PERFORMANCE OF THE ACID ROCK DRAINAGE MITIGATION WASTE ROCK TRIAL DUMP AT GRASBERG MINE[1]

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Abstract. PT Freeport Indonesia constructed a large trial waste rock dump as a part of acid rock drainage (ARD) Management Program in 1999. The purposes of constructing the trial waste rock dump were to observe physical and geochemical behaviors of field-scale waste rock dumps, and to investigate oxidation and leaching behaviors in order to optimize dump design for ARD mitigation. This paper presents the analysis and results of data collected during the 4-year test period. Results suggest that variations in oxygen and temperature profiles observed within the trial dump panels depend on the type of waste rock, particle size distribution and dumping methods. The placement of coarse rock layers was observed to promote oxygen transfer into the waste rock dump. Barometric pressure did not vary significantly between the atmosphere and the interior of the dump. The application of an impermeable surface cover was observed to have only a limited effect on oxygen concentrations within the profile of the waste rock. All of these findings support the hypothesis that advection of air flow through the coarse rock / rubble zone at the base of the dump is a primary pathway for oxygen transport in Grasberg waste rock dumps. The information gathered during the present field-scale investigations will be used to establish optimum dump designs for long-term closure issues and ARD management.

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Introduction

The Grasberg Mine, a large open pit producing copper and gold ore, began operations in 1988. The mine is located in the mountainous area of Papua Province in the eastern part of Indonesia, and has sub-alpine/alpine climate with relatively minimal seasonal variation in precipitation and temperature. The annual rainfall generally ranges between 4,000 mm and 5,000 mm, with average daily temperatures typically between 2°C and 14°C.

The Grasberg Mine will produce approximately 2,750 M tonnes of waste rock until the year 2015 (Neale et al., 2003). The waste rock has been placed in stock piles adjacent to the mine pit using truck dumping and crusher/stacker methods. About 63 % of this material will be potentially acid forming (PAF), with the remaining portion comprised of limestone. The formation of acid rock drainage (ARD) is of particular concern in the decommissioning of waste rock piles because this may lead to environmental loadings associated with contaminants (Lottermoser, 2003). Therefore, ARD mitigation becomes the most important aspect in the long-term management of waste rock at Grasberg Mine.

PT Freeport Indonesia initiated an ARD Risk and Mitigation study in 1996 by setting up leach tests in columns and 500 tones test pads. The purposes of these tests were to understand ARD kinetics under controlled and uncontrolled environments, and to assess performance of various limestone blending options for mitigation of ARD. The ARD Mitigation study continued with the construction of a larger instrumented trial dump in 1999. The objectives of the trial dump were to address the operation and engineering strategies for overburden and ARD management. The trial dump results will further confirm the leachate characteristics, loadings and blending results obtained from the previous leaching tests in the columns and test pads. Regular monitoring of temperature, oxygen (O_2), flow, and leachate quality was performed during the trial. The trial dump was decommissioned at the end of 2004.

Oxygen is transported into the dump through diffusion and advection mechanisms (Lefebvre et al., 2002; Ritchie, 2003). Diffusion is driven by O_2 concentration gradients at the interface between the dump surface and atmosphere. Temperature and density gradients are the driving forces for the advection process. Previous *in situ* measurements from full-scale dumps concluded that O_2 concentrations are significantly reduced at depth because oxygen transport into the dump is being limited. However, there are strong arguments that O_2 diffusion may be relatively insignificant compared to advection of O_2 due to the relatively high air permeability of waste rock material. Data obtained from the trial dump for the present study may help resolve issues regarding the limiting mechanism for O_2 supply within the Grasberg dumps.

This paper provides an overview and discussion of temperature and O_2 data collected from the dump trial over a four year period. The performance of blending limestone with PAF rock and placement of an impermeable cover to minimize the ARD is also discussed.

Site Description

A location in West Grasberg dumping area, which is called Batu Bersih, was selected for the trial dump. The area was chosen because it was not part of the active dumping plan and would be available for several years.

The Grasberg PAF waste rock is classified into two different waste types: i) the high PAF waste called red waste, which has a net acid generation (NAG) value greater than 35 kg

H_2SO_4/ton of waste; and ii) the blue waste, which has a NAG value between 1 and 35 kg H_2SO_4/ton of waste.

Materials and Methods

Trial Dump Design and Construction

Construction of a 480 m long, 80 m wide and 20 m high trial waste rock dump (Fig. 1) was started at end of 1999 at the Batu Bersih area of the Grasberg Mine. The dump was divided into eight 60 m by 80 m panels. Each panel was then divided into three sections. A 10 m by 10 m lysimeter was installed underneath each section, positioned approximately 15 m (L1), 35 m (L2) and 65 m (L3) from the outer edge of each panel. Each lysimeter was preloaded with waste rock to avoid damage caused by rolling down of large rocks. The lysimeter was around 0.5 m high and the underdrained pipe was installed to transfer the leachate to the collection tanks.

