Environmental Problems Related to Pyrite Oxidation from an Active Coal Washing Plant, Alborz Sharghi, Iran

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Abstract
The low grade wastes produced by coal washing plant often contain pyrite which may be oxidised and produce acid mine drainage (AMD) if it is exposed to the atmosphere. AMD is characterised by high concentrations of iron, high sulphate and low pH and it is considered to be a major cause of long-term poor water quality and the source of many environmental problems. In this study, the pollution problem associated with the wastes (which cover an area of about 1 km^2) produced by Alborz Sharghi coal washing plant, at Shahrood, Iran, was investigated by mineralogical and geochemical techniques. Mineralogical analysis indicates the presence of pyrite in the unoxidised waste and its depletion in the oxidised zone. Geochemical analysis of samples taken from different depths over the coal wastes dump up to 2 metres show that pyrite oxidation in the upper 75 cm of the dump has resulted in a peak concentration of sulphate, low pH and high concentrations of metals (pH<3.5, 349 mg/L SO_4, 270 ppm Fe, 120 ppm Mn, 375 ppm Zn, 15 ppm Cr and 10 ppm Co). The acid released from pyrite oxidation has been enough to deplete carbonate minerals in the spoil profile, so a zero concentration was detected for carbonate. It can be concluded that without the implementation of an effective remediation program, the pyrite oxidation process will continue to release acid and elevated concentrations of heavy metals and sulphate to the surface and groundwater flow systems for many more decades.

Key words: pyrite oxidation, acid mine drainage, coal washing plant, coal waste dump, Alborz-Sharghi, heavy metals

Introduction
Iran is the main coal producer in the Middle East. Coal mines have made a considerable contribution to Iranian mining industry and the national economy. Alborz Sharghi is a major coal company in north-east Iran that produces coal from many mines in the region including Tazareh, Razmjah, Razi and Gheshlagh. The coal produced by these mines is washed in Alborz Sharghi coal washing plant in order to raise its quality and remove any impurity. The wastes produced by washing process are dumped in the close vicinity of washing plant. Depending on the method used for coal processing, two kinds of waste are produced and dumped in distinct places. These are the waste produced by a jig machine and that produced by flotation process. It is estimated that the amount of the coal waste in the study area is about 3 million tons. Figure 1 shows a view of waste dump produced by the jig machine. Pyrite is oxidised within the waste dump. The overall stoichiometric reaction describing the oxidation of pyrite and AMD generation is given as:

$$2FeS_2 + \frac{15}{2}O_2 + H_2O \rightarrow 2Fe^{3+} + 4SO_4^{2-} + 2H^+ \qquad (1)$$

As Equation 1 shows, pyrite can be oxidised with direct oxidation of pyrite by O_2, forming Fe^{2+}, SO_4^{-2} and H^+ (Singer and Stumm 1970). Oxygen diffuses from zones of higher to zones of lower oxygen concentration through the air-filled pore space in the waste materials. AMD produced by the oxidation process within the dump may cause a long-term environmental problem in the study area. Such acidic drainages containing iron, sulphate and many other toxic metals can affect the quality of the receiving water bodies.

Figure 1 *Waste produced by Alborz Sharghi coal washing plant*

Although considerable attempts have been made to investigate the pyrite oxidation and AMD generation associated with mine tailings (Walter et al. 1994a, b; Wunderly et al. 1996), waste rock dumps (Cathles 1979; Cathles and Apps 1975; Lefebvre and Gelinas 1995) and strip mine spoils (Jaynes et al. 1984a, b), the literature review thus far has indicated that the pyrite oxidation problem associated with coal washing waste dumps has not been completely discussed. Hence, investigation of the environmental problems associated with coal washing waste dumps is an important consideration for the addition of alkaline material and for applying special handling techniques for neutralising purposes. In addition, it has now become mandatory in Iranian mining industries to develop a Mine Rehabilitation and Environmental Management Plan (MREMP) during the design stage of a coal mining operation and subsequent coal washing plants. In this study, the pyrite oxidation and pollution generation associated with the wastes produced by Alborz Sharghi coal washing plant, at Shahrood, Iran, were investigated by mineralogical and geochemical techniques.

Geology of the study area

The study area is located in Mehmandoost region about 400 km north-east of Tehran in Semnan province, Iran. It is a part of Tazareh coal region and is located in the Shahrood 1:100,000geological sheet. The area consists of sandstone, thin bedded coaly shale of the Shemshak formation, new alluvial deposits and old alluvial fan with gravel marl and quartz.

