

Determination of Acid-Generating Potential of Waste Rocks in Kyaukpahto Gold Mine, Myanmar

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Abstract—Kyaukpahto gold deposit is located in the Kawlin Township, Sagaing Region, Myanmar. Gold deposit is classified as a shallow level epithermal deposit and gold mineralization is characterized by stockworks quartz vein and dissemination hosted by sandstones of Eocene Male Formation. Common ore minerals of mineralization include pyrite, arsenopyrite, and chalcopyrite. Gold ore are exploited by open-pit mining and waste rocks are disposed as waste dumps near mine site. Large amount of waste rocks containing metal sulfides are exposed to the surface, favouring the metal sulfides in reaction with air and water, and produce acidic water. High values of hardness and heavy metal concentrations are observed in mine water and apparently reduce the quality of water and create potential threat to nearby environment. This work focus on the assessment of waste rocks at the Kyaukpahto waste dump in order to determine the acid-generation potential of waste rocks and prevent generation of AMD from the waste dump. The chemistry of the waste rocks was studied using XRF techniques. Net acid generation, acid neutralizing capacity, net acid-producing potential tests and two-step batch leaching tests were performed. Based on the results of the analyses, potentially acid-forming waste rocks and non-acid forming waste rocks were identified.

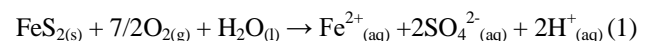
Keywords— gold deposit, waste dump, metal sulfides, acid-forming waste rocks, acid mine drainage

I. INTRODUCTION

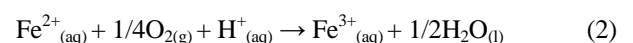
Acid mine drainage (AMD), also known as acid rock drainage (ARD), causes environmental problems that affect many countries with historic or current mining activities. It has resulted from the exposure of sulfide ores and minerals to water and oxygen. When the ores are exposed to develop AMD, sulfate and heavy metals such as iron, copper, lead, nickel, manganese, cadmium, aluminium and zinc are also released contaminate into that water [1]. Metal-rich acidic waters can also be developed in spoil heaps, waste rocks and tailings, mainly by the similar biologically reactions as in mine adits, shafts, pit-walls and pit-floors. As acid-generating minerals are more disaggregated and concentrated in these waste materials, AMD which flows from them could be more aggressive than that which discharges from the source itself. Another important consideration is that of the potential long-term pollution problem, as AMD production may continue for several years after mines was shut and tailing dams were decommissioned [2].

The most common acid-generating sulfide minerals in the ore include pyrite/marcasite (FeS₂), pyrrhotite (FeS), chalcopyrite (CuFeS₂) and arsenopyrite (FeAsS). In general, pyrite, the common sulfide mineral of waste rocks

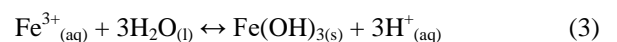
and typical of many oxidation processes during weathering, is oxidized according to the following reactions [3]:



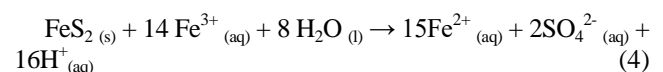
If the surrounding environment is sufficiently oxidizing, much of the ferrous ion will oxidize to ferric ion:



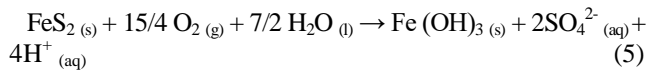
At pH value above 2.3 to 3.5, the ferric iron will precipitate as Fe(OH)₃, leaving little Fe³⁺ in solution while lowering pH at the same time:



Any Fe³⁺ that does not precipitate from solution may be used to oxidize additional pyrite:



Acid generation produces iron which is eventually precipitates as Fe(OH)₃ can be represented by a combination of reactions:



The oxidation process could take place both in short-term and long-term periods, depending on many factors involved, and will release three main chemical parameters that could influence water quality: sulphate concentration, acidity, and dissolved metals.

AMD can be prevented, and its prevention consists of several methods. Generally, the purpose of the AMD prevention is the minimization of AMD factors. These factors include oxygen supply, water infiltration and leaching, sulfide minerals availability and bacteria (related to biogeochemical process). Moreover, in the prevention method, maximizing the availability of acid neutralizing minerals or increasing the infiltrated water pH could be an option [4].

