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ESTIMATION OF ACIDIC MINE DRAINAGE (AMD) FROM COAL MINES AND ITS MANAGEMENT

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Abstract

Investigations to estimate acid mine drainage (AMD) from an underground mining complex (Madin-e-Haq) were carried out during 2004 to 2007. Measurements of seepage with V-notch method from various seepage points indicate that the mining complex is generating 126.60 liter per minute of AMD from 13 seepage locations. The pH values of the 13 AMD points range from 2.5 to 7.4. The pH at the portal of the mining complex has been determined to have a composite average value of 3.4. Two groups of AMD seepage points have been identified: Group-A seeps have pH from 5.9 to 7.4 and Group-B seeps have pH from 2.5 to 3.1. Group-A constitutes 58% of total AMD inflow in the mine complex. Based on our findings that all the inflows entering in the mine are not acidic, therefore we propose that the Group-A, water may be pumped out separately and utilized without any treatment for local irrigation, or disposal as surface effluent. We propose that the Group-B AMD, which is 42% of total inflows in the mining complex, be pumped out and neutralized with abundant local limestone prior to disposal as a surface effluent.

Keywords: Makarwal coal field, acidic mine drainage, limestone, management, neutralization.

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1. Introduction

Pakistan has huge coal resources spread throughout the country, and coal mining is one of the important industries of the country. However, the coal quality is poor. The coal typically has high amounts of pyrite and high ratios of contaminants that create unwanted combustion gases. The high amounts of pyrite in the coal also result in the generation of acid mine drainage (AMD) through oxidation reactions. The processes of pyrite oxidation and associated acid production that result in AMD have been described by Singh (2008).

Gray (1997) while discussing the environmental impact and remediation of acid mine drainage developed useful procedures to solve the AMD problem and reported as, "the importance of an interactive protocol with clear management objectives and procedures is vital to successful rehabilitation of such sites and long term protection of the environment".

Makarwal is one of the oldest coalfields of Pakistan (Fig. 1). Coal investigations and mining activities have been carried out at Makarwal since 1902. The first organized coal production started in 1911. After establishment of Pakistan's independence, private parties operated Makarwal collieries. Later, exploration and mining activities were carried out under public sector. The coal resources were estimated 19 million tons by Shah (1977). At the current time, large-scale mining activities continue to mine coal from the Makarwal coalfield. The average coal production from Makarwal Collieries is approximately 500 tons per day

The Government of Punjab has allotted five leases to various parties for coal mining from Makarwal Collieries. The long history of mining of more than one century, a network of 93 coal mines has been developed in the Makarwal coalfields. The present status indicates that out of 93 mines 67 are productive and 26 are non-productive. One of the major causes of non-productive mines is generation of AMD, which hinders safe mining operation. Operations at many mines have been frequently suspended due to the high pumping cost of AMD from deep mines.

