An In-Line System for Treatment of Mine Water

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Water quality standards imposed on mine water discharges typically require neutralization of acidity and removal of metals in excess of established effluent limits. Conventionally, neutralization is easily accomplished by addition of lime, sodium hydroxide, or other alkaline chemicals. The metals are removed as oxides or oxyhydroxides precipitated from the neutralized drainage.

The most common contaminant of concern is iron. Iron is dissolved in acid mine drainage (AMD) in the ferrous (Fe^{2+}) and ferric (Fe^{3+}) states, and precipitates from near-neutral water as ferric hydroxide ($Fe(OH)_3$). Aeration requirements for oxidation vary, based on Fe^{2+} concentrations and flow volumes. Even at saturation, mine water generally contains only 8 to 10 mg/L dissolved oxygen (D.O.), which is consumed at the rate of 1 mg/L for every 7 mg/L Fe^{2+} oxidized. To replenish the D.O., settling ponds or lagoons are constructed wide and shallow to maximize diffusion of atmospheric oxygen into the water. However, oxygen diffusion is relatively slow, so that at many sites supplemental mechanical aeration is necessary.

As an alternative to conventional neutralization and mechanical aeration, the U.S. Bureau of Mines has combined two readily-available in-line components: a jet pump aeration device and a static mixer. The combined system is referred to as the

