Energy, Mines and Resources Canada | Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

EVALUATION OF THE AIR QUALITY AND DISTRIBUTION DURING THE REST PERIOD OF BACTERIAL FLOOD LEACHING OPERATIONS IN URANIUM MINES

S.G. HARDCASTLE AND A. SHEIKH

ELLIOT LAKE LABORATORY

MAY 1987

Presented at the 3rd Mine Ventilation Symposium, Pennsylvania State University, October 12-14 1987; and

Published in the Proceedings of the 3rd Mine Ventilation Symposium., Penn State University, October 12-14; Chapter 51; pp 343-352, 1987

MINING RESEARCH LABORATORIES
DIVISIONAL REPORT MRL 87-75 (OPJ)

EVALUATION OF THE AIR QUALITY AND DISTRIBUTION DURING THE REST PERIOD OF BACTERIALLY ASSISTED LEACHING OPERATIONS IN URANIUM MINES

S.G. Hardcastle, Ph.D.
Research Scientist, Elliot Lake Laboratory,
CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario, Canada.

Akbar Sheikh
Chief Operations Engineer, Denison Mines Limited, Elliot Lake, Ontario, Canada.

ABSTRACT

In Canadian underground uranium mines, bacterial leaching is being increasingly applied to low-grade ore reserves. At Denison Mines Limited uranium operations, old stopes are used as leaching vessels; these contain a leaching muck pile brought down by drilling and blasting from the back which contained a low-grade reef. The bacteria used require atmospheric oxygen to oxidize the pyritic ore.

A study was initiated to evaluate the ventilation, including oxygen supply, specifically, of flood leaching stopes during their rest period. The method of ventilation investigated was a single ended compressed air system which feeds airlines laid under the muckpile and carried through the inlet pressure bulkhead.

The air delivery system was tested for post-blast integrity with a sulphur hexafluoride, SF_6, tracer gas technique. This was injected into the intake compressed air line and collected at the stope's borehole exhaust in grab-sampling bags. The samples were analyzed with a laboratory gas chromatograph and results provided information on the stope's airflow, average residence time, overall clearance time, volume of the airpath and the airflow distribution.

The borehole exhaust was monitored by anemometer and psychrometer and indicated that the psychrometric conditions in the stope were independent of the area's ambient climate. Evaluation of the exhaust's standard gaseous composition showed the oxygen consumption of the bacteria to be independent of the investigated flow range.

Field derived results are compared with computer models, theoretical predictions and laboratory investigations.

INTRODUCTION

Denison Mines Limited uranium operations have employed leaching for the underground recovery of uranium since the early 1960's. Research and development of the process, including the introduction of bacteria as oxidizing agents, have greatly improved its cost efficiency. Its importance to production has rapidly increased in recent years. This is demonstrated by the amount of ore assigned to heap leaching (see Figure 1) (St. Denis and Sheikh, 1987).

The ore assigned to bacterially-assisted heap leaching is commonly of low grade and contained within the back of previously mined stopes. This ore does not economically justify its haulage and hoisting to surface for processing. Denison employs two methods of biological heap leaching, trickle and flood. Of these, flood leaching is far more extensive with presently 45 individual stopes in operation containing over 1.5 million tons of ore.

The bacteria employed is thiobacillus ferro-oxidans which oxidizes elements of the pyritic quartzite matrix of the orebody. The radioactive minerals occur in association with the pyrite. The bacteria require carbon, nitrogen, magnesium and phosphorus as nutrients and atmospheric oxygen for the oxidization of the pyrite to provide energy for growth (Marchbank, 1986).

To optimize the efficiency of the bacterial flood leaching operations it is essential to quantify the environment in which the bacteria exist and the controlling parameters. Two possible areas of concern to Denison Mines have been investigated by the Elliot Lake Mining Research Laboratory (Hardcastle and Butler, 1986), and are reported here. Firstly, the aeration system study tested a tracer gas technique designed to determine the integrity of the system for the supply of oxygen to the bacteria. Secondly, the leaching atmosphere study monitored the psychrometric conditions inside the stope and evaluated the composition of the exhaust air.

AN IN-PLACE BIOLOGICAL HEAP LEACHING OPERATION

A typical in-place flood leaching operation consists of two interconnected rooms open at only one end for haulage access. Average stope