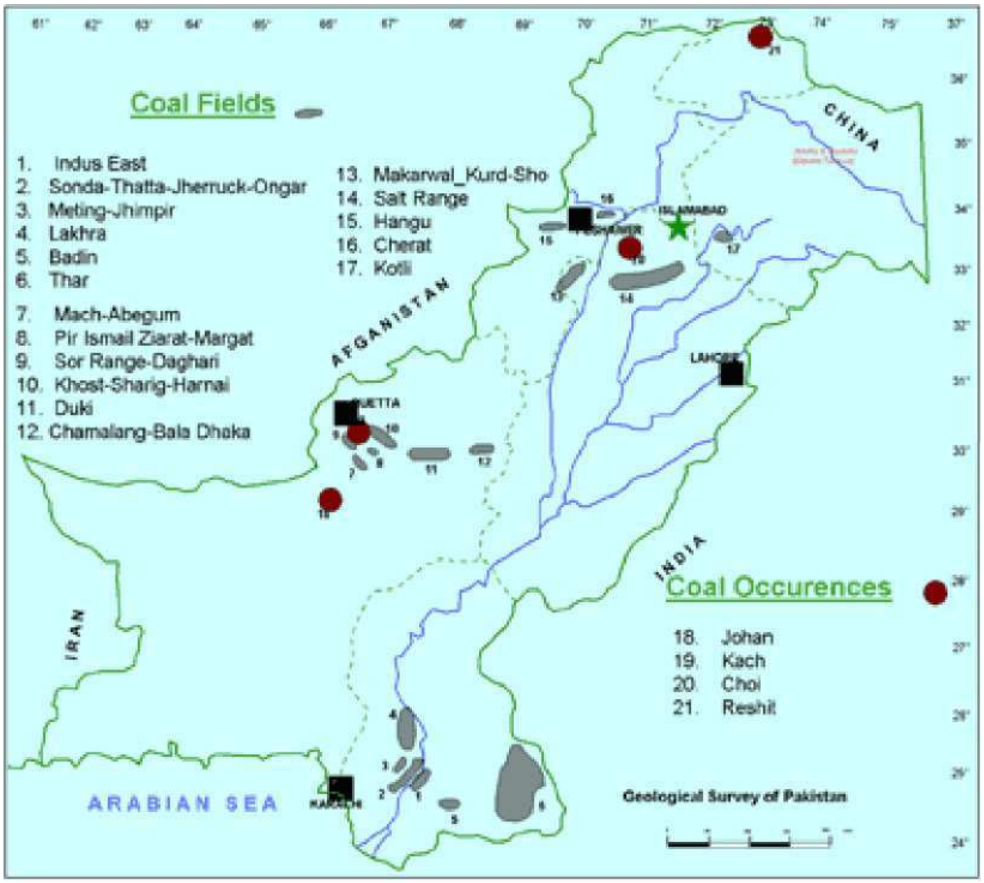

Fig. 1: Location of Makarwal Coal Field, Study Area (GSP, 2010)

Khan and Iqbal (2008) reported that the most of the coal is located in the form of deep coal seams. Due to tectonic history of the area, a number of faults cut the coal bearing formations in the study area. During precipitation the runoff is directly recharged from these faults and related structural discontinuities. The groundwater enters the subsurface through fault zones where it encounters pyrite-containing coal formations, resulting in generation of AMD. The resulting highly acidic water finds its way into mining tunnels from where it is pumped out and discharged to surface drainages or fresh water nullahs. These surface drainages recharge the local groundwater systems with the consequence of AMD contamination of potable aquifers in a large area surrounding the coal fields. Other potential sources of AMD in the area are huge coal waste dumps located at the surface near the portals of coal mine tunnels (Fig.2).

Fig. 2: Huge coal waste dumps at the portal of mine complex which is a potential source of AMD.

A number of studies indicate that AMD may be neutralized by passive treatment through limestone, such as reported by Gravotta (2008), Rotting (2008) and Maree (2004). Hence this study has been carried out in the Maden-e-Haq mine complex to estimate the quantity of AMD and investigate its treatment by using limestone. Limestone is locally abundant in the vicinity of the mining operations.

2. Materials and methods

Samples of AMD were obtained from 13 underground stations from Makarwal Collieries. The samples were collected in 1-L plastic bottles. Most of the sample points are sumps, seepage drains, or piping locations in underground tunnels. Measurements of inflows at every sampling station were also made with V-notch method to estimate total AMD inflows in the mining complex.

Six limestone random samples each 1 kg in weight were collected from the local limestone formations. Three samples with identifications numbers of LS-1, LS-2, and LS-3 were crushed in Denver Jaw Crusher (Blake type) Model HX-39149, and sieved through Tyler Standard Test Sieve Series to obtain samples varying from 1 to 4 mm in size. This size range was used for experiments. Three samples with identification numbers of LS-4, LS-5, and LS-6 were used to prepare lime by using Gallenhamps Furnace, England, at 750°C temperatures. A portable pH meter, model ELE International 2004, was used to determine the field pH values. The same meter was also used for measurement of pH in laboratory experiments.

Limestone samples from Lochart Formation, which is present in abundance around the

Makarwal collieries, were used in the experiments to test their effectiveness for neutralizing AMD. The AMD samples with lowest pH values (< 2.5) were selected for use in the neutralization experiments. Two different materials, limestone and lime were tested to establish the effectiveness for neutralizing the AMD. The neutralization tests involved measuring the change in pH after reaction between the AMD and neutralizing agents for time periods of 24, 48, 72, and 96 hours.

