

A comparison of neutralization efficiency of chemicals with respect to acidic Kopili River water

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Abstract Among all the renewable sources of energy, hydropower is the most potential source which is economical, non-polluting and eco-friendly. The efficiency of hydropower plant in the long run depends on many factors like water and sediment quality. Erosive and corrosive wear of machine parts like turbine is a complex phenomenon. The problem becomes more acute if the hydroenvironment is acidic in nature. The wear and tear due to corrosion/erosion caused by acid mine drainage (AMD) from coal mines reduces the efficiency and the life of the equipments. In this work, neutralization of the acidic water of the Kopili River, Assam, India was investigated using a number of basic chemicals and quantitatively estimating their effectiveness and actual requirement. The acidic water of the river, used as the cooling water, has been found responsible for damaging the equipments of the Kopili Hydro Electric Power Project (KHEP), Assam/Meghalaya, India by reducing the life of all metallic parts through corrosion. In this work, use is made of a number of basic materials like calcium carbonate, calcium hydroxide, calcium oxide, sodium carbonate, sodium hydroxide, and ammonia to examine their neutralization efficiency with respect to the acidic water and it was found that quick lime or raw lime (CaO) has the highest neutralization capacity. Suggestions have been made for meeting the problem of acidity of the river water.

Keywords Kopili River · Acidic water · Neutralizing agent · Hydropower · Cooling system

Introduction

Acid mine drainage (AMD), not only most common in coal and metal mining, but also in highway construction and other large-scale excavations, results from exposure of sulphide minerals to oxidizing conditions. The oxidized sulphur minerals form acidic sulphate-rich drainage. The type and quantity of sulphide minerals present determines the metal composition and concentration in AMD. Generally, sulphide-rich and carbonate-poor materials produce acidic drainage. Iron sulphides are most common but other metal sulphides may also produce AMD in the presence of water and oxygen. Metal contamination associated with AMD depends on the type and amount of sulphide mineral oxidized, as well as the type of gangue minerals present in the rock. About 90 % of the AMD reaching streams originate in abandoned surface and deep mines (Skousen et al. 2000). The acidic sulphur-rich wastewaters may also arise from the by-products of a variety of industrial operations such as galvanic processing and the scrubbing of flue gases at power plants (Johnson 2000).

The acidic waters have the additional risk of carrying elevated concentrations of metals (iron, aluminium and manganese, and possibly other heavy metals) and metalloids to the environment resulting from the exposure of the minerals to both oxygen and water (Johnson and Hallberg 2005). The pH of the AMD may be as low as 2–3, and at this low pH, the AMD contains high concentrations of metals such as Fe, Mn, Al and anions, e.g., SO_4^{2-} , as well as increased concentrations of Zn, Co, Pb, Cr, and Cu.

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When AMD contaminates groundwater, severe risk may be generated as in the case of the Wheal Jane mine in 1992 (Neal et al. 2004; Younger et al. 2005). It is, therefore, important that appropriate technologies are developed for treatment of AMD. The treatment must result in such water that sustains various organisms in water and make the water suitable for its innumerable uses (Heviánková et al. 2011, 2013). Some common techniques include limestone and lime treatment, biological sulphate reduction and passive treatment in alkalinity generating artificially constructed wetlands. The most widespread method used to mitigate acidic effluents is an active treatment process involving addition of a chemical-neutralizing agent (Coulton et al. 2003). Highly soluble magnesite, $MgSO_4$, has been found suitable for selectively precipitating metal hydroxides by raising the pH to 10 (Masindi et al. 2014).

In the present work, the problem arising from the corrosion damages caused by the strongly acidic Kopili River water on various metal parts of the Kopili Hydro Electric Power Project (KHEP), Assam/Meghalaya, India and the treatment of the acidic water by chemical neutralization have been investigated. It is observed that the water in the reservoir of the plant is acidic and the degree of acidity varies with time. Wear and tear of sensitive metallic parts of the plants registered a steep rise during the last few years and concern has been expressed about the longevity of the major structure and equipments of the plant. The plant had to replace the 90:10 Cu/Ni cooler tubes with 70:30 Cu/Ni recently, but the damages are still there. There has also been acute hazard to the biotic environment in the area,

visibly marked by the conspicuous absence of aquatic fauna in the river.

The present work, therefore, evaluates the performance of potential neutralizing chemicals to address the problem of acidic water of the Kopili River.

