

CYANIDE ATTENUATION MODELING FOR THE NEWMONT GOLDEN RIDGE LTD AKYEM PROJECT

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ABSTRACT

Newmont Golden Ridge Ltd, the Ghanaian subsidiary of Newmont Mining Corporation, has operated the Ahafo gold mill, a 7.5 Mt/a Carbon-in-Leach (CIL) cyanidation plant near Sunyani, Ghana since 2006. The gold-bearing ore zones range from saprolite to unweathered primary rock. Ores are free milling, although they contain minor amounts of gold-bearing euhedral pyrite. Cyanide consumption is low and residual cyanide in the CIL tailing slurry is typically comprised of free cyanide with slight amounts of weak and dissociable cyanide (WAD) metal cyanide complexes. As a member of the International Council on Mining & Metals (ICMM) and a signatory to the International Cyanide Management Code, Ahafo operates under the mandate to prevent wildlife mortality by operating the milling facilities to discharge less than 50 mg/L weak and dissociable (WAD-remove) cyanide at the discharge spigots into the tailing storage facility (TSF).

CIL tailings slurry feeds a two-stage countercurrent decantation (CCD) circuit. Tailing solids and solution flows are opposed whereby solids advance from the first thickener to the second and then out to the TSF while wash solution (varying proportions of raw water and TSF decant water) is introduced into the second unit and the second thickener overflow is routed to the first thickener and the first thickener overflow is routed to the plant process water pond and is reused. The objective of the CCD wash circuit is to lower the CIL tailings WAD cyanide level to less than 50 mg/l. Actual mill facilities target WAD cyanide discharge concentration is 35 mg/l to allow for circuit upsets. Thus a reduction in the WAD cyanide level of about 60% is achieved.

Natural cyanide degradation in the TSF was chosen as the appropriate cyanide destruction method. Because no cyanide destruction circuit is incorporated into the plant and TSF decant solution is utilized as a portion of CCD wash water, it was crucial to estimate the extent of degradation. Newmont developed a cyanide attenuation model to estimate the residual WAD cyanide concentration in reclaim water. After start-up the model was calibrated by comparing model output to actual operating data collected from Ahafo during the period of 2007 through 2010.

A second metallurgical circuit of similar design is under construction at Akyem, located about 120 km northwest of Accra, Ghana. For Akyem, a different TSF design was required that reduced the decant solution retention time, raising concerns that decant solution would contain WAD cyanide concentrations too high to reuse and cyanide destruction would be necessary to meet discharge limits. The calibrated cyanide attenuation model developed for Ahafo has been extended to Akyem to estimate cyanide levels in final tailings and in the TSF decant pond. In this manner, Newmont leveraged operating data from an existing site to estimate performance expected for a nearby similar site. Results from the work suggest final tailings at Akyem will contain less than 50 mg/L WAD cyanide and decant water in the TSF will contain less than 15 mg/L WAD cyanide.

INTRODUCTION

Project Background

Newmont and its wholly owned Ghanaian subsidiary Newmont Golden Ridge Limited (NGRL) are developing the Akyem project, a green-field, open-pit gold mining operation located 120 kilometers northwest of the capital city of Accra and approximately 190 kilometers southeast of Newmont's existing Ahafo mine operation. Figure 1 – Vicinity Map shows the locations of Ahafo and Akyem. The technical scope of the project includes engineering, construction, commissioning, start-up, and operation through to commercial production. The project scope also encompasses wide-ranging community development and social responsibility efforts to support local and regional goals.



Figure 1: Vicinity Map

Gold production from Akyem represents a significant addition to total production for the African region and the new mine leverages off of the existing Newmont business infrastructure. The present 240 t (7.7 Moz) gold reserve, contained in a single deposit, will be mined over approximately sixteen years, with start-up scheduled for late 2013. Target mill throughput is about 7.9 Mt/a. Nominal gold head grade is expected to be approximately 1.8 g/t (0.052 ounce per ton) over the mine life and annual gold production will vary between 14.4 t to 15.5 t (400 k to 500 k ounces).

Ore Characteristics

Ore comes from surface saprolite, a near-surface transition zone, and primary unweathered rock. Approximately four Mt of saprolite, eleven Mt of transition ore, and eighty Mt of primary ore feeds the mill. Predominate domains are saprolite, brecciated rock, altered mylonites, and metavolcanics. Ores are clean with low levels of deleterious elements such as arsenic, mercury, and copper. Gold deportment is primarily free gold with up to fifteen to twenty percent recoverable by gravity. Gold recovery is expected to range between 88% (primary ore) and 93% (saprolite).

Quartz, plagioclase, and muscovite dominate the Akyem mineralogy. In the saprolite zone, kaolinite, iron-rich chlorite, goethite (plus amorphous iron oxides) and occasionally calcite are present. In the primary ore ankerite ranges from fifteen to twenty-five percent, whereas siderite is intermittent throughout the deposit, typically ranging between one and four percent. Pyrite appears in most composites ranging from trace to six percent. No swelling clays are noted.

Process Details

The planned mill facilities for Akyem are typical for Ghanaian milling operations. Ore is mined from the single pit and is trucked to the primary crushing facility that is located approximately two km from the process facilities. Figure 2: Site General Arrangement shows the layout of the site with the two cell tailing storage facility, the processing facilities, and the mine.

