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Occurrence of Acid Mine Drainage and its Treatment by Successive Alkalinity Producing System (SAPS): An Overview

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Abstract : Acid mine drainage (AMD) is one of the most important environmental problem faced by some of the coal and many metal mines which is required to be treated and managed in economical and efficient manner. The AMD is harmful for aquatic life and corrodes the pumps, pipes and machineries in the mines. The AMD problem originates from active mines, abandoned mines, coal waste spoils and stripped area. About 40% of the AMD pollution problems originates from active mines both surface and underground and rest from others. The discharged acidic water from the mines is detrimental to environment in general and water quality in particular, because if their high acidity, high metal concentration and high sulfate content. Lots of researches are going on throughout the worlds to tackle and minimize the problems of AMD in coal mines of USA, Canada, Australia and India. Therefore it requires neutralization up to acceptable limit. Now days, various treatment systems are available for treatment of AMD. Active treatment system is costly and requires continuous supervision, whereas passive treatment system is long process. The application of SAPS utilizes the advantage of active treatment system and passive treatment system. In present paper, an attempt has been made to highlight AMD generation and application of SAPS for treatment of AMD.
Keywords : AMD, SAPS, environment, sulfide, organic substrate.

1.0 Introduction

Acid mine drainage (AMD) is severe problem produced by exposure of sulfide minerals during mining and mineral processing activities. AMD is not only limited to mining operations; it may happen whenever sulfide minerals are exposed to oxygen and water. The coal deposit and its strata such as shale usually contains iron, sulfur, mineral, pyrite (FeS_2) along with other sulfide minerals. In the below surface this sulfide minerals are found in reduced state. After removal of preventive mantle of overburden by mining operation, the sulfide presently in the coal is exposed to oxygen and water [1].

The water entering to the mine gets altered chemically and physically the extent of alteration depends

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upon the geochemistry of coal and nature of geological formations. Water chemistry changes due to soluble iron, aluminum, manganese, sulfate, acidity, hardness and dissolved solids and various metals. Acid mine drainage occurs when following conditions are present [1] -

1. When any mineral contains enough sulfide minerals to react and generate acid at a faster rate than it can be neutralized by any surrounding alkaline materials.
2. When there is adequate water and air seeping in waste material to support chemical and biological reactions.
3. The availability of surface water that infiltrates and transport the acidic drainage in the environment.

The primary cause of AMD is the oxidation of pyrite. The pyrite oxidation is a complete process and involves several chemical, biological and electrochemical reactions.

AMD generation can be explained by following reactions [2] -

$FeS_2 + 3.5\ O_2 + H_2O \longrightarrow Fe^{2+} + 2\ SO_4^- + 2H^+$ ………(1)
$Fe^{2+} + 0.25\ O_2 + H^+ \longrightarrow Fe^{3+} + 0.5\ H_2O$……………(2)
$Fe^{3+} + 3H_2O + H^+ \longrightarrow Fe\ (OH)_3 + 4H^+$……..………..(3)
$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \longrightarrow 15\ Fe^{2+} + 2SO_4 + 16\ H^+$…..(4)

In the above reaction (4), acidithiobacillus ferrooxidans and ferroplasma bacteria plays critical role.

AMD has following characteristics [2] -

1. Acidity with low pH
2. High content of iron along with other metals
3. High content of dissolved solids
4. High sulfate content and
5. Very low or nil organic matter

2.0 AMD Treatment Method

The treatment of acid mine drainage is essential to maintain environment standards of discharged water from mines. The treatment of AMD is basically classified in two categories:-

a. Active treatment
b. Passive treatment

The active system reduce acidic nature and metal content with application of active chemical but system is costly as compared to passive system. The active system is somewhat complicated in nature. Many chemicals are used as neutralizer in active system. Apart from neutralizing the AMD, these chemicals also precipitate the metals. This system requires consistence maintenance and precautions in during operation.