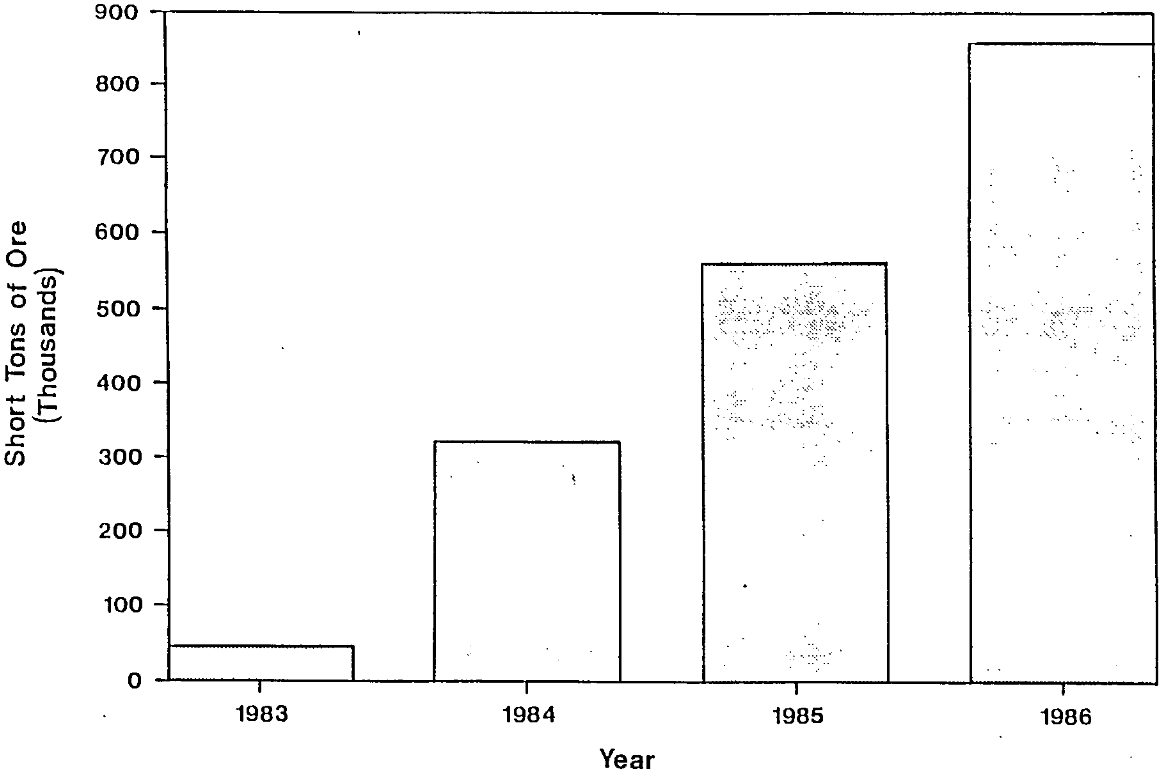

FIGURE 1. Annual Tonnage Assigned to Trickle and Flood Leaching Operations by Denison Mines Limited (1983-86).

dimensions are 70 m long, 12 m wide, and 3 m high. Inside each room are laid three air lines (see Figure 2) consisting of perforated polyethylene pipe. These are protected from the blast which creates the leaching muckpile by perforated steel pipe casing and a layer of muck. The air lines are fed from the mine's compressed air system from either the bottom or both top and bottom of the stope. This study investigated a single ended system fed from the bottom of the stope.

The leaching vessel is created by sealing the haulage access to the rooms with pressure bulkheads. An exhaust for the aeration is provided by boreholes to each room drilled from a ventilation drift above the stope.

AIRFLOW MEASUREMENT THROUGH A FLOOD LEACHING STOPE

No internal access is possible to the leaching operation after erection of the retaining bulkhead. Figure 3 gives an idealized schematic of the system. The overall airflow through the system could be measured at either end, however, this will not give any indication of the air distribution.

A tracer gas/gas chromatography technique has proven useful in providing more qualitative information in previous work (Stokes, Hardcastle and Kennedy, 1986) (Stokes, 1985). Such a technique can provide information on average and maximum residence times, airway volumes and air leakage as well as the overall airflow.

Design of a Tracer Gas Injection Method

A pulse or a continuous injection method form the two possible types of injection used (Hardcastle, Grenier and Bigu, 1986). Their applicability to any situation depends on the airflow, method of analysis, the area being studied and the operating schedule of the mine.

In the flood stopes the airflow is very small, normally $<0.06\ m^3/s$ per two rooms and their void volume is large, 3000 m^3.

The tracer gas analysis necessitated taking grab samples for later evaluation on a laboratory based chromatograph. This unit was optimized and calibrated for sulphur hexafluoride, SF_6.

The final choice of injection method (Hardcastle and Butler, 1986) was the continuous mode. This would produce a steady increase of tracer gas concentration at the exhaust until steady state was reached. Steady state would persist until the airflow was changed, or the gas injection rate changed or stopped. In this instance the gas was stopped and a steady decay should occur as the gas is removed from the stope. A 1% SF_6 mixture in air was injected into the compressed air line at 20 ml/min for 125 hours. Up to 13 hourly grab samples were taken per day at