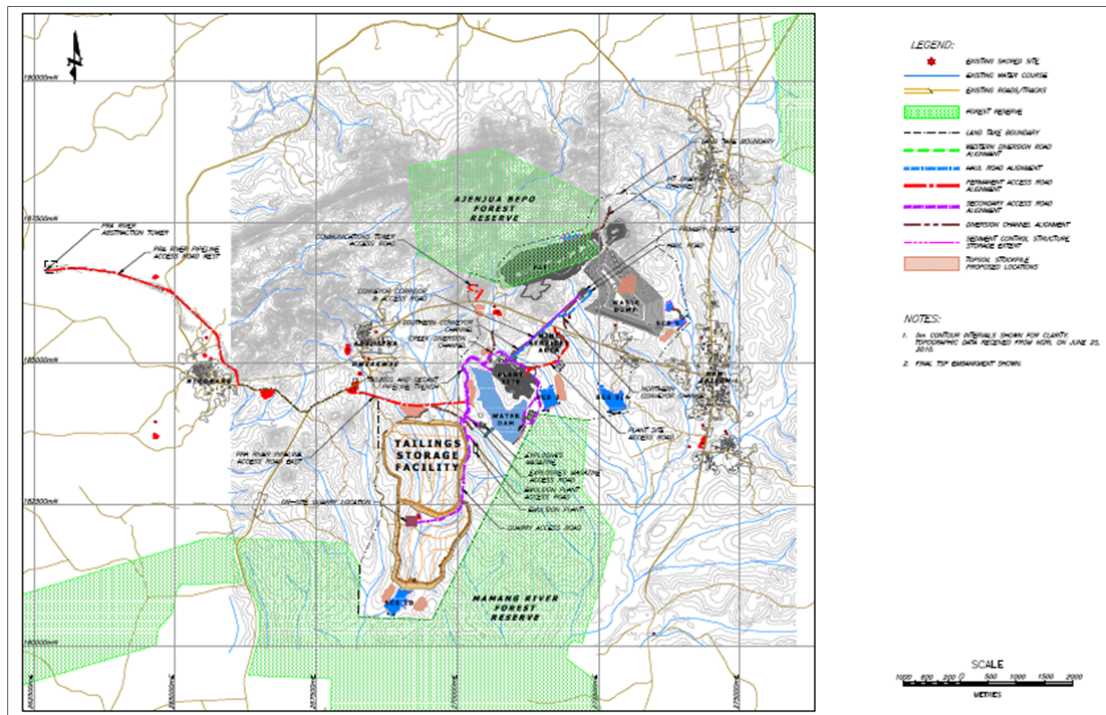


Figure 2: Site General Layout

Saprolite is fed by front end loader into a dedicated system with an MMD sizer and fed onto the 1000 mm steel-cord overland conveyor fitted with two 400-kW (298 HP) drives. Primary crushing through a Metso 5475 gyratory crusher prepares the feed to $P_{80} < 150$ mm (-6") prior to feeding onto the overland conveyor.

Ore discharges to a mill stockpile designed with three days of total capacity. Ore is withdrawn from the stockpile by three reclaim feeders onto the 1000 mm wide SAG mill feed belt. The grinding circuit consists of a 10.36 m diameter x 5 m (34' x 16.4') EGL 13 MW SAG mill and a 7.31 m diameter x 10.9 m (24' x 39') 13 MW ball mill in closed circuit with ten 660-mm (26") diameter cyclones. The final product is $P_{80} < 75\mu\text{m}$. SAG mill discharge is discharged over a pebble screen where coarse material is scalped and conveyed to a Metso MP800 pebble crusher. Cyclone underflow is recycled to grinding.

Cyclone overflow feeds a 42 m (137' diameter) pre-leach thickener. Pre-leach thickener underflow is pumped to eleven 18.6 m diameter x 15.8 m (60' x 52.4') agitated Carbon-in Leach (CIL) leach tanks fitted with 132-kW (98 HP) agitators. Design retention time provided is twenty-four hours. Thickener overflow is sent to the process solution pond. Loaded carbon is advanced to a carbon stripping system and stripped pregnant solution is transferred to electrowinning. Gold from electrowinning is smelted to produce doré. The processing facilities are based on the Ahafo processing facility design with minor modifications from lessons learned. Figure 2 – Processing Flowsheet illustrates the major process flows.

Loaded carbon is stripped in an Anglo American Research Laboratory (AARL) elution circuit and electro-won to produce doré. CIL tailing slurry is pumped to two 42 m (137' diameter) counter-current-decantation (CCD) thickeners and thickened underflow is pumped to the two-cell TSF which has a total capacity exceeding 114 Mt that allows for future additional material to be stored.

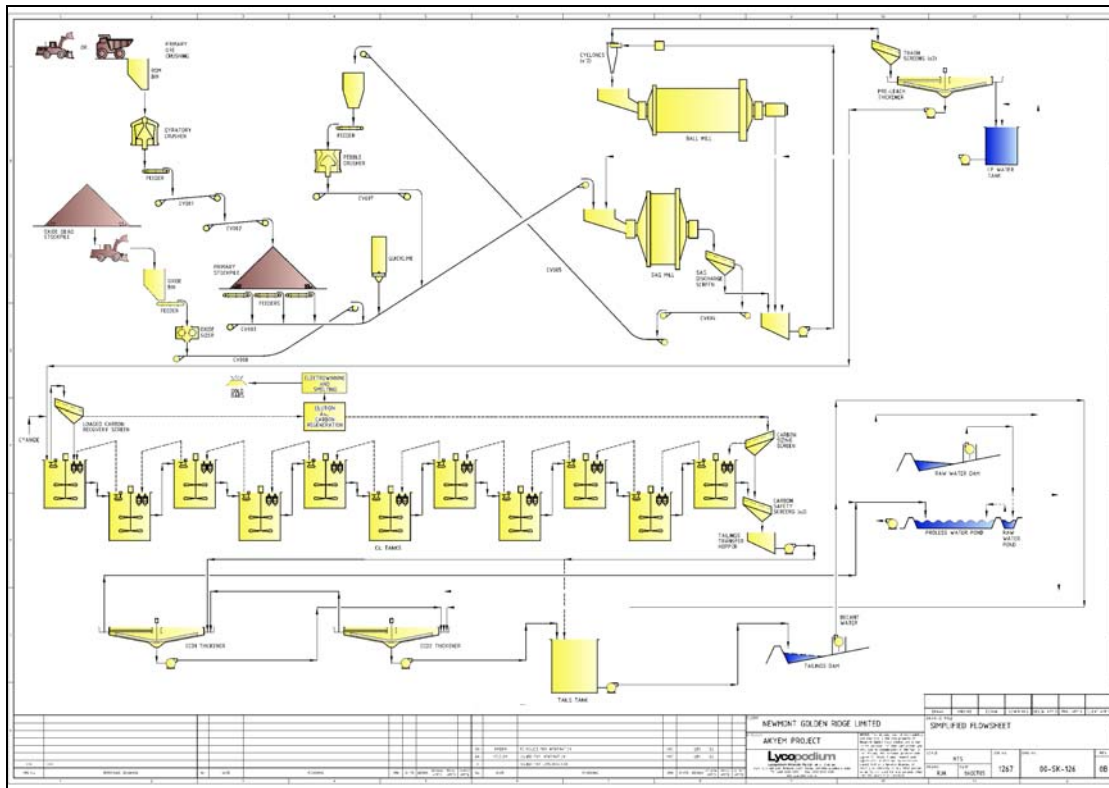


Figure 2: Process Flowsheet

The two cell TSF is designed as a cross-valley storage impoundment that progressively becomes a four-sided paddock. Slurry will be delivered to the TSF at 48% to 52% w/w solids. As part of the overall water management system, a separate water storage dam is constructed. Each facility has decant and return solution pumping to recycle decant solution and minimize raw water consumption.

