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Effects of ferric/ferrous ratio on performance of successive alkalinity producing system (SAPS) during acid mine drainage treatment

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Acid mine drainage (AMD) is becoming a serious threat for mine and its adjoining area. Therefore, the proper management of mine impacted water is essential before discharging it into natural water source. The laboratory successive alkalinity producing system (SAPS) is found effective in treatment of AMD. The SAPS was designed using cow compost, saw dust and limestone. Twelve synthetic AMDs were experimented in SAPS with variation in ferric/ferrous ratio (FFR) and total iron (TI). The performance of SAPS was assessed in terms of net alkalinity generation (NAG) for different hydraulic retention time (HRT). The higher net alkalinity generation by SAPS was found for higher ferric/ferrous ratio (FFR) and total iron (TI). It is also found that the net alkalinity generation increases with increase in HRT duration from 1 day to 10 days. The above findings can be utilized for effective design and operation of SAPS for treatment AMD.

Keywords: Acid mine drainage, successive alkalinity producing system, ferric/ferrous ratio.

Introduction

The Acid Mine Drainage (AMD) is becoming a persistent problem in mining worldwide therefore it is necessary to device an appropriate method for AMD treatment. The AMD is generated due to oxidation of pyrite minerals in presence of water[1–3]. The occurrence of sulfide minerals plays a key role in generation of AMD besides other factors like hydrogeology of area, nature of adjoining rocks, presence of water, temperature, and oxygen supply, etc.[4,5]. Jamal, Dhar, Siddharth and Tiwari (2003) and Saharan (1995) stated that the ground water seepage from working faces dissolves sulfide minerals and hydrolyses to form AMD[4,6]. There are mainly two types of AMD treatment methods are used worldwide i.e. active treatment and passive treatment method.

In active treatment method mainly chemicals like sodium hydroxide, ammonia, hydrated lime, quick lime or soda ash etc. are used to increase the pH of mine water[7]. The passive treatment system is basically low energy environmentally sustainable AMD treatment system[8]. SAPS is a modified form of anaerobic wetlands provided with additional drainage pipe provided at the bottom of limestone layer with a flush valve and standpipe which help in maintaining enough head of water in SAPS column for downward movement of AMD solution. SAPS have advantages of anaerobic wetlands and efficiency of anoxic limestone drain both[9]. The topography is one of the key constraints for installation of SAPS because sufficient head should be available for causing vertical flow of AMD[10]. The objective of the study is evaluating the effects of ferric/ferrous ratio on performance of Successive Alkalinity Producing System (SAPS) during acid mine drainage treatment.

Materials and methods

Composition of synthetic AMD:

The composition of selected AMD was presented in the Table 1.

Experimental setup

The four identical laboratory SAPS were designed using this four PVC container of 80 L filled with cow compost, saw dust and limestone with perforated drainage pipe at bottom as shown in Fig. 1, which is connected to standpipe and

Table 1. Composition of synthetic AMD

AMD sample	pH	Fe^{2+} (mg/L)	Fe^{3+} (mg/L)	Ratio (Fe^{3+}/Fe^{2+}) FFR	Total iron (mg/L) TI	FFR×TI (mg/L)	Al (mg/L)	Mn (mg/L)	Sulfate (mg/L)	Ca	Mg
AMD A_1	4.50	81.30	4.40	0.054	85.70	4.62	20.00	15.00	1020	125	100
AMD A_6	4.35	81.30	11.20	0.140	92.50	12.67	20.00	45.00	1155	125	100
AMD A_7	4.25	79.80	13.40	0.170	93.20	15.66	20.00	60.00	1177	125	100
AMD B_1	3.70	94.30	24.40	0.258	118.70	30.62	20.00	15.00	1028	125	100
AMD B_6	3.55	93.10	35.80	0.380	128.90	49.50	20.00	45.00	1178	125	100
AMD B_7	3.50	91.20	37.30	0.410	128.50	52.43	20.00	60.00	1195	125	100
AMD C_1	2.80	81.70	92.20	0.861	171.60	147.75	20.00	15.00	1030	125	100
AMD C_6	2.72	78.60	94.20	1.200	172.80	207.01	20.00	45.00	1205	125	100
AMD C_7	2.68	75.40	96.10	1.270	171.50	218.49	20.00	60.00	1225	125	100
AMD D_1	2.60	91.20	104.30	1.143	195.50	223.46	20.00	15.00	1026	125	100
AMD D_6	2.55	83.90	109.10	1.300	193.00	250.90	20.00	45.00	1232	125	100
AMD D_7	2.52	79.80	111.00	1.390	190.80	265.21	20.00	60.00	1255	125	100