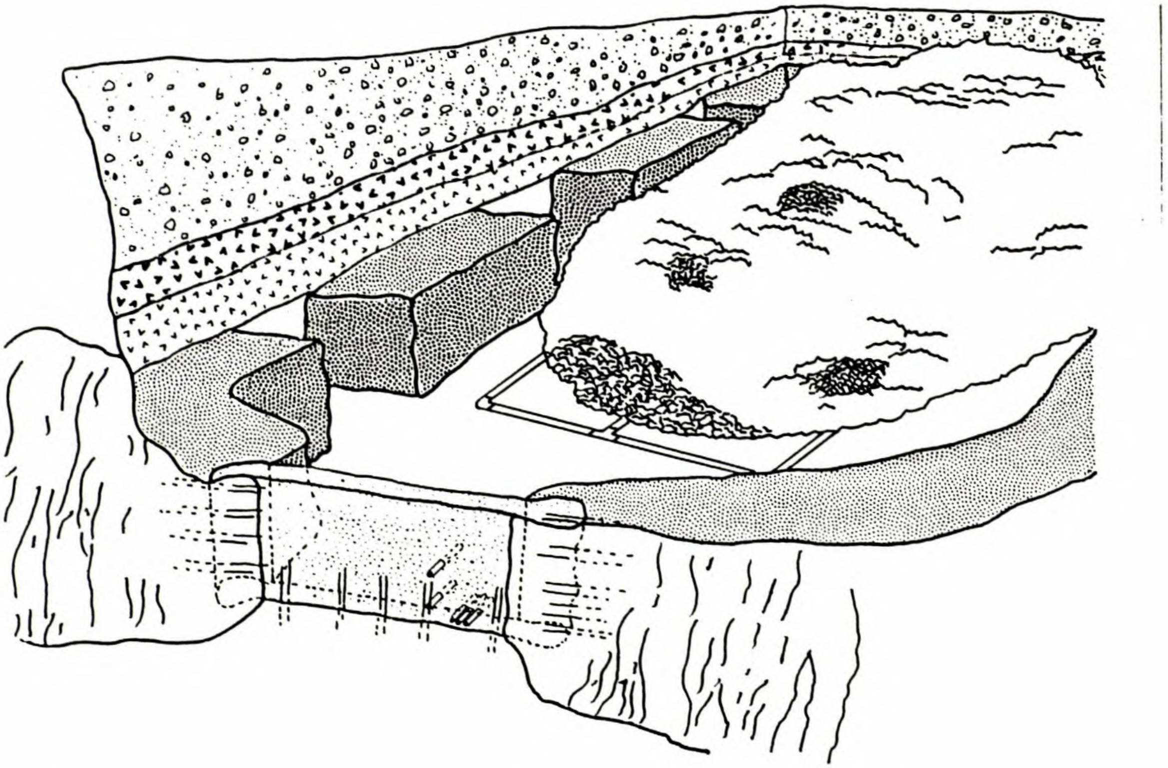

FIGURE 2. Three-Dimensional Cut-Away of one Room of a Typical Flood Leaching Block.

the exhaust over 250 hours to define the injection's build-up, steady state and decay.

To maintain a consistent injection the flow from a gas cylinder was restricted by a fine bore capillary. Also the compressed air was regulated down to below normal fluctuations. A constant pressure differential was kept across the capillary using the delivery and air line pressure (see Figure 4).

The sampling schedule only allowed one of the two exhaust boreholes to be monitored for tracer gas throughout the investigation. This borehole was also monitored continuously by a recording anemometer and synchronized measurements were taken at the other borehole.

DEFINING THE FLOOD LEACHING STOPE ENVIRONMENT

The two areas of investigation are the climate within the stope, temperature and humidity etc., and the exhaust air composition, specifically the amount of oxygen removed.

Psychrometric Evaluation of the Leaching Stope

During the tracer gas injection the wet and dry bulb temperatures and relative humidity were monitored for the leaching stope exhaust (see Figure 4). In addition to these, the barometric pressure was also measured for the ambient environment at the exhaust. The barometric pressure was logged on surface.

From the observed values the moisture content, air density and relative humidity were calculated using standard psychrometric equations.

Oxygen Consumption During the Bacterial Leaching

The bacteria employed to degrade the pyritic ore by oxidization used atmospheric oxygen. The organism is most active between 15 and 40^{o}C with 25^{o}C being the optimum (Marchbank, 1986).

During the injection and after the compressed airflow had been deregulated grab samples were taken in gas bags for later oxygen and nitrogen analysis. These values in association with the airflow produced an oxygen consumption rate for the system.

ANALYSIS OF THE CONTINUOUS TRACER GAS INJECTION

The SF_6 tracer gas injection was monitored by grab samples taken in 1 litre Tedlar sampling bags; 31 samples were taken during the build-up, 7 during steady state, and 49 during the decay. The final analyses of the samples are presented as percentages of the steady state maximum, 112.8 ppb SF_6 in air, in Figure 5.

The first two days were plagued with lost

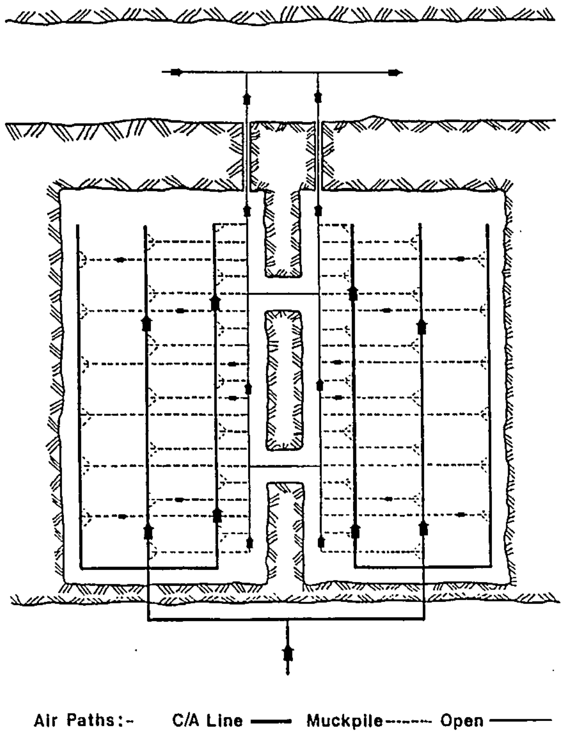

FIGURE 3. Idealized Schematic of Air Distribution Lines and Airpaths of the Aeration System.

samples and consequently the build-up is not used in any derived analyses. Through steady state the SF_6 concentration had a standard deviation of 2% from maximum.

