

# An Innovative, Economical, and Efficient Method of Metal Removal from Mine Wastewater

**Judd Sundine**, Sundine Enterprises, USA

**Scott Powell**, Powell Water Systems, Inc., USA

## Abstract

Electrocoagulation (EC) will successfully remove heavy metals, silica, and a wide range of other contaminants from aqueous solutions such as mine wastewater while withstanding a wide variety of operating conditions. The EC makes constituents in the water “separable” by floatation, precipitation, and filtration. Heavy metals are converted from ion forms to stable oxide forms, thereby preventing leaching under ambient landfill pH’s and permitting the solids to be disposed in a non-hazardous landfill. Because electrocoagulation utilizes methods that precipitate large quantities of contaminants in one operation, the technology is the distinct economic and environmental choice for industry, such as mining operations, commercial, and municipal waste treatment. The capital and operating costs are usually significantly less than chemical coagulation and other treatment options.

Untreated water is introduced into the bottom of the EC chamber and is dispersed evenly as it moves upward through the blades. Direct current (DC) is applied to the first and last blade. The liquid then becomes a conductor, allowing the current to pass freely throughout the chamber. This results in a flood of electrons into the water, neutralizing charged particles, causing them to precipitate out of solution. In addition, the metal blades react to the current by releasing charged metal ions that act similarly to chemical coagulants. Salinity levels have a major impact on the power required to remove targeted constituents. The higher salinity in the wastewater results in higher conductivity (lower resistance) so lower voltage is required for a given amperage that is needed to drive the electro-chemical reactions. Since DC power consumption is volts times amps, the subsequent power consumption is less in higher conductive waters, thus decreasing operating costs. The EC also contains an automated clean-in-place (CIP) system and an air purge system that fluidizes precipitants and reverses polarity in order to extend metal blade life and prevent contaminants from coating the blades. No chemicals, other than for CIP, are required for the treatment process. The acid solution used in the automated cleaning cycle is recycled and,

when exhausted, is routed through the EC system for final disposal. EC has become recognized as a very effective means for economically treating a wide variety of challenging water treatment applications and is available in sizes ranging from 3.8 liters/minute (L/m) to multiples of 9,500 L/m.

## Introduction

The traditional method of reducing the amount of heavy metals and colloidal material from mine wastewater has been chemical coagulation. In the past few decades, an alternative method of reducing heavy metals and colloidal material from mine wastewater has commercially evolved, called electrocoagulation.

Electrocoagulation, the passing of electrical current through water, has proven very effective in the removal of many different contaminants from water and is a viable solution for removing heavy metals and colloidal material from mine wastewater. Electrocoagulation systems have been in existence for many years (Dieterich, patent in 1906), using a variety of anode and cathode geometries, including plates, balls, fluidized bed spheres, wire mesh, rods, and tubes. One example of an EC system uses metal plates, usually iron or aluminum, arranged vertically in a chamber, taking a quantum leap in refining the EC process to: 1.) increase removal efficiency; 2.) increase throughput with respect to flow rate; and 3.) significantly lower capital and operating costs compared to chemical coagulation.

The electrocoagulation process is based on valid scientific principles involving responses of water contaminants to strong electric fields, such as electrically induced oxidation and reduction reactions, emulsion breaking, halogen complexing, bleaching by oxygen ions, seeding, and electron flooding. The degree to which each of these phenomenon occur, the removal efficiency and energy consumption per 3,800 L. treated, is a function of water quality, voltage, amp density, blade configuration, blade material, residence time, and downstream particle separation technique. This process is able to take out more than 99 percent of some heavy metal cations and also appears to be able to electrocute microorganisms in the water. Electrocoagulation increases the zeta potential and Van der Waals forces, allowing agglomeration and easy separation of colloids and the removal of significant amounts of other ions and emulsions. When the system is in place, energy intensity units range between 2-7 kWh/3,800 L., resulting in operating costs that include electric power, replacement of electrodes, pump maintenance, and labor that can be less than USD \$1.00/3,800L. for most applications. "Potential applications to agriculture and quality of rural life include removal of pathogens and heavy metals from drinking water and decontamination of food processing wash waters." (Dieterich, 1906)

