Assessment of the quality of Block 4 pit water at Iduapriem Gold Mine, Tarkwa, Ghana

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Abstract In AngloGold Ashanti Iduapriem Ltd (AAIL), large quantities of colloidal mine water was found in the Block 2/3 in-pit tailings storage facility. The water contained high concentrations of free cyanide, turbidity, conductivity and selected metals and arsenic. The mine constructed a treatment facility in collaboration with Pollution to Water (P2W) and Israeli Company that efficiently removed free cyanides and turbidity, and decreased the pH. Since the quality never met all the sector specific effluent guidelines, the partially treated water had to be stored in the block 4 pit (approximately 1.83 million cubic meters). This study aimed at assessing the current water quality of the Block 4 pit for an informed decision. Samples of water were taken at surface, middle and bottom layers of the pit for the analyses of metals and arsenic and relevant physiochemical variables indicative of pollution. It is evident from the sequence that metal and arsenic concentration of the surface water layer is a reflection of the entire water column. It was recommended that media filters and reverse osmosis be installed to handle the rest of the parameters in the block 4 pit water and any other waters on the mine for it to meet the EPA sector effluent discharge limits.

Key Words Cyanide, ozone, reverse osmosis, media filter

Introduction

AngloGold Ashanti Iduapriem Limited (AAIL) is a gold mining company registered in Ghana as a subsidiary of the AngloGold Ashanti Ghana (AGA). AAIL mines ore by conventional open pit methods. Gold bearing ore are processed through a refractory gold process consisting of milling, leaching (aggressive cyanide leach) and adsorption (CIP). The carbon used in the adsorption tanks recovers the gold cyanide complex ions out of solution. Very often, cyanidation process ensures between 95 – 99% recoveries of gold (Marsden and Fuerstenau 1993). The residual process water after the recovery contains major chemical constituents notably cyanide and other metals that form complexes with cyanide. AAIL currently treats its supernatant solutions using Pollution to water (P2W) where cyanide degradation and turbidity removal are achieved making use of the ozone process. The Ozone process alone destroys about 80% of the cyanide. This is followed by oxidation of residual cyanide by the addition of sodium hypochlorite, pH adjustment by addition of sulphuric acid, and finally passes solution through Ultra Violet (UV) light for UV oxidation. Ozone combined with UV light can oxidize all cyanide metal complexes. The treated water was then deposited into a Block 4 pit intended to be used for production activities and further treatment.

Currently, the Block 4 pit (mined out pit) holds approximately 1.83 million m^3 of water, as at the first quarter of 2010 (EMP 2010). The mines annual environmental report for 2009 indicates that approximately 1.5 million m^3 of water in Block 4 was deposited from P2W plant with the remainder contributed through direct rainfall (and runoff) and purported seepages from Block 2/3 pit.

An enforcement notice was issued by the Ghana Environmental Protection Agency (EPA) to AAIL to decommission of the Block 2/3 Tailings Storage Facility, which was operated beyond capacity. It was against this background that bathymetric and water quality assessment was carried out to ascertain the quality of Block 4 pit.

Methods and Materials

Field studies were commissioned from early 2010. Water sampling was carried out along 6 stations. An inflatable dingy was used to navigate (using etrex GPS) to the locations. An ACL-1180 Data Logging CTD (ACL-1180 Data Logging CTD) was deployed from surface to bottom at each station to measure profiles of selected water quality parameters (i.e., depth, salinity, conductivity, density and turbidity). Further, a Nansen water sampler was utilized to collect water samples from bottom and middle water layers. Geosatellite positioning (fixed with a Garmin Etrex GPS) of all locations and the respective depths recorded). Ekman grab was intended to collect sediment samples at the locations but sediment sample was not retrieved due to the hard nature of bottom substrate.

Analyses carried out for the water samples were nutrients (i.e. nitrate, orthophosphate and sulphate), metals (Cu, Cr, Cd, Fe, Mn, and Zn), arsenic and other water quality parameters (pH, Alkalinity, conductivity, dissolved solids, turbidity, COD & free cyanide; Chapman 1996).

Analysis of nitrate, phosphate, silicate, sulfate, turbidity, conductivity and total dissolved solids were carried out using data-logging spectrophotometer HACH 2010 following standard methods (APHA 2005). pH was determined with a pH meter (Wagtech). Metals and arsenic were analyzed using the Atomic Absorption Spectrophotometer (Teledyne Leeman Labs).

