Investigation of the quality of water samples in the entrance and effluents from the Sarcheshmeh copper mine tailings dam

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Abstract

Acid mine drainage generation and the associated water quality problems related to mining and mineral processing operations is unavoidable. The tailings produced by the Sarcheshmeh copper processing plant are transported as pulp to the disposal sites with a high speed and an average slope of 8 to 10 percent. There are different tailings disposal sites in the area that the oldest one was selected in this research due to the high possibility for sulphide minerals oxidation and pollutants inputs to water resources. Water samples were collected from water flowing on the tailings surface, water from the entrance and effluents of the tailings to investigate water quality and the mobility of trace elements through surface water. In this research, the water samples were analysed for major dissolved anions and, cations, pH, EC, TDS, TSS and trace elements. The results show that sulphide minerals oxidation, in particular, pyrite has resulted in the elevated concentrations of trace elements, sulphate, iron and low pH. Long-term disposal of tailings will result in the transportation of the sulphide minerals oxidation products and metallic pollutants from such site to surface water and groundwater aquifer in the area.

Keywords: tailings, sulphide mineral oxidation, pollutants leaching, water samples.

Introduction

Sarcheshmeh copper mine is located 160 km south-west of Kerman region, Iran. Geologically, in a vertical section, it is divided into three zones named oxidation, supergene, and hypogene (Shayestehfar et al. 2007). The Sarcheshmeh copper deposit is one of the world's largest Oligo-Miocene porphyry copper deposits in a continental arc setting with a well developed supergene sulphide zone, covered mainly by a hematitic gossan (Figure 1). Supergene oxidation and leaching processes have developed a chalcocite enrichment blanket averaging 1.99% Cu, more than twice that of hypogene zone (0.89% Cu) (Atapour and Aftabi 2007).

Mining activity and mineral processing operation have placed many low grade waste dumps and tailings materials that can cause many environmental problems (Doulati Ardejani et al. 2008 a). The tailings dam contains reactive sulphide minerals in particular pyrite (Figure 2). When pyrite is exposed to the air and moisture, it rapidly oxidises and produces acid mine drainage (AMD) (Ricca and Schultz, 1979; Atkins and Pooley 1982).

AMD is a major problem associated with metal sulphide mining and is noted to be an important cause of water pollution contributing high concentrations of iron, sulphate, variable concentrations of toxic metals, and acidity to receiving waters (Williams, 1975; Erickson et al., 1982; and Chen et al., 1999). AMD is generally generated due to the rapid oxidation of sulphide minerals which poses a number of water related problems (Atkins and Pooley, 1982; Rubio and Del Olmo, 1995). If the effects and magnitude of a water-related issue can be identified before commencement of mining, appropriate water management strategies can be proficiently included into the mine plan in order to minimise the socio-economic and environmental impact of mining activities.

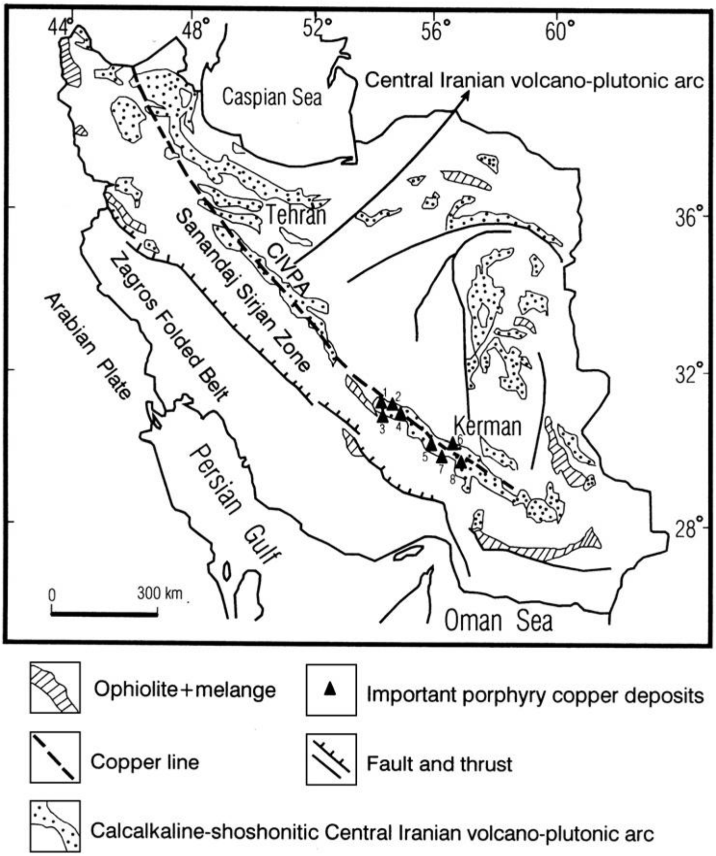

Figure 1 *A map view of Iran showing the volcano–plutonic magmatic arc and copper belt. Some important porphyry copper deposits are: 1=Kader, 2=Gode Kolvari, 3=Ijo, 4=Miduk, 5=Sarcheshmeh, 6=Dehsiahan, 7=Darrehzar and 8=Chahargonbad (Atapour and Aftabi 2007)*

