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TECHNICAL COMMUNICATION

Treatment of Acid Mine Drainage Using a Fly Ash Zeolite Column

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Abstract Acid mine drainage (AMD) and fly ash from thermal power plants both pose substantial environmental problems in India. Fly ash from the Talcher super thermal power plant was converted into zeolite and used in a column to treat AMD from the abandoned Gorbi opencast mines (Singrauli coalfields, NCL). The pH of the mine water increased, and 100 % of the total hardness, Ca hardness, Mg hardness, Mn, Zn, Pb, Cd, Ni, and acidity were removed, along with 99 % of the Fe and 90 % of the Cu.

Keywords Acidity · Column treatment · Metals

Introduction

Natural zeolites such as clinoptilolite were used by Li et al. (2008) and Motsi et al. (2009) for treatment of acid mine drainage (AMD), and their results showed that zeolites have great potential to effectively remove metals. Moreno et al. (2001) and Fungaro and Izidoro (2006) synthesized zeolitic material from coal fly ash and evaluated its effectiveness for decontamination of AMD. They showed that fly ash zeolite increased the pH of the AMD and decreased metal concentrations by cation exchange or solid precipitation. Prasad and Mortimer (2011) observed that fly ash zeolite is crystalline in nature and, due to its high cation exchange capacity (CEC), most AMD metals are retained at its surface sites. Fly ash is produced in huge amounts in thermal power plants and only about 20 % of it is beneficially used (Jain and Gaggar 2013). Converting the fly ash into zeolite has gained interest because it combines ion exchange and molecular sieve properties (Derkowski et al. 2006; Prasad et al. 2012; Quirol et al. 2002; Akcil and Koldas 2006; Azapagic 2004; Cama et al. 2005; Doye and Duchesne 2003; Inada et al. 2005; Johnson 2003; Johnson and Hallberg 2005; Leggo 1994; Mckinnon 2000; Mondragon et al. 1990; Moriyama et al 2005; Rios et al. 2008; Somerset et al. 2008; Tsishvili et al. 1992; Xenidis et al. 2002). Therefore, the problem of fly ash disposal can be reduced by preparing a zeolite that has been found to be effective for AMD treatment.

AMD from the abandoned Gorbi opencast mine has a pH < 3 and contains high concentrations of acidity and contaminants. Fly ash can easily be converted into crystalline zeolitic material by alkaline hydrothermal treatment using sodium hydroxide. In the present work, AMD from the Gorbi mines was treated using fly ash zeolite in a laboratory column test.

Methodology

AMD was collected at five sampling points of the Gorbi abandoned opencast mines (Singrauli, India), which at one time was the largest coal mining complex of the world. The AMD was collected in ten 20 L plastic containers, which were rinsed thoroughly with the AMD before sampling. The pH and conductivity, measured immediately at the field site in each sample using a Eutech Instrument multiparameter tester (35 series), were found to be similar. Samples were then brought to the laboratory and kept refrigerated until used. A fresh fly ash sample was collected from the electrostatic precipitator of the Talcher super thermal power plant in Orissa State. The fly ash was bench

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Fig. 1 Column experiment for removal of pollutants from AMD

dried and then the unburnt carbon and other volatile materials in the fly ash were removed by calcination at 800 °C for 1 h. The fly ash was then converted to zeolite in Teflon digestion bombs at a temperature of 100 °C ± 5 °C for 24 h, using 2 M NaOH as the activation agent, and a solution/sample ratio of 10:1 (Prasad et al. 2012). The transformed samples were filtered and washed repeatedly with deionised water until the pH of the wash water was 8–9. The product was then dried in an oven at 45–50 °C and kept in powdered form until use.