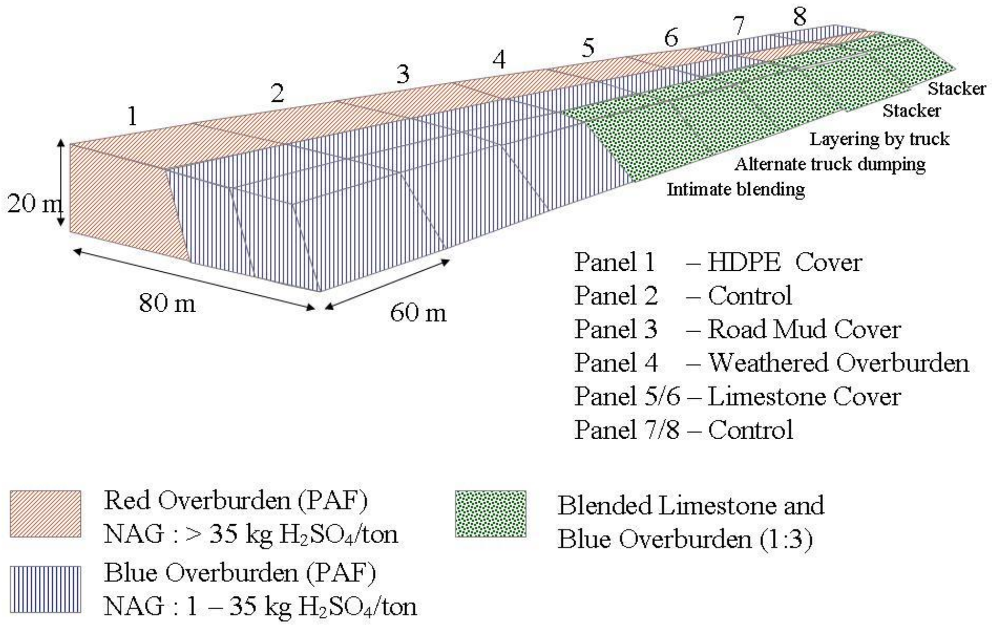

Figure 1. Configuration of the trial waste rock dump at Grasberg Mine.

A base layer for the trial dumps was constructed using waste rock graded to a 1% slope to the west and 1% slope to the north. Before constructing the trial dump, the waste rock was dumped at the back (north side) of waste dump trial location and provided the access road and the initial tipping face for placement of waste rock into the trial dump. Waste placement within each panel progresses in a southerly direction from the northern tipping face. Operational truck dispatch is used to obtain the waste rock for placement within each panel and lysimeter.

The outer slope panel, known as the face treatment, had either blue waste or a blend of blue waste and limestone. About 25% limestone and 75% blue waste were blended utilizing different truck dumping methods for the face treatments on Panels 4, 5, and 6. The different truck dumping methods included pre-mixing, alternate dumping and layering. The same blend of blue waste and limestone was placed with a stacker for the face treatment on Panel 7.

A relatively impervious cover system was constructed on the flat surface of three panels, while the panel face treatments remained uncovered. A 1.5 mm thick high density polyethylene (HDPE) geomembrane was placed on top of Panel 1 to test the impact of a ‘perfect’ water infiltration barrier. The objective was to determine if oxidation products would be generated within the dump, even if liquid water was excluded and there was no flushing of oxidation products from the dump. A 0.5 m thick mixture of road mud and limestone was placed on Panel 3 and a 1.0 m thick cover of weathered red waste rock was placed on top of Panel 4 in order to create a water and O_2 infiltration barrier. Road mud is fine grained material recovered from road grading that is required to remove road base that continually breaks down under heavy truck traffic. Since the road mud has a high in-situ water content, limestone that has a relative low water content was blended to achieve adequate compaction. Both impermeable covers were compacted using a compacter roller machine and a wheel loader.

A 3 meter limestone cover was placed on top of Panels 5 and 6 to evaluate ARD generation shutdown through an armoring mechanism previously observed on one of the limestone-capped 500 tonne dumps (Miller *et al*, 2003b).

Construction of the first and second rows of the eight panels was completed by February 2001. Due to lack of specific rock requirement in the mining sequence for the face treatment, the overall of the test dump was not completed until April 2002. Placement of cover material started in May 2002, and was completed in August 2002

Instrumentation

Instrumentation consisting of thermistors, O_2 sampling ports and tipping bucket flow meters for the lysimeters were installed in each panel. About 30 thermistor strings and 48 pore gas samplers were installed alongside the base and on the face of each panel. Further details on the trial dump instrumentation can be found in Andrina et al. (2003).

Sampling and Analysis

Waste rock samples were collected during construction of the trial dump from various locations within the test dump. Approximately 20-kg of waste rock material was collected from the tipping face as the dump advanced over each lysimeter. Samples were collected over three different periods during dump construction: i) when the lysimeter was initially being over-dumped; ii) when the lysimeter was partially over-dumped; and iii) when the lysimeter over-dumping was completed. During each sampling event, samples were collected at the crest, mid-slope and the toe above each lysimeter. In total, nine waste rock samples were collected at each lysimeter location.

Waste rock samples were analyzed for geochemical characterization including net acid generation (NAG), acid neutralizing capacity (ANC), and concentrations of total S, Cu, and Fe. A particle size distribution (PSD) analysis was also performed on the samples.

Regular monitoring of temperature, O_2, flow and leachate chemistry was carried out during the trials. Temperatures are recorded using an Ohmmeter and pore gases are monitored using a portable O_2/CO_2 meter. Leachate from each panel was collected in a 1 m^3 tank and the overflow flow rate was measured using a tipping bucket gauge and counter.

Results and Discussions

Particle Size Distribution

Results of the PSD analysis indicate significantly different particle size gradations for the blue and red waste materials (Table 1). The blue waste material contains higher amounts of gravel-size and sand-size materials. In contrast, most of the red waste material contains more cobble and gravel-size materials. The blue waste material tends to have finer particles than the red wastes because most of the blue waste material originates from 'poker chip', which is a natural friable rock type. Both waste types contain a negligible amount of clay and silt.

Table 1: Average particle size distributions of grab samples collected from the trial waste rock dump

Material classification	Particle Size (mm)	Blue Waste %	Red Waste %
Cobble	> 63	9.3	44.9
Gravel	2.36 – 63	72.4	43.4
Sand	0.06 - 2.36	14.7	9.9
Silt and clay	<0.06	2.6	1.8

A large portion of the trial dump was constructed using end-dumping and push end-dumping methods; therefore, the waste material was segregated during dump construction. The coarser fractions were observed from samples collected from the bottom of the dump, while the finer fractions were typically found in samples collected from higher sampling points. Figure 2 shows examples of material segregation observed on the slopes of the dump.