Materials and methods

Study area and description of the sampling site

The Kopili HE Plant (KHEP) of North Eastern Electric Power Corporation Limited (NEEPCO Ltd) is a 275 MW storage type hydroelectric power plant constructed on the river Kopili, a major tributary of the river Brahmaputra. The Khandong Dam of KHEP intercepts the flow of the Kopili River and retains the water in the Kopili reservoir. Khandong Power Station (2×25 MW) and Kopili Stage II Power Station (1×25 MW) draw water from the Kopili reservoir. The water is discharged to the Umrong reservoir. Kopili Power Station (4×50 W) draw water from the Umrong Reservoir via Umrong Water Conductor System for producing electricity and finally the water is discharged into the Kopili River. Figure 1 shows the layout of KHEP.

Standard chemicals and methods (APHA 2005) were used (1) to determine acidity of the water used in the Power Stations, (2) for preparation of simulated acidic water in the laboratory as is used in the Plants, (3) for detailed neutralization experiments with the acidic water in batch reactors with alkaline materials and in various

Fig. 1 The KHEP layout

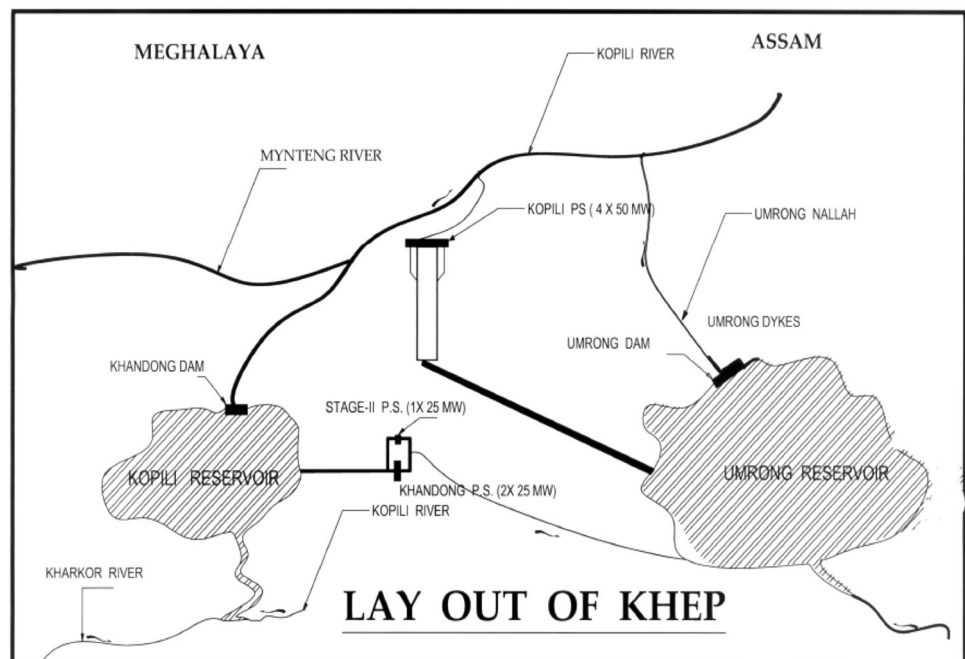


Table 1 Requirement of base for neutralization of Plant water (pH: 3.2)

Base	Normality (N)	Base required (mL)	Sample water (mL)	pH	Amount of base required for neutralization (g/m ³)
NaOH	0.05	2.6	100	6.7	52.0
Na ₂ CO ₃	0.01	8.0	100	6.6	84.8

Table 2 Requirement of base for neutralization of simulated acidic water (pH 3.2)

Normality (N) of H ₂ SO ₄ added	Water (mL)	pH of water		Acid added (mL)	Base required to neutralize (g/m ³)
		Initial	Final		
0.01	100.0	6.4	3.2	4.5	38.2 (Na ₂ CO ₃)
0.01	100.0	6.4	3.2	4.5	20.0 (NaOH)

Table 3 Neutralization of Plant water (pH 3.4) with raw lime

Water (mL)	Normality (N)	Base required (mL)	pH	Amount of neutralizing base (g/m ³)
500.0	0.1	1.7	5.0	4.8
500.0	0.1	2.1	6.2	5.9
500.0	0.1	2.2	7.1	6.2

combinations to evaluate the neutralization efficiency. Laboratory-grade basic materials, namely calcium carbonate (CaCO₃), calcium hydroxide (Ca(OH)₂), calcium oxide (CaO), sodium carbonate (Na₂CO₃), sodium hydroxide (NaOH), and ammonia (NH₃) were used for acid neutralization.

Neutralization experiments were conducted by taking 500 mL of the water sample in a 1-L beaker followed by addition of pre-weighed quantities of the bases listed above with continuous stirring. The pH was measured at each stage of addition and the amount of base required to reach pH of (a) 5.0, (b) 6.0 and (c) 7.0 was found (Systronics Model 335 Digital pH meter).