Figure 2 *Tailings surface and flowing water*

A major task in developing an effective treatment scheme and environmental management plan is the investigation of the environmental problems due to the long term generation of AMD and toxic metal pollution during the design stage of a large open pit mining operation. In this paper, the impacts of AMD on the quality of the water was investigated by collecting the water samples in the entrance and effluents from the Sarcheshmeh copper mine tailings dam and analyzing them for hydrogeochemical parameters.

Research method

Sampling

Six water samples were collected from the surface of the sarcheshmeh copper mine tailings. The sampling locations coordinates are given in Table 1. The samples were collected in pre-cleaned high density polyethylene bottles 500 mL each in capacity. At the sampling locations, bottles were washed twice with the sampled water. In each location, two water samples were collected and bottles were labelled. One was for major dissolved cations and anions analysis. They were directly stored under cool conditions at about 5°C without acidification. The second one was for dissolved trace elements. They were acidified before analysis.

Table 1 *Sampling locations coordinates in tailings disposal site*

Sampling location	N	E
A (Dam entrance)	30˚, 05’, 4.7’’	55˚, 51’, 1.8’’
B (Dam surface)	30˚, 06’, 01’’	55˚, 51’, 0.2’’
C (Dam surface)	30˚, 06’, 1.5’’	55˚, 50’, 59.8’’
D (Dam surface)	30˚, 06’, 1.4’’	55˚, 51’, 2.1’’
E (Dam surface)	30˚, 06’, 57.2’’	55˚, 57’, 20.7’’
F (Dam effluent)	30˚, 06’, 59.8’’	55˚, 59’, 45’’

XRD and mineralogical analyses of tailings samples

The XRD analysis of tailings samples revealed that the most minerals included are SiO_2 32%, muscovite and illite 17%, Chlorite 15%, Albite 15%, Orthoclase 10% and Pyrite 8%. The results of mineralogical analysis of the solid samples showed that pyrite oxidation rate decreased sharply at lower depths, up to a depth of about 2 m; below this depth, oxidation gradually decreased, and it had completely ceased at an approximate depth of 4 m (Figure 3) (Shafaei et al. 2011). A method presented by ASTM (Gladfelter and Dickerhoof 1976; Doulati Ardejani et al. 2010) was employed to determine the amount of pyrite remaining in the waste particles.

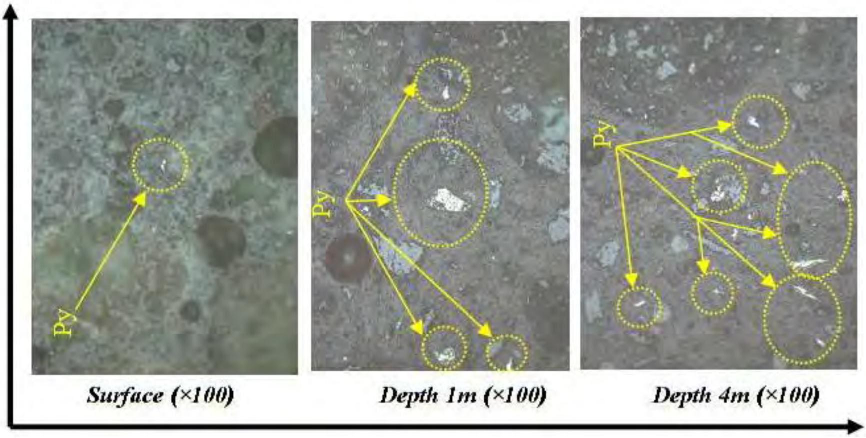

***Figure 3** Mineralogical images of tailings samples (Py: Pyrite), at different depths of the old tailings disposal site.*

Hydrogeochemical analysis

A hydrogeochemical analysis was carried out to investigate the impact of AMD on the quality of the surface water in the study area. pH was determined by a pH-meter model HANA. It varies from 2.20 to 5.78. After passing from a vacuum filter, the water samples were analysed for hydrogeochemical parameters including EC, TDS, TSS and major dissolved anions and cations in the water laboratory of National Iranian Copper Industries Company (NICICo.) (Table 2). The samples were also analysed for trace elements using an inductively coupled plasma mass spectrometer (ICP-MS) by Lab West Minerals Analysis Pty Ltd., Australia (Table 3)