Geochemical Characterization

The average sulfur content for the blue waste samples was 2% with an average NAG value of 28 kg H_2SO_4/ton. The averages values of sulfur content and NAG for the red waste samples were 4.8 % and 38 kg H_2SO_4/ton, respectively. The average S content of both waste materials was similar to the average S content of the waste material used for constructing the test pads and leaching columns. Even though quality control was employed during dump construction, geochemistry results indicate misallocation of waste rock types within the dump. Details of the waste types that were actually placed in each panel is described by Miller et. al., (2003a).

Temperature Profile

Field monitoring showed that *in situ* temperatures in the trial dump increased rapidly, which suggests oxidation of sulfide minerals. High *in situ* temperatures were recorded continuously for a long period either at the bottom of the dump or near the dump surface. Both PAF waste rock types showed that the maximum temperature was reached in the first 18 – 36 months, and then started to decline. The highest temperature recorded was approximately 70° C. This finding is consistent with the evolution of leachate chemistry where the sulfate (SO_4^{-2}) peak concentration is achieved at the same period.

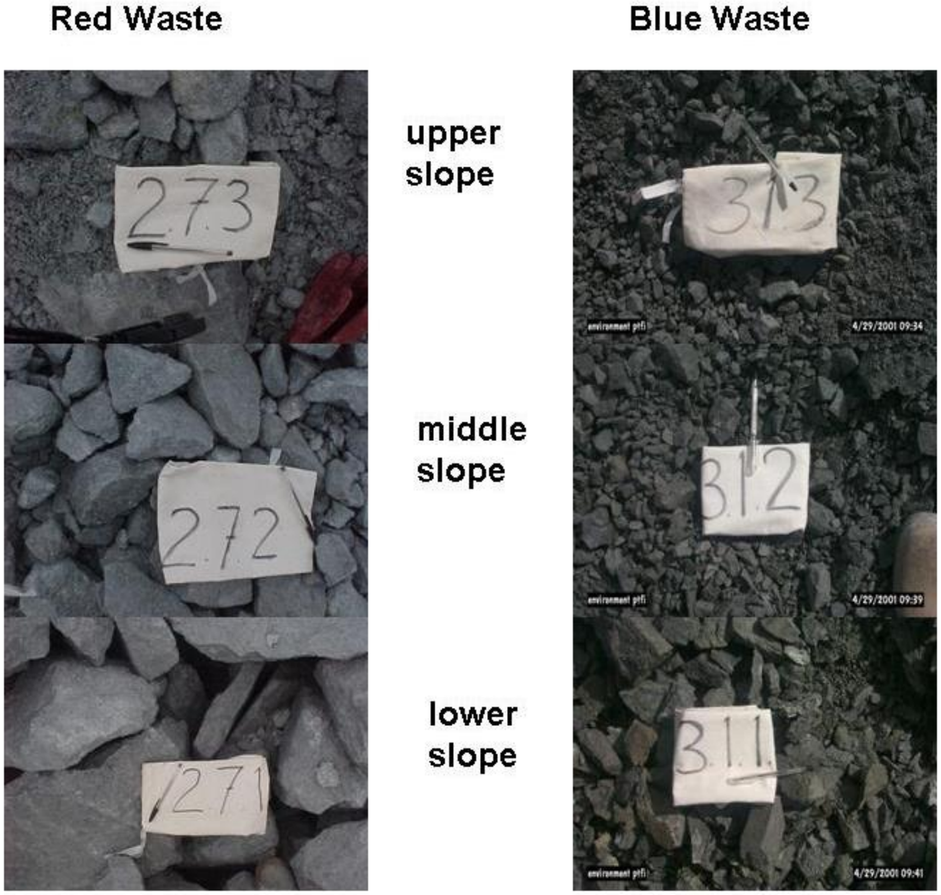

Figure 2. Photographs showing segregation of blue waste and red waste material observed on the slopes of the trial dump following construction.

Figure 3 shows the temperature evolution with time at the base of Panel 2. The high temperatures indicate that O_2 supply was sufficient at the bottom of the panel for oxidation of sulfide mineral to take place. The maximum *in situ* temperatures recorded in the blue and red waste materials were not significantly different.

Figure 4 shows the temperature profile measured at the bottom of panels containing blended and non-blended waste types. The measuring points are located five meters from the toe of the dump where the supply of atmospheric O_2 was not limited. As indicated on Fig. 4, the temperatures at the front of the panels constructed by blending blue waste and limestone are lower compared to those at the front of the panels constructed from blue waste only.

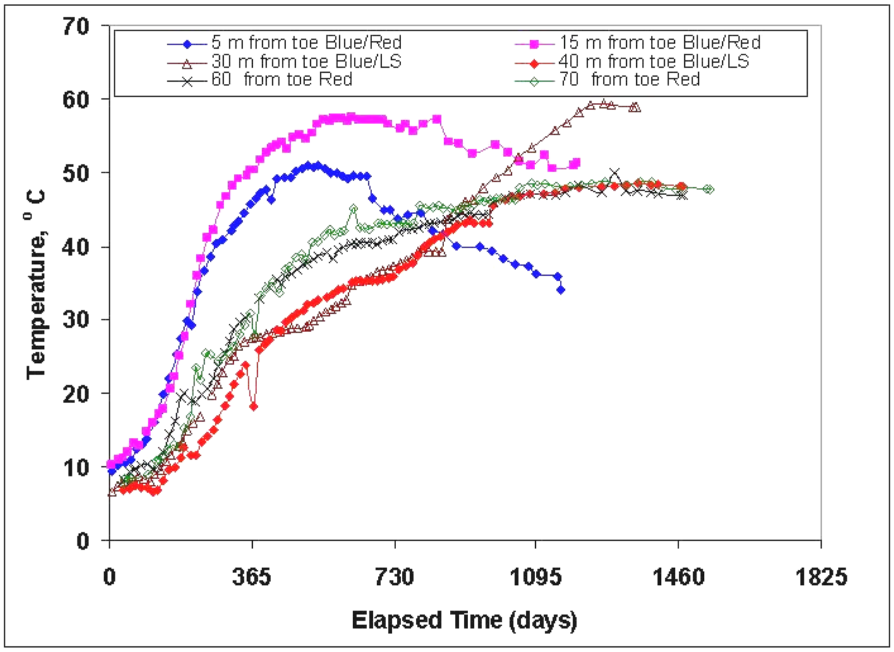

Figure 3. Temperature profile measured at the bottom of Panel 2.