Coagulation is one of the most important physiochemical operations used in water treatment. This is a process used to cause the destabilization and aggregation of smaller particles into larger particles. Water

contaminants such as ions (heavy metals) and colloids (organics and inorganics) are primarily held in solution by electrical charges. Schulze, in 1882, showed that colloidal systems could be destabilized by the addition of ions having a charge opposite to that of the colloid. (Benefield et al., 1982) The destabilized colloids can be aggregated and subsequently removed by sedimentation and/or filtration. Heavy metals are converted from ion forms to oxide forms, allowing them to be disposed in a non-hazardous landfill. “Heavy metals processed with sufficient activation energy precipitate into acid resistant oxide sludge like  $\text{NiFe}_2\text{O}_4$ , which pass the Toxic Classification Leaching Procedure (TCLP) and allow the sludge to be reclassified as non-hazardous.” (Renk, 1989; Franco et al., 1974, 1983)

Coagulation can be achieved by chemical or electrical means. Chemical coagulation is becoming less acceptable today because of the higher costs associated with chemical treatments. (e. g. the large volumes of sludge generated, safety concerns, and the hazardous waste categorization of metal hydroxides, to say nothing of the costs of the chemicals required to effect coagulation).

*Chemical coagulation has been used for decades to destabilize suspensions and to effect precipitation of soluble metal species, as well as other inorganic species from aqueous streams, thereby permitting their removal through sedimentation or filtration. Alum, lime, and/or polymers have been the chemical coagulants used. These processes, however, tend to generate large volumes of sludge with high bound water content that can be slow to filter and difficult to dewater. These treatment processes also tend to increase the total dissolved solids content of the effluent, making it unacceptable for reuse within industrial applications. (Benefield, et al., 1982)*

*EC produces an environmentally friendly sludge in the 6 to 7 pH range. Metals in the sludge at this pH range are stabilized in a non-hazardous form as oxides, and they pass the EPA TCLP and California Title 22 STLC and TTLC leach tests. Chemically produced sludge, on the other hand, is usually in the caustic pH range with metals in the form of hydroxides. In this form the metals can become soluble again at the neutral pH range of around 7. In addition, the volume of chemical sludge is much greater due to the presents (sic) of most of the added chemicals. (Mickley, 2004)*

Sludge produced by electrocoagulation can be disposed into a non-hazardous landfill, illustrated by the sequence of tables 1 and 2:

**Table 1: Recycled steam cleaner wash water lab analysis (004-263)**

Analyte	Wastewater Mg/l	Post EC & Clarification	% Reduction
Antimony (Sb)	<0.01	0.014	
Arsenic (As)	0.30	<0.01	96.7%
Barium (Ba)	8.0	<0.10	98.7%
Beryllium (Be)	<0.01	<0.01	
Cadmium (Cd)	0.141	0.031	78.0%
Chromium (Cr)	7.98	0.05	99% +
Cobalt (Co)	0.13	<0.05	61.5%
Copper (Cu)	6.96	<0.05	99% +
Lead (Pb)	7.4	1.74	76.5%
Mercury (Hg)	0.003	<0.001	66.7%
Molybdenum (Mo)	0.18	0.035	80.7%
Nickle (Ni)	0.4	<0.05	87.5%
Selenium (Se)	<0.005	<0.005	
Silver (Ag)	<0.01	<0.01	
Thallium (Tl)	<0.10	<0.10	
Vanadium (V)	0.23	<0.01	95.7%
Zinc (Zn)	19.4	1.20	93.8%

**Table 2: The dry sludge separated from the steam cleaner EC treated wastewater listed above was tested for leachability (005-462)**

Element	Total Threshold Limits Concentration (TTLC)	Max State	Soluble Threshold Limits Concentrations (STLC)	Max State
	Raw mg / kg		Raw mg / l	
Antimony (Sb)	2.4	500		
Arsenic (As)	3.85	500		
Barium (Ba)	307	10,000		
Beryllium (Be)	nd	75		
Cadmium (Cd)	nd	100		
Chromium (Cr)	59.2	2,500		
Cobalt (Co)	10.4	8,000		
Copper (Cu)	498	2,500	3.8	25
Lead (Pb)	790	1,000		
Mercury (Hg)	0.15	20		
Molybdenum (Mo)	21.3	3,500		
Nickle (Ni)	25.5	2,000		
Selenium (Se)	nd	100		
Silver (Ag)	2.7	500		
Thallium (Tl)	14.2	700		
Vanadium (V)	42.1	2,400		
Zinc (Zn)	1,798	5,000	60	250

Electrocoagulation can often neutralize ion and particle charges, thereby allowing contaminants to precipitate, reducing the concentration below what is possible with chemical precipitation, and can replace and / or reduce the use of expensive chemical agents (alum, lime, ferric chloride, ferric sulfate, ferrous sulfate, polymers, and other chemical additives).

