

## Research Article

### Natural Cyanide Attenuation in a Tailings Dam in South-Western Ghana

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**Abstract:** The aim of this study was to investigate the viability of light and aeration (oxygen) in cyanide attenuation of gold tailings material in a tropical environment. It was established that under aeration conditions free cyanide ( $CN_F$ ) concentration reduced from  $200 \text{ mg/dm}^3$  to below  $0.03 \text{ mg/dm}^3$  in 60 h weak acid dissociable cyanide ( $WAD_{CN}$ ) concentration reduced from  $200 \text{ mg/dm}^3$  to  $6 \text{ mg/dm}^3$  after 60 h. Under non-aeration conditions  $CN_F$  concentrations reduced from  $200 \text{ mg/dm}^3$  to  $60 \text{ mg/dm}^3$  within 108 h, the pH reduced from 10.80 to 9.41.  $WAD_{CN}$  concentration decreased from  $200 \text{ mg/dm}^3$  to  $73 \text{ mg/dm}^3$  within 48 h. It then increased to  $150 \text{ mg/dm}^3$  after 60 h and then gradually decreased to  $100 \text{ mg/dm}^3$  after 144 h. It was inferred that volatilisation of HCN was the dominant mechanism accounting for degradation of  $CN_F$ . Degradation of complex cyanide species and this was enhanced by sunlight and aeration. It was concluded that natural cyanide attenuation is possible but the rate of degradation particularly for  $WAD_{CN}$  is not as fast as free cyanide. Hence it is not a suitable process for cyanide degradation in tropical environment.

**Keywords:** Aeration, attenuation, cyanide, natural, sunlight, tailings dam

## INTRODUCTION

Cyanide remains the most economically-viable and therefore widely used lixiviant for gold extraction worldwide (Yannopoulos, 1991). Residual cyanide occurs in gold tailings material as free cyanide, simple cyanide compounds and complex alkali-metal cyanides (Marsden and House, 2006). Moran (1999), Kidd (1988) and Hendrickson and Daignault (1973) report that cyanide in impoundment structures is either volatilised as hydrogen cyanide gas or seeps out slowly as ferrocyanide, a Strong Acid Dissociable (SAD) form, which is stable and has negligible impact on the environment. There are reports (Smith and Mudder, 1991) that cyanide will break down into other less toxic compounds and complexes when exposed to sunlight. However, others (Oudjehani *et al.*, 2002; Hendrix *et al.*, 1987) report that not all cyanide used in mineral processing breaks down quickly. They indicate that while many of the decomposition products such as cyanate and thiocyanate are generally less toxic than the original cyanide, they are known to be toxic to aquatic organisms and may persist in the environment for significant periods of time.

Metal-cyanide complexes that may form in tailings ponds are much less soluble than free cyanide and frequently form solids that precipitate within the tailings material. If these complexes are released into the near-surface environment, they may decompose at

varying rates, releasing cyanide into the geo-environment (Botz and Mudder, 2000). For example, some of the strong metal cyanide complexes, which do not break down even in the presence of strong acids will decompose when exposed to sunlight, releasing cyanide.

In many gold-processing plants, part of the cyanide-containing solution is recycled as process solution, while the remaining residual cyanide in the tailings effluent are attenuated naturally. While this technique can be effective in arid regions where high evaporation and low rainfall rates promote rapid natural cyanide degradation, it is doubtful if this will be effective in tropical regions where rainfall is high and evaporation rates are low. This study attempts to provide information on the influence of light and aeration (oxygen) on natural cyanide attenuation in a tailings dam particularly in tropical climates.

