Managing Electro-Coagulation Projects

Use of Electro-Coagulation to Treat Oil & Gas Field Wastewaters: The MSWG Technical and Project Management Strategy

by

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The MSWG Technology

MSWG specializes in providing turnkey solutions to wastewater problems by designing and constructing wastewater treatment systems that can effectively treat both conventional and recalcitrant wastestreams.

Our principal engineers and scientists average almost 40 years of experience in project management, water treatment, waste management, environmental science and engineering, construction, field operations, and regulatory compliance consulting.

The heart of the MSWG Team’s technology is advanced electro-coagulation followed by secondary treatment trains (as required) consisting of a range of applicable conventional technologies, such as carbon filtration, regenerative carbon filtration, ultra-filtration, reverse osmosis, electro-dialysis, ozonation, ultra-violet light, and others.

The MSWG Team is the industry leader in electro-coagulation, with almost 30 years of experience in designing, fabricating, constructing, and operating systems that treat a wide variety of wastestreams: primary metals and metal finishing, food and dairy processing, laundries, domestic sewage and sanitation, refinery and petrochemical, commercial truck and tanker washing, contaminated pits and ponds, oil field exploration and production, and others.

Electro-Coagulation Technology

The Electro Process

Our treatment systems use electrochemical treatment to remove contaminants from aqueous streams (referred to as “electro-coagulation”). They can be used effectively on both influent and effluent streams. Electrochemical treatment is generally used on industrial wastestreams to allow the reuse or discharge of an industrial wastewater. The process uses electricity rather than expensive, dangerous, and sometimes toxic chemicals to remove contaminants. Electrochemical treatment can be a pretreatment for other processes such as reverse osmosis, or even a polish treatment for traditional treatment processes.

The electrode modules are constructed using either iron or aluminum materials. Analyses have been performed on a wide range of materials including lead, copper, nickel, zinc, and even titanium to find the materials that met all the criteria of successful treatment. Iron and aluminum both meet the following requirements:

- Sacrificial quality
- Cost effectiveness
- Conductivity
- Non-toxic
- Availability
- Effectiveness of treatment on the widest variety of contaminants
What It Is

Electro-coagulation is the scientific discipline of utilizing electricity as the electromotive force to drive chemical reactions in a solution, suspension, or emulsion. A special form of direct current is introduced into the aqueous stream as it passes between a predetermined array of electrodes in the electro-coagulation module. This energy from the electricity is the engine or driving force to shift the equilibrium of a reaction to less than equilibrium levels, thus providing a mechanism for removing dissolved, suspended, or emulsified molecules, elements, or ions to very minute levels in an aqueous stream.

Highly saline wastewater may prove helpful for many treatment scenarios, since high TDS conditions increase treatment matrix electrical conductivity and reduce energy demand and use. Some of the TDS itself can be removed if it can be made insoluble through the use of electro-coagulation.

Best Applications

Electrochemical treatment can precipitate dissolved heavy metals by a combination oxidation-reduction reaction that in many cases produces oxide crystals that are very stable. For example, hexavalent chromium is reduced to trivalent chromium and removed as a precipitate. Copper, lead, zinc, nickel, and other metals are oxidized into oxide crystal form and can be concentrated and removed from the sludge stream, and then recycled. Some metals require an anion to be present to form a precipitate, such as calcium, magnesium, molybdenum, and others. Many times this anion may already be present in the wastestream, but if not, it can easily added. These heavy metallic crystals can be a positive nucleus to attract the electron rich hydroxide floc and colloidal solids into a settleable precipitate. This precipitate can then be separated in a settling pond or in a clarifier after some of the heavy metals are classified and concentrated.

Electro-coagulation will break colloidal suspensions which allows the precipitation and removal of suspended particles. The colloidal particle is flooded with electrons since the electricity is the flow of electrons. The excess of electrons causes the colloidal particles to attract to a sacrificed metallic cation which comes from the electrodes as the electric current passes through the electrode in accordance with Faraday’s Law. This metallic cation acts as a nucleus to attract the electron laden colloidal particles together into a floc precipitate. This generates a large heavy floc which can then be separated by a secondary separation process such as skimming, settling, clarification, or centrifugation.

