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Technical Communication

Acid-Base Accounting: A Geochemical Tool for Management of Acid Drainage in Coal Mines

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Abstract. Acid-base accounting tests are generally used as a screening tool to delineate and define the geochemical character of different rocks. Geochemical investigations indicated that the rocks of the study area could be grouped as either acid producing or acid neutralizing. An experiment conducted in the laboratory indicates that allowing the acid mine water to drain through friable, alkaline sandstone neutralizes the mine water. This may be an inexpensive option to use at this site.

Key words: Acid-base account, acid mine drainage, acid production potential (APP), neutralization potential (NP), physical model

Introduction

The incidence of acid mine drainage (AMD) in a geological terrain is mostly governed by the acid-base content of the various rock units and their physico-chemical properties. The occurrence of AMD is common in mines around the world. It also occurs in a few coal mines in India (Dhar 1990; Jamal 1990; Jamal et al. 2000). Several methods have been suggested and used for management of AMD (Skousen et al. 1997; Starck and Williams 1994; Ziemkiewicz et al.1997), but there is no universally acceptable, eco-friendly method to solve the problem on a long-term basis without any other environmental consequences. In developed countries, conventional and passive water treatment is commonly used, but due to economic factors and monitoring requirements, these methods are not commonly being used in developing countries like India. The work presented in this paper examines the implication of applying acid-base accounting (ABA) to demarcate acid and base producing litho-units and then use the alkaline units to manage the AMD.

Description of the study area

The study area (an underground coal mine) is part of the South Eastern Coalfields Ltd., in the state of Madhya Pradesh, in central India (latitude $23^0 17'$ to $23^0 25'$; longitude $82^0 28'$ to $82^0 33'$). The area experiences a moderate climate. In winter months, the temperature goes down to 10^0C but because of altitude, the summer months are not very oppressive. Rainfall in the area is quite high, averaging 150 cm per year. Physiographically, the land is undulating. The main waterway in the area is the Hasdo River, which receives the mine effluent and is also used by nearby villagers and their animals. The coal-bearing rocks (Barakar Formation) are Upper Carboniferous to Lower Permian in age and consist primarily of sandstone with a minor amount of shale. The study area is covered by sandstone except in the north, which is covered by igneous rocks. A thick dolerite sill demarcates the northern boundary of the study area. Megascopically, the sandstones are fine- to coarse-grained and friable. The colour of the sandstone varies from white to yellowish white. The coarse-grained Barakar sandstones are usually loosely cemented with high porosity, and can be disintegrated with one's fingers. The overall proportion and surface exposure of the white coarse-grained sandstone is rather high compared to the other varieties.

Materials and methods

Water sampling locations included seepage, inclines, working faces and sumps within the mine. The water was sampled during the month of May using properly cleaned polythene bottles. Important water quality parameters like temperature, pH, and TDS were measured at the mine site using a portable water analysis kit, whereas parameters such as concentration of iron and sulphate were determined in the laboratory (Standard Methods 1995). Analytical results are provided in Table 1.

Fresh rock and coal samples were collected both from the ground surface and working faces within the mine. For mineralogical study, thin-sections of sandstone were prepared and studied under the microscope. Powder samples were also prepared to determine the geochemical characteristics of coal and associated rocks. Paste pH, acid production (AP), and acid neutralization (NP) potential were determined

Table 1: Chemical composition of mine water at various locations

Parameters	Sampling site			
	Seam Incline	Sump water	Seam Incline	Seam Incline
Temperature (^{0}C)	30.2	31.8	29.4	30.8
Colour	Yellowish brown	Yellowish brown	Yellowish brown	Yellowish brown
Odour	Pungent	Pungent	Pungent	Pungent
pH value	2.76	2.69	2.71	2.61
Total suspended solids	69.72	73.0	63.40	81.86
Total dissolved solids	2654	2505	2284	2928
Sulphate as SO_4	2323.50	2189.50	1913.40	2361
Iron	33.2	41.8	37.42	49.64
Calcium	122.84	127.64	119.24	117.2
Sodium	31.4	39.18	43.4	36.52
Potassium	21.18	24.02	18.24	23.36
Magnesium	12.8	114.02	108.3	126.4
Bicarbonate	BDL	BDL	BDL	BDL
Carbonate	BDL	BDL	BDL	BDL

All values are in mg/L except temperature, colour, odour, and pH

using standard procedures (Dhar et al.1987; O'Shay et al. 1990; Sobek et al. 1978).