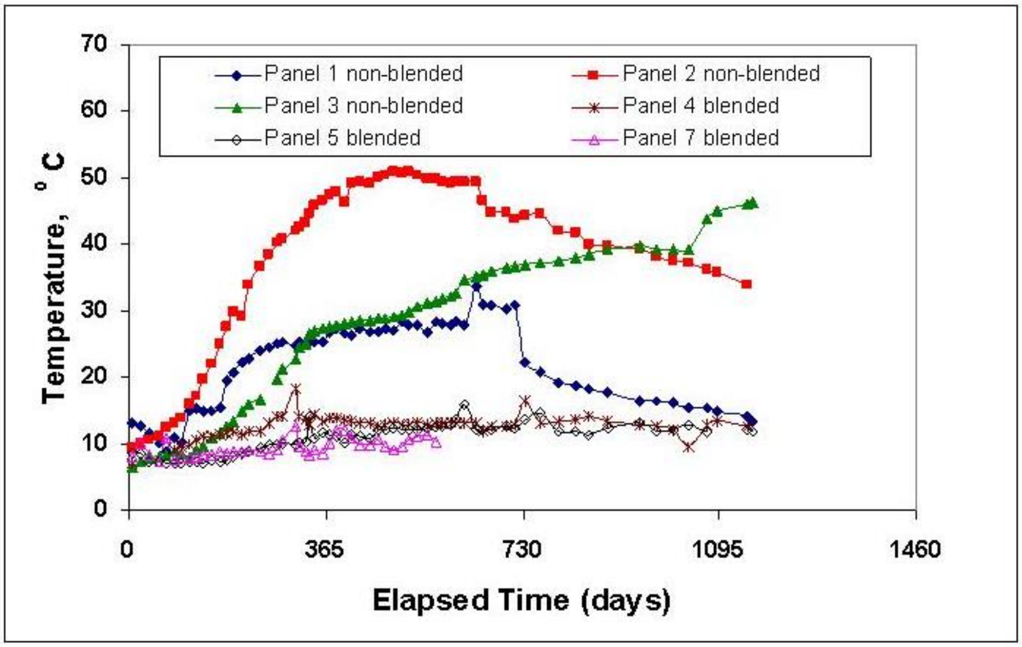

Figure 4. Temperature profile measured at the bottom of non-blended and blended panels.

Oxygen Profile

The O_2 concentration was recorded over most of the dump. Considering the waste rock is relatively reactive material, the available O_2 is believed to be consumed instantaneously. Since significant O_2 depletion was not recorded inside the dump, the results suggest little restriction of O_2 movement within the dump profiles. Higher O_2 concentrations were observed at locations closest to the base of the dump profile or near the dump surface as shown on Fig. 5. Both diffusion and advection mechanisms were involved in the O_2 transport.

Variability in O_2 concentrations were recorded within a single panel, and between different panels. Additionally, there were no apparent trends over time in any of the panels. Low O_2 concentrations were measured as shown on Fig. 6. In general, low values of O_2 concentration were measured at the back of the panel. The data suggest that O_2 consumption was higher than O_2 supply and did not have significant impact on the overall rate of sulfide oxidation.

The variation in O_2 concentrations may be the result of changes in barometric pressure when advection has a role in O_2 supply (Wels et. al., 2003). In order to understand the impact of the barometric pressure on O_2 concentration, a series of barometric pressure measurements were conducted using O_2 ports located along the bottom of Panel 4. Barometric pressure measurements were carefully observed prior to collection of air samples for the measurement of O_2 concentration. As shown on Fig. 7, results suggest the changes of barometric pressure in the interior of dump and ambient pressure were not significant, while a significant change in O_2

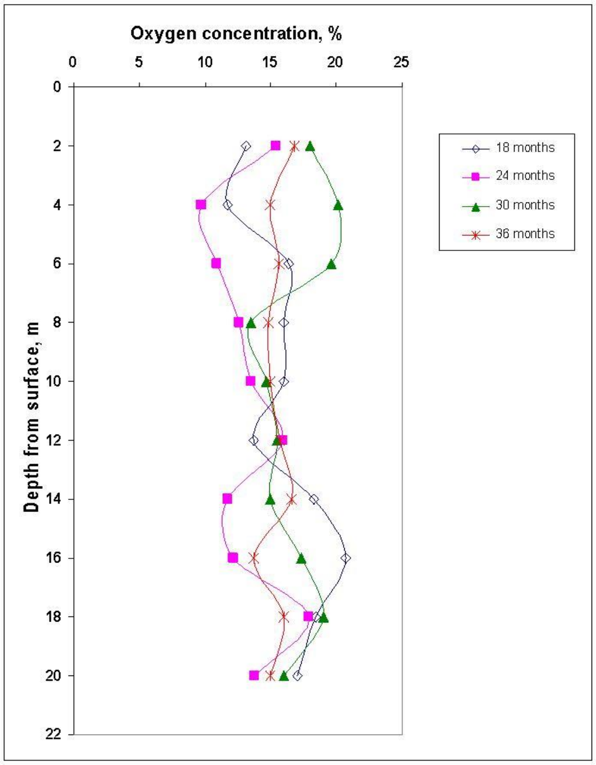

Figure 5. Oxygen concentrations recorded on the slope of Panel 6 located 31 m from the dump toe.

concentration was recorded at one measuring points. In this case, a minor correlation between change of O_2 concentration corresponded to a decrease in barometric pressure.