*Although the electrocoagulation mechanism resembles chemical coagulation in that the cationic species are responsible for the neutralization of surface charges, the characteristics of the electrocoagulated flock differ dramatically from those generated by chemical coagulation. An electrocoagulated flock tends to contain less bound water, is more shear resistant, and is more readily filterable. (Woytowich, et al., 1993)*

*Electrocoagulation has reduced contaminated water volume by 98%; and lowered the treatment cost by 90% for bilge water containing heavy metals and oil emulsions. Although electrocoagulated water may vary because of the individual chemistry of process mine waters, a few examples of water treated by electrocoagulation include:*

- *Dissolved silica, clays, carbon black, and other suspended materials in water are generally reduced by 98%;*
- *Heavy metals in water such as arsenic, cadmium, chromium, lead, nickel, and zinc are generally reduced by 95% to 99%. (Powell, 2010)*

Electrocoagulation through the reaction chamber produces several distinct electrochemical results independently. These observed reactions could be explained as:

- **Seeding** resulting from the anode reduction of metal ions that become new cores for larger, stable, insoluble complexes that precipitate as complex metal oxides;
- **Emulsion breaking** resulting from the oxygen and hydrogen ions that bond into the water receptor sites of oil molecules, creating a water insoluble complex separating water from oil, driller's mud, dyes, inks, etc.;
- **Halogen complexing** as the metal ions bind themselves to chlorines in a chlorinated hydrocarbon molecule, resulting in a large insoluble complex separating water from pesticides, herbicides, polychlorinated biphenyl's (PCB's), etc.;
- **Bleaching** by the oxygen ions produced in the reaction chamber oxidizes dyes, cyanides, bacteria, viruses, biohazards, etc.;
- **Electron flooding** of the water eliminates the polar effect of the water complex, allowing colloidal materials to precipitate, and the increase of electrons creates an osmotic pressure that ruptures bacteria, cysts, and viruses;

- **Oxidation** - Reduction reactions are forced to their natural end point within the chamber, which speeds up the natural process of nature that occurs in wet chemistry;
- **EC induced pH** swings toward neutral.

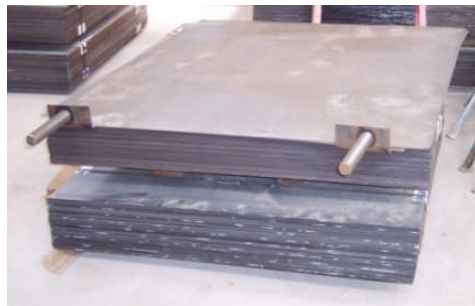
The electrocoagulation systems are optimized by controlling reaction chamber materials (iron, aluminum, titanium, graphite, etc.), amperage, voltage, flow rate, and the pH of the water. The electrocoagulation technology handles mixed waste streams (oil, metals, and bacteria) very effectively. Variables such as temperature, pressure, and availability of clean power have little effect on the process. Typically, the only portion of the electrocoagulation unit requiring clean power and an uninterrupted power supply is the programmable logic control (PLC) and computer. Because electrocoagulation utilizes methods that precipitate out large quantities of contaminants in one operation, the technology is the distinct economic and environmental choice for industries such as mining, commercial, and municipal waste treatment. The capital and operating costs are significantly less than chemical coagulation.

## Methodology

Chemical precipitation in wastewater treatment involves the addition of chemicals to alter the physical state of dissolved and suspended solids and to facilitate their removal by sedimentation. The chemicals used in wastewater treatment include alum, ferric chloride, ferric sulfate, ferrous sulfate, and lime. “The inherent disadvantage associated with most chemical unit processes (activated carbon adsorption is an exception) is that they are additive processes. (Metcalf and Eddy, 1991) These chemicals are not only expensive, but, more importantly, the net increase in the dissolved constituents in the wastewater render it impractical or impossible for reuse and often requires hazardous waste disposal protocol.

In contrast with chemical coagulation, electrocoagulation systems use electricity to efficiently remove a wide range of contaminants within wastewater with a single step system, thus eliminating the arduous and time consuming steps of adding chemicals and later their removal. In addition, the EC process results in water that is available for reuse, and the separated solids are available for resale, reuse, or for simple removal to a non-hazardous landfill. Using patented chambers, EC passes electricity through water using bipolar electric sacrificial (Figure 1a) metal plates/blades (Figure 1). The power is attached to the first and last blades and uses the water to conduct the electricity to other blades. The EC system converts alternating current (AC) to direct current (DC) voltage. Electrons from the metal blades flood the water and destabilize suspended solids, emulsified or dissolved oil, and convert metal ions to oxides, making the contaminants separable. A secondary separation system then separates the solids from the water. The EC systems are mounted on a steel skid (Figure 2), which includes a cross-linked polyethylene reaction chamber, current controlled power supply, polarity reversing, and system pump. Options include

a cleaning in place automated valve system and remote controls, rather than the standard manual cleaning system (Figure 3). The EC units are operated by advanced PLC systems with normally open and normally closed contact input for pH, float, or specific probe control. Secondary clarification systems, such as vacuum clarifiers, belt filter press, dissolved air flotation (DAF), dewatering centrifuge, inclined plate clarifier, bag filters etc., can be integrated with the EC unit and controlled by the PLC for a complete automated process system.