Results and discussion

Neutralization of the plant water

- (i) Neutralization experiments with sodium hydroxide (NaOH) and sodium carbonate (Na₂CO₃)

The preliminary experiments showed that to neutralize 1 cu m of plant water (pH 3.2), 52 g of NaOH and 84.8 g of Na₂CO₃ (Table 1) would be sufficient to bring up the pH of the supplied water to near neutral range that could be used safely.

A second set of experiments done with simulated acidic water of the same pH as the plant water (pH 3.2) showed that 1 cu m of distilled water acidified with H₂SO₄ to pH 3.2 needs 20.0 g of NaOH and 38.2 g of Na₂CO₃ (Table 2)

to bring up the pH to near neutral range. The much smaller requirement of base in this case shows that the actual Plant water due to the presence of various other salts, etc., requires a large dose of base to come to the same level of neutralization.

- (ii) Neutralization experiments with calcium oxide (CaO) (raw lime)

In this set, neutralization of the Plant water is done with addition of raw lime (CaO) following the same procedure and the results are shown in Table 3. The base is added in the form a suspension in distilled water to obtain 0.1 N strength and the amount of base required to reach three different stages of neutralization (pH 5.0, 6.2 and 7.1) is found out. It is observed that the raw lime requirement (4.8–6.2 g for 1 cu m of Plant water) is much lower compared to those of NaOH or Na₂CO₃. Thus, raw lime will be a cheaper alternative in neutralizing acidic Plant water.

In a separate set of experiments, the raw lime suspension in water is filtered and the filtrate is used to neutralize the Plant water. The results are shown in Table 4. Now, a much larger amount of lime is necessary (39.2 to 43.4 g for 1 cu m of Plant water and the values are in the range of NaOH or Na₂CO₃ requirement.

- (iii) Neutralization experiments with calcium carbonate (CaCO₃)

The results of neutralization experiments with lime stone or calcium carbonate suspension in water are

Table 4 Neutralization of Plant water (pH 3.2) with filtrate of raw lime suspension

Water (mL)	Normality (N)	Base required (mL)	pH	Amount of neutralizing base (g/m ³)
100.0	0.1	2.8	5.2	39.2
100.0	0.1	3.0	6.1	42.0
100.0	0.1	3.1	7.2	43.4

Table 5 Neutralization of Plant water (pH 3.7) with calcium carbonate suspension

Water (mL)	Normality (N)	Base required (mL)	pH	Amount of neutralizing base (g/m ³)
500	0.1	0.2	4.8	4.0
500	0.1	0.3	6.0	6.0
500	0.1	0.7	7.2	14.0

Table 6 Neutralization of Plant water (pH 3.8) with hydrated lime (Ca(OH)₂)

Water (mL)	Normality (N)	Base required (mL)	pH	Amount of neutralizing base (g/m ³)
500	0.1	0.9	5.0	13.3
500	0.1	1.7	6.4	25.2
500	0.1	1.9	7.1	28.2

presented in Table 5. The requirement of limestone is shown at three stages of neutralization corresponding to pH 4.8, 6.0, and 7.2 and it is seen that the limestone requirement is 4.0, 6.0 and 14.0 g, respectively, for 1 cu m of Plant water. The results indicate that CaCO₃ is as effective as CaO in the neutralization process of the Plant water and an amount of 14.0 g will be required for each cu m of Plant water for complete neutralization.

(iv) Neutralization experiments with hydrated lime, calcium hydroxide, Ca(OH)₂

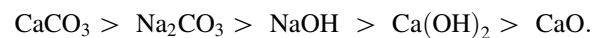
This set of experiments that uses calcium hydroxide as the neutralizing base has the results given in Table 6. Compared to raw lime or lime stone, the amount of Ca(OH)₂ needed to reach the same state of neutralization is high (13.3 to 28.2 g for 1 cu m of Plant water to reach pH of 5.0, 6.4 and 7.1, respectively).

Comparative study of neutralization

After the preliminary set of experimentation as described above, the neutralization experiments were repeated in a comprehensive scale with several sets of experiments. The averages of the results obtained are given in Table 7 which present a comparative study of the five bases with respect to their neutralization capacity.