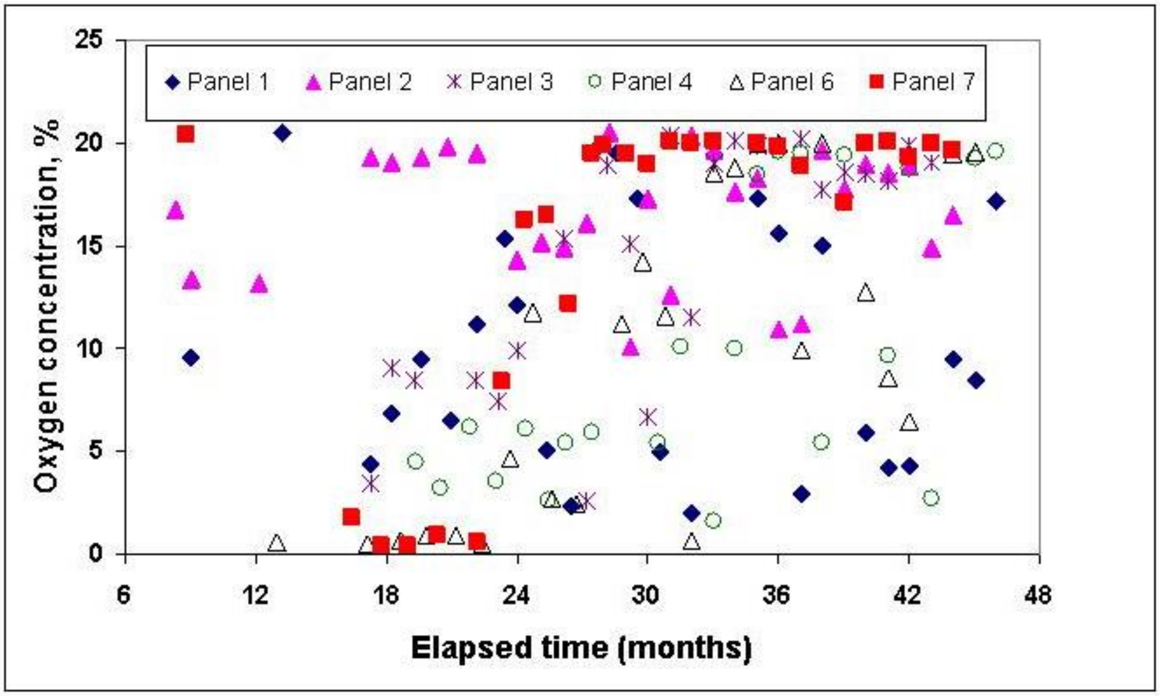

Figure 6. Oxygen concentration measured at the base near the back section of panels, located 65 m from the dump toe.

Limestone Blending

As shown on Fig. 8, the leachate chemistry showed that the blending using the truck-dumping method did not prevent acid generation because the leachate turned acidic within a short period. On the other hand, the pH of leachate that originated from the panel built with the stacker continued to remain above 6.

Layering of acid material and limestone was observed during the excavation of Panels 5 and 6 carried out during dump decommissioning. Where the truck-dumping blending method was utilized, pockets and layers of different material were formed. Most of the limestone materials are dominated by coarse particles and therefore, the limestone layers created a pathway for transporting O_2 and vapor. As a result, higher temperatures were recorded primarily at the thermistors buried on the slope of the dump for blended panels. These thermistors were buried on the face of Panel 5 and located 12.5 meters from the toe of the dump. The impact of blending limestone to reduce material reactivity was not significant because O_2 was still available and sulfide oxidation continued.

