of tracer gas/time curve (ppb.s).

The concentration of tracer gas/time curves as measured at the outlet (Fig. 3) are computer drawn after the original curves from the chart recorder are digitized onto a computer and corrected for calibration. Computer analysis also provides the area under the curve that allows the determination of airflow and average residence times, etc.

On converting the concentration curves into percentage removal against elapsed time curves (Fig. 4) further analysis may be performed, this is also facilitated by the computer analysis of the results.

It has been previously shown [7], that the shape of these curves is the same as a concentration build-up recorded from a continuous injection under the same conditions. Therefore, the t_{50} percentile time from these graphs equals the average residence time of the air inside the stope. Similarly, any other required percentile, t_0 through to t_{100}, may also be readily obtained.

The combined derived results from both the continuous and pulse injections are given in Table 1. The continuous injection gave two distinct sets of values.

5. DISCUSSION OF RESULTS

5.1 Airflows through stope 8260

At each regulator setting a different airflow through the stope was measured, and as expected, with one exception, the airflow decreased with increasing regulation. The only exception was during the continuous injection when an external influence changed the airflow.

5.2 Average residence time of stope 8260

As expected, with the same exception as above, the average residence time increased with decreasing airflow.

5.3 Stope volume

The calculated average and standard deviation of the seven stope volumes was 26,582 ± 753 (2.8%) m^3. This compares well with a volume estimation made from a large scale surveyor's plan of 24,730 m^3.

5.4 Relationship between residence time and airflow

From pulse and continuous injections average residence times have been obtained for seven different stope airflows. Figure 5 shows these seven points plotted as residence time versus the airflow. The theoretical line for this stope is found from a rearrangement of eqn. 2:

$$Q = \frac{V_s}{t_{50}} \quad (4)$$

where V_s is the average calculated stope volume.

All data points lie close to the theoretical line confirming that for the range of airflows tested the average residence time was inversely proportional to the airflow through the stope.

5.5 Comparison of pulse and continuous injections

This study demonstrated that results obtained by either pulse or continuous injections were contiguous. Under the same regulator opening and airflow regime they predicted the airflow within 1%. Both methods also

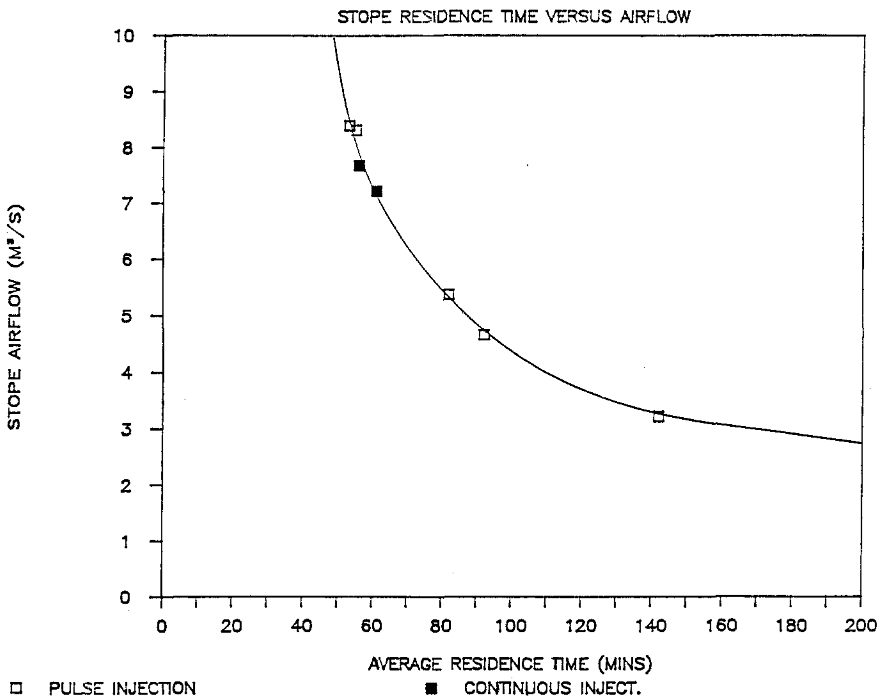

Fig. 5. Stope residence time versus airflow.

gave comparable stope volumes and agreed with the theoretical relationship of residence time and airflow.

The continuous injection was advantageous in allowing evaluation of airflow stability in the stope, this is not possible with a pulse release. It is arguable that the pulse injection curves are easier to interpret and more readily provide the t_0 and t_{100} percentiles.

A major advantage of the pulse injection technique over continuous is that it is much quicker. In this study, two injections could be performed in the time to complete a single continuous injection. It is also much easier to dispense a measured volume of tracer gas for a pulse injection than maintain a steady continuous flow of gas from a gas cylinder. However, in order to use the pulse technique successfully a large number of measurements are required to define the resultant curve. For a number of injections, grab sampling becomes impractical and an in situ monitor becomes a necessity.