Myanmar, one of the Southeast Asian nations, is highly endowed with various mineral resources, such as gold, silver, copper, and lead [5]. Kyaukpahto gold mine is the first open-pit gold mine excavated in Myanmar and located about 30 km east of the Kawlin and 250 km north of the Mandalay, in northern Myanmar (Figure 1). Exploration works and calculations of ore reserves at in this mine have been conducted since 1982. By the 1990s, a total of more than 300 drill holes had been drilled and the reserve was estimated at approximately 6 million tons at an average grade of 3.0 g/t Au with a cut-off grade of 1.0 g/t [6, 7]. The important ore minerals of gold mineralization are pyrite, arsenopyrite and chalcopyrite with minor amounts

of other sulfides. Gold can be observed as free particles and/or locked inside sulfides such as pyrite, arsenopyrite, chalcopyrite and tetrahedrite [7,8]. When the sulphur content of the mine is within the range of 1-5% in the form of Pyrite (FeS_2), there is potential of AMD occurrence. AMD degrades the water quality in terms of lowering the pH of the surrounding water resources and increasing the level of dissolved heavy metals [9]. Currently, the water pollution due to AMD generation is not detected in the surrounding water monitoring points at Kyaukpahto gold mine based on the environmental report from the currently operating mining company. However, the risk of AMD generation from Kyaukpahto gold mine have to be evaluated in order to avoid the severe environmental impacts for the future.

This work focuses to address the current conditions of AMD generation in Kyaukpahto gold mine and identifies the acid-generating waste rocks from waste dump. Section I contains the introduction of AMD and its prevention methods, location of research area (Kyaukpahto gold mine), AMD problem there and the objective of the present research. Section II contains the related works to the present study. Section III explains the research methodology describing about sampling, analytical methods and procedures in detail for the current research. Section IV mentions about results and discussion which contains the result of various test and analyses, in order to determine the geochemical properties of waste rocks and geological classification of the collected samples. Section V concludes the research works and recommends the future directions.