Passive treatment system is slow process than active treatment system and accomplished by gravitational, geochemical and biological processes. The passive treatment system efficiently removes acidity and metals from AMD in bio-system. These systems are eco-friendly, low energy and sustainable AMD treatment system. Passive treatment system generally used are anoxic limestone, open limestone channel successive alkalinity producing system (SAPS), reducing and alkalinity producing system, limestone ponds, reactive walls [3]. This paper discusses the working of successive alkalinity producing system (SAPS) and its effectiveness in the treatment of AMD.

3.0 Successive Alkalinity Producing System (SAPS)

3.1 General

Now days, successive alkalinity producing system (SAPS) is becoming popular for treatment of AMD. SAPS are also known as vertical flow system. It is combination of anaerobic wetlands and anoxic limestone drain system (ALD). It also eliminates the limitations of both the system. SAPS possess the advantages of both the system active as well as passive treatment system. The acidic water with ferric iron and aluminum in low concentration with low dissolved oxygen can be treated by ALD system, but if iron and aluminum presents in high concentration with high dissolved oxygen the performance of ALD system get reduced by armoring of limestone. However high metal containing AMD can be efficiently treated with anaerobic wetland but area requirements is very large.

To overcome the above mentioned problem, successive alkalinity producing system (SAPS) is recommended. In the SAPS, AMD is allowed to flow in vertical direction (i.e. upwards or downwards), which increases the efficiency of SAPS. In SAPS system, a layer of alkaline material such as limestone, dolomite or slag of about 0.5-1m thick at the bottom is placed which is overlain by second layer of organic substrate of about 0.5-1m thickness. The top portion of 1-2 m is filled with pounded AMD water. The purpose of organic substrate is to provide food for sulfate reducing bacteria which generate alkalinity by reducing sulfate to sulfide and remove the dissolved metals. One of the important functions of organic substrate is to reduce ferric to ferrous iron and eliminate the dissolved oxygen and aluminum from AMD before it enters the limestone layer (Fig.1).

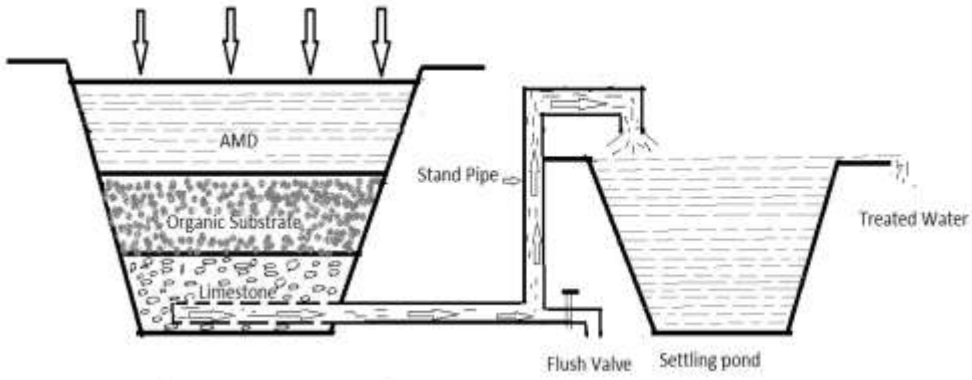

Fig- 1.Conceptual diagram of successive alkalinity producing system (SAPS)

In the SAPS, the water moved downwards and passes through the different layers and the final effluent passes through drain pipe placed at the bottom. The downwards flow increases reaction time between AMD and organic substrate which creates anaerobic environment in SAPS. A flushing system is provided at the bottom of SAPS to flush out the SAPS time to time for avoiding chocking of pipe. Then at last, effluent passes through various oxidation cells (settling pond) where metal gets precipitated and finally treated the AMD.

