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ABSTRACT

Acid Mine Drainage is water that has a low pH and filled with heavy metals. Acid Mine Drainage (AMD) is created by groundwater that travels through mines and then rejoins the watershed, polluting it. AMD is an urgent environmental issue in mining regions as it makes the affected water uninhabitable, devastating the ecosystem. Current cleanup systems use inexpensive limestone beds to remove the metals and neutralize the pH. New research is developing to create more efficient treatment systems using new resources such as further developed passive systems and the incorporation of living organisms like algae or microbes and food waste. Further development of these new techniques on a larger scale is the next step to solving this environmental issue.

KEYWORDS: Acid Mine Drainage, limestone, algae, nanofiltration, pH neutralization

INTRODUCTION

Acid mine drainage (AMD) is currently one of the biggest negative environmental impacts local watersheds face. Worldwide, thousands of kilometers of rivers and streams are affected by this issue, making this a widespread problem.[1] AMD occurs when ground water runs through a mine, oxidizes the metals located in the mine (most commonly iron) and leads to a lowered pH.[2] This water continues to run, leading to a larger scale of contamination throughout the watershed.[2] AMD makes it nearly impossible for life to survive because the life is adapted for neutral conditions. The metal contaminated water with low pH is toxic to wildlife, devastating the ecological food chain.[2] These toxic metals affect organisms at the cellular level and cause failures of basic functions like cell division.[3] For example, mussels in AMD affected areas exhibited 100% early mortality rates, much higher than mussels in unaffected water.[4] When one species is eliminated from an environment, all of the life depending on that species will also suffer. The region with AMD affected waters will also suffer economically because of the damaged wildlife and infrastructure from the acidic water. Overall, it would be environmentally and economically beneficial to implement these solutions to affected watersheds.

Currently, private organizations are implementing cleanup systems in affected areas, such as limestone beds. Limestone beds are increasingly being improved upon. Also, new techniques are being developed using sources of remediation including microbes, algae, food waste, and nanofiltration. These methods help neutralize acidic pH and removed common metals like iron and zinc. The new techniques discussed below are geared towards remediation of the pollution.

CURRENT CLEANUP TECHNIQUE: LIMESTONE

Currently, limestone neutralization is the most economical method to treat AMD.[5] Typically, limestone will be incorporated into a passive system where the water flows through using gravity.[6] One study found when the polluted water was run through their limestone drain (a type of limestone neutralization), it increased the water's pH from 3.5 to 6.2 in a time period of 3 hours.[7] The removal of iron was more successful than expected but armoring of the limestone throughout the process lowered the efficiency of the system.[7] Armoring is the buildup of metals on the surface of the limestone, preventing the limestone from being fully effective.[7] There is another limestone method that is avoiding the armoring process by creating pulsed limestone bed reactors where flow could be controlled on a timer.[5] Before installing the pulsed beds, the researchers found it takes 48 hours for regular limestone to become armored and therefore, less effective.[5] One study in Korea found, within 5-10 years, the non-pulsing limestone bed was less effective at raising the pH and would need to be replaced or altered to increase efficiency.[8] All basic limestone techniques are successful at removing iron from the water and achieving a more neutral pH.[8,6,7]

Recently, along with limestone systems, there are systems being developed that combined the limestone with barium carbonate to further decrease concentrations of harmful excesses of sulfate in the water, which is sometimes neglected with regular limestone passive systems.[9] Barium worked well to control sulfate levels but it is not cost effective.[9] To compensate, researchers completed a bench scale where it was combined with limestone and wood shavings.[9] This new treatment was found to be successful at raising pH and removing metals within drinking standards except for barium which can be solved by changing the concentration of the barium carbonate in future experiments.[9] This is an example of a successful combination system. Many other techniques, like this one, have been combining to successfully cleanup all aspects of AMD because this environmental impact is so complex.

NEW MICROBIAL RESEARCH

New microbial studies are currently coming out with different AMD control methods. One suggests microbes as a new bioremediation source.[10] This small-scale experiment used sulfate reducing bacteria(SRB) and iron reducing bacteria (IRB) along with different nutrients and metals to discover the microbial relationships involved with AMD formation.[10] Under the right conditions, the bacteria was able to effectively reduce the AMD.[10] As also seen in table 1, this microbe technique was able to remove iron and sulfates from the water as well as bring the pH up to 7.[10] Further research with these bacteria on a larger scale is the next step to the research since the most recent studies have only been bench scale. Microbes combined with algae to form a more complex treatment system will be discussed in the next section.[11]