Figure 3: Akyem Two Cell Tailing Storage Facility illustrates the extent and orientation of the facility.

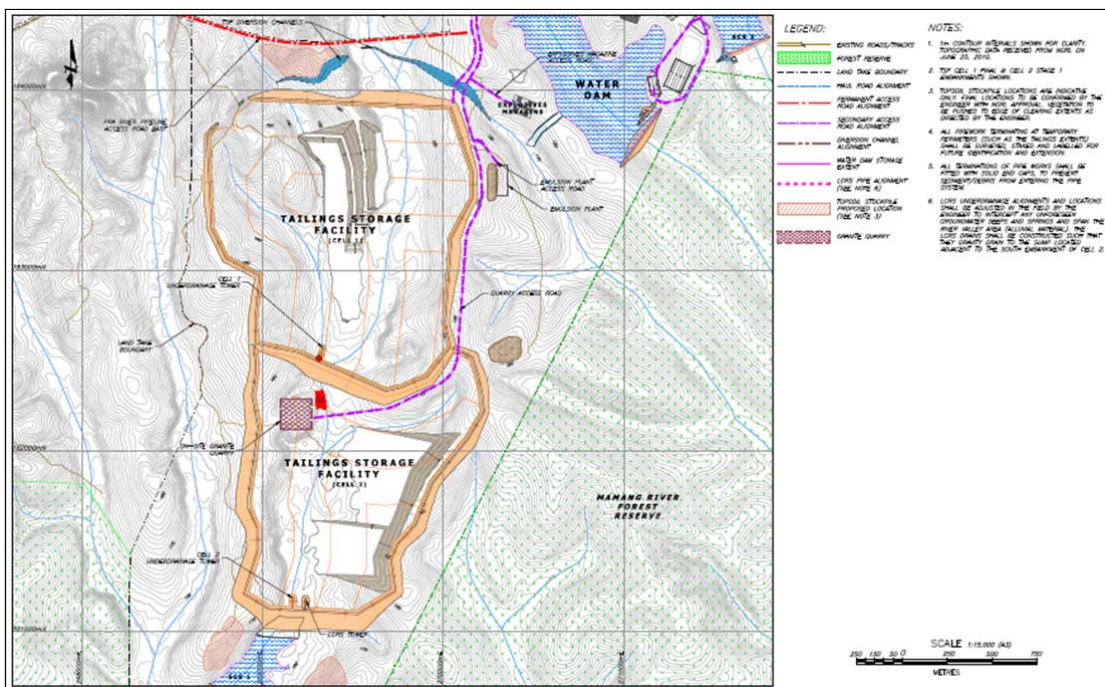


Figure 3: Two Cell Tailing Storage Facility

Climatology

The climate of Ghana is tropical and temperatures vary seasonally. At the site two rainy seasons occur from April to July and from September to November. Akyem precipitation statistics are shown in Table 1 – Akyem Precipitation and Evaporation. In most years, net evaporation barely exceeds precipitation. Relative annual humidity averages 60%.

Table 1: Akyem Precipitation and Evaporation

Afosu Data Month	Average Rainfall (mm)	1 in 25 Wet Rainfall (mm)	1 in 100 Wet Rainfall (mm)	1 in 100 Dry Rainfall (mm)	Average Evaporation (mm)
January	13	22	55	0	162
February	41	37	26	14	160
March	114	83	95	51	159
April	132	188	175	169	132
May	171	115	347	80	121
June	208	130	219	104	113
July	151	257	321	71	97
August	84	128	90	86	93
September	176	461	455	135	92
October	186	332	165	183	109
November	66	138	139	36	108
December	33	11	53	0	125
Annual Total	1,376	1,901	2,141	930	1,471

* Class A Pan Data

INTERNATIONAL CYANIDE MANAGEMENT CODE

Newmont is a signatory to the International Cyanide Management Code (ICMC)¹, a voluntary industry program for the gold mining industry to promote:

- Responsible management of cyanide used in gold mining
- Enhance the protection of human health, and
- Reduce the potential for environmental impacts.

Companies that become signatories to the Code must have their operations audited by an independent third party to demonstrate their compliance with the Code. The Code provides standards of practice and guidance for measuring and monitoring compliance. One section, Standard of Practice 4.4, requires companies to “*Implement measures to protect birds, other wildlife and livestock from adverse effects of cyanide process solutions.*”

The Code provides guidance regarding this standard. “*Process solutions impounded in a Tailing Storage Facility (TSF), leaching facilities and solution ponds can attract birds, wildlife and livestock. A concentration of 50 mg/l WAD cyanide or lower in solution is typically viewed as being protective of most wildlife and livestock mortality other than aquatic organisms. Where birds, wildlife or livestock have access to water impounded in TSFs, leaching facilities or solution ponds, operations should implement measures to limit the concentration of WAD cyanide to a maximum of 50 mg/l. Various treatment methods are available to reduce cyanide concentrations in mill effluents to achieve this concentration.*”

Newmont applies the ICMC-recommended guidance to the tailings discharge spigot points.

¹ “International Cyanide Management Code For the Manufacture, Transport and Use of Cyanide in the Production of Gold” (Cyanide Code), www.cyanidecode.org.

CYANIDE ATTENUATION MODELING

Cyanide attenuation is a complex process and may include mechanisms such as volatilization, oxidation, reduction, photolysis, hydrolysis, precipitation, complexation, biologically mediated reactions and sorption. Cyanide compounds are naturally attenuated when present in open ponds. The rate of attenuation is dependent on local weather conditions, pond geometry, solution chemistry, and pond inflows and outflows. With solutions exposed to the atmosphere, the predominant route of cyanide loss is currently believed to be hydrogen cyanide (HCN) volatilization². The overall effect of cyanide attenuation is the lowering of cyanide concentrations below what would occur through dilution alone.