The problem of AMD in the mining industry has been investigated by researchers in various ways. Investigations have been performed to understand the phenomena of formation of AMD and to assess the various methods of treating the AMD. Work has been done under both the treatment methods, viz., active and passive treatment, and investigators have worked with various kinds of raw materials, bacteria, and chemicals so as to establish the efficacy of the treatment method. Investigations from the researchers show that SAPS are effective in treatment of AMD. Although an enormous literature exists on the AMD, some of salient investigations have been considered as under for the outline of the Research Statement.

3.2 Some SAPS related research work

SAPS treatment system is a sustainable approach for AMD treatment. SAPS produces 10 times more alkalinity and requires 40% less area for their construction as compared to traditional wetlands [4]. Ochre armoring does not take place in SAPS system where lime stone is placed at bottom because most of ferric iron gets converted in to ferrous iron during passing through organic substance layer. The Ochre armoring is one of the reasons of failure of anoxic limestone drain treatment system.

A study was performed to investigate SAPS unit using PVC column [5]. In this study the lab scale SAPS unit with PVC column of 1.3m of length and 0.25m of diameter in which three successive layers of identical thickness (limestone + organic substrate+ free standing water) were disposed. After 30 days of experiment, reductions of about 65% in acidity, 100% in Al, 27% in Mn and 99.5% in total Fe, had been achieved. Although sulfate content is not removed by passing through the SAPS, it is reduced in a 32% after going through wetland. The average pH obtained for the SAPS effluent was 7.1 units. The redox potential measurements show the presence of reduction environment in its interior. At the end of the experiment, ferric oxides armoring the limestone used in the SAPS could not be seen. 4 units increase in pH have been reported in this study.

In another study, field and laboratory investigations on the SAPS were performed [6]. Eight SAPS units in the field were studied for two years while conducting a monthly sampling. The SAPS units comprised of limestone layer, overlying bed of mulch, and a subsurface drainage network. The SAPS units were planted with cattails or bulrushes. The parameters of study included flow, residence time, pH, Fe, Mn, sulfate, alkalinity, non-Mn acidity. The study showed that the net alkalinity generation from SAPS is proportional to natural log of residence time. The net alkalinity generation from SAPS has a linear correlation with total iron and non-Mn acidity. The analysis from this field studies shows the dependence of SAPS performance on the residence time and influent water quality. This study could not address the effect of microbial sulfate reduction on the generation of net alkalinity. Column studies with a three column in series were also conducted in laboratory, wherein vertical scaled columns were constructed. 24 hour sampling was performed. The columns comprised of high calcium limestone and composted hardwood bark mulch. Using synthetic AMD, for three different residence times, sampling was performed in it was observed that shorter residence times did not permit the DO concentration to fall below 1 mg/l. Higher residence time (60 hours) resulted in lower dissolved oxygen (less than 1 mg/l). Non-Mn acidity affected the performance of the SAPS. Mn removal was minimal in the SAPS columns, but it was significantly removed in the oxidation barrels. In the column studies the net alkalinity generation from SAPS was not affected by the residence time because the systems reached saturation levels with respect to calcite. A model was developed to estimate the net alkalinity (mg/l of $CaCO_3$) based on the parameters of residence time, Fe, and Non-Mn acidity. A theoretical retention time for each of the SAPS was estimated.

To test the effectiveness of treatment process detail investigation was performed [7]. The effectiveness of the treatment process was observed to depend on the organic substrate chosen to supply the bacteria carbon source. Six natural organic materials were characterized in order to investigate how well these promote sulfate reducing and metal precipitation by SRB. Batch experiments tested nine reactive mixtures in duplicate using 2000 ml glass reaction flasks at room temperature (22±1°C). Synthetic AMD was prepared over 3 days to ensure minimal oxygen and heightened reducing conditions. Maple wood chips, sphagnum peat mass, leaf compost, conifer compost, poultry manure and conifer sawdust were investigated in terms of their carbon (TOC, TIC, DOC) and nitrogen (TKN) content, as well as their EAS contents. Single substrate , ethanol a mixture of leaf compost (30% w/w) poultry manure (18% w/w) and maple wood chips (2% w/w) and the same mixture spiked with formaldehyde were then tested in a 70 days batch experiments to evaluate their performance in sulfate reduction and metal removal from synthetic AMD. Metal removal efficiency in batch reactors was as high as 100% for Fe, 99% for Mn, 99% for Cd, 99% for Ni and 94% for Zn depending upon reactive mixture. The mixture of organic materials was most effective in promoting sulfate reduction followed by ethanol and maple wood chips and single organic natural organic substrate.