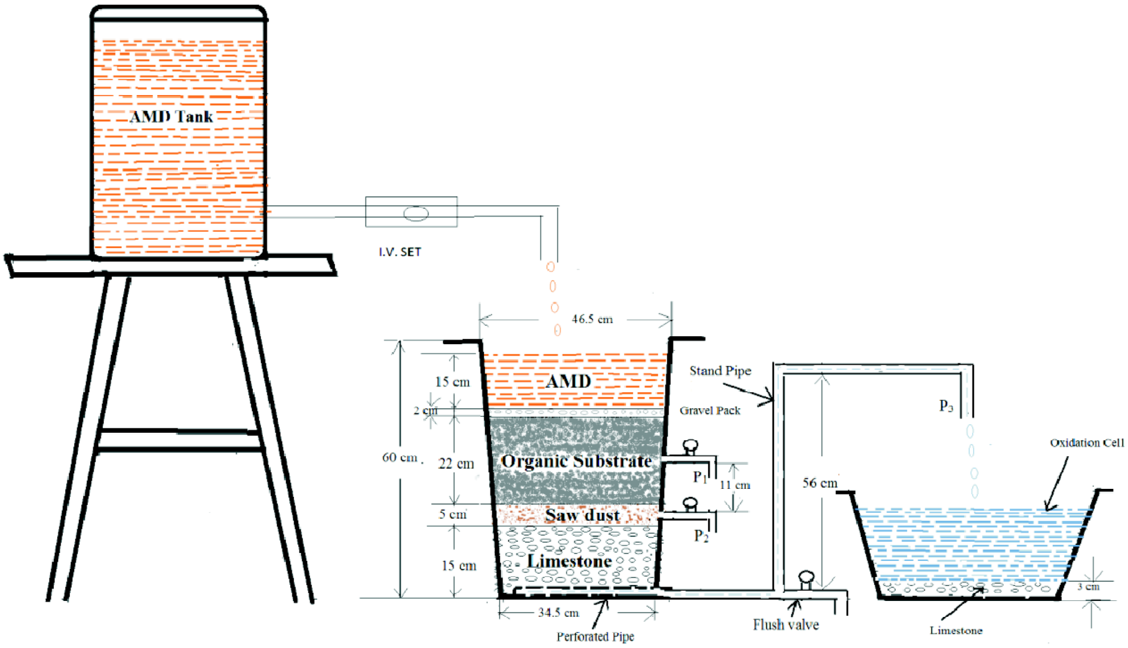

Fig. 1. Laboratory arrangement for SAPS column study[11].

flush pipe outside the SAPS cell. The standpipe fitted with a flush valve to flush out the SAPS cell time to time for proper maintaining the flow the treated AMD discharges into oxidation cell. Experiments were conducted for 12 different synthetic AMDs in three phases in SAPS column with identical conditions and similar composition of limestone, organic substrate (cow compost) and saw dust. Therefore, the effect of above parameters will be equal in all the SAPS, hence the details of effects of above parameters were not considered. The study was conducted between 13.6°C to 43.3°C. SAPS units were allowed for fifteen days acclimation period for sufficient growth of enough bacteria. After acclimation period AMD solution were allowed to flow in SAPS cell with controlled flow rate with different hydraulic retention time (HRT). Experiments were conducted for five hydraulic retention time 1 day, 2 days, 4 days, 7 days and 10 days. The intravenous infusion (I-V) set was used to regulate the flow rate. Sampling were done at influent AMD tank, at port P_1, port P_2 and port P_3 as shown in Fig. 1 The, DO, ORP, pH, temperature and EC of samples are instantly measured by portable WTW multi 3620 IDS digital meter. The measurement and analysis of alkalinity, acidity total iron, ferric iron, ferrous iron, aluminum, manganese, magnesium, calcium and sulfate were carried out as per standard methods of APHA[12]. The flow rates were measured by volumetric cylindrical flask and stops watch.