## MATERIALS AND METHODS

Tailings material was obtained from a gold mine in Ghana. The tailings material from this mine is impounded in a 10-ha structure. Tailings dam conditions were simulated using a 4-m HDPE poly pipe that was blanked with flanges at both ends to prevent leakages. An opening was made at the top of the pipe for light penetration, aeration and for sampling. To

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simulate non-aeration condition a similar pipe was constructed; the opening at the top was covered and only opened for sampling and thereafter covered. To study free cyanide ( $CN_F$ ) attenuation 10 L of a 200  $mg/dm^3$  cyanide solution at a pH of 10.80 conditioned with lime was poured into each of the HDPE poly pipes. Samples from both pipes were taken at 12-h intervals after start of experiment for pH measurement and free cyanide analysis.

To investigate the effect of Weak Acid Dissociable Cyanide ( $WAD_{CN}$ ) attenuation, 10 L of a 200  $mg/dm^3$  cyanide solution containing 150  $mg/dm^3$  Cu was poured into each of the HDPE poly pipes. Samples from both pipes were taken at 12 h intervals, the  $CN_F$  and Cu-cyanide complex concentrations were determined. To provide information on cyanide complexes degradation in a normal tailings dam 15 L of tailings material was filtered. The pH of the filtrate was 10.62,  $CN_F$  was 200  $mg/dm^3$  and  $WAD_{CN}$  was 139.6  $mg/dm^3$ . About 10 L filtrate was poured into each the of HDPE poly pipe. Samples from each were taken at 12 h intervals for analyses. The daily average day and night temperatures were 32°C and 26°C, respectively.

**Cyanide analyses:** Free cyanide concentration was determined by silver nitrate titration using rhodamine as indicator. The concentration of  $WAD_{CN}$  was determined using the Picric acid method. Solutions pH was measured using an OAKTON pH 510 series, while Dissolved Oxygen (DO) levels were measured with a Digital-Temp-O<sub>2</sub>-Mat-Model 4000.

## RESULTS AND DISCUSSION

The results of the experimental work are presented in the following sections:

**Free cyanide attenuation under aeration condition:** The results of  $CN_F$  attenuation under aeration and non-aeration conditions are presented in Fig. 1 and 2 respectively. In Fig. 1 it is observed that a sharp reduction in  $CN_F$  concentration from 200  $mg/dm^3$  to 80  $mg/dm^3$  occurred within the first 12 h. Thereafter, there was a gradual reduction until the  $CN_F$  was completely attenuated at 60 h. The results show that a 200  $mg/dm^3$   $CN_F$  from solution was naturally attenuated within 60 h. Within this period the pH declined from about 10.80 to 9.41 suggesting that volatilization may be the route of

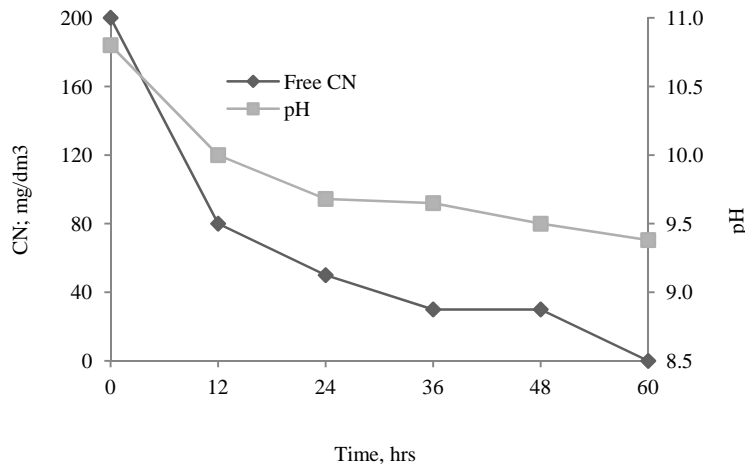


Fig. 1: Variation in free CN- concentration and pH values under aeration attenuation