2.1 Geology of Makarwal coal field

The coal units of the Makarwal Coal Field are part of the Hangu Formation. The Hangu formation is comprised of sandstone with minor amount of mudstone, clay stone and coal seams. Shah (1977) reported, “The basal Paleocene Makarwal coal is the result of earliest Cenozoic transgression. The coal perhaps has been transformed from the vegetation, which flourished in the area following the Cretaceous Regression and prior to Paleocene transgression which caused the deposition of sandy plain type sediments called as Hangu Formation.”

There is one major coal bed in the most of mining areas and its thickness varies. The measurements by Khan and Iqbal (2006) in the Maden-e- Haq coal mine complex indicate that there are two coal seams in this area. The upper coal seam is 2-ft thick and is hard, compacted, and slightly pyritic. The lower coal seam is 5.6-ft thick and contains 3-5 % pyrite. The degree of hardness of the lower seam varies from top to bottom. These two coal seams are separated by clay stone in Dip-1, of the Level-3 of the mine complex. The claystone is slightly coaly and micaceous and has a thickness of 2 ft.

3. Results and discussion

Measurements of AMD inflows in the mine complex are given in Table 1. A total of 126.60 L/min AMD is being generated. The AMD flow is collected in underground sumps from where it is pumped out and drained in the effluents. Out of the 126.60 L/min total AMD flow, 58% has pH ranging from 5.9 to 7.4. This portion is not considered to

Table 1: Estimation of AMD being generated from 13 seepage and leakage locations, entering into the underground mining complex.

Sample No.	Location	pH	Group	AMD Liter/minute	Remarks
S-1	Sum p at SP-1	5.9	A	40	Composite measurement of AMD from four seepage locations.
S-2	Fault near SP-1	6.9	A	30	Composite measurement of two leakage points.
S-3	SP-2	2.6	B	10	-
S4	Dip-1, Level-3	3.1	B	40	Total measurement from two seepage zones.
S-5	Near exit of the tunnel-2	7.4	A	3	-
S-6	Dip-2, Level-3	2.9	B	0.5	-
S-7	Seepage near SP-2	2.5	B	0.8	-
S-8	Seepage near SP-3	2.8	B	2.3	-
S-9	Shallow barren dug well in private land	4.6	-	-	Shallow dug well sample from the surrounding of the mining complex
S-10	PMDC Tubewell	8.5	-	-	Water supply tube well 16-km away from the mine complex

be acidic drainage. The remaining portion of 42 % has pH ranging from 2.5 to 3.1 and is acidic enough to require treatment before discharge. Hence, all the drainage points are categorized into two groups: Group-A, comprised of samples S-1, S-2, and S-5 with pH from 5.9 to 7.4, and Group-B, comprised of samples S-3, S-4, S-6, S-7, and S-8, with PH from 2.5 to 3.1. The present practice in the mine is to collect all drainage water in underground sumps from where it is pumped out and discharge to the surface effluent or seasonal nullah.

Recently, we have proposed that drainage water from all the locations related to Group-A would be collected separately and pumped to the surface where it could be stored in surface reservoir. This reservoir of non-acidic water will be used for local irrigation under gravity flow. All drainage water from locations belonging to Group-B (AMD water) will be collected separately, treated to neutralize acidity, and subsequently discharged to the surface.

Year wise comparison of AMD inflows over the time span of 2004 to 2007 shows variations in water quantity which are related to seasonal water recharge (Table 2). The maximum flow rate of

AMD measured during July 2006 is 142 L/min, which is related to the monsoon precipitation recharge. The minimum AMD flow rate of 110 L/min was measured during the months of December 2005, which is probably due to dry season. Hence, approximately 30% increased inflows entering into the mine complex from July to October of most years are related to the monsoon precipitation.

Table 2: Year wise comparison of AMD quantity and its pH from Coal Mine Complex

Year	**AMD Liter per minute**	**pH**		**Remarks**
		Minimum	**Maximum**	
August 2004	126.60	2.5	7.4	Sampling was made during monsoon period from 13- locations.
December 2005	110.25	3.5	-	Only one composite measurement for AMD quantity was made from outlet of the pumping station
July 2006	142.00	4.3	-	Measurement from effluent.
December 2007	112.00	3.4	-	Measurement of the AMD from effluent.