Electro-coagulation will break oil emulsions and release the tied up emulsified oil to float to the surface where it can be skimmed off and recovered, if viable. Oil becomes emulsified as shearing action from pumps or chemicals cause an open or broken bond in the hydrocarbon chain which then attaches itself with a weak bond to the water molecule. Even though this is a weak bond, it is a protected bond and consequently very difficult to break by conventional means. As the electricity passes through the water being treated, electrons and energy are available as well as hydrogen ions or protons from the electrolysis of the water itself, and oxygen or hydroxide ions as a chemical feed stock for reaction completion. These subsequent reactions cause the weak bond to be broken and the oils to return to being a complete molecule, and the emulsion is broken. At this point the oil again becomes hydrophobic and generally floats to the surface due to differences in specific gravity, where it is recovered.
**Electro-coagulation Can Remove > 99% of Organics, Metals, and Suspended Solids from a Wastestream, Enhance the Performance of Secondary Treatment Steps Such as Filtration, Reverse Osmosis, etc.**

Electrochemical force drives the reactions to remove complex ions such as phosphates, silicates, carbonates, etc. Frequently, these anion radicals help to form insoluble precipitates such as calcium carbonate or calcium aluminum phosphate which aid in cation removal. The electro-coagulation force breaks down complex compound and organic halogens such as bromoform and dioxin. In all of these cases it is necessary to understand the chemical material balance of the reactions taking place, to make sure there is sufficient potential substance to balance with the available contaminants. The subsequent reaction will form insoluble precipitates or harmless by-products.

Electro-coagulation overwhelms microorganisms and other biological pathogens by excess electrons causing them to be crushed by the pressure exerted by the attractive force of the electrons toward the nucleus of the cell. This crushing pressure causes viruses, bacteria, and cysts to be eliminated from aqueous steams. Small molds and algae are removed in the same manner as colloidal particles. Destruction of biological pathogens typically exceeds 90%, and can be higher than 99%. If necessary, the residual pathogens can be killed by ozonation, ultraviolet light, or chlorination through the addition of a polishing step.

Depending on the type, solubility, and matrix (in solution, or sorbed to TSS), most radionuclides can be significantly removed from the wastestream. Those radionuclides which cannot be significantly removed with electro-coagulation can be removed with secondary treatment stage technologies such as filtration, reverse osmosis, etc.

**Applications with Limitations**

No single technology can economically remove all contaminants. However, the benefit of electro-coagulation as the primary stage is that it can produce a clean / clear influent to a secondary stage treatment system (such as filtration, reverse osmosis, etc.) which leads to superior performance by the second stage.

Electro-coagulation does not fully remove infinitely soluble materials such as sodium chloride, potassium compounds, or sugars since it cannot form an insoluble precipitate of these compounds. It
also does not fully remove miscible liquids such as alcohols, glycols, or soluble gases such as ammonia or cyanide. It sometimes has difficulty with chelated compounds such as copper amide or gold cyanide; however, it is possible to oxidize or air strip these compounds and then remove the metallic contaminants with electro-coagulation.

Electro-coagulation works best on aqueous streams of 1% solids or less for normal treatment processes. When enhanced with polymers, electro-coagulation can handle as much as 5% solids if the treated effluent is centrifuged. If higher solids are in the wastestream, then it may be necessary to loop back some of the treated water as a diluent for the influent water in the wastestream. Additionally, contaminants that are resistant to electro-coagulation treatment may be effectively treated by the inclusion of a carbon polish filter in the system configuration. Highly soluble elements such as sodium and potassium may be treated effectively with the addition of reverse osmosis.

**Summary**

In summary, electro-coagulation can remove significant quantities of contaminant mass:

- Metals in low salinity host water > 99+%  
- Metals in high salinity host water > 99+%  
- Hydrocarbons in low salinity host water > 99+%  
- Hydrocarbons in high salinity host water > 99+%  
- Microorganisms > 90% to > 99%  
- Soluble chemicals (phenols, sugars) > 25% to > 90%  
- TSS > 99+%  
- TDS or salinity up to 10% without RO/ED  
- TDS or salinity > 99% with RO/ED  
- Radionuclides up to 90% to 99%, function of type

These are not hard and fast rules, but rather are a function of the type of influent wastewater, including individual constituents and their concentrations.

**Designing the Right System**

**Overview**

MSWG designs, constructs, and operates advanced water treatment systems that incorporate proprietary, patented electro-coagulation technology as the primary treatment step in the overall treatment regiment. Electro-coagulation will remove >99% of most hydrocarbons, metals, suspended solids, and other non-saline constituents in the influent water. The overall process flow diagram is shown below.
A secondary treatment train consisting of carbon filtration, regenerative carbon filtration, reverse osmosis, and/or oxidation may be required to remove any residual contaminants such that the discharged effluent will satisfy the site or facility's treatment criteria/end points.

A supplemental approach may include some combination of the segregation of certain wastestreams for special pretreatment, equalization, etc. This will depend on the success of the electro-coagulation unit, the relative volumes and concentrations of the various wastestreams, and other factors.