**Figure 1: 1,900 Liters per Minute (L/m) Metal Blades (New)**



**Figure 1a: 190 L/m Sacrificial Metal Blades (New and Used)**



**Figure 2: 1,368 L/m Electrocoagulation Unit**



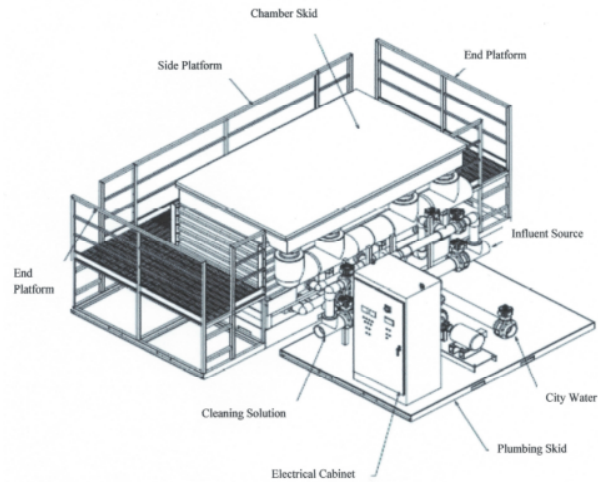


Figure 3: 1,368 L/m Schematic EC Unit

## Reaction Chamber

The reaction chamber is the heart of the electrocoagulation system (Figure 4). The reaction chamber produces an electrochemical reaction that allows organic and inorganic colloids to precipitate as solids that can be removed through simple filtration, such as sedimentation, inclined plate clarification, vacuum clarification, centrifuge, ultra-filtration, or other approved industry separation devices. Dissolved air flotation can also be incorporated; however, often the precipitate floats to the surface as it is carried from the gas bubbles formed at the cathode and anode. The degree at which the gas bubbles are formed, the amount of elemental metal dissolved into the solution at the anode, and the mixing intensity are a function of the amp density.

The EC reaction chamber was designed to process water or wastewater on a continuous-flow basis. The reaction chamber is made of cross linked polyethylene and contains a series of either mild steel or aluminum blades that are spaced appropriately to protect the operator from electrical shock and allow a multitude of pollutants to be processed through the system. Direct current (DC) is applied to the blades within the chamber. The metal blades react to the current by releasing charged metal ions into the liquid at a rate of approximately 0.44 kilograms (kg) per 3,800 liters (L.) treated. The flooding of electrons into the liquid neutralizes charged particles, allowing them to increase in size and to be removed through simple clarification. An average of 2 to 7 kilowatts of electricity is used per 3,800 L. of treated water on a typical waste stream. The EC reaction chamber includes an automatic air purge system to keep debris

from accumulating inside the chamber, and polarity reversing is applied to extend blade life and prevent contaminants from coating the blades.



**Figure 4: 1,900 L/m Reaction Chamber**

## Power Supply

The electrocoagulation systems utilize power from the grid by converting alternating current (AC) to direct current (DC) through full wave rectification (Figure 5). The unique design of the chamber eliminates the need for a power transformer reducing operating costs and improving overall performance. A solid-state control system allows the DC power to be introduced into the blades within the reaction chamber gradually for protection against highly conductive liquids. Additional uninterrupted power supplies are used within the system to operate critical components such as relay switches, electric valving, lighted displays, and the programmable logic control system; however, the power to the blades may utilize “dirty” power. This is a distinct operational advantage when used in remote, third world countries that do not have a reliable power grid.



**Figure 5: 950 L. Power Supply**

## Controller and Valving

The electrocoagulation system is manufactured using standard industrial electronic components. The programmable logic control system (PLC) controls solenoid valves, float switches, and sensors for a smooth hands-free operation. Polarity reversing, air purge operations, flow rate, and power settings are

also controlled by the PLC. The PLC is equipped with an operator interface screen that allows complete monitoring and control by a single individual.

## **Operator Safety**

The electrocoagulation system is safe and easy to operate. The enclosed reaction chamber with protective liner prevents any electrical shock. The automated functionality of the system requires little supervision and no actual contact with valving or components while the system is in use.