Requirements of chemicals for acidity neutralization

It is seen that the amount of base required for neutralization depends on the initial pH. Even a slight variation in the initial pH may alter the results. On the basis of the data in Table 8, it is found that the neutralizing bases can be arranged in the following order with respect to the amount required to achieve complete neutralization (pH 7.0):



Quick lime or raw lime (CaO) has the highest neutralization capacity while limestone has the minimum neutralization capacity among the bases used. The amount of the base required by 1 cu m of the Plant water (pH 3.2) is as follows:

1	CaCO ₃	45.41 g
2	Na ₂ CO ₃	37.10 g
3	NaOH	20.00 g
4	Ca(OH) ₂	18.52 g
5	CaO	17.94 g

It may be noted that the differences among the last three bases are not much. The choice of a suitable material for acidity neutralization will also depend on the cost and since

Table 7 Comparative study of requirement of neutralizing base (0.1 M suspension/solution in distilled water) for neutralization of Plant water to different stages of pH

S/N	Base	Initial pH	Final pH	Base requirement (g/m ³)
1	CaO (Quick Lime, Calcium oxide)	3.7	5.0	10.65
2		3.7	6.0	16.82
3		3.7	7.2	17.94
4	Ca(OH) ₂ (Hydrated Lime, Calcium Hydroxide)	3.7	5.1	13.34
5		3.7	6.2	17.78
6		3.7	7.2	18.52
7	CaCO ₃ (Limestone, Calcium Carbonate)	3.7	5.0	13.01
8		3.7	6.1	32.03
9		3.7	7.2	45.41
10	Na ₂ CO ₃ (Soda Ash, Sodium Carbonate)	3.7	5.0	20.14
11		3.7	6.2	27.56
12		3.7	7.1	37.10
13	NaOH (Caustic Soda, Sodium Hydroxide)	3.8	5.0	14.40
14		3.8	6.3	19.20
15		3.8	7.2	20.00

Table 8 Requirement of quick lime (CaO) for neutralization up to pH 7.0

S/N	Water requirement		Chemical quantity		Total requirement (kg/h)
	LPM	Cu m/h	g/cu m	kg/cu m	
<i>A. Kopili Power Station</i>					
1	24000	1440	17.94	0.01794	25.8
2	2160	130	17.94	0.01794	2.3
3	2160	130	17.94	0.01794	2.3
4	6720	403	17.94	0.01794	7.2
5	1200	72	17.94	0.01794	1.3
6	400	24	17.94	0.01794	0.4
7	4320	259	17.94	0.01794	4.7
Total	40960	2458	125.58	0.12558	44.0
<i>B. Khongdon Power Station</i>					
1	6400	384	17.94	0.01794	6.9
2	300	18	17.94	0.01794	0.3
3	1600	96	17.94	0.01794	1.7
4	1500	90	17.94	0.01794	1.6
5	160	10	17.94	0.01794	0.2
6	480	29	17.94	0.01794	0.5
Total	10440	627	17.94	0.01794	11.2
<i>C. Stage II Power Station</i>					
1	3200	192	17.94	0.01794	
2	150	9	17.94	0.01794	3.4
3	800	48	17.94	0.01794	0.2
4	750	45	17.94	0.01794	0.9
5	80	5	17.94	0.01794	0.8
6	240	14	17.94	0.01794	0.1
Total	5220	313	17.94	0.01794	5.7

limestone is locally available and cheaper than the other materials, it may be the ideal choice for neutralization.

Based on actual cooling water requirement of the Plants, the chemical requirement for neutralization is presented in Table 8.

The work further established that the lowering of the pH of Kopili River water is due to release of AMD (acid mine drainage) in a diffuse manner from a large number of small and medium coal mines in the catchment area. The strongly acidic Kopili River water has damaged the machines of the Kopili Hydro Electric Power Project (KHEP), Assam, India through heavy corrosion and the KHEP units have suffered rapid wear and tear of the metallic parts arising from the acidic cooling water. This has resulted in a decreasing efficiency of the coolers leading to damage/failure of the main equipments. The cooling water pipelines and valves are getting corroded rapidly creating serious problems of frequent failure and costly replacement. The damages to the ecology and the human habitation in the nearby areas dependent on the Kopili River water have not been estimated and the low pH of the water might have solubilised various heavy metals from the rocks making the water hazardous to humans as well as all forms of life.

It is suggested that some field trials be conducted by adding the basic chemical before the trash rack, i.e., before the water enters into the circulation system. It may be noted that the choice of a suitable basic material for acidity neutralization will depend on the cost. Since limestone is widely available in Karbi Anglong and nearby areas of Assam and is also cheaper than the other materials, it may be the ideal choice for neutralization. Ideally the material

should be added at the storage pond with facilities for continuous stirring and agitation (so that the base quickly interacts with the acidity) and the neutralized water should go to circulation.

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