Hydrogen Cyanide Volatilization

It has been found that HCN volatilization from solution occurs according to a first order rate equation, which means the rate of HCN volatilization is directly proportional to the HCN concentration in solution. Mathematically this is represented by:

$$(1) \quad \frac{d[HCN]}{dt} = -K[HCN]$$

where [HCN] represents the concentration of HCN in the impoundment decant solution, t is time and K is the first order rate constant. For a pond which is assumed to be completely mixed, the rate constant K is given by:

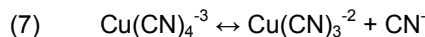
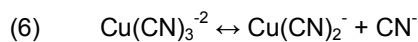
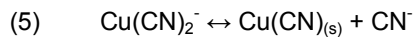
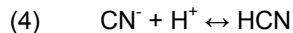
$$(2) \quad K = \left(\frac{A}{V}\right)K_v$$

where A is the surface area of the pond exposed to the atmosphere, V is the pond volume and K_v is the first order volatilization rate constant for HCN. Substituting this into Equation (1) yields:

$$(3) \quad \frac{d[HCN]}{dt} = -\left(\frac{A}{V}\right)K_v[HCN]$$

A key component of the cyanide attenuation model is the calculation of the HCN concentration in the pond solution. The HCN concentration in solution is required in order to utilize Equation (3) and is affected by the solution temperature, pH and the concentrations of metals and cyanide. The solution HCN concentration is estimated by calculating the detailed metal-cyanide equilibria conditions for cyanide, copper, iron, nickel and zinc in pond solution. These metals are the primary constituents present in the tailings slurries with respect to total and WAD cyanide complexation.

As an example, the equilibria relations for free cyanide and the copper-cyanide compounds are shown below. Analogous relations exist for iron, nickel and zinc and these metals were also included in equilibria calculations.



Over time as HCN volatilizes from solution, the metal-cyanide equilibria shifts and must be recalculated according to the reduced concentrations of metals and/or cyanide. Metals precipitation from solution as insoluble metal-hydroxide and metal-cyanide compounds was estimated by considering their respective solubility products.

² Schmidt et al. 1981; Simovic et al. 1985; Botz and Mudder 2001

Iron-Cyanide Photolysis

Due to the relatively high stability of iron-cyanide complexes, they are only slightly dissociated under ambient conditions, except when exposed to ultraviolet and visible radiation (sunlight). When exposed to sunlight, iron-cyanide complexes slowly dissociate through photolysis reactions to yield free cyanide. In the absence of sunlight, iron-cyanide complexes are stable and naturally attenuate at a very slow rate. The photolysis rate equation for iron-cyanide is:

$$(8) \quad \frac{d[Fe - CN]}{dt} = -K_p[Fe - CN]$$

where [Fe-CN] is the concentration of iron-cyanide in solution and K_p is the photolysis rate constant. The photolysis rate constant is a function of sunlight intensity, pH, temperature, iron-cyanide concentration and pond depth. Sunlight intensity in turn is a function of latitude, elevation, time of year and ice cover on the pond. The dissociation of iron-cyanide through photolysis yields free cyanide, which can then re-complex with other metals such as copper or volatilize from solution as HCN gas according to Equation (3). Cyanide can form complexes with iron in both the ferrous and ferric forms, however for oxidized surface waters, the ferric complex normally dominates.

Equations (3) and (8) are the fundamental relations used to calculate the rate of cyanide attenuation in a pond due to iron-cyanide photolysis and HCN volatilization. When used in conjunction with the pond water balance and cyanide mass balance, the resultant concentrations of total and WAD cyanide in the pond can be calculated. The general structure of the cyanide attenuation model utilized in this work is discussed by Botz and Mudder (2000).

MODEL CALIBRATION PARAMETERS

The cyanide attenuation model utilized for the Akyem project was the original Ahafo model calibrated using actual operating data. The Ahafo and Akyem projects are similar with respect to ore geochemistry, metallurgical processing, weather conditions and tailings disposal. The model was calibrated by introducing three empirical parameters into the attenuation calculations:

1. An empirical parameter (F1) was introduced into the cyanide attenuation model to adjust the value of the hydrogen cyanide volatilization rate constant (K_v) as follows:

$$(9) \quad K_v = K'_v \times F_1$$

where K'_v is the unadjusted hydrogen cyanide volatilization rate constant calculated by the cyanide attenuation model (see Equation (3)). A value of zero for the F1 parameter would eliminate hydrogen cyanide volatilization as an attenuation mechanism, while a value greater than one would increase the volatilization rate above that calculated using a generalized correlation. A value of one for the F1 parameter would yield no change in the rate of hydrogen cyanide volatilization versus that calculated using a generalized correlation.

2. An empirical parameter (F2) was introduced into the cyanide attenuation model to adjust the value of the iron-cyanide photolysis rate constant (K_p) as follows:

$$(10) \quad K_p = K'_p \times F_2$$

where K'_p is the unadjusted iron-cyanide photolysis rate constant calculated by the cyanide attenuation model (see Equation (8)). A value of zero for the F2 parameter would eliminate iron-cyanide photolysis as an attenuation mechanism, while a value greater than one would increase the photolysis rate above that calculated using published data. A value of one for the F2 parameter would yield no change in the rate of iron-cyanide photolysis versus that calculated using the USEPA photolysis model GCSOLAR.

3. A third empirical parameter was introduced into the attenuation model to fine-tune modeling results beyond what calibration factors F1 and F2 can affect. This third parameter (k) was applied as an overall attenuation rate coefficient for total cyanide using the conventional first-order decay equation:

$$(11) \quad C = C_0 e^{-kt}$$

where C (mg/l) is the concentration at time t (day), C₀ (mg/l) is the initial concentration and k (1/day) is the empirical overall attenuation rate coefficient for total cyanide. The empirical factor k can be utilized to account for undefined reactions that contribute to the removal of cyanide from decant solution, such as cyanate formation and/or biologically-mediated reactions.