## **Maintenance and Blade Replacement**

Maintenance requirements for the electrocoagulation system are minimal. The metal blades will require replacement, depending upon the water being treated with typical change times of every 3 to 4 months. Metal blades are 3.175 millimeters (mm) thick and are of standard size, making them readily available. Metal blades become sacrificial in a typical wastewater stream and release approximately 0.44 kg of metal per 3,800 L. of treated water. Blade replacement consists of simply removing the lid of the reaction chamber, sliding the old blades out of the top of the chamber, and sliding the new blades into place. Blade replacement may be performed by one or two individuals. Time required for replacing blades will depend on the size of system. Typically, all the blades can be replaced within a few hours. While blades are being replaced, it is a good time to inspect the positive displacement air diaphragm pump.

## **Cleaning the System**

Occasionally, some liquids being processed through the EC system can contain contaminants that naturally tend to attract to the blades while processing. If this occurs, the blades will need to be cleaned. This can be done manually or by introducing a cleaning solution into the chamber to clean contaminants from the blades. A variety of chemicals may be used in the cleaning process, depending on the particular waste stream being treated and the blade material being used. The cleaning cycle can be automated with control valves. The automatic cleaning in place valve system typically takes less than ten minutes per cleaning cycle. A surge tank can be used to accumulate water during the cleaning cycle to allow a continuous incoming flow from the plant operation.

## **System Requirements**

The EC system requires all influent water to be pre-screened to 0.7938 mm. In addition, the EC system must be placed on a concrete platform and protected against rain and freezing conditions.

## Data

The following two examples (Tables 3 and 4) illustrate the efficiency of electrocoagulation in removing even minute quantities of certain constituents in the wastewater. In both of these cases, it was important for the clients to obtain very high removal rates or non-detect (ND) for every constituent of concern.

**Table 3: Protected mining client, Alberta, Canada.  
Raw water sample in mg/L and post electrocoagulation results in mg/L**

Analyte	Raw	Post EC & Clarification	% Reduction
Aluminum (Al) Total	191.0	0.005	99+
Cadmium (Cd) Total	0.00049	0.00005	89.8
Copper (Cu) Total	0.0228	0.0097	95.7
Lead ((Pb) Total	0.00711	0.0001	98.6
Zinc (Zn) Total	0.605	0.001	98.6

**Table 4: Protected gold and silver mining client, Nederland, Colorado.  
Raw water sample in mg/L and post electrocoagulation results in mg/L**

Analyte	Raw	Post EC & Clarification	% Reduction
Cadmium (Cd)	0.0039	ND	99+
Copper (Cu)	0.0068	ND	99+
Lead (Pb)	0.0073	ND	99+
Zinc (Zn)	0.42	ND	99+

The following two protected metal plating company's results (Tables 5 and 6) illustrate some typical metal removals that can be expected for both mining and metal plating operations.

**Table 5: Protected metal plating client. Raw water sample in mg/L and post electrocoagulation results in mg/L**

Analyte	Raw	Post EC & Clarification	% Reduction
Chromium (Cr)	44.5	0.16	99+
Cyanide (Cn)	1.98	<0.01	99+
Copper (Cu)	86.5	0.25	99+
Nickel (Ni)	104.4	0.47	99+
Zinc (Zn)	15.5	0.73	99+

**Table 6: Protected metal plating client. Raw water sample in mg/L and post electrocoagulation results in mg/L**

Analyte	Raw	Post EC & Clarification	% Reduction
Chromium (Cr) Total	37.9	0.10	99+
Chromium (Cr) hexavalent	21.0	>0.05	99+
Zinc (Zn)	18.1	0.16	99+

The following report was performed for a protected client in New York. Analyte groups that were analyzed were chlorinated pesticides, polychlorinated biphenyl (PCB), semi-volatile organics, volatile organics, as well as biochemical oxygen demand (BOD<sup>5</sup>), total suspended solids (TSS), carbonaceous biochemical oxygen demand (CBOD), and metals. Because most mining companies will have experience with metals, the metal portion of the report is listed (Table 7).

**Table 7: Protected mining engineering client in New York. Raw water sample is from hydraulically dredged wastewater containing metals. Raw water results are reported in ug/L and post electrocoagulation results in ug/L**

Analyte	Raw	Post EC & Clarification	% Reduction
Arsenic	30	3.2	89.3
Cadmium	10	0.32	96.8
Chromium	330	13.0	96.1
Copper	230	3.2	98.6
Iron	22000	29.0	99+
Lead	590	3.2	99+
Mercury	0.72	0.0031	99+
Zinc	2,200	6.4	99+

In the following table (Table 8), this Missouri-based protected client mining operation was facing stiff penalties because chemical coagulation was not meeting their discharge standards.