Series tests were conducted for proposing two new parameters for performance of SAPS[8]. Based on this time series study, two geochemical parameters are proposed for the performance evaluation of SAPS. The two parameters are Fe influent: Fe effluent and sulfate influent: sulfate effluent. Over a six year period, influent water to the SAPS and effluent water from the SAPS were studied. Dissolved cations were determined using an inductively coupled plasma atomic emission spectrophotometer. It was found that proposed performance ratio of sulfate (sulfate influent: sulfate effluent) ratio and iron removal ratio (Fe influent: Fe effluent) can be representative of SAPS performance under steady state operation that possibly sets in after a month. It was also found that sulfate reduction to sulfide is stopped within a year possibly because of decreasing concentration of dissolved organic carbon. The study showed that aluminum concentration exhibits a negative relationship, i.e. one increases at the expense of the others.

A Case study of an abandoned mine of South Korea with SAPS was conducted to further investigate the effectiveness of SAPS [9]. From this case study it was found that SAPS were effective in treatment of AMD. It indicated that a decrease in dissolved organic carbon (DOC) over time likely contributed to a decrease in biological sulfate reduction. Several other operational and site specific problem may also have contributed to the decreased performance. It was also observed that within 2-3 years of operation, the DOC source was nearly exhausted in compost, and the substrate composition needs to be improved by adding a higher percentage of lignin-cellulosic material in the compost.

An experiment was conducted for the removal of metal in bioreactors [10]. In this experiment, the mechanism of metal removal, assessment of long-term stability of spent reactive mixture as well as potential metal mobility after treating highly contaminated acid mine drainage (AMD pH 2.9-5.7) using column bioreactors. Several physicochemical, microbiological and mineralogical analysis were performed on spent reactive mixtures collected from 4 bioreactors , which were tested in duplicate for two hydraulic retention time (HRT) of 7.3 days and 10 days, with download flow over an 11-month period. It was found to possess very high concentration of metals (Fe, Mn, Cd, Ni and Zn) in the top and bottom layers of the reactive mixtures from all columns. More over the concentration of Fe (50.8-57.8g/kg) and Mn (0.53-0.78g/kg) were up to twice as high in bottom layers, where as the concentration of Cd (6.77-13.3g/kg), Ni (1.80-5.19g/kg) and Zn (2.53-13.2g/kg) were up to 50 times higher in top layers. Chemical extractions and elemental analysis gave consistent results, which indicated a low fraction of metals removed as sulfides (up to 15% of total metals recovered in spent reactive mixture). Moreover Fe and Mn were found in a more stable form (residual fraction was found 42-74% for Mn and 30-77% for Fe) relative to Cd, Ni, or Zn which seemed more weakly bound and showed higher potential mobility. Also, besides identifying hydroxide and carbonate minerals, the mineralogical analysis identified metal sulfides containing Fe, Cd, and Zn. Metal removal mechanism were, therefore mainly adsorption and other binding mechanism with organic matter (for Cd, Ni and Zn) and precipitation as (Oxy) hydroxide minerals (for Al and Mn). After 15 months the column bioreactors did not lose their capacity for removing metals from AMD.