5.6 Comparison of pulse injection tracer gas technique and conventional anemometry

During injections and measurement of tracer gas, the airflow was measured for consistency by a conventional anemometer with data logging facilities. The conventional anemometers showed that the airflow remained constant for the duration of each injection.

As the outlet area of the stope exceeded 15 m^2 the air velocities varied between 0.2 and 0.5 m/s for the full range of regulator openings, thus measurement there was impractical.

The stope airflow could only be measured by anemometer at the regulator which effectively operated as an orifice and created a vena contracta. This is not an advisable loca-

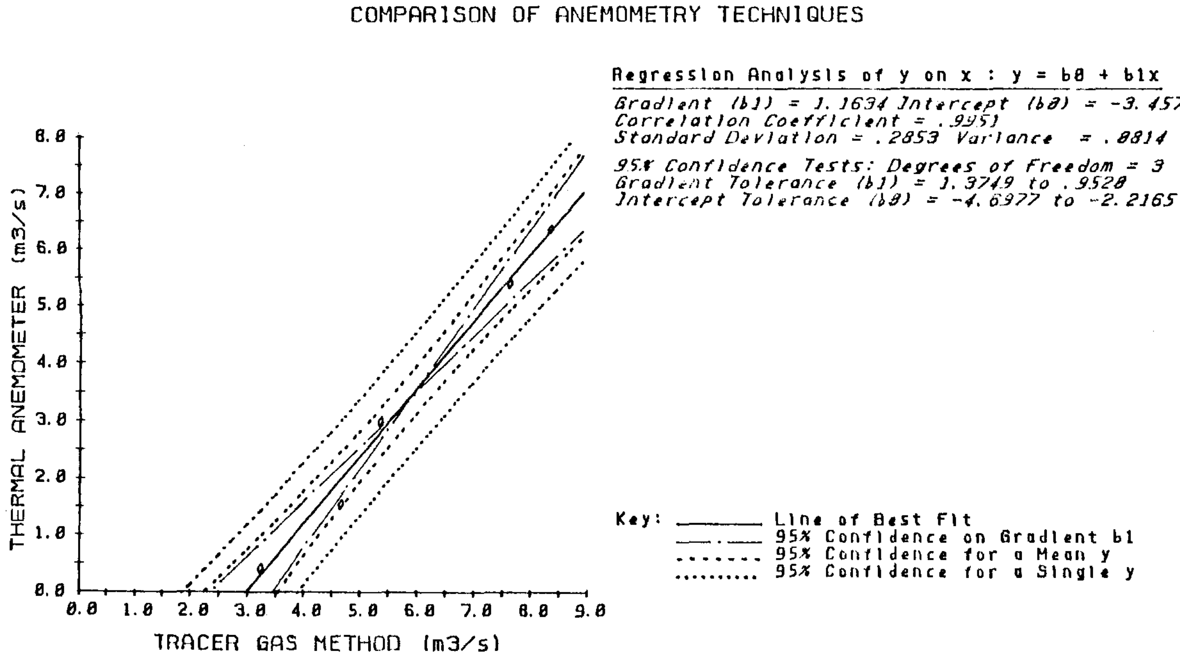

Fig. 6. Comparison of tracer gas and anemometry determined airflows.

tion for conventional airflow measurement and this is supported by the compared results. Figure 6 shows a linear regression of derived airflows obtained by tracer gas versus those from the conventional anemometry techniques. Although the two methods show a high degree of linear correlation 0.995, the regression line shows the shortcomings of the conventional method, it being only responsive when the airflow is in excess of 3 m^3/s.

6. CONCLUSIONS

The prototype gas chromatograph developed for rapid sequential analysis of SF_6 in underground environments performed very well in this field trial. Further modifications are, however, necessary to make the instrument more portable and suitable for permissible underground environments.

The versatility of a tracer gas technique has been greatly increased with the use of a rapid sequential gas analyzer. With the ability to measure tracer gas concentration every ten seconds the pulse injection method has been shown to be more flexible and easier to use than the continuous injection. It is envisaged that the value of the pulse injection technique will be furthered with the availability of other tracer gases which can be analyzed by the same chromatograph.

The studies performed in stope 8260 provided verification of the relationship between stope airflow and residence times inside the stope. This information is invaluable in investigating radon daughter decay in such stopes, and good correlation has already been reported [8].

In large airpaths where the velocity is less than 0.5 m/s, and in locations of rapidly changing cross-sectional areas such as regulators, the measurement of airflow by conventional means can be extremely difficult and/or inaccurate. In these instances the use of a tracer gas technique is extremely beneficial and more accurate.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation for the help and cooperation extended by the mine in which this exercise was performed, in particular to the engineers and staff of the ventilation department.

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