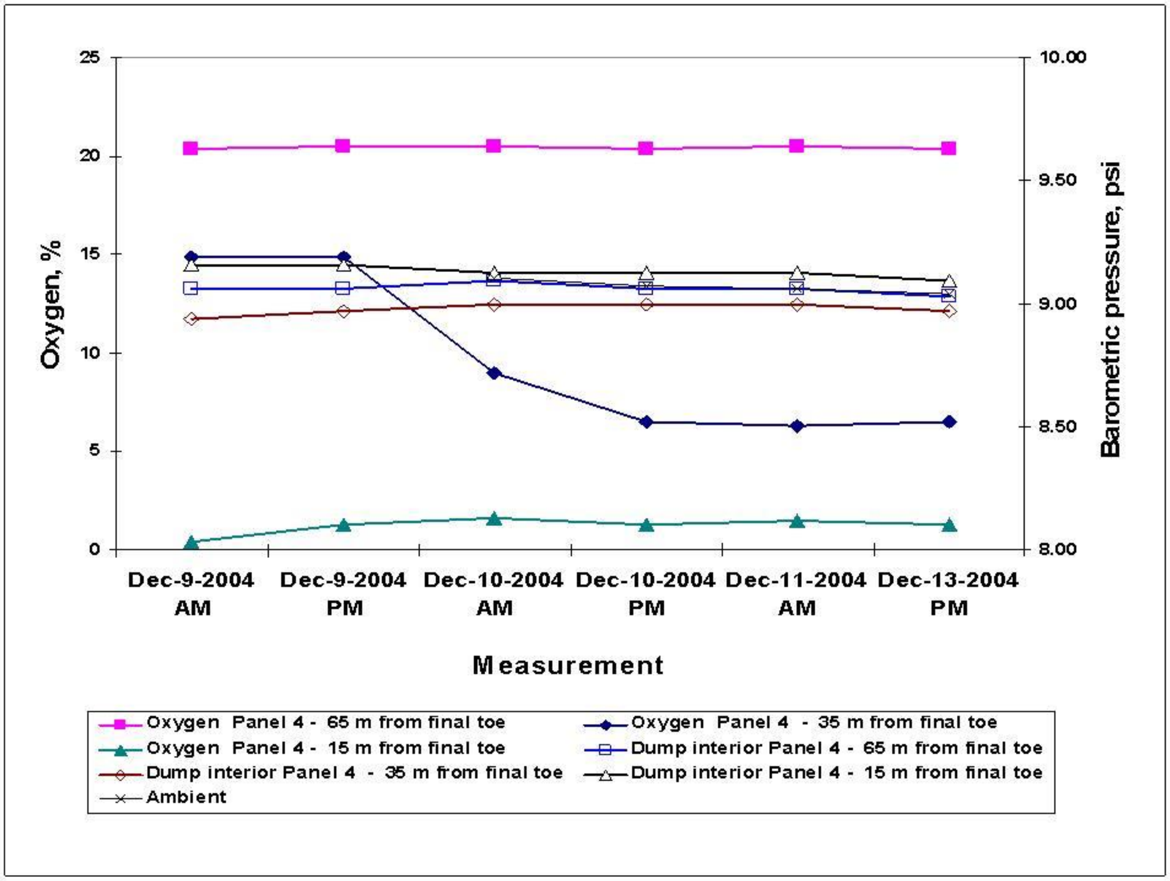

Figure 7. Barometric pressure and oxygen measurement inside the dump

Layering of acid material and limestone was observed during the excavation of Panels 5 and 6 carried out during dump decommissioning. Where the truck-dumping blending method was utilized, pockets and layers of different material were formed. Most of the limestone materials were observed to be dominated by coarse particles and therefore, the limestone layers created a pathway for transporting O_2 and vapor. As a result, high temperatures were recorded primarily at the thermistors buried on the slope of the dump for blended panels as shown on Fig. 9. These thermistors were buried on the face of Panel 5 and located 12.5 meters from the toe of the dump. The impact of blending limestone to reduce material reactivity was not significant because O_2 was still available and sulfide oxidation continued.

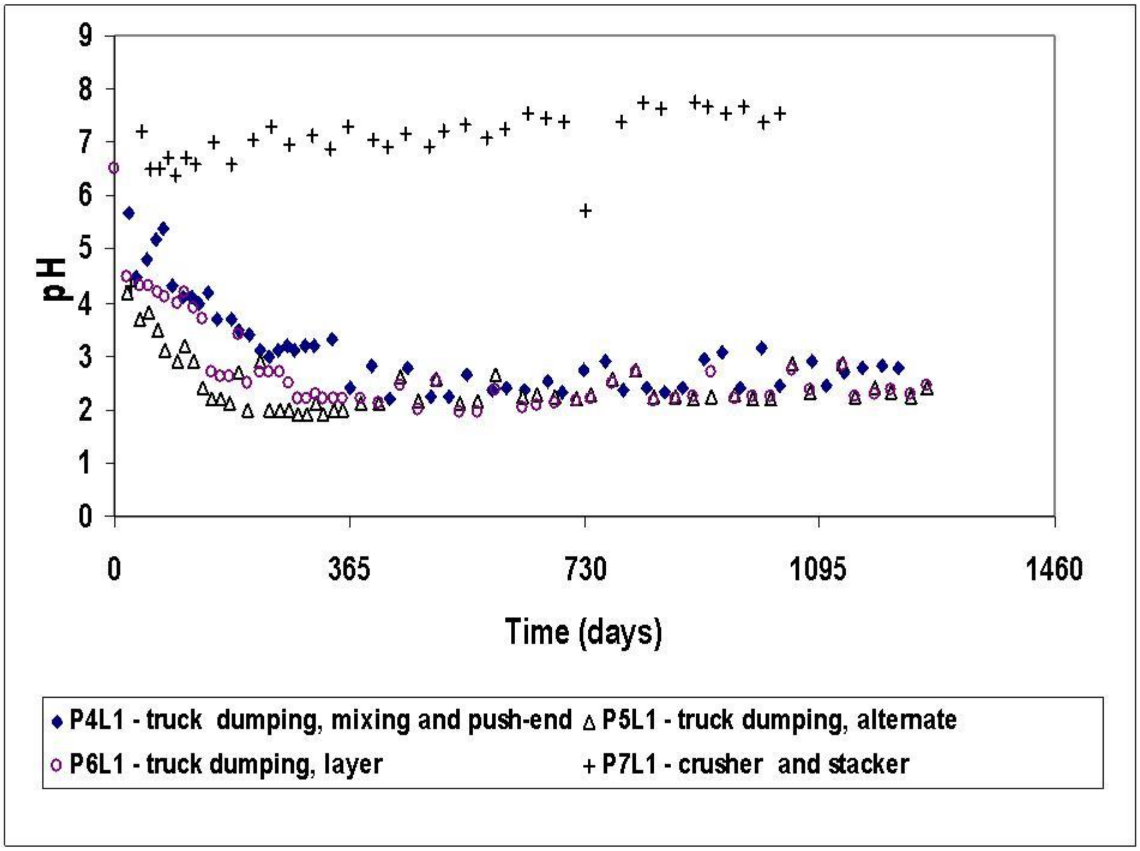

Figure 8. pH of leachate from blending of limestone and blue waste panels

In contrast, acidic conditions were not observed in the blended section of Panel 7 during decommissioning of the dump trial. The paste pH of samples collected from different locations had neutral pH. The limestone layer or the blue waste layer could not be distinguished because when the crushed limestone and the poker chip blue waste were placed using the stacker, well blended conditions were achieved. The armoring of sulfide minerals by limestone particles was also evident and oxidation products did not appear. As a result, *in situ* temperatures at the front of Panel 7 remained around 20° C, and the pH of the leachate stayed above 6.