For Ahafo model calibration work, the following values for the empirical calibration parameters were found:

- F1** Variation of the hydrogen cyanide volatilization rate constant using parameter F1 had little effect on the modeling results for Ahafo. This is due to the low level of free cyanide calculated in decant pond solution (most cyanide in decant solution was found to be complexed with copper, iron, nickel and zinc). In view of this, the value for F1 was set to one (i.e., no change in the hydrogen cyanide volatilization rate constant was introduced).
- F2** Variation of the iron-cyanide photolysis rate constant (using parameter F2) had a noticeable effect on the calculated decant solution total cyanide concentrations. A value of 4.6 for F2 was found to yield calculated data that closely match observations at the Ahafo site for iron-cyanide levels in decant solution. The value of 4.6 for F2 suggests the iron-cyanide photolysis rate at the Ahafo site proceeds more rapidly than calculated using published data.
- k** Following adjustment of calibration factors F1 and F2, results from the Ahafo cyanide attenuation model did not adequately match actual site observations for decant solution cyanide levels. The overall attenuation rate coefficient (k) was therefore used to adjust modeling results until output adequately matched actual site observations. A value of 0.37/day for k was found to yield calculated data that closely match actual data from the Ahafo site. The need to utilize the parameter k for the Ahafo site suggests that undefined reactions are significant and contribute to the removal of cyanide from decant solution.

Figures 3 and 4 show results from the Ahafo model calibration work with respect to WAD cyanide levels in final washed tailings and the TSF decant pond. Agreement between the calibrated model output and actual site observations was considered suitable to allow utilization of the model for the Akyem project. Similar agreement was found for total cyanide levels.