Results and Discussions

The distribution of the mean and standard deviations of CTD data (Conductivity, Temperature, and Depth) across the sampling sites depict a relatively similar pattern except turbidity (Fig. 1). Mean average turbidity of the water was 132.8±16.7 NTU, higher than the regulatory standard of EPA (75 NTU). Average turbidity values across all locations were non-compliant (Fig. 1) and the depth-related variations of temperature, conductivity, and salinity were not apparent.

Summary of the results of the water quality assessment in Block 4 pit is shown in table 1, while the mean concentrations of individual sampling stations are shown in tables 2 and 3. As indicated, pH values across the stations table 1 were uniform and moderately basic but higher than the permissible limit (6—9) of Ghana EPA (EPA 2000). The high pH values could be linked to supernatant solutions from tailings, which value is close to a pH of 10.5 during the cyanidation process for gold recovery.

Electrical conductivity and total dissolved solids were higher than EPA limits in the surface and middle water layers, whereas in the bottom layer values were within limits. The conductivity and TDS showed declension with water depth in that bottom waters recorded lower values compared to surface and middle. This observation is indicative of ion-rich water overlying the surface (Koerselman 1989). It further indicates non-mixing of surface and bottom waters which is corroborated by the significant difference obtained between surface and bottom waters (One-way ANOSIM, p=0.006) utilizing all the dataset. Conductivity itself is not a human or aquatic health concern, but can serve as an indicator of other water quality problems. Elevated conductivity of water indicates a source of dissolved ions in the vicinity. The conductivity showed strong correlations with some of the metals including copper (r=0.66) and chromium (r=0.53) at 95% confidence interval. Turbidity concentrations ranked highest generally in the bottom water samples. Values recorded for surface and middle water column

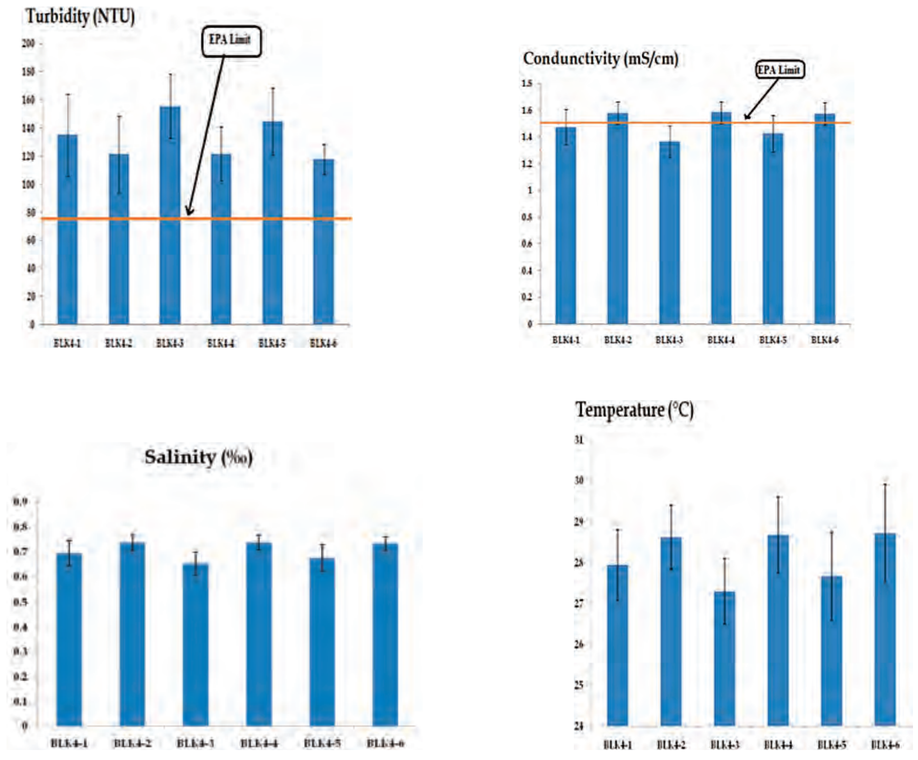

Figure 1 *Mean distribution of conductivity, salinity, temperature and turbidity of block sampling locations. Error bars indicate 95% confidence interval.*

Table 1 *Mean concentrations of water quality in Block 4 of AAIL with asterisks if >EPA limit.*