A 300 mm long column with an inside diameter of 100 mm was constructed from glass pipe and filled with 1110 g of the prepared Talcher fly ash zeolite (Fig. 1). The bed volume of the filled column was determined using ASTM D 4874–95 (1995) and calculated as 750 mL. Every alternate day, one bed volume of Gorbi AMD was passed through the column, so that in a week, three bed volumes and in a month, 12 bed volumes of AMD had been treated. This experiment was continued for more than a year (July 2011–August 2012, during which time, a total of 140 bed volumes (105 L) of mine water passed through the zeolite column. The water quality of the leachate from each bed volume was analysed for pH, electrical conductivity (EC), total hardness, Ca hardness, Mg hardness, chloride, acidity, total dissolved solids (TDS), sulphate, and various metals. Total hardness, Ca hardness, Mg hardness, chloride, sulphate, and TDS were analysed by Indian Standard IS: 3025 (2009). Metal concentrations were measured using an atomic absorption spectrophotometer (Arnold et al. 1992).

Results

Treatment of the Gorbi Mine Water

The AMD collected from the abandoned Gorbi opencast mine had an average initial pH of 2.63. After the first bed volume of AMD passed through the zeolite column, the pH had increased to 10.36 due to the alkaline nature of the zeolite bed. A slow decrease in leachate pH was observed over time. A pH of 7.0 was obtained after 76 bed volumes of AMD had been treated (Fig. 2); at 140 bed volumes, the pH was 4.29.

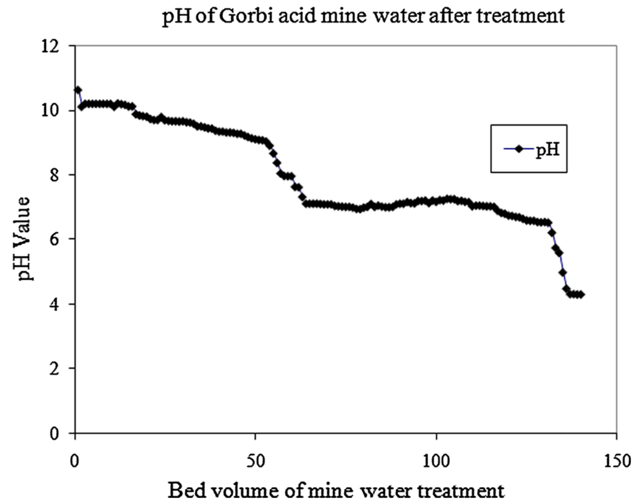

Fig. 2 The pH of Gorbi acid mine water after treatment

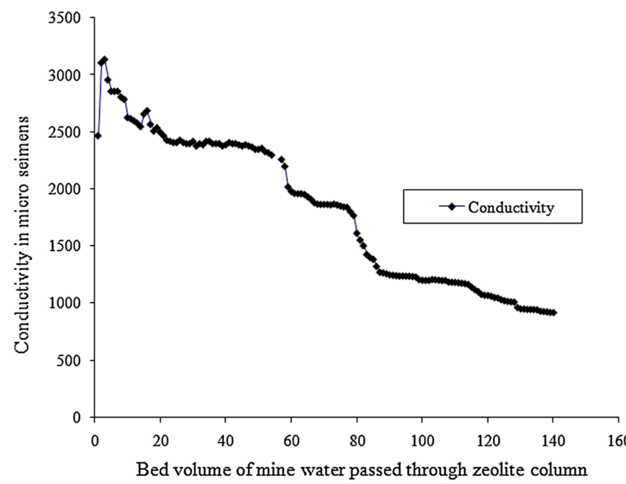

Fig. 3 Conductivity of Gorbi mine water after zeolite column treatment

The AMD had an initial EC of 1780 µS, which increased at the beginning of the treatment, potentially due to release of Na ions from the zeolite bed into the treated mine water. The EC of the treated mine water decreased over time (Fig. 3); by the end of the experiment, the EC had decreased to 919 µS. This was almost half of the initial EC of the mine water, indicating ion removal.