Impermeable Cover

The impact of the HDPE geomembrane cover as a water infiltration barrier could be detected in the leachate volume recorded by the lysimeter as shown in Fig. 10. The volume of leachate was observed to decrease within two months following placement of the HDPE cover in August 2002. However, it was not possible to completely shutdown all infiltration of meteoric water because the slope of the dump was uncovered.

Oxidation products such as jarosite and $Fe(OH)_3$ were discovered under the HDPE geomembrane down to a depth of 1.5 m at the time of dump decommissioning (Fig. 11). Low paste pH was measured in samples collected near the surface. The same oxidation products were also observed underneath other high performance covers but to a lesser extent. Oxygen continued to enter into the panel by diffusion and/or advection from the face of the dump. In conclusion, it appears that the HDPE liner could not fully shut down the oxidation of sulfide mineral.

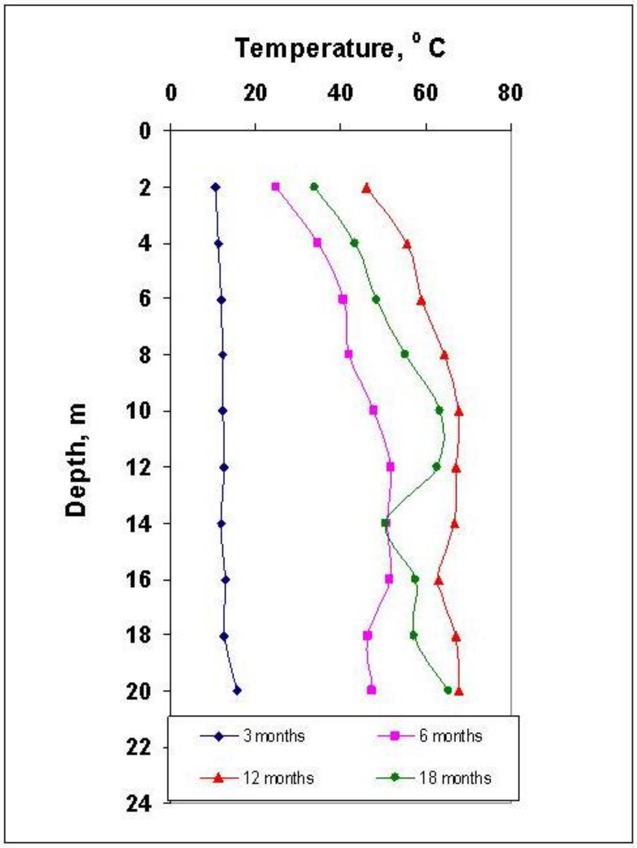

Figure 9. Temperatures recorded on the slope of Panel 5 located 12.5 m from the dump toe.

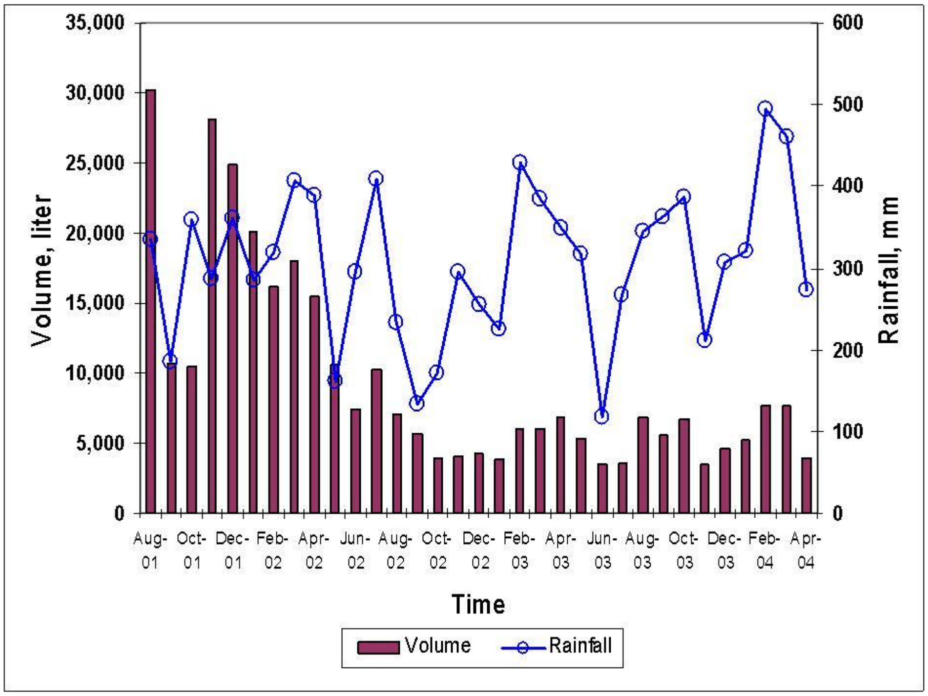

Figure 10. Leachate volume recorded from lysimeter 1 of Panel 1

Figure 11. Oxidation products discovered underneath the HDPE geomembrane cover during decommissioning of the trial dump.

A decrease in temperature was observed after the installation of the HDPE geomembrane cover for thermistors located at the base of the panel near the front and middle sections of the panel (Fig. 12). However, in situ temperatures at the base near the back of the panel increased. Based on these data, the temperature decline is considered to be ARD evolution rather than the impact of the HDPE cover.

The O_2 concentration did not change significantly, either in sampling points located at the face or the bottom of the dump. A decreasing trend in O_2 concentration was only detected at the sensor located 15 m from the dump toe and occurred a year after the HDPE geomembrane was installed.