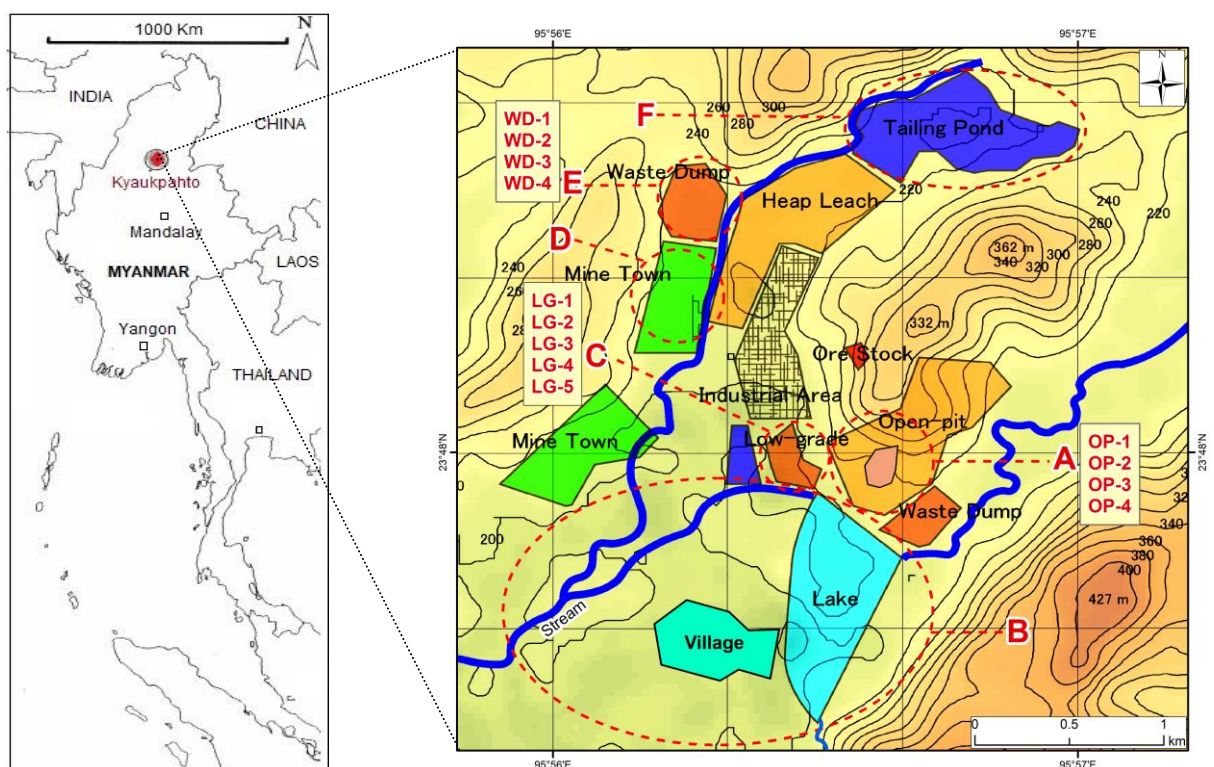


Figure 1. Location map of Kyaukpahto gold mine: red letters indicate Water-sampling areas; Open-pit (OP), Low-grade ore dump (LG), and Waste dump (WD) indicate waste rock sampling areas.

II. RELATED WORK

In Kyaukpahto gold mine, gold ore are exploited by open-pit mining method and waste rocks are disposed as waste dumps near the mine site. Large amount of waste rocks containing metal sulfides, such as pyrite and chalcopyrite, are exposed to the surface, favouring these sulfides in reaction with air and water, and produce acidic mine water. Potential generation of acidic miner water has been reported due to metal sulfide-bearing waste rocks in the open-pit backfilling at Monywa Copper deposit located to the south of Kyaukpahto gold mine [10]. Higher values of hardness and heavy metal concentrations are observed in this water which apparently reduce the quality of water and create potential harm to the nearby environment. Arsenopyrite is the source of arsenic in Kyaukpahto mining waste disposal. Based on the experiment on stream sediments and water samples, it was found that arsenic concentrations in the surface water and tailings are higher than WHO (World Health Organization) standard guidelines whereas groundwater samples showed that arsenic and zinc concentrations are below that guidelines [11]. Geochemical characteristics and the increase of total reactive surface area of the sulphide-bearing waste rock

due to weathering processes at waste dumping area have potential to boost the oxidation of sulphide minerals which are commonly present as pyrite (FeS_2), leading to AMD generation [12].

III. METHODOLOGY

A. Sampling

Field investigation was carried out in Kyaukpahto gold mine in order to understand the field conditions in mining area with respect to waste rocks. An environmental report from the mining company states that no water pollution due to AMD is currently detected at the wastewater quality monitoring point outside the mining area owing to the current water treatment producers. However, there are residential areas adjacent to the mining area, and so, assessment of the potential contamination risk from AMD from the Kyaukpahto gold mine is required to protect the health of the residents and enable the sustainable development of the gold. Acidic water with red-brick color was found in the open-pit and low-grade ore dump (Figure 2) and basically the water flow is north to south.



(a) Pit water

(b) Surface runoff in the pit

(c) Surface water near low-grade ore dump

Figure 2. Field photos showing AMD generation in open-pit and low-grade ore dump.

Water samples for pH and electric conductivity (EC) measurements were collected from a total of 41 points in the areas A, B, C, D, E, and F, which are shown in Figure 1. These areas are respectively located in the tailing pond, a waste dump, the mine town, the low-grade ore dump, the open pit, and downstream of the drainage from the mine area. The water samples were introduced into an Agilent 7500 Series Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) after adding 0.1% of HNO_3 . Waste rocks were sampled from three areas in the mine site as marked in (Figure 1): the open pit (Area A), the low-grade ore dump (Area C), and the largest waste dump (Area E). These samples were named OP-1, OP-2, OP-3, OP-4, LG-1, LG-2, LG-3, LG-4, LG-5, WD-1, WD-2, WD-3, and WD-4. A paste pH, a net acid generation (NAG) test, acid-base accounting (ABA), and X-ray fluorescence (XRF) analysis were performed to characterize the geochemical characteristics of the waste rocks [13].

B. Analytical Methods and Procedures

In the paste pH test, rock samples were dissolved with de-ionized water after pulverization of the samples. The change of pH was described as paste pH after 12 hours of the dissolution process. Rock samples were dissolved with H_2O_2 by forced oxidation process in NAG test. The potential of acid producing of samples were quantified on the basis on the change of pH which was reported as NAG pH after the dissolution process. NAG pH indicated the change of water quality when the rock samples were dissolved completely. The measured result of NAG pH indicates the net acid and/or base left in the rock sample after the acid producing and consuming occurred. The balance of acid producing capacity and potential of neutralization of rock sample were calculated based on Maximum Potential Acidity (MPA) and Acid Neutralizing Capacity (ANC) in ABA test [13, 14]. MPA was calculated based on total sulfur content whereas ANC was calculated