The untreated AMD contained 992 mg/L of total hardness, 668 mg/L of Ca hardness, 78.7 mg/L of Mg hardness, and 750 mg/L of acidity. The zeolite was still removing 99.6 % of the total hardness, 100 % of the Ca hardness,

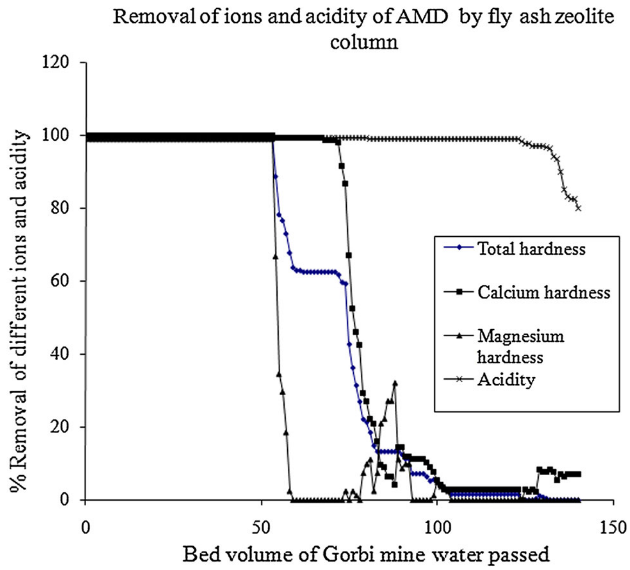

Fig. 4 Removal of ions and acidity from AMD by fly ash zeolite column

98.8 % of the Mg hardness, and 100 % of the acidity after 53 bed volumes (40 L) had been treated (Fig. 4; Table 1). Afterwards, a gradual decrease in total hardness removal was observed. Up to 91.6 % of the Ca hardness was still being removed after 73 bed volumes had been treated; similarly, more than 93 % of the acidity was being removed after 134 bed volumes had been treated. Even at the end of the experiment, after 140 bed volumes (105 L), 80 % of the acidity was being removed.

The TDS and sulphate concentrations in the untreated AMD was 1771 and 1122.3 mg/L, respectively. When the water was treated by the zeolite column, the TDS in the leachate initially increased; over time, it subsequently decreased (Table 1). However, no change in sulphate concentration was observed (Table 1).

The zeolite column was been found to be very effective in removing many metals, removing 99 % of the Fe, 100 % of the Mn, 90 % of the Cu, 100 % of the Zn, 100 % of the Pb, 100 % of the Cd, and 100 % of the Ni until a large volume of water had passed through the column (Table 2). The initial concentration of these metals in the untreated water was 10.0 mg/L Mn, 0.12 mg/L Cu, 12.4 mg/L Zn, 0.04 mg/L Pb, 3.85 mg/L Ni, 72.4 mg/L Fe, 0.006 mg/L Cd and 0.03 mg/L Cr. After passing 140 bed volume of mine water through zeolite column, the concentration of these metals in treated mine water has been decreased to 1.65 mg/L Mn, 0.00 mg/L Cu, 3.00 mg/L Zn, 0.00 mg/L Pb, 3.2 mg/L Ni, 0.01 mg/L Fe, 0.00 mg/L Cd and 0.01 mg/L Cr. Fe which was the main metal present in the AMD, with an initial concentration of 72.4 mg/L, was still being removed very effectively by the zeolite column at the end of the experiment.

Discussion

The fly ash zeolite treated the AMD efficiently. The energy used to transform the fly ash into zeolite markedly improved its remedial properties (due to a markedly increased CEC). An earlier batch study experiment (Prasad and Mortimer 2011) showed the effects of different doses of a fly ash zeolite on removing metals from AMD.

Table 1 Concentration (in mg/L) of different parameters in treated Gorbi acid mine water

Bed volume of mine water treated	pH	Conductivity (µS)	Total hardness	Ca hardness	Mg hardness	Acidity	TDS	Sulphate
Initial	2.63	1780	992	668	79	750	1640	1122
1	10.63	2470	4.0	0.0	0.97	0.0	1640	50.26
10	10.2	2630	4.0	0.0	0.97	0.0	2140	1144.5
20	9.8	2500	4.0	0.0	0.97	0.0	1941	–
30	9.66	2420	4.0	0.0	0.97	0.0	1793	1067.5
40	9.34	2390	4.0	0.0	0.97	0.0	1703	1051
50	9.1	2350	4.0	0.0	0.97	0.0	1677	–
60	7.95	1981	368	4.0	88.45	4.0	1581	1051
70	7.08	1866	372	8.0	88.45	4.0	1614	1049.7
80	6.98	1613	780	488	72.96	4.0	1582	–
90	7.1	1250	868	572	71.93	8.0	1586	1055.9
100	7.16	1203	940	632	74.84	8.0	1281	1056.6
110	7.02	1184	976	648	79.70	8.0	1503	1065.6
120	6.73	1070	976	648	79.70	8.0	1409	–
130	6.53	951	984	616	89.42	20.0	1563	–
140	4.29	919	992	620	90.40	152	1478	1076.4