Parameter	Surface	Middle	Bottom	Entire layer	EPA Guideline Value
pH	9.85*	9.94*	9.91*	9.90*	6.0-9.0
Conductivity (µS/cm)	1592*	1537.33*	1449.67	1526.33*	1500
TDS (mg/L)	1094.50*	1067.17*	1025.83*	1062.50*	1000
Turbidity (NTU)	34.33	44.17	416.67*	165.06*	75.0
Nitrates (mg/L)	8.27	8.50	7.83	8.53	50.0
Phosphate (mg/L)	1.29	1.43	1.50	1.41	2.0
Sulphate (mg/L)	435.00	433.33	438.33	435.56	250
Free cyanide (mg/L)	0.37*	0.17	0.16	0.23*	0.2
Arsenic (mg/L)	1.54*	0.09	0.75	0.79	1.0
Cadmium (mg/L)	0.03	0.03	0.03	0.03	0.1
Chromium (mg/L)	0.01	0.01	0.01	0.01	5.0
Copper (mg/L)	12.53*	9.21*	8.49*	10.08*	5.0
Iron (mg/L)	0.17	0.10	0.16	0.14	10.0
Manganese (mg/L)	0.05	0.06	0.08	0.06	0.30
Zinc (mg/L)	0.02	0.03	0.02	0.02	10.0

Table 2 *Mean physico-chemical parameters.*

Sample ID	pH	Cond. (µS/cm)	Turbidity (NTU)	TDS	NO_3	PO_4	SO_4	Free CN
BLK4- 1S	9.85	1593	34	1095	9.2	1.41	420	0.19
BLK-4 1M	9.93	1497	45	1047	9.6	1.28	420	0.15
BLK4-1B	9.88	1438	75	1020	7.8	1.4	440	0.12
EPA Limit	6-9	1500	75	1000	50	2.0	250	0.2

All other concentration values are in mgL^{-1}

Table 3 *Mean concentration of arsenic and selected metals.*

Sample ID	As	Mn	Zn	Fe	Cu	Cr	Cd
BLK4- S	1.54*	0.05	0.02	0.17	12.53*	0.01	0.03
BLK-4 M	0.09	0.06	0.03	0.02	9.21*	0.01	0.03
BLK4-B	0.75	0.08	0.02	0.16	4.48	0.01	0.03
EPA Limit	1.0	0.3	10.0	10.0	5.0	5.0	0.1

All concentration values are in mgL^{-1}

samples were lower than permissible by EPA. However, the average for the entire water column was non-compliant according to the EPA guideline. The turbidity profiles for all the six sampling locations revealed elevated levels towards bottom. There was strong significant correlation ($p<0.05$) between turbidity and manganese ($r=0.73$), chemical oxygen demand ($r=0.95$), phosphate ($r=0.40$), and sulphate ($r=0.38$) which either indicate similar sources or influence.

Although nitrate concentrations were generally low than EPA guideline, the recorded values were manifold higher than normal background levels of 0.1 mg/L, that indicated aquatic pollution and may lead to eutrophication.

The mean concentration level of free cyanide at the surface and also the entire water column was higher compared to EPA guideline. Orthophosphate levels were uniform and lower than prescribed by Ghana EPA as limit. The significant correlation between phosphate and manganese ($r=0.39$, $p<0.05$) may indicate similar sources possibly sedimentary material. Frequent re-suspension episodes of fine-grained sediments often results in elevated concentrations of phosphorus in the water column.

The chemical oxygen demand (COD) increased with increased water depth, in that the bottom samples recorded elevated values. However, the recorded values were lower than EPA guideline. Elevated COD values have grave implication for aquatic life. This means that the demand for dissolved oxygen by aquatic organisms becomes higher due to low dissolved oxygen (anoxic conditions) concentration (Chapman 1996). Metal and arsenic sequence in the water column layers were as follows:

Surface: Cu>As>Fe>Mn>Cd=Zn>Cr;
Middle: Cu>Fe>As>Mn>Zn>Cd>Cr;
Bottom: Cu>As> Fe >Mn>Cd>Zn> Cr;
Entire layers: Cu>As>Fe>Mn>Cd>Zn> Cr.

It is evident from the sequence that metals and arsenic concentration of the surface water layer is a reflection of the entire water column.

Conclusions

The results indicate that the general water quality of the pit showed high pH and elevated concentrations of conductivity, dissolved solids, turbidity, copper, and arsenic (surface layer), which were not compliant for discharge. The conductivity showed significant ($p < 0.05$) correlations with copper ($r = 0.66$) and chromium ($r = 0.53$), indicating similar sources. It is evident from the sequence that metals and arsenic concentration of the surface water layer is a reflection of the entire water column. Congruently, the four most important metals in the Block 4 pit that gave an indication of pollution are Cu, As, Fe, and Mn. The results also indicate significant difference between the surface and bottom water samples indicating that there is no mixing of those waters. It was recommended that media filters and reverse osmosis be installed to handle the rest of the parameters in the block 4 pit water and any other waters on the mine for it to meet the EPA sector effluent discharge limits.

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