In another study, the performance of bioreactors with respect to hydraulic retention time (HRT) was investigated [11]. This investigation involved the effect of two retention times (HRTs) of 7.3 days and 10 days on performance of passive bioreactors over 11 months period for treatment of highly contaminated AMD. Six Plexiglas columns were used for the SO_4^- reducing bioreactors with downwards flow. Each column was packed with same reactive mixture consisting of 60% organic materials and 40% inorganic materials. Artificial AMD with high $SO_4^-$and metal concentrations was used as influent for six column bioreactors. Samples of AMD and treated effluent were collected and analyzed on a weekly basis over 11 months period. It was found that bioreactors were effective at both HRTs for increasing the pH and alkalinity of contaminated water for SO_4 and metal removal (60- 82% for Fe and up to 99.9% for Cd, Ni and Zn).Higher HRTs (7.3d and 10d respectively) and lower Fe concentration (around 500mg/L) significantly improved the bioreactor effectiveness and helped to achieve a steady-state quality of treated effluents.

In order to assess the reactive mixture characterization a detailed experimental study was performed [12]. This study involved the assessment of four natural organic material characteristics for their ability to serve as substrate along with other parameters that link organic carbon sources with their biodegradability. In the first part of study, four organic waste material (maple wood chips, maple saw dust, composted poultry manure and leaf compost) were thoroughly characterized in terms of biodegradability and ability to serve as organic carbon source for SRB during AMD treatment. In the second part, two reactive mixtures reported efficient in batch test (41-71days) and third mixture developed for purpose of this study, were comparatively assessed (120-152 days). All three mixtures were successful for sulfate reduction and metal (Fe, Ni, Cd, Zn and Mn) removal (91.8-99.8%). Higher efficiencies were observed in the reactors with 30% (w/w) cellulosic waste which decrease sulfate concentrations from 5500mg/L to <1mg/L, than in reactor with 2-3% cellulosic waste, where final sulfate concentrations were in range 2000-2750mg/L . It was found that higher C/N ratio, COD/SO_4^{2-} ratio and DOC/ SO_4^{2-}ratio were associated with better sulfate reducing conditions and metal removal.

A review of SAPS performance for AMD treatment was conducted [13]. It was observed that sulfate reducing bioreactor is reasonable alternative technology for AMD treatment possible to be applied even on remote sites without power and with extreme winter condition also. The SRP mediated anaerobic bioremediation process is not limited to acidic mine water, it can be applied to various industrial waste of different pH that are high in sulfates and metals and organic contaminants. It was indicated from this review that the efficiency of bioreactor depends upon activity of SRP, which mainly controlled by the composition of the reactive mixture. Also, higher sulfate reduction rates were reported with reactive mixture containing more than one organic source. It was propounded that for anaerobic systems, removal will occur as long as carbon source are present in anaerobic environment.

Zipper et al (2010) found alkalinity generation increase with influent net acidity loading for all system types.

In another study, the alkalinity generation was found to increase with influent net acidity loading for all system types [14].

A batch experiments for various combination of natural organic substrate in bioreactors was conducted [15]. This study evaluated various combinations of natural organic substrate as a replacement for mushroom compost for a long term successful treatment of AMD in passive bioreactors. Several prospective substrate such as mushroom compost, cow manure, saw dust, wood chips and cut rice straw were characterized for their ability to serve as a source of food and energy for sulfate reducing bacteria. Twenty bench scale batch experiments were conducted for a period of 35 days to evaluate the performance of organic substrate. Two type of artificial AMD water were prepared one for acidic (pH 3) and other for moderate pH (pH 6), based on actual water quality data of two Coal mines of South Korea. Overall reactive mixtures showed satisfactory performance in generating alkalinity , reducing sulfate and removing metals (Al> Fe> Mn) (up to 100%) as saw dust and cow manure was found as most effective where as mixture containing 40% cut rice straw gave limited efficiency, suggesting organic carbon released from this substrate is not readily available for biodegradation under anaerobic conditions. The mushroom compost based bioreactor released significant amount of sulfate, which may raise a more concern upon the start up of bioreactors. It was found that the correlation between the extent of sulfate reduction and dissolved organic carbon /SO_4^{2-} ratio was weak and this indicates that the type of dissolved organic carbon plays a more important role in sulfate reduction than the absolute concentration and that the ratio is not sensitive enough to properly describe the relative effectiveness of substrate mixtures.