Table 2 Concentration (in mg/L) of Fe, Mn, Cu, Zn, Pb, Cd, Ni, and Cr in treated mine water by a zeolite column

Bed volume of mine water treated	Fe	Mn	Cu	Zn	Pb	Cd	Ni	Cr
Initial	72.4	9.99	0.12	12.4	0.04	0.006	3.85	0.03
1	0.46	0.00	0.03	0.08	0.00	0.00	0.00	0.00
10	–	0.00	0.00	0.03	0.00	0.00	0.00	0.00
20	0.13	0.00	0.02	0.01	0.00	0.00	0.00	0.00
30	0.06	0.00	0.03	0.03	0.00	0.00	0.00	0.00
40	0.06	0.00	0.01	0.06	0.00	0.00	0.00	0.00
50	0.07	0.00	0.01	0.02	0.00	0.00	0.00	0.00
60	0.04	0.00	0.01	0.13	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
80	0.06	0.00	0.01	0.47	0.00	0.00	0.00	0.01
90	0.01	0.00	0.01	0.53	0.00	0.00	0.00	–
100	0.00	1.26	0.00	0.28	0.00	0.00	0.57	0.02
110	0.05	1.75	0.00	0.25	0.00	0.00	1.08	0.00
120	0.02	1.80	0.00	2.17	0.00	0.00	3.03	0.02
130	0.06	1.60	0.00	2.37	0.00	0.00	2.00	0.01
140	0.01	1.65	0.00	3.00	0.00	0.00	3.20	0.01

The present column experiment was intended as a prelude to a pilot-scale field experiment, where continuous treatment of AMD with a fly ash zeolite column might be possible.

Conclusions

AMD from the Gorbi opencast mine was effectively treated with a fly ash zeolite column. The pH of the mine water was increased, and 100 % of the total hardness, Ca hardness, Mg hardness, and acidity were removed. The zeolite column also removed 99 % of the Fe, 100 % of the Mn, 90 % of the Cu, 100 % of the Zn, 100 % of the Pb, 100 % of the Cd, and 100 % of the Ni until a large volume of mine water had been treated by the column. A field investigation is necessary to evaluate the comparative costs of active and passive treatment.

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References

Akcil C, Koldas S (2006) Acid mine drainage (AMD): cause, treatment and case studies. J Clean Prod 14:1139–1145. doi:10.1016/j.jclepro.2004.09.006

Arnold EG, Lemore SC, Andrew DE (1992) Standard methods for examination of water and waste water, 18th edn. American Public Health Association, Washington DC

ASTM D 4874–95 (1995) Standard test method for leaching solid material in a column apparatus. Annual book of ASTM standards, vol 11.04. American Society for Testing and Materials (ASTM), West Conshohocken, pp 78–84

Azapagic A (2004) Developing a framework for sustainable development indicators for the mining and minerals industry. J Clean Prod 12:639–662. doi:10.1016/S0959-6526(03)00075-1

Cama J, Ayora C, Querol X, Gonor J (2005) Dissolution kinetics of synthetic zeolite NaP1 and its implication to zeolite treatment of contaminated water. Environ Sci Technol 39:4871–4877. doi:10.1021/es0500512

Derkowski A, Franus W, Beran E, Czimerova A (2006) Properties and potential applications of zeolitic materials produced from fly ash using simple method of synthesis. Powder Technol 166:47–54

Doye I, Duchesne J (2003) Neutralisation of acid mine drainage with alkaline industrial residues: laboratory investigation using batch leaching test. Appl Geochem 18:1197–1213. doi:10.1016/S0883-2927(02)00246-9

Fungaro DA, Izidoro JDC (2006) Remediation of acid mine drainage using zeolites synthesised from coal fly ash. Quim Nova 29(4):735–740