**Table 8: Protected mining operation client in Missouri. Raw water sample in ug/L and post electrocoagulation results in ug/L**

Analyte	Raw	Post EC & Clarification	% Reduction
Cadmium (Cd) Total	36.0	0.15	99+
Copper (Cu) Total	3.0	ND	99+

Lead (Pb) Total	1,285.0	0.64	99+
Zinc (Zn) Total	6,675.0	13.0	99+

## Discussion

The two main expenses of operation and maintenance (O&M) are electricity and blade replacement. Electricity is used in the typical range of 2 to 7 kilowatt hours (kWh) per 3,800 L. treated. For example, if the cost of electricity is US\$0.08/kilowatt, and, if a particular mine water used 5 kWh per 3,800 L. treated, the cost of electricity per 3,800 L. treated would be USD \$0.40. The second cost is blade replacement. The typical dissolving rate is 0.44 kg per 3,800 L. treated when steel blades are used and 0.22 kg per 3,800 L. treated when aluminum blades are used. For example, a 1,900 L/m EC unit has an iron blade weight of 66,836 kg, at a 0.44 kg sacrificial loss per 3,800 L. treated, then the replacement of the blades would be needed approximately every 200 days, assuming a 24/7 operation. At a cost of USD \$0.23 per kg for carbon steel, the cost per 3,800 L. would be USD \$0.10/3,800 L.

The power supply for the electrocoagulation unit is oversized to accommodate the occasional extra contamination that often occurs in wastewater treatment. The electrical breaker is recommended to be 50% additional to the rated capacity. The AC power for a 1,900 L/m power supply is 480 volts AC three phase and 1,300 amps. The 57, 114, 190, 342, 513, 950, 1,368, and 1,900 L/m units are 480 volt AC input. The 11.4, 22.8, and 38 L/m units are 220 volts AC single phase. The 5.7 L. unit is 110 volts AC single phase at 30 amps.

A small amount of compressed air is supplied inside the chamber to assist the coagulated material to flow with the water and exit the top of the chamber. For commercial units, the positive and negative connections reverse polarity to also assist coagulated material from fouling the blades.

Chemical usage for electrocoagulation is limited to pH control and/or system cleaning. No polymers or flocculants are used in the electrocoagulation process. This means that no ions are added to the water during the water treatment process. “When compared with alum treatment, electrocoagulation provided approximately 83% less sludge volume and a 76% improvement in filtration rate.” (EPA, 1993) Total dissolved solids (TDS) removal rates are dependent upon the type of ions causing the TDS. EC is not effective in removing carbon chains of less than 5. Sodium or chlorides are not removed significantly with the electrocoagulation process. Chrome, zinc, arsenic, cadmium, lead, uranium, etc. are removed in the high 90% range (Figure 6). When sodium and chloride need to be removed, it is recommended that secondary separation be accomplished by settling ponds (figure 7), clarifiers, belt presses, vacuum clarification, dissolved air flotation, decant tanks, etc., followed by reverse osmosis (R.O.).

Figure 6: Electrocoagulation: Correlation of Removal Levels with Periodic Chart

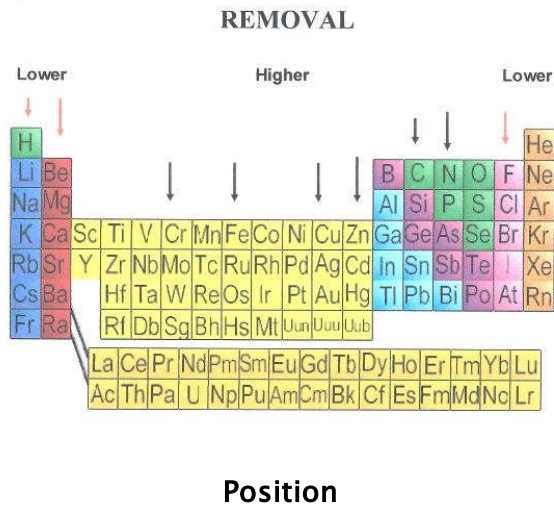
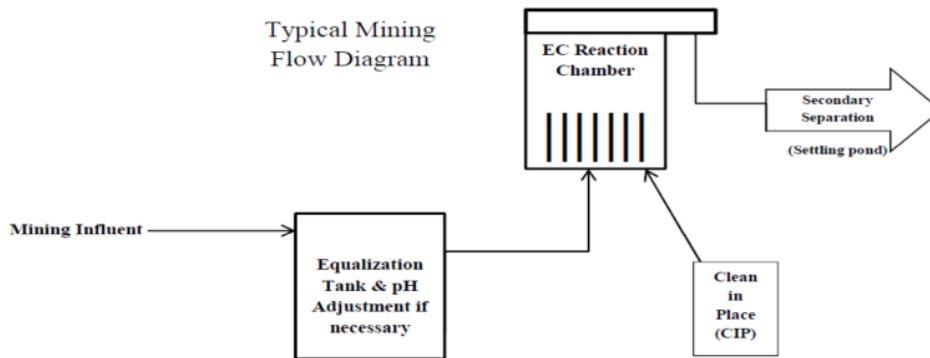