Table 2 *Hydrogeochemical parameters and major dissolved anions of water samples. All concentrations are in Mg/L and EC is given in unit of µs/cm.*

Sample No.	**pH**	**EC**	**TSS**	**TDS**	**CO_3**	**HCO_3**	**NO_3**	**NO_2**	**SO_4**	**Cl**
A (Dam entrance)	8.93	4220	33	2058.0	46.4	0	70	0.65	100.8	188.8
B (Dam surface)	3.62	43400	294	46404	0	0	306.0	0.00	19215	1293
C (Dam surface)	2.67	44600	273	41875	0	0	537.0	0.00	21269	5261.6
D (Dam surface)	3.20	10540	50	6375.0	0	0	608.0	0.00	1930.0	495.2
E (Dam surface)	4.45	7260	1266	9107.0	0	0	398.0	0.08	1959.0	177.2
F (Dam effluent)	5.78	9570	<20	3310.0	0	0	596.0	0.00	1459.0	495.2

Table 3 *Cations and major elements in tailings samples (Mg/L).*

Sample No.	**Al**	**Ca**	**Cu**	**Cr**	**Fe**	**K**	**Mg**	**Na**	**P**	**S**	**Sr**
A (Dam entrance)	452	523	709	0.158	2.68	649	1010	11600	1.35	4510	17.5
B (Dam surface)	895	541	426	0.346	5.92	448	1530	6680	2.07	4670	10.5
C (Dam surface)	0.125	329	0.07	< 0.001	5.13	98.0	16.9	669	0.12	688	2.89
D (Dam surface)	8.64	501	0.06	0.001	4.69	50.0	84.2	1020	0.78	830	7.72
E (Dam surface)	0.117	268	0.08	< 0.001	3.31	82.0	13.7	549	0.17	632	2.16
F (Dam effluent)	0.017	< 0.05	0.004	0.001	3.01	0.32	0.05	0.17	0.02	1	0.01

Result and discussion

Al, Sr, S, P and Ti values were much more than their allowable limits. The geochemical results given through Tables 1 and 2 show that pyrite oxidation process has resulted AMD in old tailings disposal site that subsequently changed the quality of water in the study area.

Investigation shows that the pH value of groundwater varies between 6.3 and 7.1 that this range is in the acceptable limit (Stiefel and Busch 1983). In order to investigate pyrite oxidation problem in the oldest tailings site, water samples were collected from its entrance and effluents. The pH of water flowing on tailings surface was low (2.67-4.45). It was high (pH=8.93) in the water sample collected from the dam entrance, close to new tailings site of mineral processing plant. The concentrations of CO_3 and HCO_3 were very low due to pyrite oxidation and AMD generation. The Electrical Conductivity (EC) values correlate well with SO_4^{-2} and Cl^- concentrations. The TSS and TDS of dam surface were higher than those of dam entrance and effluents. The concentrations of SO_4^- (100.8-21269 Mg/L) and Cl^- (188.8-5261.6 Mg/L) were very high in comparison with their standard permissible values. Peak concentrations of SO_4 and Cl were observed in sample C. The concentration of NO_3 was very high in almost all water samples in comparison with it standard value. The concentrations of major dissolved cations were elevated in the water samples flowing on the tailings surface (Table 3).

Low pH value and high concentrations of SO_4 and Fe describe pyrite oxidation. This process at the surface layers of tailings has resulted in the elevated concentration of Fe (from 2.68 to 5.92 Mg/L). Sulphur concentration in the water samples varies from 1 to 4670 Mg/L. Peak concentration of Sulphur was observed in sample B.

Conclusion

Acid Mine Drainage is one of the major problems in the Sarcheshmeh copper mine; affecting the quality water bodies. Sulphide minerals oxidation mainly pyrite have increased the anions, cations and trace elements concentrations to gather with TSS, TDS, pH and EC. The results of polished sections show that the pyrite oxidation decreased with an increase in depth. Hydrogeochemical analysis of water samples in the entrance and effluents of tailings indicated the elevated concentrations of trace elements. The concentrations of SO_4, NO_3 and Cl were high in the water samples. The pH ranges for surface and groundwater samples were 2.67-8.93 and 6.3-7.1, respectively. Although pyrite oxidation and AMD generation processes in tailings is obvious, however, geochemical studies and hydrological data will provide appropriate remediation plans to prevent metal inputs to soil and water resources.

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