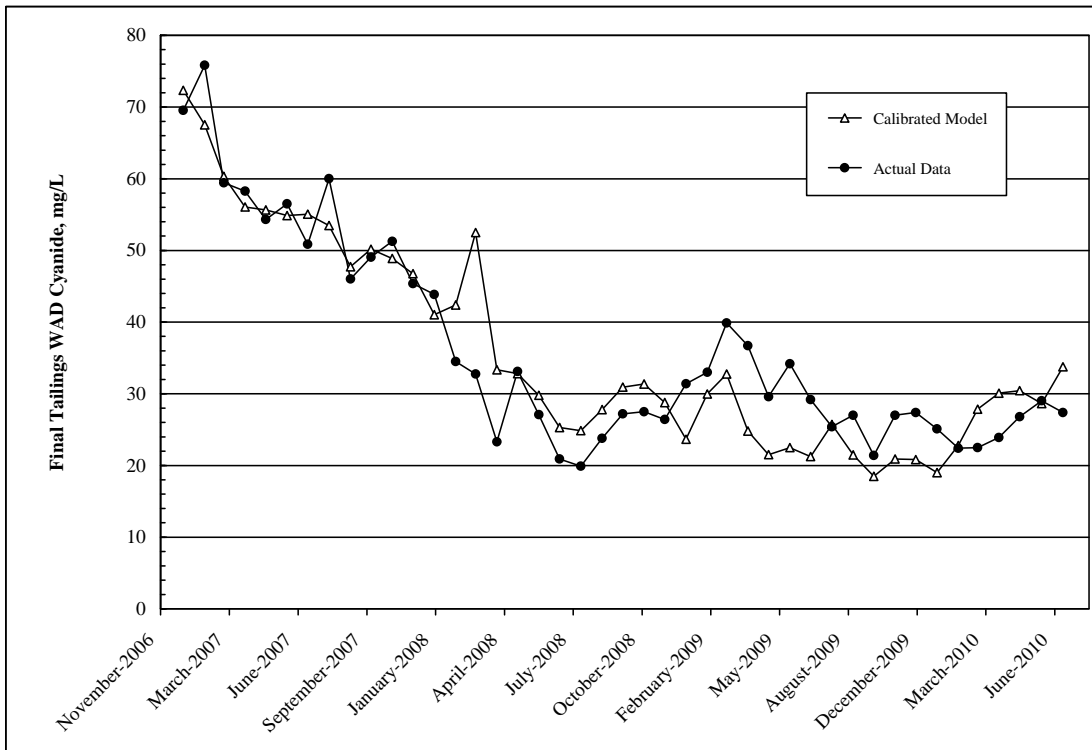


Figure 3: Ahafo CIL Tailings Slurry Washing Modeling Results

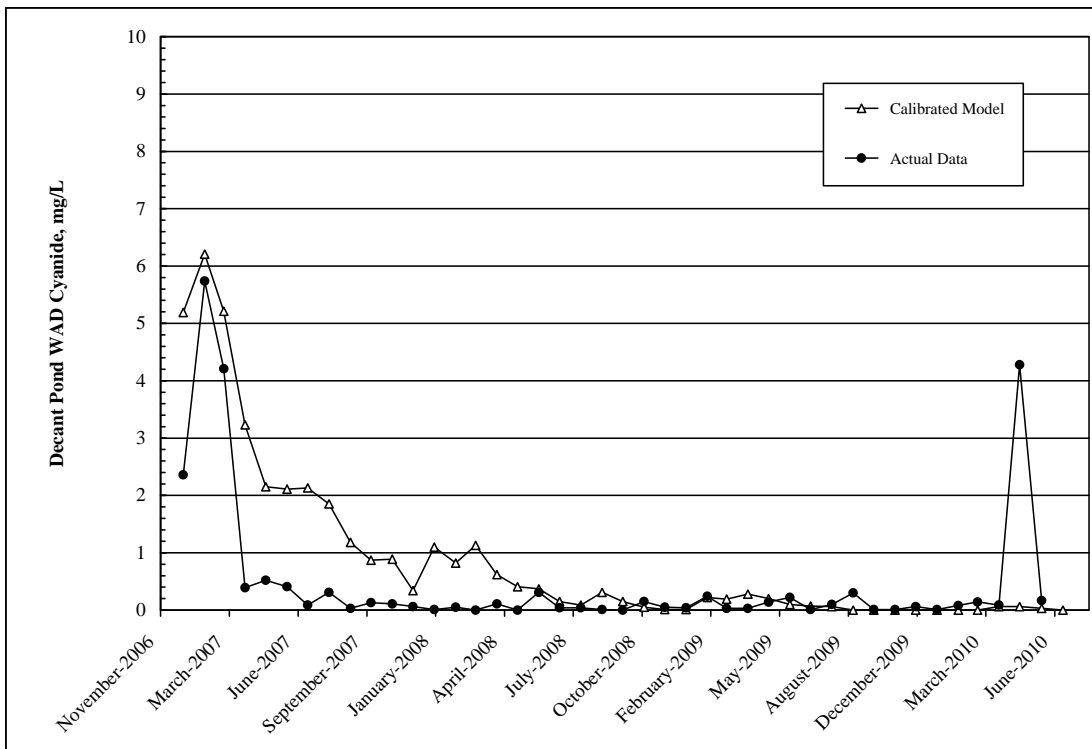


Figure 4: Ahafo TSF Decant Pond Cyanide Attenuation Modeling Results

AKYEM MODEL INPUTS

The CCD circuit and TSF at Akyem were modeled to estimate the levels of total and WAD cyanide in the TSF decant pond. The system included a two-stage CCD tailings wash circuit and a surface impoundment for storage of washed CIL tailings. Reclaim water from the tailings impoundment and fresh water make-up were used as wash solution in the CCD circuit, with solution exiting the CCD circuit returned to the milling circuit. Modeling calculations extended from June 2013 through December 2027.

Key input assumptions utilized in the cyanide attenuation model for Akyem included the following:

1. The decant pond was assumed to be completely mixed such that concentrations of metals and cyanide were laterally and vertically uniform throughout the entire pond. For the Akyem project, two storage cells will be utilized in the TSF: Cell #1 will be active from June 2013 through April 2020 and Cell #2 will be active from May 2020 through August 2026. .
2. Water balance data for the two-cell tailings impoundment were provided by the firm contracted to design the TSF.
3. It was assumed the levels of metals and cyanide in seepage collected from the tailings impoundment area would be the same as their respective concentrations in the tailings slurry times a dilution factor. A dilution factor of one would specify the seepage chemistry to be identical to the tailings slurry, while a dilution factor of zero would specify the seepage to contain no cyanide or metals. A dilution factor of 0.05 was utilized for this work based on evaluation of the chemistries of CIL tailings slurry and seepage solution observed at the Ahafo site. The dilution factor is an empirical value related to the overall subsurface attenuation and dilution of cyanide and metals.
4. It was assumed solution entrained in the settled tailings solids has the same chemistry as tailings slurry entering the impoundment. Estimation of cyanide attenuation mechanisms and rates within the settled tailings solids or in the seepage collection system was not considered.
5. Concentrations of cyanide, copper, iron, nickel and zinc present in CIL tailings slurry were specified using obtained from laboratory bottle roll test work (Table 2). . These data were utilized along with the assumption that all soluble iron is present in the cyanide complex $Fe(CN)_6$.

Table 2: Akyem CIL Tailings Slurry Chemistry

Constituent	CIL Tailings Slurry
Cyanide, Total (mg/L)	95.9
Cyanide, WAD (mg/L)	91.1
Copper (mg/L)	6.5
Iron (mg/L)	1.7
Nickel (mg/L)	0.4
Zinc (mg/L)	0.7

6. Based on operating data collected from Ahafo, the tailings impoundment decant pond pH and temperature were assumed to be 8.5 and 28.5°C, respectively, year round.
7. The source of wash water in the CCD circuit was assumed to be 100% of reclaim water collected from the TSF decant ponds (Cells #1 and #2) plus sufficient fresh water to yield a total of 825 m³/hour wash solution. During operation of Cell #1, only reclaim water from Cell #1 was available for CCD washing. During operation of Cell #2, reclaim water from both Cell #1 and Cell #2 was available for CCD washing.

MODELING RESULTS

Results obtained from the calibrated cyanide attenuation model utilized for Akyem are presented in Figures 5 through 8. In summary, the following were observed:

- Figure 5:** Calculated decant pond total and WAD cyanide levels for Cell #1 are shown on Figure 5. During operation of Cell #1, both the total and WAD cyanide levels vary from about 3 to 15 mg/L, and following transfer of operations to Cell #2, the total and WAD cyanide levels quickly decrease to less than about 0.5 mg/L. Seasonal variations in estimated cyanide levels are primarily due to variations in the photolysis rate and the fresh water flow utilized as wash in the CCD circuit.
- Figure 6:** Calculated decant pond total and WAD cyanide levels for Cell #2 are shown on Figure 6. During operation of Cell #2, both the total and WAD cyanide levels vary from about 7 to 11 mg/L, and following completion of milling operations, the total and WAD cyanide levels quickly decrease to less than about 0.5 mg/L.
- Figure 7:** Performance of the CCD circuit used to wash CIL tailings during operation of Cell #1 is shown on Figure 7. CIL tailings slurry is expected to contain 95.9 mg/L total cyanide and 91.1 mg/L WAD cyanide. After washing in the CCD circuit with reclaim and fresh water, the final washed tailings contain about 38 to 48 mg/L of total and WAD cyanide.
- Figure 8:** Performance of the CCD circuit used to wash CIL tailings during operation of Cell #2 is shown on Figure 8. CIL tailings slurry is expected to contain 95.9 mg/L total cyanide and 91.1 mg/L WAD cyanide. After washing in the CCD circuit with reclaim water, the final washed tailings contain about 38 to 44 mg/L of total and WAD cyanide.