Observation for the release of oxidation products, increases in temperature and lack of decline in O_2 concentrations suggest that air flow through the coarse rock at the base of the dump is a primary mechanism for O_2 transfer in the Grasberg waste rock dumps. Advection occurs both vertically and laterally. Clearly, O_2 transfer due to diffusion also occurs at shallow depths below the dump surface due to the coarseness of the waste rock material.

Conclusions

A rapid increase in temperature was recorded at the dump trial. The evolution of *in situ* temperatures coincided with increases in sulfate concentrations. Variations in *in situ* O_2 and temperature profiles observed within the panels were found to be dependent on the waste rock type, particle-size distribution and the method of waste rock placement.

Blending of acid waste rock with limestone using conventional truck-dumping methods seems to have limited benefit for minimizing ARD generation. The formation of limestone and acid rock layering due to segregation promotes O_2 path. On the other hand, blending of limestone through stacker dumping is more beneficial for the ARD control since the segregation between the limestone and acid rock does not occur. The result suggests a partial limestone blending for the dump that constructed by truck dumping methods not as effective. In general, the limestone excess that might be available in the future should be prioritized for limestone blending of a crusher/stacker dump and limestone cover.

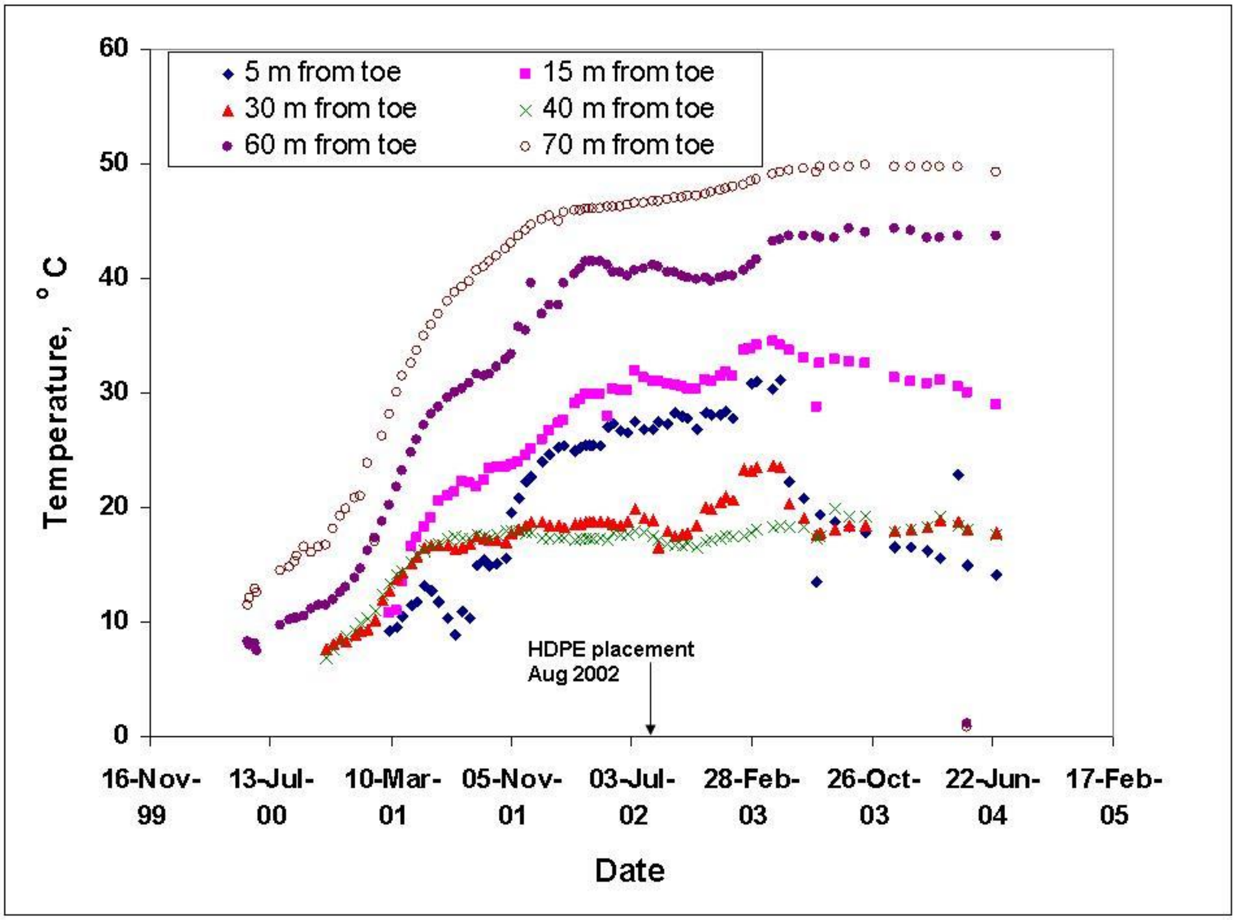

Figure 12. *In situ* temperatures measured at the base of Panel 1.

The application of a relatively impermeable surface cover was observed to have only a limited effect on O_2 concentrations within the profile of the waste rock dump. After two year of cover placement, the impact of cover on the ARD minimization is not yet significant. The effort to compact the cover will be the issue in application of the impermeable cover since the mine site has a wet climate almost a long the year. Therefore, application of a relatively impermeable cover might not be the practical option for minimizing the ARD in Grasberg mine.

In general, the placement of coarse rock layers was observed to promote O_2 transfer. All of these findings support the hypothesis that advection of air flow through the coarse rock/rubble zone at the base of the dump was a primary mechanism for O_2 transfer in the Grasberg waste rock dump trial.

The observations and information gathered from this study provide ongoing insight for understanding ARD generation mechanisms in full-scale waste rock dumps. The information gathered will also be useful for establishing an optimum dump design in consideration of long-term closure issues and ARD management at the Grasberg Mine.

Acknowledgements

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