3.1 Neutralization of AMD with Lime

In laboratory studies, a very fast reaction was observed when AMD was treated with lime prepared from local Lochart limestone (Table 3). The AMD with an initial pH of 2.5 showed an increased in pH to 11 within 24 hours. After the initial period of rapid pH increase, the reaction was observed to become progressively slower until it became almost constant after 72 hours. It is notable that neutralization time for AMD of same pH from different locations is also different, which is probably due to variation in their chemical composition.

Table 3: Measurement of the acidity reduction of AMD after mixing with lime prepared from limestone of Lochart Formation.

Sample No.	Time in Days				
	05-08-2004 Initial pH	06-08-2004 After 24 hours	07-08-2004 After 48 hours	08-08-2004 After 72 hours	09.08.2004 After 96 hours
S3-1	2.4	8.9	10.9	10.9	10.9
S3-2	2.5	9.1	10.8	11.2	11.3
S3-3	2.5	10.5	10.9	11.3	11.3
S3-4	2.6	11.8	11.0	11.6	11.6
S3-5	2.5	12.0	11.6	11.6	11.6
S3-6	2.5	11.4	11.8	11.6	11.6
S3-7	2.5	11.9	11.5	11.8	11.9
S3-8	2.4	11.8	11.4	11.8	11.8
S3-9	2.5	10.8	11.4	12.0	12.0
S3-10	2.5	11.8	11.9	12.1	12.1

3.2 Neutralization of AMD with Limestone

The rate of reaction between AMD and Lochart Limestone increased the pH value 1.82/day which is slower than the observed reaction between AMD and lime where the pH increased 8.5/day for the same quantities. It is interesting to note that even though reaction rates were slower, the AMD with initial pH of 2.5 still attained a pH of 6.14 within 48 hours. A pH of 6.14 is acceptable for disposal. The increase in pH continues beyond 48 hours attains the average value of 7.73 after 72 hours (Table 4). In contrast to the neutralization tests with lime, the tests with limestone showed continuous increase in pH with longer residence time.

Table 4: Measurement of acidity reduction of AMD after mixing with limestone of Lochart Formation.

Sample No.	Time in Days				
	05-08-2004 Initial pH	06-08-2004 After 24 hours	07-08-2004 After 48 hours	08-08-2004 After 72 hours	09.08.2004 After 96 hours
S3-1	2.4	3.7	4.5	5.1	6.3
S3-2	2.5	3.6	5.0	7.9	8.4
S3-3	2.5	3.4	5.1	8.0	8.9
S3-4	2.6	3.3	5.0	8.0	8.9
S3-5	2.5	3.5	5.8	8.0	8.8
S3-6	2.5	3.7	6.6	8.0	8.9
S3-7	2.5	3.9	7.1	8.0	8.8
S3-8	2.4	3.9	7.2	8.1	8.9
S3-9	2.5	4.1	7.4	8.1	8.9
S3-10	2.5	4.5	7.7	8.1	8.9
Average	2.49	3.76	6.14	7.73	8.57

4. Conclusions and recommendations

Most of the seepage water (58%) entering the subsurface mines has near neutral pH as exemplified by samples S-1, S-2, and S-5 with pH from 5.9 to 7.4. These near neutral pH values are attributed to the passage of infiltrating water through carbonate strata prior to entering the subsurface mines and collected in mine sumps. Reactions with the carbonates yield enough alkalinity to prevent AMD formation and water quality is acceptable for direct discharge. In contrast, 42% of the seepage water as exemplified by samples S-3, S-4, S-6, S-7, and S-8 are AMD with pH 2.5 to 3.1 due to exposure to pyrite-bearing coal formations.

The present practice is to collect all seepage in pipelines or drains into under ground sumps from where it is pumped out through a single large diameter pipe and drained in the surface effluent.

We propose a new practice in which the AMD seepage points belonging to two different groups should be pumped out separately without mixing and brought to the surface. The Group-A, seepage (58 % of total seepage) should be pumped separately to the surface. This near neutral character of the Group-A, seepage would allow it to be used for local irrigation, or directly discharged to surface drainages without treatment. Hence, the new practice would greatly decrease the amount of AMD requiring treatment prior to surface discharge. The Group-B (42%) seepage, which is strongly acidic, should be neutralized with lime or local limestone before discharge to surface drainages.

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