The performance of locally available substrate in bioreactor was examined in another investigation [16]. The efficiency of sulfate reducing bioreactors for the treatment of AMD was assessed. The performance of locally available substrate (manures, wood chips, millet fodders and sugarcane waste) were examined for the treatment of AMD. Experiments with 10 bench scale bioreactor with 1 litre transparent narrow mouth glass bottles with inlet at the top and outlet at lower part were conducted. The base of the reactor was filled with pebbles of about 5mm size up to 25 mm height (to increase the porosity and to provide the solid surface to SRB's and each one was filled with 500 cc of different single substrate. The manures showed efficient removal of metals and other pollutants. With cow manure, buffalo manure and goat manure pH increased from initial 2.70 to 6.25, 6.25, 7.10 and 7.50 respectively. All cellulosic waste also raised pH in a range of 4.83-5.32. Significant reduction was observed in Eh, acidity and sulfate concentration also. He observed that 51.49-99.32% of Fe, 84.95-99.97% of Cu, 35.11-99.78% of Zn, 17.87-99.14% of Ni, 63.55-99.02% of Co and 12.68-73.86% of Mn were removed in maximum retention period of 10 days. This study also suggested future work for research on the depletion rate of organic matter in bioreactor to accelerate the treatment of acidic mine waste in the abandoned mine which is yet key problem for the mining industry.

Using column test three combinations of organic substrate were tested [17]. In this study, mushroom compost, wood chips saw dust, cow manure and rice straw as organic substrate were tested in three combinations as prospective substrate during the treatment of acidic (pH 3) and moderate (pH 6) mine drainage in 3.5 L column bioreactors operated for 167 days, at 3 days of hydraulic retention time, mixture gave comparable performance in each pH condition with satisfactory efficiencies. A total of six column tests were performed for a 167 days period to evaluate the efficiencies of the three best combination of organic substrate, as found during batch tests, in increasing pH, reducing sulfate and removing dissolved metal (Fe, Al and Mn). Two types of artificial mine drainage were prepared .One for acidic pH (pH 3) and the other for moderate pH (pH6) column (10cm dia×45cm height) were built with acrylic polymer with total volume of 3.5L. After less than a 2-week acclimation period, the bacteria become active, which is indicated by pH increase and sulfide production. DOC consumption was higher in acidic conditions, where as sulfate removal mainly occurred in the early reaction period. There were significant differences in the sulfate and DOC result from acidic relative to moderate mine drainage columns. Aluminum was readily removed (nearly 100%) by all the reactors. Iron removed was better for acidic (98-99%) than for moderate (73-85%) mine drainage. Manganese, mostly leached out from substrate materials, prevailed in early reaction time followed by steady decrease toward the end.

The evaluation of efficiency of single and mixed substrate in bioreactor was studied [18]. A batch experiments for treatment of AMD to evaluate the efficiency of both single and mixed substrates for mine impacted water were conducted. Synthetic mine water was used in all experiments. The batch test were performed by using different media such as crushed limestone (CLS) and uncrushed limestone (LS) for alkalinity generation, activated sludge (AS) as source of bacteria and spent mushroom compost (SMC) as an electron donor to feed the SRB in synthetic mine water . Wood chips (WC) were used to increase the permeability of media in the bioreactor. The different ratios of all treatment media combined as mixed substrate were also tested. He found that spent mushroom compost (SMC) has the best potential for both heavy metals and sulfate removal with overall removal efficiency of 89.98%. After mixing all the treatment media, the SMC which was good in reducing sulfate helps the overall treatment in mixed substrates. In fact he investigated that activated sludge also showed its potential for heavy metal removal but not in sulfate removal with 97.98% and 43.75% of removal efficiency respectively, which made up the AS to fall below SMC with only 88.94% for overall removal efficiency .The potential use of mixed substrate as treatment media for AMD has been shown by uncrushed lime stone 2 (LSR2) i.e. less than 5cm in size with overall removal efficiency of 88.15%. Despite small reduction in Fe, LSR2 can reduce most of heavy metals and excellent in reducing sulfate.