Experimental setup

Samples of Barakar sandstone were chosen for laboratory drain model experiments after getting favourable preliminary ABA results and considering the geological setting of the study area. To assess the applicability of the Barakar sandstone of the area, a physical laboratory drain model was designed and fabricated to simulate actual field conditions. A photograph of the experiment is shown in Figure 1. The model simulated an open zig-zag drain and was made of galvanized aluminium sheet. The total length of the drain was 18 m. Width and depth were 8 and 10 cm respectively. A rotameter was used to monitor the rate of discharge of the mine water in the drain.

Sandstone samples collected from the surface of the study area were cut into rectangular slabs. The width of each slab was approximately 8 cm. The slabs were 0.5, 1.0, 1.5, and 2 cm thick. Sandstone slabs of a particular thickness were placed along the 18-m length of the simulated drain. Sump water of pH 2.60 was allowed to flow over the sandstone slabs at a particular rate of discharge. Water samples were collected at the discharge point of the drain at fixed intervals of time and analysed for pH, TDS, and concentration of iron and sulphate. The objective of the experiment was to assess the possible use of the sandstone to mitigate AMD and modify the chemistry of the mine effluent.

Figure 1. A photograph of the laboratory experiment

Results and Discussion

Physico-chemical characteristics of mine water

It is evident from Table 1 that the drainage water is highly acidic and contaminated. Among the dissolved solids, the concentrations of iron and sulphate are well above the recommended permissible limit of industrial effluent discharge. This mine water is continuously being discharged untreated into the

Table 2: Paste pH of coal and associated rocks

Type of sample	Average paste pH
Shale	1.95
Coal	2.31
Coarse grained sandstone	9.17
Medium grained sandstone	9.01
Fine grained sandstone	8.89

nearby surface water bodies, potentially damaging the aquatic ecosystem and deteriorating the water quality of the receiving stream.

Geochemical characters of coal and associated rocks

Paste pH values were determined to quickly provide general information about the acid or alkaline nature of the coal and associated rocks (Table 2). The coal and shale were acidic in nature, presumably due to the presence of sulphide minerals, whereas the Barakar sandstones, irrespective of grain size and physico-mechanical properties, were alkaline in nature. The coarser-grained Barakar sandstones were more alkaline than the fine- and medium-grained varieties, due either to its mineralogical composition and nature/type of matrix/cementing material.

Mineralogically, the Barakar sandstones are composed of quartz (44.9-59.8%), feldspar (3.7-25.2%), cement/matrix (18.4-40.4%), mica (2.6-6.4%) and minor amounts of iron oxides and rock fragments. The matrix of the Barakar sandstones is mostly calcareous and argillaceous (Table 3).

The APP and NP of the coal and associated rocks are summarized in Table 4. On the basis of the ABA of the study area, the stratigraphic profile was divided into an acid-producing zone and a base-producing zone. The shales were more acid producing than the coal and, within the coal seam, the APP of the coal varies along with the sulphur content. The middle section of the coal seam has a relatively low APP, while the sulphur content is enriched at the base and top of the coal seam. The alkaline rocks have high NP irrespective of grain size and colour. It may be inferred from the water quality that despite the high proportion of acid-neutralizing rocks, AMD is a problem in this underground mine because the alkaline rocks have little interaction with the mine water as it travels from coal face to underground sump and is then subsequently discharged.

Experimental results

The experimental results are summarised in Table 5. We observed that at a discharge of 2.25 L/min of mine water (2.60 pH), the pH value increased with time, though the rate of increase in pH was not constant. Initially, there was a rapid increase in pH for 160-180 minutes, after which there was a marginal decrease in the rate of increase of pH. The initial rapid increase in pH is probably due to the friable nature of the rock and the fresh surface of the sandstone. It may also be noted that thicker sandstone slabs caused higher pH values, due to the greater available surface area of the sandstone in the drain, which provided more alkalinity. The friable nature of the sandstone is responsible for the easy liberation of the alkaline components of the sandstone. It also means that armoring will not be a problem. At the end of the experiment, the treated water was analyzed and we observed that along with neutralization of the AMD, there was a considerable decrease in the