The decay from steady state was the most valuable part of the analysis. This was well defined for 96 hours after stemming the SF_6 flow. Beyond this time the airflow was deregulated to return it to normal.

Total Airflow Through the Leaching Block

The tracer gas analysis provides the total airflow through the block using the following equation:

$$Q = \frac{v.10^9}{C} \quad (1)$$

where, Q is the stope airflow (m^3/s)
v is the flow of SF_6 (m^3/s)
C is the steady state concentration of SF_6 (ppb).

The exhaust concentration, 112.8 ppb SF_6, was produced by a 0.026 m^3/s airflow.

<u>Anemometer Analysis</u>. Synchronized anemometer measurements for the two boreholes indicated that the continuously monitored borehole exhausted 63% of the air entering the block. The anemometers

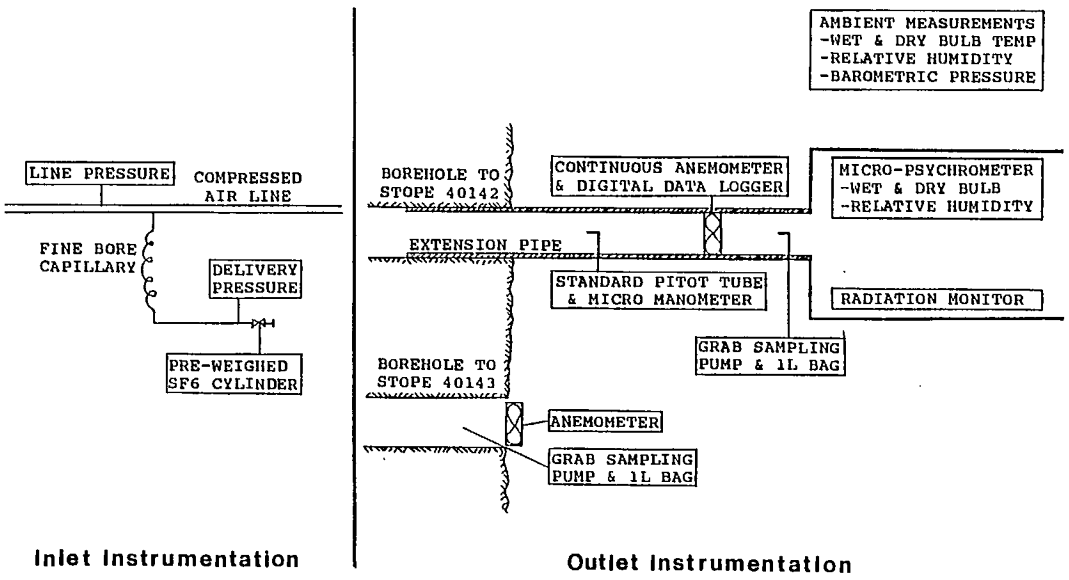

FIGURE 4. Monitoring Instrumentation to Evaluate the Aeration of a Flood Leaching Stope.

also over-estimated the airflow, when compared to the tracer gas, which was expected as they were not ideally suited to their measuring locations.

The continuous anemometry provided information on the consistency of the airflow through the flood leaching block during the injection, its decay and the final flow after deregulation of the compressed air.

The anemometer record highlighted that the air flow through the block gradually increased throughout the injection. During the tracer gas build-up period the airflow was consistent at 0.024 m^3/s, although there was some fluctuation during steady state which coincided with a weekend and through the tracer gas decay it increased from 0.025 to 0.028 m^3/s. After deregulation the airflow increased to 0.046 m^3/s.

The average residence time of the air through the system can be obtained directly from the time against relative concentration plot for a continuous injection. The average residence time is given directly by the t_{50} percentile intercept of either the build-up or decay.

The injection decay curve (see Figure 5) gave a t_{50} or average residence time of the block of 33.5 hours.

Similar to the average residence time the total clearance time is given by the t_{100} on the build-up or t_0 on the decay. For this injection neither were well defined. On the decay it takes of the order of 100 hours for the SF_6 to decay away. It should be noted that the airflow was deregulated at 98 hours.

Flow Integrity and An Equivalent Pulse Injection

Differentiation of a concentration versus time trace of a continuous injection will produce a curve equivalent to that produced from a pulse injection. This conversion is necessary to evaluate the integrity of the flow inside the stopes. Operational constraints did not originally allow a pulse injection analysis.

Differentiation of the decay section of Figure 5 generated a histogram which is presented in Figure 6. This also contains a smoothed curve to show the general trend of an equivalent pulse injection measured at the exhaust. From this curve it is possible to infer flow regimes in the stope (Hardcastle and Sheikh, 1987).