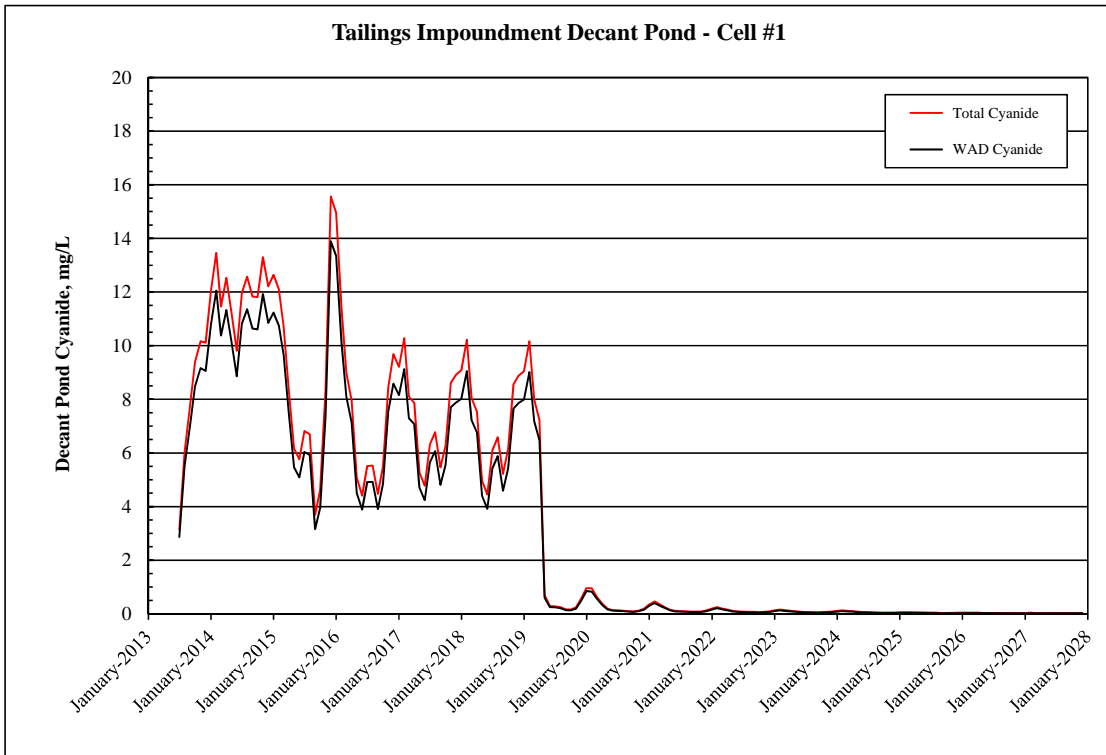


Figure 5: Akyem Cyanide Attenuation Modeling Results – Decant Pond Cell #1

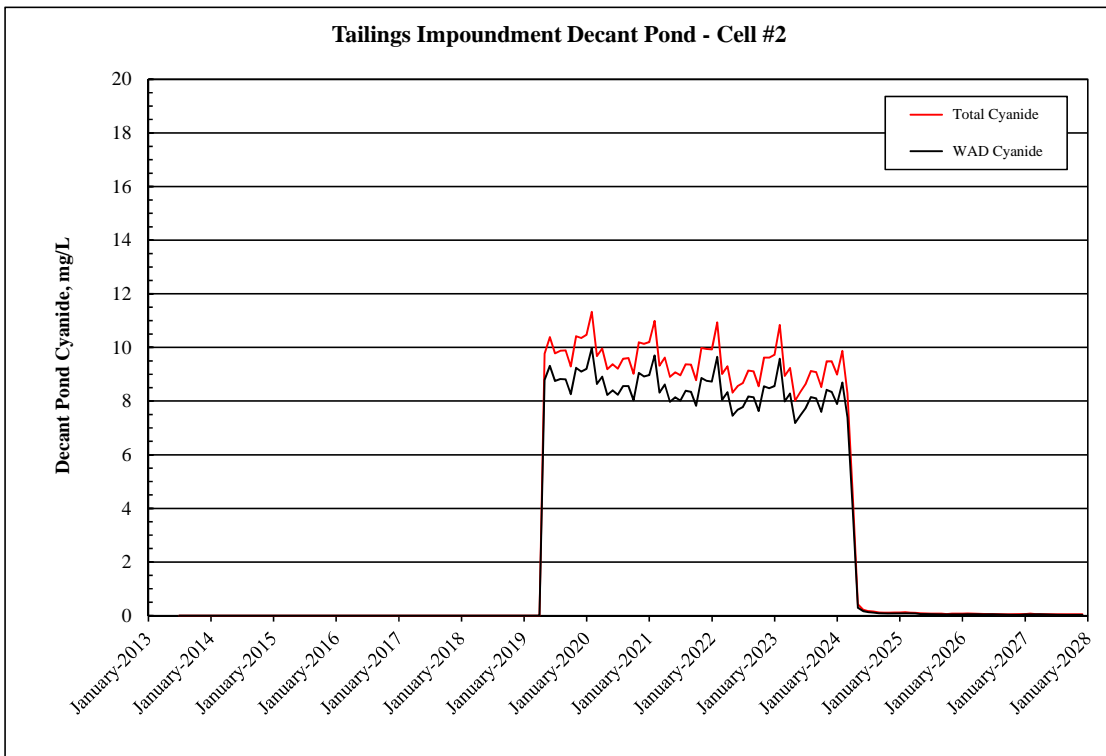


Figure 6: Akyem Cyanide Attenuation Modeling Results – Decant Pond Cell #2

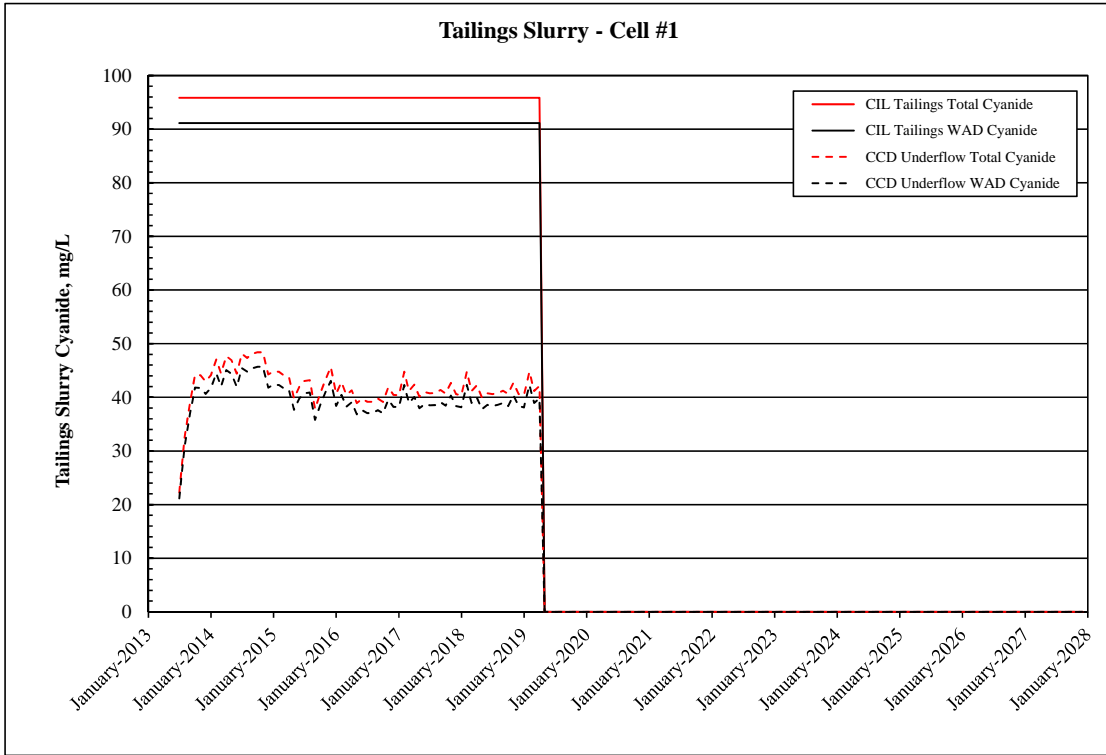


Figure 7: Akyem CIL Tailings Slurry Washing Modeling Results – Cell #1

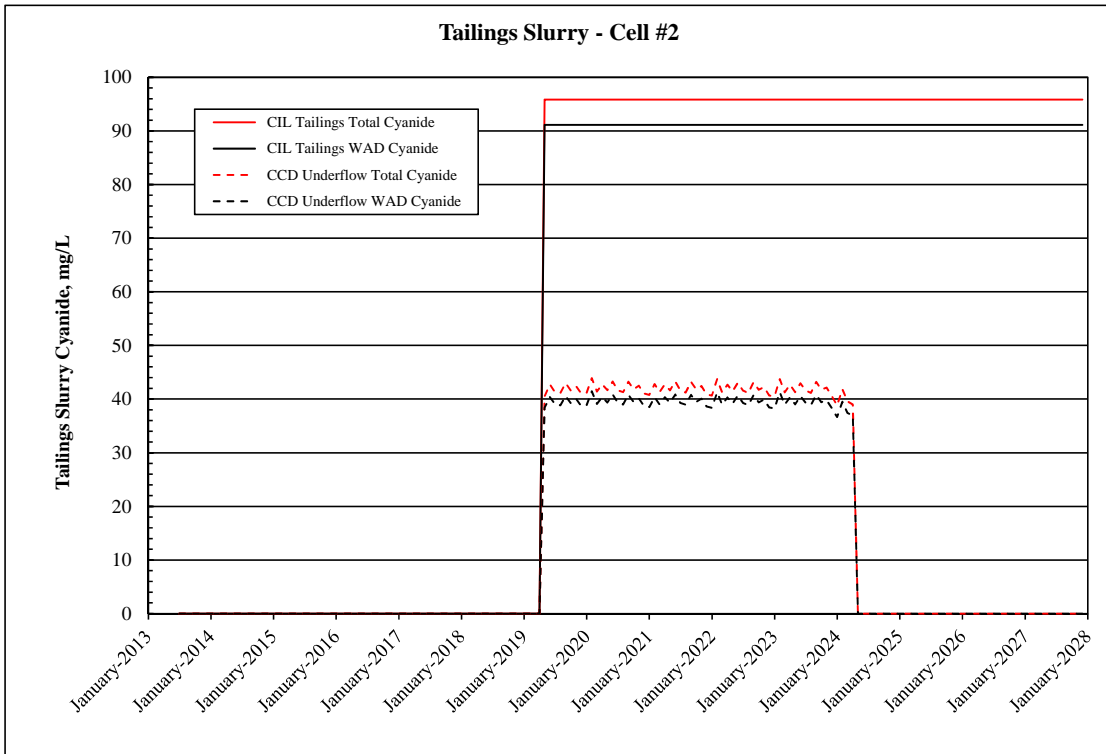


Figure 8: Akyem CIL Tailings Slurry Washing Modeling Results – Cell #2

SUMMARY

A cyanide attenuation model was developed for the Ahafo site to estimate levels of total and WAD cyanide in the tailings impoundment decant pond. The work involved estimating rates of natural cyanide attenuation that would occur in the decant pond, taking into account specifics for the site, such as weather conditions, design of the tailings impoundment, tailings solution chemistry and the cyanide mass balance. Using actual operating data from the Ahafo site collected over the period of January 2007 through July 2010, the cyanide attenuation model was then calibrated in order to match model output to operating data. Model calibration was conducted by introducing three empirical parameters into attenuation calculations. The objective of calibrating the cyanide attenuation model was primarily to yield a tool that could be used to model the tailings impoundment decant pond at the nearby Akyem site. The Akyem project is scheduled to enter production in 2013, and Newmont anticipates the projects will be similar with respect to ore geochemistry, metallurgical processing, weather conditions, tailings chemistry and tailings disposal.