Table 3: Mineral constituents of Barakar sandstone

Sample No.	Type of sandstone	Quartz	Feldspar	Mica	Rock fragments	Heavy minerals	Cement/ Matrix	Nature of cement
$Chsst_1$	Coarse grained	50.8	19.6	2.6	1.8	0.7	24.4	Argillaceous
$Chsst_2$	Coarse grained	53.0	18.9	3.6	1.2	0.2	23.1	Calcareous
$Chsst_3$	Coarse grained	47.1	25.2	3.6	1.2	0.9	22.0	Calcareous
$Chsst_4$	Coarse grained	48.9	19.7	3.0	2.4	0.2	25.8	Argillaceous
$Chsst_5$	Coarse grained	46.8	23.2	3.1	1.6	1.0	24.3	Calcareous
$Chsst_6$	Medium grained	59.8	14.3	3.2	3.7	0.6	18.4	Argillaceous
$Chsst_7$	Medium grained	55.4	14.7	3.6	1.7	0.5	24.0	Calcareous
$Chsst_8$	Medium grained	56.1	15.5	3.0	0.6	Nil	24.8	Calcareous
$Chsst_9$	Medium grained	58.5	14.2	3.4	1.9	0.8	21.3	Ferruginous
$Chsst_{10}$	Medium grained	59.3	14.3	3.7	2.0	1.0	19.8	Argillaceous
$Chsst_{11}$	Fine grained	49.5	5.2	6.4	2.1	Nil	36.8	Ferruginous
$Chsst_{12}$	Fine grained	44.9	6.8	5.4	2.4	Nil	40.4	Argillaceous
$Chsst_{13}$	Fine grained	49.8	8.3	5.0	1.2	0.4	35.3	Calcareous
$Chsst_{14}$	Fine grained	52.5	3.7	3.0	1.5	0.6	38.7	Calcareous
$Chsst_{15}$	Fine grained	48.8	8.5	4.7	3.4	Nil	34.6	Calcareous

Table 4: Acid-base accounting test results

Lithological unit			Reactive Sulphur %	Paste pH	APP Kg of $CaCO_3$/ton	NP Kg of $CaCO_3$/ ton	NAPP = APP-NP
Barakar sandstone		Coarse grained	Nil	9.40	Nil	75.91	-75.91
		Medium grained	Nil	9.19	Nil	68.24	-68.21
		Fine grained	Nil	9.03	Nil	57.50	-57.50
	Shale	Fine grey shale	1.86	2.95	58.12	6.42	+51.70
Coal		Top	1.68	3.18	52.5	Nil	+53.50
		Middle	1.44	3.38	46.0	Nil	+46.00
		Bottom	1.74	3.04	54.38	Nil	+54.38

Table 5. Variation in pH of mine water with interaction duration at different thickness of sandstone slabs: initial pH of mine water=2.60, rate of discharge=2.25 L/min., total length of the drain=18 m

Time of Observation	Thickness of sandstone slabs (cm) 0.5	1.0	1.5	2.0
	Change in pH value			
0 min.	2.60	2.60	2.60	2.60
20 min.	2.75	2.78	2.81	2.85
40 min.	2.98	3.07	3.10	3.16
60 min.	3.17	3.29	3.39	3.40
80 min.	3.29	3.47	3.53	3.57
100 min.	3.43	3.61	3.68	3.72
120 min.	3.50	3.75	3.80	3.85
140 min.	3.75	3.89	3.94	3.97
160 min.	3.93	4.01	4.09	4.14
180 min.	4.10	4.15	4.23	4.29
200 min.	4.17	4.31	4.39	4.47
220 min.	4.29	4.40	4.49	4.58
240 min.	4.35	4.48	4.58	4.69
260 min.	4.38	4.57	4.67	4.77
280 min.	4.44	4.66	4.75	4.86
300 min.	4.47	4.69	4.81	4.93
320 min.	4.51	4.73	4.87	4.99
340 min.	4.60	4.77	4.91	5.03
360 min.	4.63	4.81	4.95	5.04
380 min.	4.62	4.85	4.96	5.08

concentration of total dissolved solids, iron, and sulphate.

Conclusions

The AMD problem is very severe in the study area and needs immediate control measures. Based on ABA, the rocks of the study area can be divided into acid- and base-producing zones. The shale and coal are principally responsible for the problem of AMD. Our experiment, conducted in a model of a mine drainage channel, strongly suggests that it would be possible to utilize the alkaline sandstone of the study area to treat the AMD. This could be done underground or at the land surface. The friability of the sandstone ensures that armoring will not be a problem.

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