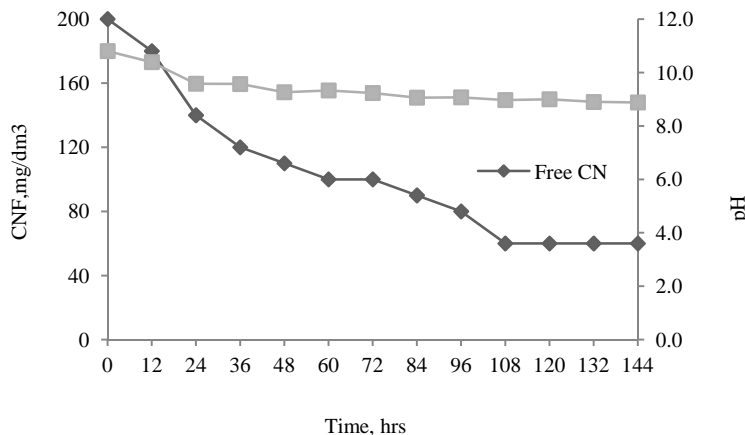


Fig. 2: Variation in CN- concentration and pH under non-aeration attenuation

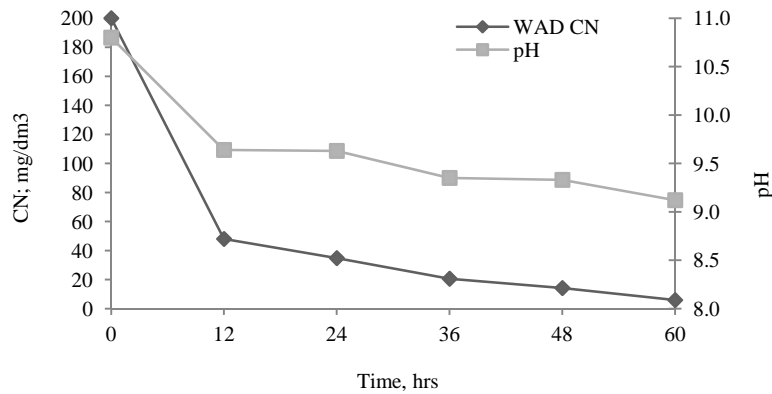


Fig. 3: Variation in WAD<sub>CN</sub>, vs. and pH values under aeration condition

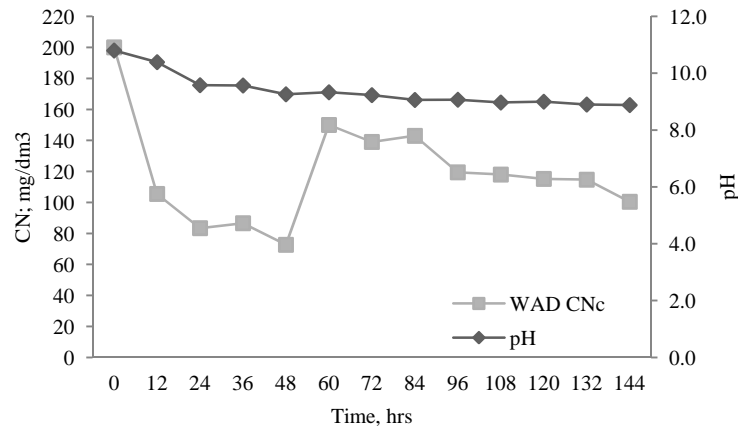


Fig. 4: Variation in WAD<sub>CN</sub>, vs. and pH values under non-aeration condition

attenuation of CN<sub>F</sub> under the experimental conditions. This result confirms results of similar work by Lorosch (2001).

From Fig. 2 it can be seen that there was a gradual reduction in CN<sub>F</sub> from 200 mg/dm<sup>3</sup> to 60 mg/dm<sup>3</sup> within 108 h and thereafter there was no significant reduction. The results show that a 200 mg/dm<sup>3</sup> CN<sub>F</sub> solution could not naturally attenuate under non-aeration conditions probably due to the absence of aeration and light. The above observation confirms the work of Simovic *et al.* (1985) that oxygen and light are essential for natural attenuation of cyanide in tailings materials.