For the removal of TDS, salinity, and chlorides, MSWG employs a combination of conventional reverse osmosis and electro-dialysis, as shown below. The benefit of using electro-coagulation as the primary treatment step is that a clean, clear influent to the reverse osmosis/electro-dialysis system can be accomplished, such that the reverse osmosis unit will have superior performance.
MSWG’s Water Treatment Philosophy

When properly designed and operated, electro-coagulation/electro-flocculation is a powerful, robust method of treating recalcitrant wastewaters in a matter of minutes. The MSWG Team system is continuous flow, as opposed to other systems which can only function in a “batch mode.” This results in higher throughput and less operating difficulties. Further, unlike some systems which are still in the R&D stage, our system has been successfully implemented on numerous projects and is fully commercial with high reliability.

Electro-coagulation uses the electrolytic addition of coagulating metal ions directly into the treatment zone from sacrificial electrodes. Appropriately constructed and operated, this technology can be used to rapidly coagulate a wide array of pollutants and float them to the surface as a floc or to the bottom as a sludge, where they can be readily removed using proprietary clarification systems. Since no chemicals (like alum) are added, there is no increase in the salinity of the treated water, and the resultant residual sludge is greatly reduced, usually by 75 – 80 percent.

Successful treatment is a Venn diagram of many parameters that are unique to electro-coagulation, including the appropriate sizing, configuration, voltage, and current density of the electrodes to effect contaminant removal; temperature; supplemental reagents and pH; treatment residence time; throughput and floc removal rates; and the ability to remove the resultant electro-floc from both the surface and bottom of the treatment chamber using proprietary and patented technologies. The “proprietary recipe” for successful treatment is generally kept within our “black box.” In addition to technical parameters, the MSWG Team views treatment as an “art” based on almost 30 years of experience.

MSWG’s water treatment philosophy also revolves around the concept of “project risk mitigation” to ensure project success by implementing three primary phases of the work.

- **Phase I**
  
  Conduct an engineering feasibility study and prepare a cost estimate for implementation. This will require the completion of laboratory bench-scale treatability studies (“mock up”) to define treatment metrics and “zero in” on the optimum treatment regimen, prior to designing a full-scale scale treatment project.

- **Phase II**
  
  Design, fabricate, and install a full-scale treatment system, including ancillary systems such as foundations, tanks, piping, sumps, electrical power systems, instrumentation and controls, etc.

- **Phase III**
  
  Commission the new facility, which includes initial on-site operational adjustments and training of operators, etc., and providing technical support as needed.
**Engineering Feasibility Study**

Phase I consists of two primary tasks that will answer the following questions:

- Is electro-coagulation a technically feasible system for the planned project?
- What supplemental technologies are required to meet the treatment criteria / end points?
- What are the associated capital and operating costs?

**Task 1**

Our experience gives us confidence that electro-coagulation is the “right solution” for most projects in the oil and gas business sector. However, the exact performance metrics are unknown, which will ultimately drive both the final design of the full-scale system and the associated capital and operating costs. Electro-coagulation has been compared to a “howitzer.” Still, it needs “zeroing in.”

Thus, laboratory bench-scale testing, while not absolutely critical to performance of the scope of services, is very useful from an engineering and scientific perspective in minimizing project risk by confirming that the untreated influent water can be successfully treated using MSWG’s proposed treatment technologies to satisfy the performance requirements of the new treatment system. Laboratory testing also helps confirm anticipated per unit treatment costs by allowing MSWG to perform sensitivity analysis on parameters such as pH adjustment, temperature, stoichiometry, reagent use, residence time, identification of recalcitrant compounds, etc.

To conduct this study, we ask our Client to collect composite samples of untreated influent water from the facility’s surge and equalization system and ship the samples to MSWG for testing. Multiple composite grab samples should be collected over a given operating period of time, at a rate that will ensure that we capture the “ebb and flow” of the influent wastewater stream. The sum of these samples will form the basis for the design of the full-scale unit, and will be deemed to be representative of the anticipated variability of influent water streams that will feed the electro-coagulation unit. This approach also minimizes the possibility of anomalous constituents or concentrations that could affect the performance of the system in the future, after installation.

MSWG will test the samples in our treatability laboratory which is a small-scale mock-up of a full-size system that simulates the performance of the full-scale electro-coagulation system by allowing the varying of treatment parameters to determine the optimum “treatment recipe” for the given influent conditions.