Inada M, Tsujimoto H, Eguchi Y, Enomoto N, Hojo J (2005) Microwave assisted zeolite synthesis from coal fly ash in hydrothermal process. Fuel 84:1482–1486. doi:10.1016/j.fuel.2005.02.002

Indian Standard IS: 3025 (2009) Methods of sampling and test (physical and chemical) for water used in industry, Bureau of Indian Standards, New Delhi

Jain KA, Gaggar S (2013) Present status of availability, utilization and other options to increase effective use of fly ash in India. Presented, 3rd Annual International Summit: fly ash utilisation, New Delhi, India, Mission Energy Foundation, Mumbai, India

Johnson DB (2003) Chemical and microbiological characteristics of mineral spoils and drainage waters at abandoned coal and metal mines. Water Air Soil Pollut 3:47–66. doi:10.1023/A:1022107520836

Johnson DB, Hallberg KB (2005) Acid mine drainage remediation options: a review. Sci Total Environ 338:3–14. doi:10.1016/j.scitotenv.2004.09.002

Leggo PJ (1994) Use of zeolitic tuff for control and recycling of effluents. In: Institution of Mining and Metallurgy, Hydrometallurgy, Springer, Netherlands, pp 815–824

Li LY, Tazaki K, Lai R, Shiraki K, Asada R, Watanabe H, Chen M (2008) Treatment of acid rock drainage by Clinoptilolite - Adsorptivity and Structural stability for different pH environments. Appl Clay Sci 39(1–2):1–9

McKinnon W, Choung JW, Xu Z, Finch JA (2000) Magnetic seed in ambient temperature ferrite process applied to acid mine drainage treatment. Environ Sci Technol 34:2576–2581. doi:10.1021/es9910863

Mondragon F, Rincon F, Sierra L, Escobar J, Ramirez J, Fernandez J (1990) New perspectives for coal ash utilization; synthesis of zeolitic materials. Fuel 69:263–266. doi:10.1016/0016-2361(90)90187-u

Moreno N, Querol X, Carles A (2001) Utilisation of zeolites synthesized from coal fly ash for the purification of acid mine waters. Environ Sci Technol 35:3526–3534. doi:10.1021/es0002924

Moriyama R, Takeda S, Onozaki M, Katayama Y, Shiota K, Fukuda T, Sugihara H, Tani Y (2005) Large scale synthesis of artificial zeolite from coal fly ash with a small charge of alkaline solution. Fuel 84:1455–1461. doi:10.1016/j.fuel.2005.02.026

Motsi T, Rowson NA, Simmons MJH (2009) Adsorption of heavy metals from acid mine drainage by natural zeolite. Int J Miner Process 92(1–2):42–48

Prasad B, Mortimer RJG (2011) Treatment of acid mine drainage using fly ash zeolite. Water Air Soil Poll 218:667–679

Prasad B, Maity S, Kumari S, Mortimer RJG (2012) Synthesis and characterisation of zeolite prepared from coal ash by hydrothermal process. Environ Technol 33(1):37–50

Rios CA, Williams CD, Roberts CL (2008) Removal of heavy metals from acid mine drainage using coal fly ash, natural clinker and synthetic zeolites. J Hazard Mater 156:23–35. doi:10.1016/j.jhazmat.2007.11.123

Somerset V, Petrik I, Iwuoha E (2008) Alkaline hydrothermal conversion of fly ash filtrates into zeolite: the removal of mercury and lead ion from wastewaters. J Environ Manage 87:125–131. doi:10.1016/j.jenvman.2007.01.033

Tsishvili GV, Andronikashvili TG, Kirov GN, Filizova LD (1992) Natural zeolites. Ellis Horwood Ltd, London

Xenidis A, Mylona E, Paspaliaris I (2002) Potential use of lignite fly ash for control of acid generation from sulphidic wastes. Waste Manage 22:631–636. doi:10.1016/S0956-053X(01)00053-8

Quirol X, Moreno N, Umana JC, Alastuey A, Hernandez E, Lopez-Solar A, Plana F (2002) Synthesis of zeolites from coal fly ash: an overview. Int J Coal Geol 50:413–423