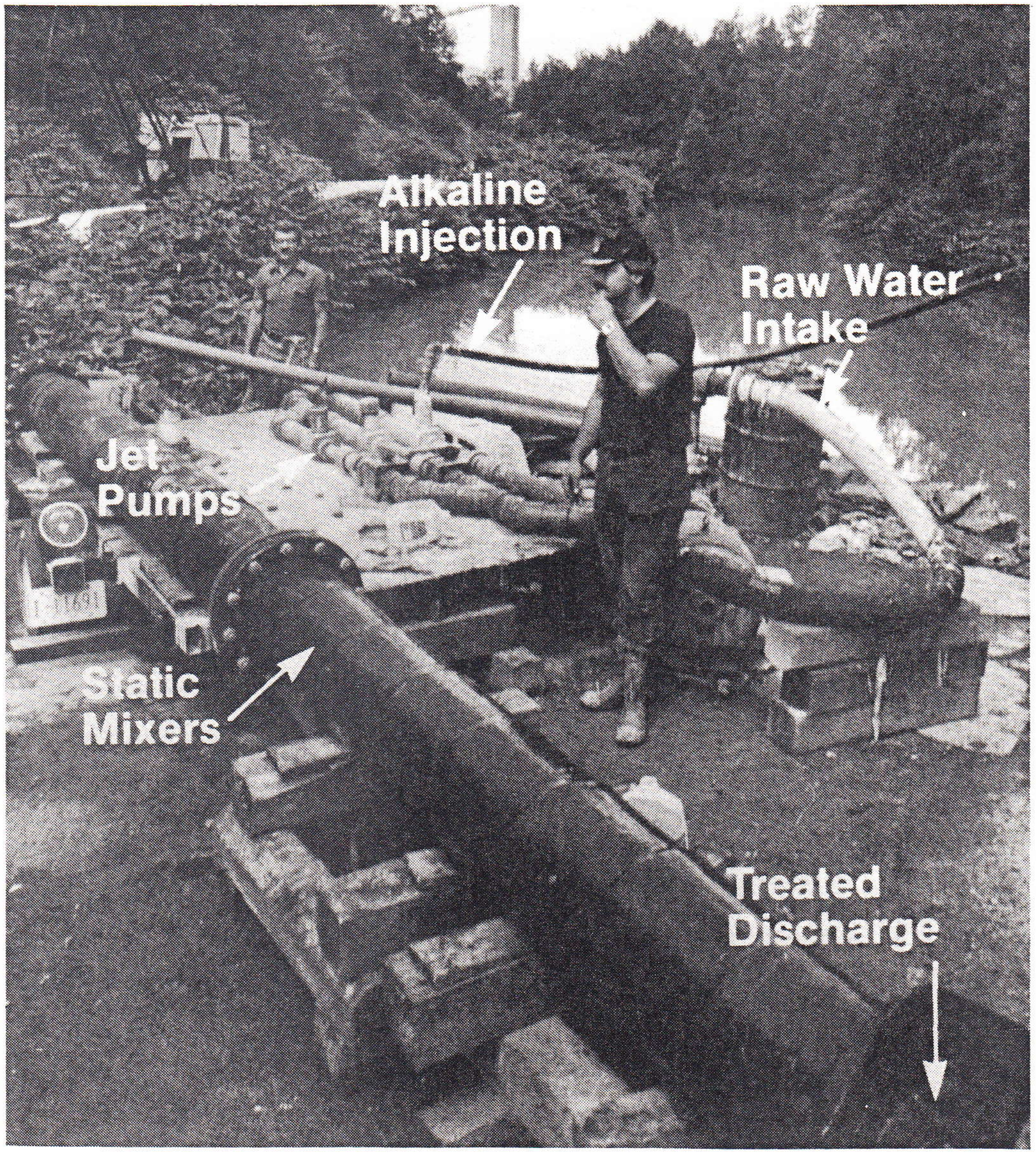

Figure 1. -- Portable 3-Jet Pump In-line System

In-line System or ILS. Jet pumps are simply nozzles that entrain air by venturi action. The jet pump used in this application was made of polyvinyl chloride (PVC) to resist corrosion. Water enters under pressure and is converted by the jet pump into a high-velocity stream, which passes through a suction chamber that is open to the atmosphere. If the system is being used for neutralization as well as aeration, the suction chamber also serves as the injection point for the alkaline material. Multiple jet pump units may be placed in parallel as long as water pressures of at least 20 psi (138 k Pa) per jet pump are maintained.

After passing though the jet pump, the flow of air and liquid enters the static mixer to aid oxygen dissolution. There are various types of static mixers. One design, used extensively in the field, consists of eight 1-ft (0.3-m) sections of pipe made of copolymer polypropylene resins, laminated with fiberglass. Inside each section is a helical element that forces the water to follow a spiral path. Each section is rotationally offset 90° from its neighbor to enhance the mixing action. Figure 1 depicts an actual ILS set-up at a mine site. The ILS unit shown is portable and can treat, at most, about 500 gpm. Larger ILS units have been constructed to treat flows up to 2800 gpm.

An alternative static mixer design consists of vertical airlift aeration units that contain trickling media (hollow plastic cylinders with internal baffles). These media are used routinely in sewage and industrial waste treatment. Based on our laboratory tests, they increase the mixing capacity and oxygen transfer of the ILS by enhancing bubble shear and by extending the air-water contact time.

Field Tests

Coal Mine Drainage

The ILS proved to be effective in treating acidic mine water at a number of sites. The variety of raw water qualities successfully treated with the portable ILS unit are shown in table 1. In general, a pH of 6.9-7.7 lowered iron concentrations of up to 300 mg/L to less than 3 mg/L (the typical U.S. coal mine effluent limit). At site 8, a second pass through the ILS was necessary to meet effluent requirements due to the limitations of the portable system. At two sites, neutralization costs for the ILS could be compared with the costs of conventional treatment. Influent water quality and site data for these two sites are shown in tables 1 and 2.

Table 1.— Raw water qualities effectively treated to within effluent standards

Parameter	Field sites 1*	2*	3	4	5	6	7	8	Effluent standards Daily max.	Monthly avg.
pH	5.3	2.9	2.9	4.5	6.7	3.7	3.1	2.8	between 6 and 9	
Net acidity	991	736	808	810	-222	510	382	3772	N/A	N/A
Ferrous Fe	527	82	77	190	15.6			965	N/A	N/A
total Fe	529	145	150	260	20.2		23	1011	6.0	2.0
Mn	14.1	121	9.6	0	0	181	20.4	68.4	4.0	2.0

*Field sites discussed in this paper.

Table 2. — Conventional Treatment at Sites 1 and 2

Site Description	Site 1	Site 2
Operation	Abandoned underground coal mine	Surface coal mine
Raw water	Mine pool	Pond
Sludge settling	Clarifier	Pond
Aeration	Mechanical	None
Neutralization	$Ca(OH)_2$ (lime)	NaOH
Normal flow	1500 gpm (95 L/s)	220 gpm (13.9 L/s)

At the first site, the mine water was pumped into an existing basin, then pumped through the ILS and discharged via a flume into a large clarifier. A diesel-powered, submersible pump operated the 3-jet ILS used at this site. Neutralization consisted of pumping a lime slurry from a mix tank into the suction chamber of one jet pump. An average of 91 pct of the Fe^{2+} and 68 pct of the Mn was removed at pH 7. At pH 7.7, 98 pct of the Fe^{2+} was removed; at pH 8.4, over 99 pct of the Fe^{2+} was removed. Effluent manganese concentrations were less than the legal limit of 2 mg/L at pH 7.7 and above.