through titration process with hydrochloric acid. These values are expressed in unit of kg H₂SO₄/ton. In addition, the percentage of total sulfur, as a represented index of acid potential, was obtained from XRF analysis using a Rigaku RIX 3100 spectrometer. Based on the MPA and ANC results, NAPP was calculated by acid–base balance calculation method from the formula NAPP (kg H₂SO₄/ton) = MPA – ANC. Rock samples were classified as Potentially Acid Forming (PAF) if the NAG pH ≤ 4.5 and the NAPP ≥ 0 and were classified as Non-Acid Forming (NAF) if NAG pH ≥ 4.5 and NAPP ≤ 0 [15]. Rocks not classifiable as PAF or NAF were classified as uncertain (UC).

Standardized batch leaching tests were conducted to study the leaching properties of metals from waste rocks. Two-steps sequential leaching procedure, based on CEN prEN 12457-3, was adopted to discuss the dissolution behaviour of metals under the different L/S ratio and contact time [16]. The pulverized rock samples were dissolved with a rotation of 200 rpm under the L/S = 2 for the first step and the L/S = 8 for the second step. The duration of rotation

was 6 and 18 hours for the first and second step, respectively. The water samples from batch leaching tests were measured for pH, EC and heavy metals by ICP-MS Agilent 7500 Series after filtered through 0.45 mm filters.

IV. RESULTS AND DISCUSSION

Table 1 summarizes the water quality results for surface water in areas A, B, C, D, E, and F (locations are shown in Figure 1). The measured pH was less than 3.0, and the measured EC was more than 2.0 mS/cm in areas A and C. Furthermore, high concentrations of Fe, As, Al, Cu and Zn were detected in these areas samples when compared with those of areas B, D, E and F. These values exceed the Myanmar National Environmental Quality standards (MNEQs) [17], which are pH=6-9, Fe <2.0 mg/L, As <0.1mg/L, Al<3 mg/L, Cu <0.3 mg/L, Zn < 0.5 mg/L. Although both the pH and the Fe and As concentrations also exceed standard levels at several points in B, D, E, and F, the very low pH values and extremely high Fe and As concentrations in areas A and C make these the main AMD source areas.

Table 1. Chemical concentrations (mg/L) in water samples from the research area. EC is in mS/cm.

Area	No	pH	EC	Fe	As	Al	Cu	Zn	Area	No	pH	EC	Fe	As	Al	Cu	Zn
A	1	2.61	3.8	9519	373	370	14	23	D	22	8.64	0.64	1	0	2	0.3	0.8
A	2	7.23	0.93	359	10.7	7	0.9	1	D	23	8.25	0.59	1	0	3	0.5	2.1
A	3	6.76	3.7	522	9.8	49	8.8	2.1	D	24	8.2	0.67	2	0	3	0.3	2.8
A	4	2.59	2.7	170	1.6	78	14	5.1	D	25	8.35	0.05	0	0	1	0.2	0.8
A	5	7.24	2.2	233	3.7	57	11	1.2	D	26	8.59	2.7	55	0.4	69	17	78
A	6	2.68	2.7	114	0.7	64	9.7	5.3	D	27	8.19	1.09	4	0.1	8	2.9	8
A	7	2.85	3.9	79	0.3	142	20	10.	D	28	8.31	0.85	2	0	3	1.6	2.6
A	8	2.66	2.7	87	0.3	102	15	6.6	D	29	8.41	0.53	3	0.1	4	0.5	9.6
A	9	2.53	4	171	0.5	116	16	37	D	30	8.89	0.64	3	0.1	4	1.7	5.4
B	10	7.63	0.49	2	0	4	0.5	2	D	31	8.77	0.92	3	0	4	0.7	4.8
B	11	7.62	0.44	1	0	1	0.5	0.6	E	32	7.67	1.67	99	0.4	161	37	12
B	12	7.6	0.39	1	0	1	0.4	1	E	33	7.44	1.56	31	0.4	64	12	18
B	13	7.94	0.38	1	0	1	0.3	0.3	E	34	7.92	1.64	41	0.4	38	7.5	21
B	14	7.73	0.42	11	0	6	0.4	0.3	E	35	8	0.73	1	0	1	0.7	1
B	15	7.19	0.66	2	0.5	2	0.6	0.6	E	36	8.18	1.31	13	0	24	3.6	22
B	16	7.98	0.59	0	0	1	0.4	0.2	E	37	5.18	1.28	12	0.1	34	6.9	32
B	17	8.3	0.31	0	0	0	0.1	0.1	F	38	5	1.46	4	0	4	0.7	0
B	18	8.41	0.36	0	0	0	0.1	0	F	39	4.87	1.48	2	0.1	5	0.6	0
C	19	2.57	6.5	299	0.2	163	30	16	F	40	6.48	1.43	2	0.1	6	3.7	0.8
C	20	2.5	6	539	1.5	234	15	99	F	41	6.58	2.04	21	0.2	18	4.7	6.6
C	21	1.54	12.6	5586	132	1449	119	269	-	-	-	-	-	-	-	-	-