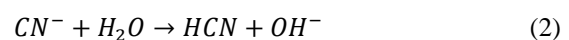
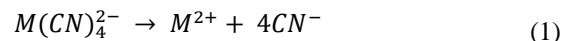
**Attenuation of copper cyanide complexes (WAD<sub>CN</sub>):** Results of copper-cyanide complex attenuation are presented in Fig. 3 and 4 respectively. It can be seen that that under aeration condition there was a reduction in WAD<sub>CN</sub> from 200 mg/dm<sup>3</sup> to 6 mg/dm<sup>3</sup> after 60 h. The pH decreased from 10.8 to 9.1 within the same period. There was no free cyanide after 60 h.

Under non-aeration conditions (Fig. 4) WAD<sub>CN</sub> concentration decreased from 200 mg/dm<sup>3</sup> to 73 mg/dm<sup>3</sup> within 48 h. It then increased to 150 mg/dm<sup>3</sup>

after 60 h and then gradually decreased to 100 mg/dm<sup>3</sup> after 144 h. Within the same time interval pH decreased from 10.80 to 9.26 and then rose to 9.33 before gradually reducing to 8.88 after the 144 h. Thus, it can be inferred that under non-aeration conditions WAD<sub>CN</sub> is not attenuated easily confirming the assertion that light is important in natural cyanide degradation.

**Attenuation of cyanide species in an existing tailings dam:** Results of attenuation of cyanide species in an existing tailings liquid phase are presented in Fig. 5 and 6 under aeration and non-aeration conditions respectively. Under aeration conditions (Fig. 5) the CN<sub>F</sub> decreased gradually from 200 mg/dm<sup>3</sup> to below detection within 84 h. For WAD<sub>CN</sub> cyanide a zigzag pattern was observed (Fig. 6)

It is possible that during the night attenuation of WAD<sub>CN</sub> cyanide takes place and during the day WAD<sub>CN</sub> cyanide concentration increases again. The mechanism of attenuation can be depicted as follows:



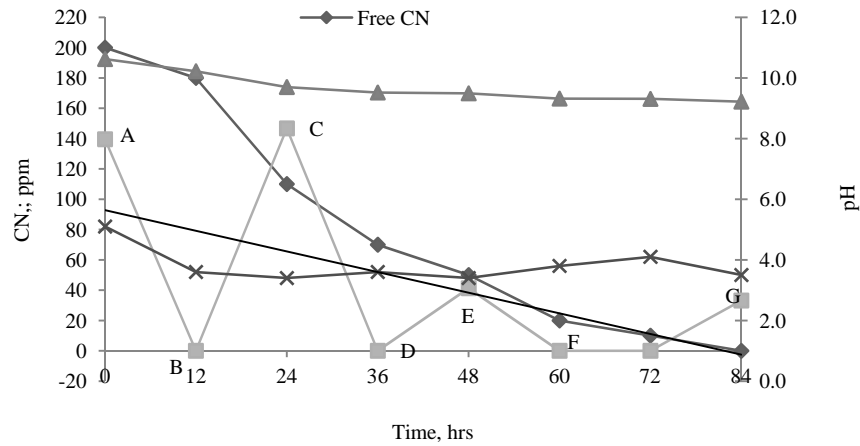


Fig. 5: Variation in WAD<sub>CN</sub>, vs. and pH, DO in an existing tailings dam under aeration condition