At the second site, water was pumped from a raw water pond, through a 2-jet configuration of the ILS, and discharged into a sludge settling pond. NaOh was injected into one jet with a metering pump. With one exception, Fe^{2+} concentrations were reduced to less than 1 mg/L at pH values of 7.2 and up, regardless of operating pressure. Effluent Mn concentrations were found to be above effluent limits until the pH was raised to 9.1.

Metal Mine Drainage

The ILS was also tested at a base metal mine in Idaho to evaluate its possible use in the treatment of metal mine drainage. Drainage at this site contained elevated concentrations of lead, zinc, cadmium, copper, and manganese. Influent water quality and effluent limits are listed in Table 3. The ILS was operated in parallel with the existing 5 MGD water treatment plant. To achieve effective zinc removal in the existing plant, some of the sludge from the treatment process had to be recycled and mixed with the lime slurry (at about 5:1 slurry/sludge ratio). Sludge recycling had no effect on ILS performance.

In general, after settling, ILS effluent water met all regulatory limits when the pH of the water was raised to 8.5 or greater. This is the same pH required for conventional neutralization in the plant, but represents reduced operating and maintenance costs in that no sludge recycling was necessary.

At coal mine site 2, the average rate of NaOH use in the existing plant for a 6-month period was determined from company records. When compared to the NaOH feed rates required with the ILS to meet effluent standards, a 29 pct reduction in NaOH use was observed. The ILS feed rates were measured in the field and confirmed by chemical analysis. At this site, it appears that the enhanced efficiency of the ILS was due to the superior oxygen transfer capability of the ILS, which allowed contaminant removal at a lower pH than was possible with the existing treatment plant.

Table 3. — Conditions at Site 3

Parameter	Average Raw Water Quality	Water Quality Standards to be Met: Daily Maximum	Monthly Average
pH	6.25	6-9	6-9
Fe (mg/L)	2.154	NA*	NA
Zn (mg/L)	78.570	1.48	0.73
Cd (mg/L)	0.457	0.10	0.050.30
Pb (mg/L)	1.292	0.60	0.15
Cu (mg/L)	0.015	3.00	NA
Mn (mg/L)	35.01	NA	

*NA - not applicable.

Neutralization Cost Comparisons

In a conventional AMD treatment facility, lime is slurried with water and then mixed with the mine water. In practice, this means that a great deal of lime falls to the bottom of the aeration tank and is wasted. At site 1, the ILS proved to be 30 pct more efficient than the normal plant requirements, based on actual lime used. Based on analysis of the neutralized water and sludge, it appears that this enhanced efficiency is due to the superior mixing action of the ILS.

The oxidation rate for most AMD contaminants generally increases with increasing pH, so it is common practice to raise the pH to 10 or greater to achieve adequate floc formation and to precipitate manganese. Improving the aeration and mixing processes is much less expensive and at least as effective.

Conclusions

The in-line aeration and neutralization system is a simple and effective method of treating AMD and can reduce treatment costs. Field tests have shown the performance of the ILS to be at least equivalent and in most cases superior to conventional treatment methods. The ILS has many advantages over conventional treatment methods: it is significantly less expensive than conventional neutralization and aeration, has no moving parts, has reduced space requirements, and can easily be made portable, which allows for versatility in surface mining operations. The portable ILS is also an excellent system for short-term treatment situations often encountered in reclamation operations. Mechanical aerators and aeration basins, as well as the associated capital, operating, and maintenance costs, are eliminated with the ILS. The ILS operates by water pressure, usually provided by an existing mechanical pump; however, given enough elevation difference [46 ft (14 m) or greater], the ILS can be operated by gravitational head pressure. Capital costs are reduced relative to the use of mechanical aerators. Operating and maintenance costs should also be low because the system has no moving parts.