Figure 7: Simple Process Design for EC System

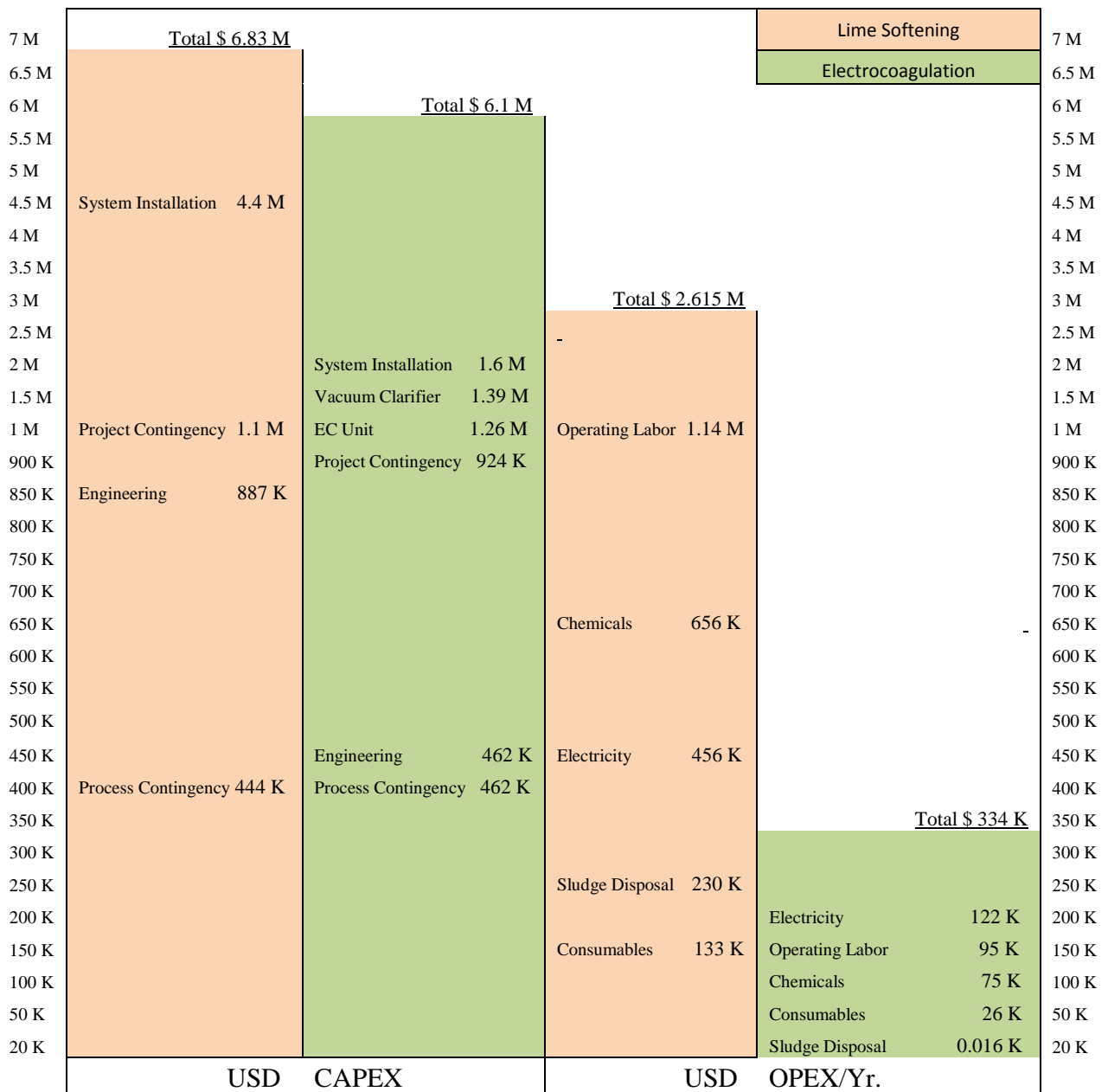


## Conclusion

EC will efficiently and economically remove heavy metals, silica, and a wide range of items including suspended solids, colloidal solids, emulsions, fats, grease, bacteria, cysts, viruses, hardness, boron, selenium, radioactive material, and organics from mining wastewater. Its operations and maintenance cost (OPEX) have distinct advantages. Because of the simplicity of the EC system, there is a significant savings both in man hours and minimal chemical costs. Since the EC works best between a pH of 5 and 12, chemicals can be used for very low pH mining water. High-temperature water such as silica-laden water from geothermal water (Canada Tar Sands) or boiler blow down water can be treated and re-used. EC chambers can be specified to withstand very hot water which allows for a continual and complete treatment process without the added expense of cooling the water as is needed before using membrane or chemical coagulation technologies. Even the largest systems can be operated with only 1 or 2 operators per shift, again resulting in significant savings in manpower expenses. Operator training is straightforward. EC has no moving parts, and the simple design ensures the system is reliable and cannot be damaged by operator error or process upset. Besides manpower, the only operating costs are power, clean in place (CIP) for the blades, and periodic metal blade replacement. Typical power consumption is only 4 kWh/3,800 L. Metal blade maintenance is limited to periodic replacement of the generic flat blade/plate that can be purchased locally, saving the costs of custom manufacturing and shipping. The metal blade consumption is about 0.44 kg/3,800 L. treated. Most contaminants are precipitated as oxides that render them non-hazardous and able to pass the toxicity characteristic leaching procedure (TCLP) test. In addition, EC results in less sludge that is more readily filterable through a secondary separation system such as settling ponds. Since no additional lime, polymers, flocculants, or other chemical agents are added; the waste volume is minimal and can typically be discharged into dumpsters for haul-off to a non-hazardous landfill, significantly saving the transportation costs and the very high hazardous waste disposal fees. EC protects and prolongs the life of