In another study, the effect of three HRTs on the system efficiency of SAPS was determined[19]. The effects of three hydraulic retention times (1, 2 and 4 days) on change in system efficiency, reactive mixture and microbial activity in bioreactor under upward flow conditions were studied. In this study, seven 5L laboratory reactors were constructed using acrylic columns (73×10cm) and acrylic caps at both ends. The columns were packed. It was found that HRT had a strong influence in reactive mixture composition and microbial activity during treating acid mine drainage. Seven bioreactor used in this study were found to be efficient for increasing pH and alkalinity and removing sulfate (>60%) and metals (85-99% for $Fe^{2+}$and 70-100% for Zn), without significant differences between the three retention times. The 4 days HRT generated higher alkalinity and excess residual sulfate in the effluent. The 1 day HRT washed out biomass and increased input of DO in the reactor leading to higher ORP, which decreased metal removal efficiency. Low flow in 4 days HRT reactor favored growth of microorganism that rapidly consumed organic nitrogen and organic carbon in the reactive mixture. Also, it was observed that HRT strongly influenced performance of reactors and resulted in physical and biological inhibitions of SRB and failures in the reactor. As a result, HRT must be a balance between rate and removal efficiency.

The potentiality of using anaerobic packed bed bioreactor (PBR) was studied[20]. In this study, a laboratory scale PBR was used to treat the waste water collected from the mining industries. The PBR was operated towards upflow direction. The influent reservoir tank was equipped with a pH control system to maintain pH during operation. The column was constructed of an acrylic sheet of overall height 74.5 cm, internal diameter 3.9 cm and working volume of 889.5 mL. The multiple process parameters such as pH, HRT, concentration of MWE, TOC, and sulfate were optimized together using Taguchi design . The order of influence of the parameters towards biological sulfate reduction was found to be PH > MWE >Sulfate>HRT> TOC. At optimized conditions (pH-7, 20% (v/v) MWE, 1500mg/L sulphate, 48h. HRT and 2300 mg/L TOC),98.3% and 95% sulfate at a rate of 769.7mg/ L/d and 732.1mg/l/d was removed from AMD collected from coal and metal mine.

In order to optimize the properties of reactive mixtures for improving AMD treatment in column reactors a detailed study was performed [21]. The optimization of the hydraulic properties of reactive mixtures in passive systems were found to improve treatment efficiencies of iron-rich acid mine drainage (Fe-rich AMD). The efficiency and evolution of hydraulic conductivity of three reactive mixture, first two types of dispersed alkaline substrate (DAS), composed of wood ash (50% V/V-WA50) or calcite (20% V/V-C20) and one mixture consisting mainly of organic matter (70% W/W), typically used in passive biochemical reactor (PBR) were tested in 1.5 L column (height 22cm, inner diameter 10cm). The columns are equipped with perforated drain pipe placed at the bottom. Total 8 column reactors were used. Four reactors were filled with WA50 and operated at four different HRTs. Each reactor was in operation for a 30day period. Two other column reactors were used to evaluate the efficiency of C20, at two HRTs. Two column reactors having the same size as the DAS reactor were used as PBR filled with 70% organic materials. The reactors were operated with HRTs of 1 to 5 days over a period of 16-63 days. In the WA-DAS reactors result showed that minimum HRT of 2 days was required to remove 33-62% of Fe in AMD with 2500 mg/L Fe. The calcite-DAS showed limited Fe removal (<10%) in AMD at >1500mg/L Fe, over a 7 day period, at 2 days of HRT. Slight increase of the PBRs efficiency was found (77% and 91%), at initial Fe concentration of 500mg/L, when the HRT was doubled (from 2.5 days to 5 days), All reactor removed other metals (37-99.9% for Al, Zn and Pb, 20-98% for Ni except in C20) and SO_4^{2-}(5-37%). It was found that the Fe removal was HRT dependent. The study suggested that water quality, especially Fe concentration should be among the design criteria for long term treatment of Fe-rich AMD.