Effect of FFR and total iron on NAG:

The effects of iron in AMD on alkalinity generation by SAPS can be only understood better if its composition in the form of ferric iron and ferrous iron is taken into account along with iron. The ferric iron/ferrous iron ratio gives an idea about redox status of the AMD solution. Therefore, total iron must be considered along with ferric iron/ferrous iron ratio. Generally, in very acidic AMD the ferric iron concentration is higher than ferrous iron and during treatment by SAPS, most of ferric iron is converted to ferrous iron form.

The effect of ferric iron/ferrous iron ratio (FFR) and total iron (TI) in the form of their product, viz. FFR×TI, on net alkalinity generation was studied by keeping effects of aluminum and manganese at constant. The concentration of aluminum was 20 mg/L concentration of manganese was 15 mg/L for phase I AMDs. The experimental results showed that the insignificant manganese removal was observed up to 4d HRT where corresponding pH level was less than 8. Some researchers have reported that manganese precipitation starts at the pH level of 8 and above[13–15]. Therefore, in this study the net alkalinity generation data up to 4d HRT is taken into consideration for maintaining uniform effect of manganese irrespective of its concentration.

Based on the experimental observations phase 1 (in case of AMD A_1, B_1, C_1, D_1) (Table 2), for 1d HRT, the increase in the FFR×TI from 4.62 to 223.46 has resulted in an increase in the NAG from 430 mg/L to 690 mg/L (while the aluminum (20 mg/L) and manganese (15 mg/L) are maintained constant). This increase in NAG can be attributed towards the increase in the FFR×TI of the AMD. Thus, it is concluded that the NAG of the SAPS unit increases with the increase in the FFR×TI of the AMD. This finding applies well for 2d and 4d HRT of SAPS treatment.

Similarly in case of phase VI AMDs where the FFR×TI ranged from 12.67 to 250.90, the NAG for the SAPS unit has been observed to be in the range of 440 mg/L to 740 mg/L for 1d HRT, 545 mg/L to 975 mg/L for 2d HRT, 710 mg/L to 1190 mg/L for 4d HRT. The NAG of the SAPS unit has been found to increase with the increase in the FFR×TI of the AMD.

Similarly in case of phase VII where the FFR×TI ranged from 15.66 to 265.21, the NAG for the SAPS unit has been observed to be in the range of 440 mg/L to 770 mg/L for 1d HRT, 550 mg/L to 1000 mg/L for 2d HRT, 725 mg/L to 1240 mg/L for 4d HRT. The NAG of the SAPS unit has been found

Table. 2. NAG, Al, Mn and FFR×TI for Phase I, VI and VII for 1d, 2d and 4d HRTs

Phase	AMD	Fe^{3+}/Fe^{2+} ratio FFR	Total iron (mg/L) TI	FFR×TI	Al (mg/L)	Mn (mg/L)	Net alkalinity generation (mg/L)		
							HRT = 1d	HRT = 2d	HRT = 4d
I	A_1	0.054	85.70	4.62	20	15	430	520	690
	B_1	0.258	118.70	30.62	20	15	450	580	785
	C_1	0.861	171.60	147.75	20	15	615	775	930
	D_1	1.143	195.50	223.46	20	15	690	830	1010
VI	A_6	0.137	92.50	12.67	20	45*	440	545	710
	B_6	0.384	128.90	49.50	20	45*	475	680	810
	C_6	1.198	172.80	207.01	20	45*	680	820	1005
	D_6	1.300	193.00	250.90	20	45*	740	975	1190
VII	A_7	0.168	93.20	15.66	20	60*	440	550	725
	B_7	0.408	128.50	52.43	20	60*	480	680	850
	C_7	1.274	171.50	218.49	20	60*	680	825	1010
	D_7	1.390	190.80	265.21	20	60*	770	1000	1240

Note: *The increase in net alkalinity generation for 1d, 2d and 4d HRT is insignificant with increase in manganese concentration[14].

to increase with the increase in the FFR×TI of the AMD. It was found that in case of phase I AMDs (Table 2), for 1d HRT, the magnitude of increase in the NAG due to increase in FFR×TI is 260 mg/L (=690–430 mg/L). For 4d HRT, the magnitude of increase in the NAG due to increase in FFR×TI is 320 mg/L (=1010–690 mg/L). Thus, the magnitude of rise in NAG has been higher at higher retention time (i.e. 320 mg/L) and it is lower (260 mg/L) at lower retention time.