Air Transit Time Through the Compressed Air Line. To interpret the equivalent peak injection curve it is necessary to calculate the average travel time through the air lines from their physical dimensions.

For the airflow, 0.026 m^3/s, and six air lines the average transit time is less than 5 seconds. This is insignificant in comparison to the residence time and thus it can be assumed that the tracer gas is introduced to all points within the stope simultaneously.

Flow Paths Within the Flood Leaching Block. As the gas is released simultaneously to all points of the stope, the profile of Figure 6 relates purely to the flows inside the stope.

The pulse injection profile shows no single significant peak that dominates the profile during the first 90 hours. Rather, there is a rapid rise followed by a slow decay with a number of small peaks superimposed onto it. This indicates that air was released along virtually the whole length of the pipes in the stope.

There is, however, a single detached peak which arrived at 96 hours. This trailing peak, which contains 10-15% of the area under the profile, demonstrates that the same proportion of air vacates the air lines close to the stope inlet. After this no gas or air is released for a distance prior to the main body of gas being released.

Volume of the Air Paths in the Stopes. A peak in a pulse injection profile is the result of a major airpath. Of primary interest is the apparent volume of the stope, which is given by the average airflow and the transit time of the last peak/ first release in the stope.

The last peak, the release at the inlet, gave a volume of 2790 m^3 for the stope, which is less than the 3150 m^3 value obtained from the mine survey plans. The lower apparent volume is indicative of a non-linear release weighted towards the inlet.

Airflow Distribution From the Air Lines. The nature of the release and the air distribution system make it impossible to accurately determine whether all parts of the system are being aerated and by what amount.

A generalized analysis of minor peaks in the pulse injection profile (Hardcastle and Sheikh, 1987) has been performed. This indicated that the release decreased on average from 2.6 to 0.9%/m. Such a decrease is typical of a single ended delivery system where the resistance increases, and the driving pressure decreases with distance.

Distribution System Resistance and Flow Indices

Inside the air distribution system and stope, both laminar and turbulent flow exist. In the airlines the flow is predominantly fully turbulent and in the stopes it is laminar excepting the exhaust boreholes.

Theoretical Resistance of the System It is possible to approximate the system resistance from theoretical relationships. This requires the determination of individual resistances of elements in the distribution system and combining them in series and parallel to form an equivalent total resistance.

The resistance of each air line necessitated the use of a computer to calculate its equivalent resistance. The perforations were treated as

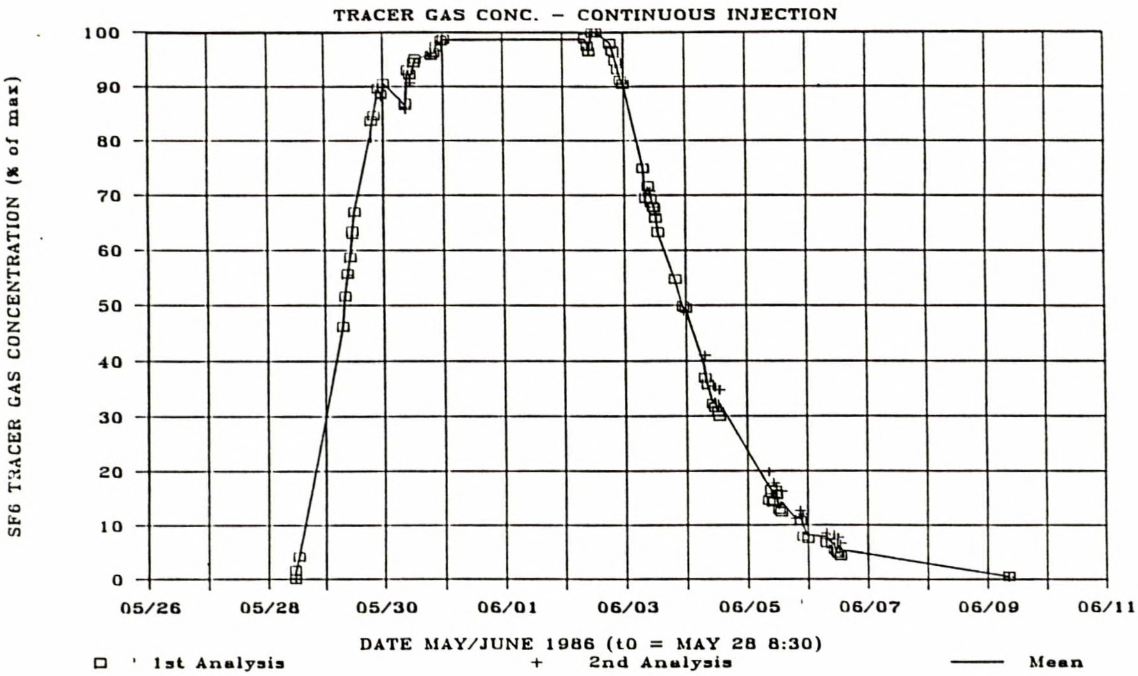

FIGURE 5. Relative SF_6 Concentration of a Continuous Injection as Measured at the Exhaust of the Test Stope.