Data generated with the calibrated cyanide attenuation model suggest final tailings at Akyem will contain less than 50 mg/L WAD cyanide and decant solution in the TSF will contain less than 15 mg/L WAD cyanide. When calibrating the cyanide attenuation model for the Ahafo site, HCN volatilization was found to be the primary route of cyanide attenuation. However, when low levels of iron-cyanide are present in solution it was found the rate of photolysis may be the primary factor governing the concentration of total cyanide in solution. For Ahafo, it was found necessary to empirically adjust the photolysis rate in order to match actual operating data to model output. Further, it was found necessary to introduce an empirical parameter to reduce the cyanide level in decant solution due to undefined reaction(s). Given the high level of sunshine and high decant solution temperature at Ahafo, it is possible the undefined reaction(s) are biologically mediated.

REFERENCES

1. Botz, M.M. and Mudder, T.I., "Modeling of Natural Cyanide Attenuation in Tailings Impoundments", *Minerals and Metallurgical Processing*, Vol. 17, No. 4, pp. 228-233, November, 2000.
2. Schmidt, J.W., Simovic, L. and Shannon, E., "Natural Attenuation of Cyanides in Gold Milling Effluents", *Proc. Sem. Cyanide and Gold Mining Industry Seminar*, Environment Canada, Ottawa, Ontario, Jan. 22-23, 1981.
3. Simovic, L., Snodgrass, W., Murphy, K., and Schmidt, J. "Development of a Model to Describe the Natural Attenuation of Cyanide in Gold Mill Effluents", *Cyanide and the Environment*, Vol. II, Colorado State University, Fort Collins, Colorado, pp. 413-432, 1985.