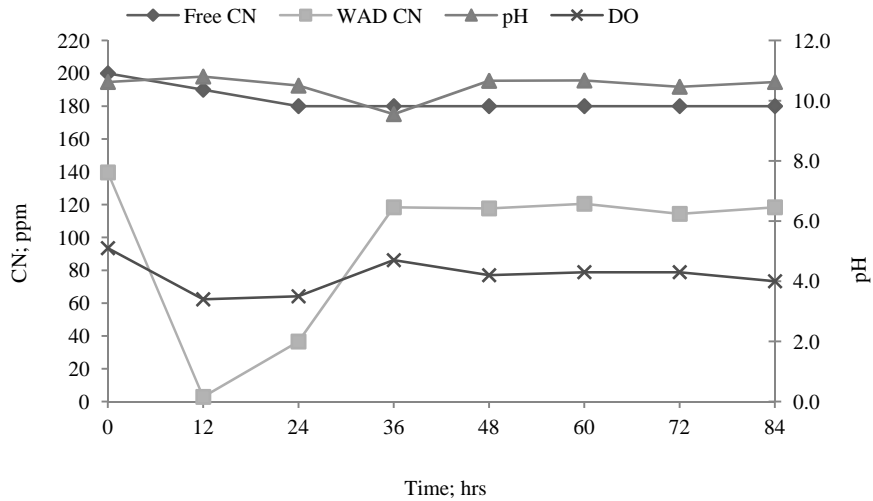


Fig. 6: Variation in WAD<sub>CN</sub>, vs. and pH, DO in an existing tailings dam under aeration condition

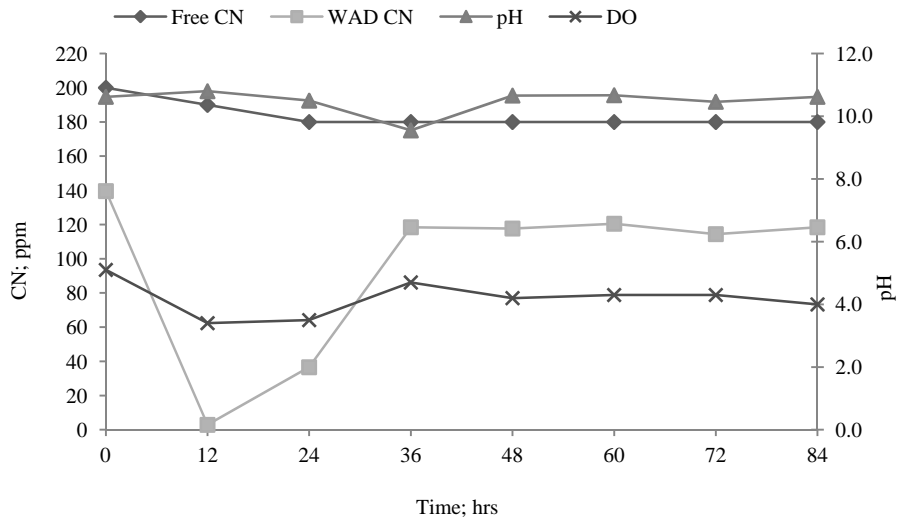
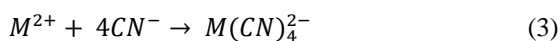


Fig. 7: Variation in free CN<sup>2</sup>, WAD<sub>CN</sub>, vs. and pH, DO in an existing tailings dam under non-aeration condition



During the day dissociation of the  $WAD_{CN}$  complex occurs,  $CN_F$  then hydrolyses. During the night depending on the available  $CN_F$ ,  $WAD_{CN}$  cyanide is formed again hence the zig-zag pattern. This trend was not observed in the case of closed system. Hence light and oxygen enhance attenuation of  $WAD_{CN}$  species. From Fig. 7 points B, D, F and G show the trend of  $WAD_{CN}$  attenuation during the night where there was absence of light, while C, E and G shows the day condition where the  $WAD_{CN}$  concentration increases again in the presence of light and oxygen.

### CONCLUSION

The following conclusions can be drawn from the studies:

- Natural attenuation of cyanide species in alkaline medium is accompanied by reduction in pH. It was found out that pH declined from 10.81 to 9.01. Under this condition free cyanide is attenuated within 60 h.
- Oxygen and sunlight are essential for natural attenuation of cyanide species. The study revealed that natural attenuation rapidly takes place during the day and during the night free cyanide from undecomposed cyanide may re-complex with metal ions in solution, thereby retarding attenuation of  $WAD$  cyanide in tailings dams.
- Natural attenuation of cyanide is not a suitable process for cyanide degradation in tropical environment.

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