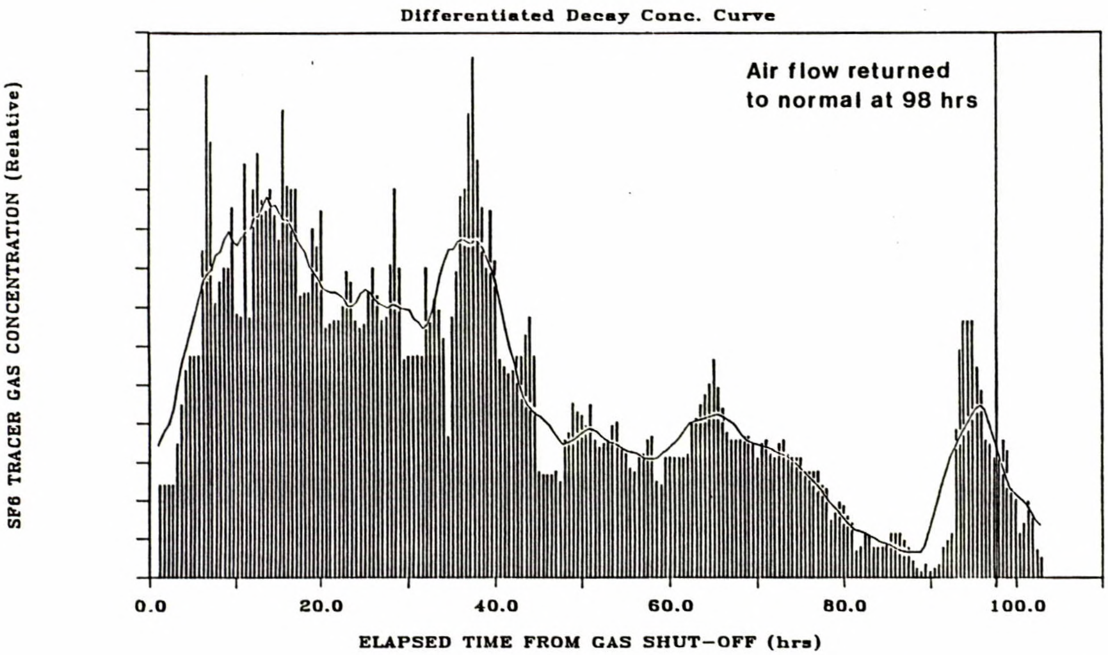

FIGURE 6. Computer Derived Differentiated Curve of the Decay of the Continuous Injection.

orifices. In combining the resistances, only those of the air delivery system proved significant.

The theoretical resistance of the distribution system calculated using average flows for each section at each of the two airflows were as follows:

i) 3.2×10^7 Ns^2/m^8 at 0.026 m^3/s, and
ii) 4.4×10^7 Ns^2/m^8 at 0.046 m^3/s.

These values assume a turbulent flow index of n = 2 in the general airflow relationship:

$$P = R.Q^n \qquad (2)$$

where, P is the pressure drop (Pa),
Q is the airflow (m^3/s), and
R is the resistance (Ns^2/m^8).

Observed Flow Index and System Resistance. Equating the flows and frictional pressure drops through the whole system at two airflows will give an indication of the flow index and whether it tends toward laminar or turbulent flow. For the whole system the pressure drops were 79 and 207 kPa at the low and high flows respectively. These gave an overall flow index of n = 1.66 which shows a predominantly turbulent flow.

The overall system resistance has been determined using Equation 2 and the above index as 3.5×10^7 Ns^2/m^8. This value compares very favourably with the theoretical values of the distribution system.

EVALUATION OF THE BACTERIAL LEACHING ENVIRONMENT

Primary measurements taken to evaluate the leaching environment are the wet and dry bulb air temperatures, relative humidity and barometric pressure. Excepting the pressure, measurements were taken both in the exhaust from the stope and in the ambient air at the exhaust. The surface barometric pressure was also monitored.

Derived from these measurements were the air moisture content, density and relative humidity. The calculated values of humidity were pressure compensated, as compared with an electronic psychrometer which made no compensation. The difference, however, proved negligible in this instance.

The calculated conditions inside the stope used the ambient airway barometric pressure and were not corrected for the frictional loss of 15-50 Pa in the borehole.

Bagged air samples were taken during the investigation for oxygen and nitrogen analysis by a laboratory gas chromatograph. This was a dry air analysis which was corrected to wet using the water vapour pressure to determine the water content of the air and appropriate ratio correction. The vapour pressure was derived using standard tables.

The Climate Provided for Bacterial Leaching

Wet and dry bulb temperature traces of the ambient and stope air (see Figures 7a and b) show the ambient traces to be extremely variable and the stope traces to be reasonably constant. The ambient traces which reflect the surface environment seem to have little effect on the stope temperatures. Inside the stope both of the temperature traces varied by less than 1°C once they stabilized.

The initial drop in temperatures of the stope result from the stope being closed prior to the start of the monitoring period. With no airflow the initial temperature, 15.8°C, would be tending toward the virgin strata temperature.

While the airflow through the stope was 0.026 m^3/s the average dry bulb temperature of the stope's exhaust air was 13.6°C. This is below the prime activity range of the bacteria. The average wet bulb temperature was 13.1°C.