It can be inferred that the effect of FFR×TI on the NAG of the SAPS unit increases with the increase in the retention time. It can be concluded that higher the retention time, the more is the effect of FFR×TI on the NAG of the SAPS unit. Similar conclusion applies to the experimental observations in case of phase VI and phase VII AMDs.

It is observed from Fig. 2 that the net alkalinity generation increases with increase in FFR×TI. This shows linear relationship between net alkalinity generation and FFR×TI with acceptable R^2 value ranges from 0.96 to 0.99 for phase I.

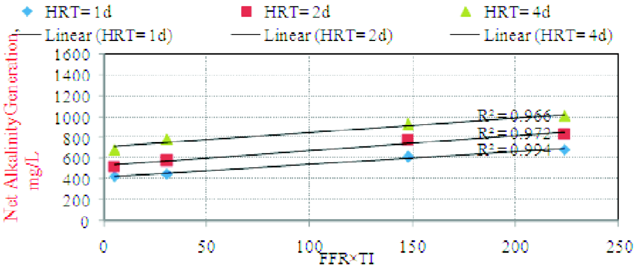

Fig. 2. Effect of FFR×TI on NAG (with constant Al and Mn effects) Phase I.

It is observed from Fig. 3 that the net alkalinity generation increases with increase in FFR×TI. This shows linear relationship between net alkalinity generation and FFR×TI with acceptable R^2 value ranges from 0.92 to 0.99 for phase VI.

It is observed from Fig. 4 that the net alkalinity generation increases with increase in FFR×TI. This shows linear relationship between net alkalinity generation and FFR×TI with acceptable R^2 value ranges from 0.90 to 0.99 for phase VII.

In general, it can be concluded that the effect of increase in FFR×TI has to increase the NAG of the SAPS unit and that it is found that FFR×TI exhibits a linear relationship with NAG.

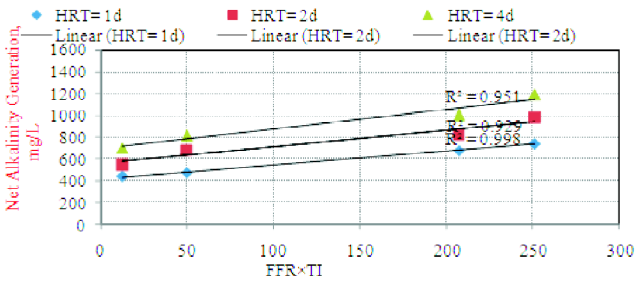

Fig. 3. Effect of FFR×TI on NAG (with constant Al and Mn effects) Phase VI.

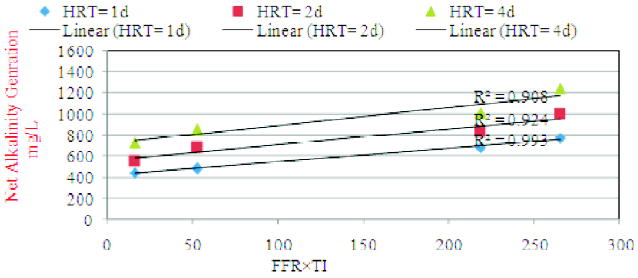

Fig. 4. Effect of FFR×TI on NAG (with constant Al and Mn effects) Phase VII.

Effluent quality after SAPS treatment:

In all the AMDs the effluent quality after SAPS treatment were found encouraging. The maximum pH was raised up to 8.30 for AMD D_7 with corresponding NAG as 1640 mg/L (as $CaCO_3$) for 10d HRT. Similar trends were observed for all the remaining AMDs.

Conclusions

The experimental results showed that the insignificant manganese removal was observed up to 4d HRT where corresponding pH level was less than 8.

It is concluded that the NAG of the SAPS unit increases with the increase in the FFR×TI of the AMD.

The net alkalinity generation increases with increase in FFR×TI. This shows linear relationship between net alkalinity generation.

The magnitude of rise in NAG has been higher at higher retention time (i.e. 320 mg/L) and it is lower (260 mg/L) at lower retention time.

The parameter FFR X TI can be used as evaluating parameter for performance of SAPS.

The NAG trends was found increasing with increase in HRT.

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