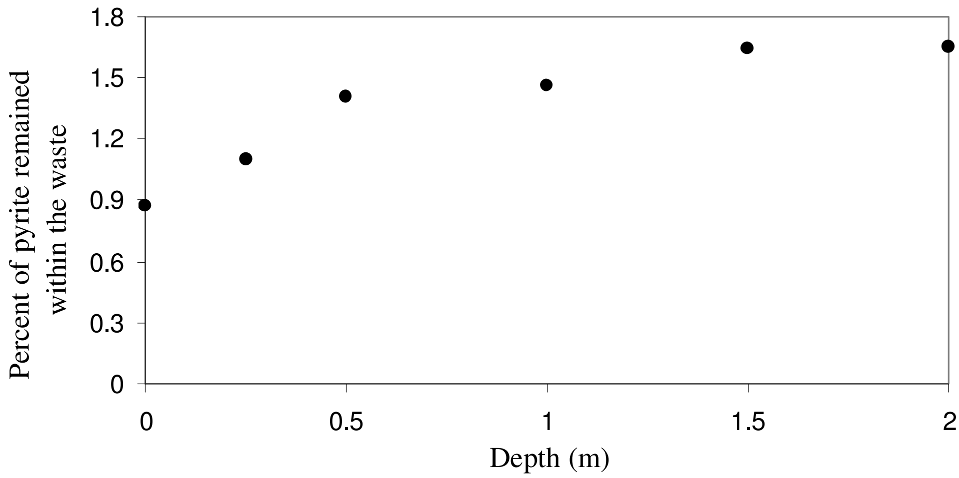
Methodology and analytical Approach

Several coal waste samples each 4 kg in weight were taken from different depths at three points (No 1, No 2 and No 3) on the dump in order to investigate pyrite oxidation and pollutant generation.

Analysis for pyrite remaining within waste particle

The samples were first sieved in the mineral processing laboratory at Shahrood University of Technology to obtain a particle size < 75 μ. HCl acid was used to dissolve sulphates. Pyrite was extracted from coal using HNO_3 acid. An AA–670 Shimadzu atomic absorption was used to measure iron from the solution, then employed to determine the fraction of pyrite remaining within the waste particles. Figure 2 illustrates the percent of pyrite remaining within the waste particles versus depth at sampling location No 3.

Figure 2 *Field data for the fraction of pyrite remained within the waste particles as a function of depth at point No 3*



As the figure illustrates well, the rate of pyrite oxidation decreased sharply with depth up to 0.5 m, where oxygen concentration decreased rapidly. The process decreased gradually in the zone between 0.5 m and 1.5 m. For deeper layers (below 1.5 m) where no oxygen is available to oxidise pyrite, the pyrite oxidation reaction was completely ceased.

Geochemical analysis of the samples

The samples were also analysed by the atomic adsorption method to determine geochemical parameters such as various anions, cations and toxic metals due to pyrite oxidation and acid generation within coal wastes. The results are given in Table 1.

Geochemical analysis of samples taken from different depths over the coal wastes dump up to 2 metres show that the pyrite oxidation in the upper 75 cm of the waste dump has resulted in a peak concentration of SO_4 (349 mg/L), low pH (pH<3.5) and high concentrations of metals (270 ppm Fe, 120 ppm Mn, 375 ppm Zn, 15 ppm Cr and 10 ppm Co, 5 ppm Cu, 304 ppm Mg). The acid released from the pyrite oxidation has been enough to deplete carbonate minerals in the spoil profile, so a zero concentration was detected for the CO_3^{2-} ion.

Table 1 *Geochemical analysis of the samples taken from different depths on the waste dump at sampling point N0 3*

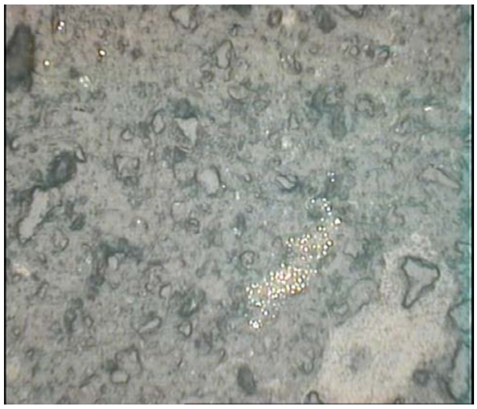
Depth (m)	Parameter (ppm)														
	pH	Ca	Mg	Na	Fe	Mn	Cu	Zn	Cr	Co	SO_4^{2-}	HCO3	Cl^-	$CO3^{2-}$	$EC\times10^3$
0	3.9	36	30	170	95	80	5	20	20	0	128	20	5	0	23.4
0.5	3.7	38	304	8.5	110	83.5	5	25	0	0	349	0	0	0	35.0
1.0	4.1	22	224	78.5	105	60	5	15	0	0	324	0	0	0	32.4
1.5	4.36	32	29	545	145	78	5	40	15	5	290	87.5	225	0	60.4
2.0	3.43	40	20	534	270	120	5	375	15	10	291	75	225	0	59.2

Mineralogical analysis

Mineralogical analysis indicates the presence of pyrite in the unoxidised waste and its depletion in the oxidised zone. At the dump surface, oxygen is readily available, so the rate of pyrite oxidation is very high. A thin section from the dump surface (Figure 3.a) indicates the lack of pyrite. However, particles of pyrite can be seen in the section from depth 1.5 m (Figure 3.b) where no oxygen is available to oxidise pyrite.

Figure 3 *Thin section of sample No 3; indicating pyrite within the coal waste, the sample was taken at* *(a) dump surface, (b) depth 1.5 m*

(a)



(b)

Conclusions

This study investigated the pollution problems associated with the wastes produced by Alborz Sharghi coal washing plant, at Shahrood, Iran. Both mineralogical and geochemical studies demonstrated the pyrite oxidation process within the waste dump. Geochemical analysis of samples taken from various depths in the dump showed that the pyrite oxidation formed acid mine drainage and toxic metal leaching. pH dropped to 3.5 and a peak concentration of sulphate equal to 349 mg/L was formed at depth 0.5 m. CO_3^{2-} was depleted in the spoil profile. Toxic metals such as Zn and Co were washed in the surface layers of the dump. An effective rehabilitation plan can be develop to reduce pollutant potential caused by pyrite oxidation and pollutant leaching associated with the wastes produced by coal washing process.

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