The ambient barometric pressure at the sampling station changed in direct relation to the surface pressure (see Figure 7c). Variations away from the ambient would have been minimal. The average station pressure was 104.3 kPa.

The moisture content of the air, similar to the temperatures, showed great variation in the ambient air and minimal fluctuation for the stope exhaust air (Figure 7d). Excepting an initial rapid drop in moisture content with the initiation of the airflow the exhaust air average moisture content was 0.009 kg H_2O/kg air.

The air density and relative humidity showed similar trends to those of moisture content and temperatures in that the ambient climate had little effect on the stope's internal climate. The relative humidity in the stope was high at an average of 95.3% and 1.26 kg/m^3 was the average air density at the exhaust.

All the psychrometric properties of the air show that the conditions inside the stope are independent of the ambient climate. Their only influences were:

a) the virgin strata temperature, a constant;

b) a surfeit of water left after draining the stope to maintain the moisture content. This would be easily maintained at the measured flow rate by 600 L of water for the normal 21 day rest period of the stope;

c) chemical activity inside the stope. The leaching process also promotes the oxidization of pyrite which is an exothermic reaction, thus heat generation is dependent on bacteria number and pyrite content; and

d) the airflow through the system.

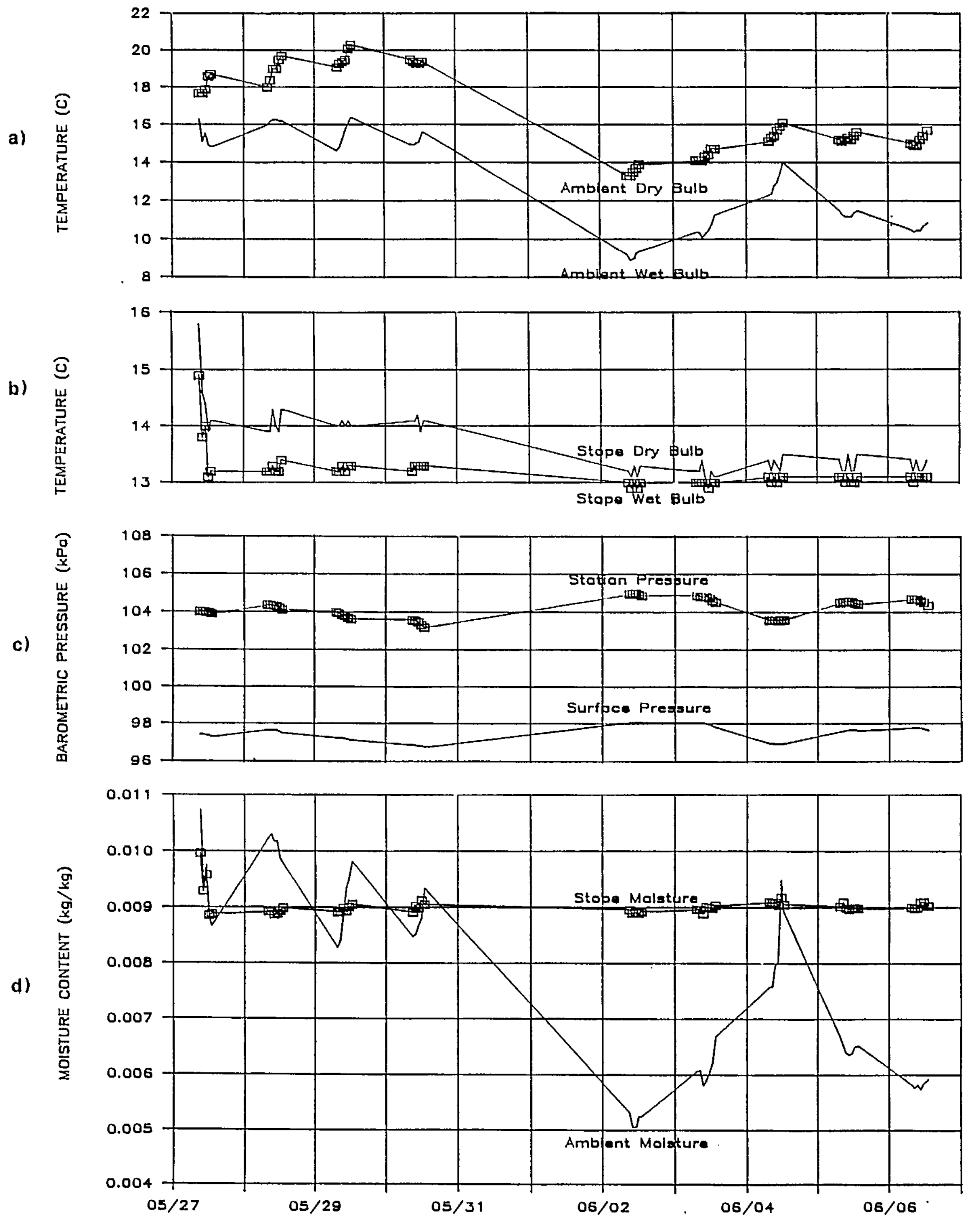

FIGURE 7. Climatic Conditions of the Test Stope Exhaust and Ambient Air: a) Area Ambient Wet & Dry Bulb Temperatures; b) Stope Exhaust Wet & Dry Bulb Temperatures; c) Comparative Barometric Pressure, Surface versus Area Ambient; and d) Comparative Moisture Content of the Area Ambient and Stope Exhaust Air.