filtration membranes by virtually eliminating suspended solids before the filtration process. The evaluation of the efficiency and economical savings when using EC rather than chemical coagulation for wastewater treatment was clearly summed up by Robert Hamilton in his report to a major gas and oil company when he stated (chart 1): *“The results of the economic evaluation indicate the levelized cost of a 500 GPM electrocoagulation system to be about one-fifth the levelized cost of a comparable 500 GPM lime softening system. This difference is realized by lower operating costs across the board.”* (Hamilton, 2009).



Chart 1: EC vs. Lime Softening – 1,900 L/m – CAPEX and OPEX



## References

- Benfield, L.D., Judkins, J.F., and Weand, B.L. 1982. *Process Chemistry for Water and Wastewater Treatment*. Prentice-Hall, Englewood Cliffs: 212.
- Barkley, N.P., Farrell, C., and Williams, T. 1993. *Electro-pure Alternating Current Electrocoagulation*, EPA/540/s/93/504, United States Environmental Protection Agency, September: 4.
- Dieterich, A.E. 1906. *Electric Water Purifier*, United States of America Patent No. 823,671 June 19, 1906.
- Duffey, J.G. 1983. Electrochemical Removal of Heavy Metals from Waste Water. *Products Finishing*, August 1983: 72.
- Franco, N.B. 1974. Electrochemical Removal of Heavy Metals from Acid Mine Drainage. *Environmental Protection Agency Report EPA-67012-74-023*. May 1974.
- Hamilton, R. 2009. *Evaluation of Lime Softening vs. Electrocoagulation for Treatment of Produced Water*. Prepared for Proprietary Energy Technology Company, Process Technology, Separations-Gas & Water.
- Metcalf and Eddy. 1991. *Wastewater Engineering Treatment Disposal Reuse*. McGraw-Hill, Third Edition: 301-303.
- Mickley, M. 2004. *Pretreatment Capabilities and Benefits of Electrocoagulation*. Prepared for Office of Naval Research, under contract no. N00014-04-C-0027.
- Powell, S.W. 2010. *Overview of Electrocoagulation*. Web document, viewed 10 June 2010, <http://powellwater.com/ec-overview.htm/>.
- Renk, R.R. 1989. *Treatment of Hazardous Wastewaters by Electrocoagulation*. In 3rd Annual Conference Proceedings. Colorado Hazardous Waste Management Society.
- Woytowich, D.L., Dalrymple, C.W., and Britton, M.G. 1993. *Electrocoagulation (CURE) Treatment of Ship Bilgewater for the US Coast Guard in Alaska*. *Marine Technology Society Journal*, 27(1), Spring 1993: 62.