The geochemical properties of the waste rocks are summarized in (Table 2). The geochemical classification of collected rock samples is seen on Figure 3. OP-1, OP-2, OP-3, OP-4 in the open pit area and LG-1, LG-2, LG-3, LG-4 and LG-5 in the low-grade ore dump area were classified as PAF. The paste pH for all samples (except LG-2, LG-3, LG-4 and LG-5) ranged from 3.60 to 5.20, which exceeds the official standard value for pH. NAG pH ranged from 2.05 to 3.27, and NAPP showed positive values in the open-pit and low-grade ore dump areas. Thus, there is a potential risk of AMD in this area. This result is

consistent with the findings from the water quality results that the major areas of AMD are located at A and C. On the other hand, WD-3 was classified as NAF, and WD-2 and WD-4 were classified as PAF. WD-1 was classified as UC due to its positive NAPP and NAG pH of more than 4.5. In the Area E waste rocks has high carbonate mineral such as CaO and MgO can be produce neutralized in an absence of AMD in Area E, where the measured pH of the wastewater can be seen to range from 5.18 to 8.18 in (Table 1). Although WD-2 and WD-4 were classified PAF and its paste pH were 7.80, its NAG pH was 2.00 and 2.03,

and its NAPP was 140.49 kg H₂SO₄/ton and 105.74 kg H₂SO₄/ton. The more positive NAPP values of rock indicates the higher capacity in producing acid while a more negative value informing that less capacity in producing acid and higher capacity in neutralizing the acidity within the system. NAG pH indicates acid potential after complete dissolution of the rock sample with H₂O₂, indicating that WD-2 and WD-4 are AMD contamination risk in the future, although there is currently no AMD in area E.

The geological classification of collected rock samples can be seen on (Figure 3). The results indicated that only one sample (sample WD-1 with NAG pH= 5.54, NAPP= 10.78 kg H₂SO₄/ ton) was identified as “UC” (uncertain) due to the conflict of NAG pH and NAPP values. However, overall result in classification indicated that NAG test was enough to classify most waste rocks as PAF (except one sample from Area E). In general, the results indicated that Area E contained both NAF and PAF materials, whereas Area A and C contained only PAF materials. The presence of PAF indicated the potency of AMD.

Table 2. Summary of geochemical characteristics static test results from the Kyaukpahto gold mine area.

Location	Sp. ID	Paste pH	Paste EC (mS/cm)	Total S mass %	MPA*	ANC*	NAPP*	NAG-pH	Classification
Open-pit (Area A)	OP-1	5.10	1.17	0.39	11.90	0.84	11.07	2.97	PAF
	OP-2	3.90	3.00	1.82	55.59	2.03	53.56	2.40	PAF
	OP-3	5.20	2.10	2.59	79.29	2.99	76.30	2.05	PAF
	OP-4	4.40	1.52	1.16	35.47	2.94	32.53	2.57	PAF
Low-grade ore dump (Area C)	LG-1	3.60	2.10	0.60	18.47	0.84	17.63	3.27	PAF
	LG-2	6.10	1.06	1.03	31.47	1.80	29.67	3.05	PAF
	LG-3	7.00	1.07	1.69	51.73	0.60	51.13	2.33	PAF
	LG-4	6.40	1.27	1.02	31.08	0.48	30.60	2.90	PAF
	LG-5	6.20	1.49	1.16	35.63	2.28	33.36	2.68	PAF
Waste dump (Area E)	WD-1	8.10	1.81	2.04	62.28	51.50	10.78	5.54	UC
	WD-2	7.80	3.90	4.91	150.19	9.70	140.49	2.00	PAF
	WD-3	8.70	1.08	0.71	21.68	55.56	-33.88	8.49	NAF
	WD-4	7.80	2.70	3.52	107.77	2.04	105.74	2.03	PAF

Note. * in kg H₂SO₄/ton

MPA: Maximum Potential Acidity

ANC : Acid Neutralizing Capacity

NAPP: Net Acid Potential Production

NAG : Non- Acid Generation

Calculation:

MPA= Total S% * 30.6

NAPP = MPA – ANC

Classification:

NAF : NAG pH ≥ 4.5; NAPP ≤ 0

PAF : NAG pH < 4.5; NAPP > 0

PAF: Potentially Acid Forming

NAF: Non-Acid Forming

UC: Uncertain

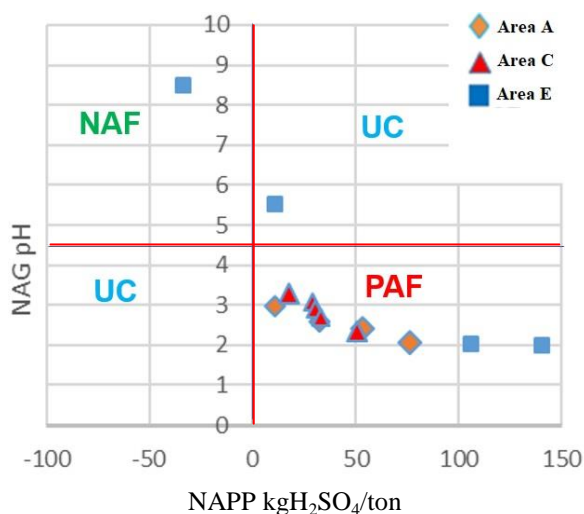


Figure 3. Geochemical classification of rock samples collected from Kyaukpahto gold mine. PAF-potential acid-forming rocks; NAF-Non Acid-forming rocks; UC-Uncertain rocks.

The XRF analysis results of rock samples, as shown in (Table 3), OP-1, OP-2, OP-3, LG-2, LG-3 and LG-5 in area A and C showed a high concentration of Arsenic. This is consistent with the detection of a high As concentration in surface water in area A and C (Table 1). The high concentration of Fe, Cu, As and S observed in areas A and C can be attributed to the common occurrence of pyrite, arsenopyrite, and chalcopyrite in the waste rocks, as geological investigations indicate the presence of these minerals in the rocks produced at the mine. Moreover, waste rocks in area E showed higher concentrations of Mg and Ca than in other areas. This suggests the presence of carbonate minerals, which will have contributed to the acid neutralization capacity reported in (Table 2) for rocks from this area.

The effectiveness of AMD generation can be observed from the relationship between NAG pH and Paste pH as shown in (Figure 4). The study of NAG pH and Paste pH values offers an indication of relative reactivity of material.

Table 3. XRF analysis results of analyzed samples from the Kyaukpahto gold mine area.

Location	Sp. ID	SiO ₂ mass %	Al ₂ O ₃ mass %	FeO mass %	MnO mass %	MgO mass %	CaO mass %	S mass %	Cu ppm	Zn ppm	Au ppm	As ppm
Open pit (Area A)	OP-1	93.4	2.86	0.85	0.001	0.12	0.02	0.39	8	8	21	5691
	OP-2	78.78	10.06	2.32	0.004	0.35	0.03	1.82	69	81	29	852
	OP-3	73.96	9.51	4.62	0.002	0.43	0.01	2.59	8	24	14	23524
	OP-4	85.14	7.22	1.56	0.002	0.28	0.03	1.16	45	2	25	249
Low grade ore dump (Area C)	LG-1	87.32	6.95	0.72	0.001	0.23	0.02	0.60	5	8	32	169
	LG-2	84.80	7.45	1.46	0.004	0.44	0.05	1.03	205	50	16	426
	LG-3	83.82	6.27	2.37	0.004	0.49	0.07	1.69	201	67	31	826
	LG-4	81.25	9.38	1.56	0.005	0.60	0.03	1.016	112	72	19	293
	LG-5	79.79	9.90	1.79	0.005	0.68	0.04	1.16	64	88	26	506
Waste dump (Area E)	WD-1	67.19	12.82	4.35	0.085	1.44	2.25	2.04	0	28	22	404
	WD-2	61.46	11.82	7.56	0.03	1.10	1.24	4.91	4	24	23	910
	WD-3	67.27	13.46	4.03	0.136	2.22	2.68	0.71	3	53	26	90
	WD-4	66.08	12.83	5.95	0.028	1.31	0.36	3.52	2	29	28	637

Table 4. Result of two-step batch test (elution amount of element eluted per unit weight of rock sample).