SAPS was tested in various countries in the coal collieries of New Zeeland, South Korea, U.K. and U.S.A [22]. In this extensive study, it was found that more than 90% removal efficiencies of total iron and manganese occurred at circum neutral pH (6-8). It was also found that most of iron can be removed by SAPS alone from mine water and it requires less than 50% area as compared to aerobic wetland. The study suggested that a series of SAPS units should be installed for treatment of highly acidic AMD.

3.3 Findings from Existing Researches related to SAPS

From the above review it is observed that the existing research work has been directed towards the treatment of AMD, its acidity, and its removal of high metals. Amongst the governing factors of the AMD treatment the crucial factors observed by the various researchers include - hydraulic retention time, composition of organic substrate, influent quality and presence of heavy metals. Studies were conducted by using high calcium limestone and composted hardwood bark mulch, maple wood chips, sphagnum peat mass, leaf compost, conifer compost, poultry manure and conifer sawdust, maple saw dust, composted poultry manure, leaf compost, mushroom compost, cow manure, saw dust, wood chips, cut rice straw, millet fodders and sugarcane waste.

Based on the both field and laboratory investigations, it is found that the net alkalinity generation from SAPS is proportional to natural log of residence time and it is having a linear correlation with Total Iron and Non-Mn acidity. The performance of SAPS is dependent on the residence time and influent water quality as the DO concentration is governed by residence time during treatment process. Higher residence time resulted in lower dissolved oxygen (less than 1 mg/l). The organic substrate provides food to the bacteria. The biodegradability and ability to serve as organic carbon source governed the effectiveness in promoting sulfate reduction. Higher sulfate reduction rates are observed with reactive mixture containing more than one organic source. The ratio of sulfate (sulfate influent: sulfate effluent) ratio and iron removal ratio (Fe influent: Fe effluent) was found to be representative of SAPS performance under steady state operation.

It is also reported that the decrease in dissolved organic carbon (DOC) over time contributed to a decrease in biological sulfate reduction. Metal removal mechanism was mainly adsorption and binding mechanism with organic matter (for Cd, Ni and Zn) and precipitation as (oxy) hydroxide minerals (for Al and Mn). Iron removal was found to be dependent on HRT. Fe concentration should be among the design criteria for long term treatment of Fe-rich AMD. HRT strongly influenced performance of reactors and resulted in physical and biological inhibitions of SRB. It governed the removal efficiency. In a study related to organic matter, it is found that the saw dust and cow manure were most effective in generating alkalinity, reducing sulfate and removing metals (Al, Fe and Mn).

4. Conclusions

The acid mine drainage formation is natural phenomenon and its formation cannot be completely stopped. Preventive measures play important role in controlling AMD generation but even if AMD generation continues at dangerous level, one should plan for proper treatment of AMD. AMD treatment should not be first priority but it should be last option. Active treatment system are costly and requires large maintenance work from time to time where as passive treatment are slow process and cost effective but requires large space. Successive alkalinity producing system possesses the advantage of active as well as passive treatment system. Presently SAPS system has been found very effective in treating highly acidic and high metal (like Fe, Al and Mn) containing AMD with low dissolved oxygen (2-5 mg/L).

In this overview study it is found that SAPS's working life are satisfactory, which is an essential requirements for success of SAPS installation. SAPS treat AMD in efficiently, timely and cost effective manner that's why SAPS are becoming popular. SAPS also eliminate armoring of limestone which an important advantage over other method and consequently life of SAPS increase. More numbers of SAPS should be preferred in series installation for large scale treatment of AMD for obtaining good results.

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