Of these four influences the contribution of the exothermic chemical reaction is probably the most variable on a block by block basis and the hardest to quantify and control.

Gaseous Composition of Leaching Stope Air

Selected grab-samples, taken at the flood leaching stope's exhaust, were analyzed to determine their dry oxygen and nitrogen concentrations. These samples were collected during the injection and its decay and after the air had been deregulated.

Upon correction for moisture removed during the analysis, the following composition was obtained at each airflow:

1) At 0.026 m^3/s - Nitrogen 81.2%, Oxygen 17.9%
2) At 0.046 m^3/s - Nitrogen 79.9%, Oxygen 19.2%

In order to compare these with the ambient composition, (Nitrogen 78.1% and Oxygen 20.9%), corrections to the relative proportions purely resulting from oxygen removal are necessary.

The bacterial process does not consume any atmospheric nitrogen, thus its physical amount does not change.

After correction, the oxygen concentrations become 17.2 and 18.8% for the low and high airflows, respectively. These represent 3.7 and 2.1% oxygen removal values, and for both flows they equate to an apparent oxygen depletion rate of 0.0001 m^3/s.

DISCUSSION OF THE FLOOD LEACHING STOPE EVALUATION

This evaluation has shown a tracer gas technique to be suitable for measuring airflow parameters of a flood leaching stope's ventilation system.

For the stope evaluated, the tracer gas injection and various associated measurements produced the following:

a) The overall system airflow during the injection was 0.026 m^3/s, and 0.046 m^3/s on deregulation.

b) At the low flow the system had a residence time of 33.5 hours and a total clearance time of approximately 100 hours.

c) At least 85% of the air was passing through the muckpile. A major leak at the inlet accounted for the rest.

d) The air release was non-linear and weighted towards the inlet. On the average it reduced from 2.6 to 0.9%/m over its 70 m length.

e) The stope and distribution system had a flow index of $n \simeq 1.7$ in $P = RQ^n$. This is indicative of both laminar and turbulent flow being present.

f) The resistance to airflow of the whole system was measured at 3.5×10^7 Ns^2/m^8.

More information on flow paths and the integrity of the distribution system could have been provided if:

1) sampling was performed on a more continuous basis, and possible substitution of a pulse injection method;

2) both exhausts were monitored with the same sampling schedule; and

3) the chromatograph analysis was upgraded with either a rapid portable SF_6 analyzer or a portable multiple tracer gas analyzer.

The climatic and gaseous evaluation of the flood leaching stope demonstrated:

a) The climate inside the leaching stope was independent of the external atmosphere and thus dictated purely by strata temperature, airflow, excessive water and exothermic reactions in the stope.

b) The evaluated stope had the following climatic averages at 0.026 m^3/s:

Dry bulb temperature	13.6°C
Wet bulb temperature	13.1°C
Moisture content	0.009 kg/kg
Relative humidity	95.3%
Air density	1.26 kg/m^3.

c) The stope's average oxygen consumption at 13.6°C was 0.001 m^3/s.

CONCLUSIONS

Denison Mines Limited can evaluate an aeration system of their totally enclosed bacterial flood leaching operations using a tracer gas technique. Also, the climate and gaseous make-up of the flood leaching environment may be readily determined with common standard psychrometric instruments and a gas analyzer.

Such a capability would provide a control measurement when determining other parameters affecting the uranium recovery of an extremely complex operation.

ACKNOWLEDGEMENTS

The authors would like to thank the staff of Denison Mines Limited, Elliot Lake, for the help and cooperation afforded in this investigation.

REFERENCES

Hardcastle, S.G. and Butler, K.C., 1986, "Evaluation of the Climate and Air Flow in a Flood Leaching Stope," Division Report M&ET/MRL 87-68(TR), CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Hardcastle, S.G., Grenier, M.G. and Bigu, J., 1986, "Determination of Environmental Variables Underground - Measurement Techniques and Instrumentation," Division Report M&ET/MRL 86-30(OP), CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Hardcastle, S.G. and Sheikh, A., 1987, "Applying Tracer Gas Techniques to Evaluate the Air Distribution in Flood Leaching Stopes," Division Report MRL 87-41(OP,J), CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Marchbank, A., 1986, "Underground Biological In-Place Leaching of Uranium Ores," August, Denison Mines Limited, Elliot Lake, Ontario.

St. Denis, G. and Sheikh, A., 1987, "Underground Biological Heap Leaching at Denison Mines Limited," Proceedings of the 8th Underground Operators Conference, Elliot Lake, CIM.

Stokes, A.W., 1985, "The Use of SF_6 to Determine Leakage from an Auxiliary Ventilation Duct in a Long Single Heading," Division Report ERP/CRL 85-76(TR), CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Stokes, A.W., Hardcastle, S.G. and Kennedy, D.K., 1986, "A Real-Time Tracer Gas Analyzer - An Investigation Tool for Mine Ventilation Studies," Division Report ERP/CRL 86-95(J), CANMET, Energy Mines and Resources Canada, Ottawa, Ontario.