Step	Location	Sample	pH	EC mS/cm	Al mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg	As mg/kg	SO ₄ ²⁻ mg/kg	
MNEQ* guidelines (2015)			6-9	-	3	-	2	0.3	0.5	0.1	-	
First step	Open pit (Area A)	OP-1 (L/S = 2)	5.08	0.93	2.3	1.5	12.2	0.2	2.7	2.3	977	
		OP-2 (L/S = 2)	4.03	2.0	80.3	2	64	2.5	0.1	0.04	4640	
		OP-3 (L/S = 2)	4.73	2.1	1.7	1	13.5	0.1	52.2	52.2	2409	
		OP-4 (L/S = 2)	4.15	1.51	40	2.1	72.3	0.2	0.6	0.65	2747	
	Low grade ore dump (Area C)	LG-1 (L/S = 2)	4.18	0.91	26.4	0.6	12.3	0.3	0.23	0.23	1548	
		LG-2 (L/S = 2)	4.23	1.96	59.1	4.6	24.5	2.6	0.19	0.19	4434	
		LG-3 (L/S = 2)	4.08	2.0	137.5	2.6	61.8	3.3	0.3	0.28	5673	
		LG-4 (L/S = 2)	4.36	2.4	40.6	2.3	13.3	1.8	0.1	0.1	4962	
		LG-5 (L/S = 2)	4.28	2.5	70.8	2.1	19.4	1	0.21	0.21	5346	
	Waste dump (Area E)	WD-1 (L/S = 2)	7.87	1.83	1.4	0.1	1.1	0.2	0.21	0.21	2769	
		WD-2 (L/S = 2)	7.39	3.1	3.8	1.1	2	0.3	0.25	0.25	708	
		WD-3 (L/S = 2)	8.18	0.92	1.3	0	1.2	0.2	0.12	0.12	619	
		WD-4 (L/S = 2)	4.23	4.8	55.1	44.1	157.7	0.2	0.25	0.25	14605	
	Second step	Open pit (Area A)	OP-1 (L/S = 2~8)	5.42	0.20	18.8	1.6	11.4	0.4	1.7	45.62	523
			OP-2 (L/S = 2~8)	4.12	0.57	75.9	1.0	48.6	2.8	5.3	0.1	3109
			OP-3 (L/S = 2~8)	5.23	0.63	2.7	0.5	10.2	0.3	0	217.8	1747
OP-4 (L/S = 2~8)			4.26	0.48	80.1	1.1	96.1	0.6	0.6	0.55	2445	
Low grade ore dump (Area C)		LG-1 (L/S = 2~8)	4.29	0.28	31.7	0.2	13.2	0.4	0	0.28	1138	
		LG-2 (L/S = 2~8)	4.41	0.44	48.8	2.1	33.1	1.8	0.9	0.36	2103	
		LG-3 (L/S = 2~8)	4.17	0.58	114.2	1.3	69.7	3.7	3.1	0.39	2984	
		LG-4 (L/S = 2~8)	4.44	0.67	30.4	1.4	8.1	2	2.5	0.11	3119	
		LG-5 (L/S = 2~8)	4.41	0.72	38.9	1.2	25.2	1.4	2.8	0.36	3375	
Waste dump (Area E)		WD-1(L/S = 2~8)	8.15	0.58	5	0.6	7.2	0.6	3.5	1.17	1703	
		WD-2(L/S = 2~8)	7.36	1.69	2.9	2	2.7	0.5	0.1	0.68	5759	
		WD-3(L/S = 2~8)	8.65	0.35	4	0	2.6	0.5	2.1	0.91	421	
		WD-4(L/S = 2~8)	4.20	1.53	54.4	33.4	244.3	0.4	0.9	0.6	723	

Final pH value for rock sample (NAG pH) is measured after all sulfides available is oxidized using hydrogen peroxide (H_2O_2), whereas Paste pH shows the current pH value as the result of material reaction with water. Sample contains reactive sulfide minerals (e.g. pyrite) will apparently be the most responsive in Paste pH test [18]. As we can see in (Figure 4), NAG pH value from area A and area C are below 3.27. Therefore, it is possible that acid generation could be occur in long-term period. NAG pH value of WD-1 and WD-3 from area E reach above pH 5.54. Therefore, possibility of acid generation is quite low. Moreover, they can create neutralization condition due to the present of carbonate minerals in the waste rock.