BIOREMEDIATION OF AMD USING ALGAE

Along with their strong ecosystem indicator ability, algae has been found to be efficient at the removal of metals from AMD polluted waters.[1,12] Different strains of algae are attracted to different heavy metals that become stored in the algae vacuoles.[12] An effective system would include the strains that best deal with specific metals present in that region of AMD.[12] Algae also makes a good candidate for pH stabilization of AMD because of its alkalinity.[12] Algae are also being looked at for their electron donor characteristics.[3] Lipid-extracted algae and whole cell algae were tested as electron donors and proved their ability to reduce sulfate ions in the AMD water.[3] They were also effective at the removal of Cu^{2+}.[3] Researchers are using this same electron donor technique with microalgae-bacteria combination to achieve the same effect.[13] In an experiment to determine the sulfate removal success using a RAB (revolving algal biofilm) reactor, researchers found sulfate levels that are too high are toxic to certain strains of algae.[11] This RAB reactor, which utilized bacteria and algae combined, was successful at removing sulfur, sulfate, ammonia, and phosphorus.[11] For future research, algae strains need to be studied and placed in various types of systems to determine which methods and environmental conditions are most conducive for heavy metal removal and pH neutralization. Because algae are living organisms, conditions must be perfectly set for the algae to thrive in a waste removal system.

NEW RESEARCH WITH FOOD WASTE AND BY-PRODUCTS

Many recent studies have also been looking into the use of chicken eggshells as a solution because of their heavy metal removal and alkaline abilities.[14] One experiment used eggshell residue and paired it with an alkaline material such as cement or limestone while also alternating the materials, it was found to reduce acidification of AMD tailings.[15] Specific tailings, the waste produced from the mine, each need their own metal analysis because some worked better with more sodium hydroxide neutralization while others work best with calcium hydroxide neutralization.[15] Eggshells when ground into a powder have also been successful.[16] Once finding the most efficient particle size to make the powder, it was added to the AMD and found successful in full removal of iron and aluminum from the water but only partially successful at removing Mn.[16] The authors have stated this eggshell powder would work best in a passive sediment pond system for further research.[16] Eggshell powder can be used in watersheds mostly affected by iron, copper, zinc, and aluminum while it has not shown success with removing sulfate.[16, 14] From this conclusion, it is possible for a watershed affected by the previous metals mentioned and sulfate to effectively be treated in a combined treatment system including eggshell powder and another method proven to remove sulfate.

NANOFILTRATION

Nanofiltration is one of the latest techniques being developed where water is pumped from the source through a filtration membrane.[17] Nanofiltration membranes are able to pull out specific ions from the water and separate them.[17] One bench scale study compared two NF membranes, the NF270 and the 7pHT, and their ability to filter AMD water.[17] Another study compared the NF270 model with the NF90 model.[18] NF270 was more successful because it had a lower resistance rate for AMD to filter through and its greater permeability made it better at capturing metals in the water.[18] After use, the membranes had a 99% recovery rate which would allow a long term, continuous use of this system.[18] These studies did not discuss the effect on pH levels but more studies in the future can be conducted to determine pH changes during the nanofiltration process. Because there are many more models being produced like the NF270, NF90, and 7pHT, studies can also be conducted to test the efficiency of more models on a larger scale and how they compare to one another.

CONCLUSION

While AMD continues to be a threat to the environment, bringing attention to this issue can help continue research and bring real solutions to this subject. Many new research techniques are being developed using a wide variety of methods such as the use of organic materials like eggshells, algae, and microbes, and nanofiltration techniques. These techniques are compared in Table 1. AMD is a unique problem for each watershed affected so each mine will need individualized attention for a treatment plan. Mines that are secreting more iron and sulfate may work best with microbes, algae, or nanofiltration treatment and less with limestone. A watershed affected by aluminum will work best with limestone techniques. All methods besides nanofiltration appear to have adequate pH neutralization capabilities. Because these methods each target different heavy metals, some of these methods may be combined to eliminate all metal and acidic pH issues in a specific watershed. Each affected region needs close study to determine which methods are most useful for solving the specific problems apparent in that watershed. If these methods continue to be studied and modified on a larger scale and combined to solve the complex problems this issue poses, an efficient solution will be reached to stop the pollution of watersheds

	Table 1: Effectiveness of new AMD treatment research				
Reference	**Method**	**Heavy metals and compounds removed**	**Original pH**	**Treated pH**	**Time of treatment**
8.	Limestone bed	Fe, Zn, Al, Cu	(3.2-5.1)	(6.4-8.1)	Normal river flow
6.	Modified Limestone bed	Cu^{2+}, Fe^{3+}, Zn^{2+}, Ni^{2+}	1.5	9	24 hours
7.	Limestone drain	Al^{3+}, Fe^{3+}, Fe^{2+}, Mn^{3+}	3.5	6.2	3 hours
9.	Limestone and barium carbonate	Cu, Ni, Pb, Zn, Al, Fe, SO_4	2.4	(6.9-7.6)	N/A
12.	Algae	Mn, Fe, Pb, Zn, Cu, Ni, SO_4	(1.8-3)	(6.78-8.5)	N/A
11.	RAB reactor	SO_4, NH_3, P, S	N/A	N/A	28 days
10.	Microbes	Fe, SO_4^{2-}	4.5	7	28 days
14.	eggshells	Fe, Cu, Zn, Pb, Ni, Co	2.3	(6-8)	6 hours
17.	nanofiltration	Fe^{2+}, Zn^{2+}, Cu^{2+}, SO_4^{2-}	N/A	N/A	N/A

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