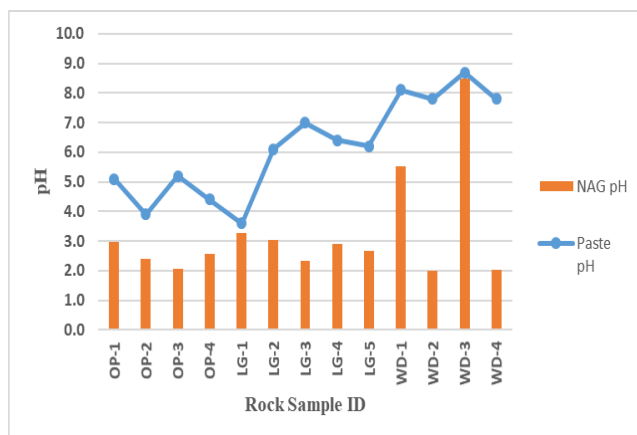


Figure 4. The relationship between NAG pH and Paste pH

The result of the two-step batch test, as shown in Table 4, the elution amount (mg / kg) of the element eluted per unit weight of the rock sample. In geochemical test results of rock, the PAF rocks classified both 1st step and 2nd step, the acidic water around pH = 4 generates for both first and second step from the rock samples of OP-2, OP-3, OP-4, LG-1, LG-2, LG-3, LG-4, LG-5 and WD-4 which are classified as PAF. A lot of metals and sulphate ions are dissolved under the acidic conditions in the first step: aluminum (1.7~137 mg/kg), manganese (0.6~44 mg/kg), iron (13.3~157.7 mg/kg), copper (0.1~3.3 mg/kg), zinc (0.1~52.2 mg/kg), arsenic (0.1~52.21 mg/kg), sulphate ion (1548~14605 mg/kg) for OP-1, OP-2, OP-3, OP-4, LG-1, LG-2, LG-3, LG-4, LG-5 and WD-4. The leached amount under the neutral conditions shows quite lower values compared to acidic conditions in the first step: aluminum (1.3~3.8 mg/kg), manganese (0~1.5 mg/kg), iron (1.1~12.2 mg/kg), copper (0.2~0.3 mg/kg), zinc (0.12~2.7 mg/kg), arsenic (0.12~2.3 mg/kg), and sulphate ion (619 ~ 2769 mg/kg) for WD-1, WD-2, and WD-3. High As can be seen in OP-3 and OP-1 rock samples. The elution amount from the sample OP -3 containing a large amount of As in the rock is found to be the largest. Also, in Al, Fe, Cu, Zn which showed excessive elution in the acidic environment in the 1st step, the elution amount in the 2nd step was largely reduced, but As eluted from OP-3 did not decrease in the second stage. This indicates that As eluted from rocks containing a large amount of As such as OP-3 may elute over a long term compared to other metal ions.

Therefore, the countermeasures to minimize AMD generation for long-term considering the dissolution behavior of As have to be discussed in Kyaukpahto gold mine.

V. CONCLUSION

Kyaukpahto gold mine is the first open-pit gold mine excavated in Myanmar. Gold ore are exploited by open-pit mining method and waste rocks containing metal sulfides are disposed as waste dumps near the mine site, favouring these sulfides in reaction with air and water, and produce acidic mine water. This work focuses to address the current conditions of AMD generation in Kyaukpahto gold mine and identifies the acid-generating waste rocks from waste dump. This study conducted geochemical tests and batch leaching tests on rock samples and quality analysis on wastewater from the immediate vicinity of Kyaukpahto gold mine in Myanmar to evaluate the potential contamination risk from AMD. Standardized batch leaching tests were conducted to study the leaching properties of metals from waste rocks. It was found that, although the pH and heavy metal concentrations of surface water outside the mine area currently meet official standards for wastewater quality because AMD is treated before being discharge from the mine area, this is not so in the mine area itself. The pH and concentrations of toxic chemical elements (e.g. Fe, As, Al, Zn, etc.) exceed the standards at several points, and there is a major area of AMD near the open-pit mine and at a low-grade ore dump, where the pH is less than 3.0 and the concentrations of Fe and As are very high.

In addition, during the processes of weathering the oxidation of pyrite will still go on due to increasing of total reactive surface area, and it should also be taken into consideration. Moreover, the results of NAG and two-step sequential leaching tests indicate a potential As-bearing AMD contamination risk in the future in the waste dump area, through the quality of its wastewater indicates that there is currently no AMD there. In conclusion, to ensure the sustainable development of resources at this mine, long-term contamination of wastewater by As and metal dissolutions should be considered in AMD prevention measures regardless of the evidence for AMD at the present time.

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