Upon receipt of each sample, MSWG will [a] photograph the influent water, [b] perform a chemical analysis of the influent water, [c] run bench-scale testing on the sample to determine the optimum treatment regiment, [d] photograph the treated effluent water, [e] perform a chemical analysis of the effluent water, and [f] compute the contaminant removal rates. The chemical analysis will include the analysis of indicator/surrogate parameters, TPH, VOCs, SVOCs, and heavy metals. Additionally, the GC-Traces of both the influent and effluent will be evaluated. The pH, specific ions, and other parameters will also be evaluated.
Task 2

Following the bench-scale testing, MSWG will provide the Client with a Level I Design Basis for consideration of a full-size unit. This task will require a site reconnaissance, and a review of existing facility information, such as: site layout, design of the existing wastewater treatment system, review of site facilities and ancillary systems (e.g., access roads and ports, location of underground utilities, location of sumps, tankage and piping, control room, electrical power system, safety considerations, etc.).

The Design Basis will be a formal report that will include discussion of the following:

- General layout and description of a full-scale system, with dimensions.
- Underground and over-head obstructions and access restrictions or limitations.
- Process flow diagram of the electro-coagulation system and any required supplemental or secondary treatment train that may be necessary to achieve the treatment criteria / end points.
- Alternative process configurations, including: a single large system, two parallel systems each rated at 100%, and three parallel systems each rated at 50%, and the relative advantages and disadvantages of each. Series versus parallel treatment units will also be evaluated.
- Evaluation of secondary project requirements, such as the addition of an oil-water separator system.
- Ancillary requirements for a full-scale system, including dimensional land requirements, foundation requirements, configuration of influent tanks and piping, configuration of effluent tanks and piping, control system, etc.
- Alternative ancillary configurations, including: number and sizing of influent surge and equalization tanks, number and sizing of effluent surge tanks, compliance monitoring, etc.
- Operating metrics of the new system, including removal efficiencies and effluent parameters for various contaminant, indicator, and surrogate parameter groups, etc.
- Electrical power requirements.
- Operating labor requirements, and training.
- Definition of battery limits and interfaces of the new facility with the existing operations.
- Capital cost estimate for a full-scale system, and electrical, labor, electrode replacement, and other OM&R costs for a full-scale system.
- Recommendations for future expansion in terms of physical space requirements, equipment layout and arrangement, electrical power, tankage and piping, etc.

- Recommendations for segregation of problematic wastestreams (if that becomes an issue).

**Modes of Deployment and Types of Systems**

**Overview**

MSWG can deploy our electro-coagulation technology in three basic modes:

- Transportable systems
- Fixed base systems
- In-situ treatment systems

**Transportable Treatment System**

MSWG offers trailer-mounted transportable treatment systems for technology demonstrations and conducting field pilot studies. Based on the performance of the transportable system, a permanent or dedicated wastewater treatment system incorporating the same technologies (i.e., electro-coagulation, filtration, reverse osmosis, etc.) can be designed, fabricated, and installed at the project site. The transportable system has a throughput rating of about 10 – 25 gpm, depending on the influent and the type of treatment required. This system is shown below.
Fixed Base System

One of the benefits of an electro-coagulation based treatment system is the small footprint. For a nominal 25 – 100 gpm throughput unit, a typical field footprint is on the order of 30 feet x 50 feet, exclusive of ancillary piping, tankage, and support infrastructure such as roads and power lines. Since the technology is modular in design, larger throughput systems require only incrementally larger physical footprints. A photograph of a typical 300 gpm fixed base system consisting of electro-coagulation plus a secondary stage dual carbon filtration system is shown below. Note the size of the system compared to the man and the temporary surge basins and field office.

In-Situ Treatment System

The same patented technology can be deployed in a mobile system that is capable of the in-situ treatment of wastewaters. This system is ideal for the treatment of impoundments, such as subsequently shown. The electro-coagulation electrodes are lowered directly into the water in the impoundment where it is treated in situ. A patented system removes the floc, resulting in clean water.
Economic Analysis

MSWG’s policy is that we do not provide project cost and unit rate treatment cost information in sales and marketing literature. The reason for this is the high variability associated with the design and operation of a treatment system which can vary significantly from site to site, and according to other considerations such as the complexity of the treatment train, throughput and utilization factor, cost of labor and electrical power, and other factors. Thus, even “ball park” numbers can be misleading.

Instead, we generally request influent data analysis and target treatment criteria from a potential Client, and then perform internal bench-scale mock-up studies to design and evaluate the performance of various alternative systems to satisfy project requirements. Based on this work, we are able to provide the Client with a more meaningful cost estimate. Cost estimates may be structured according to: time and material estimates, unit rate costs, daily rates, lump sum, or other basis.

Additionally, MSWG does not sell treatment systems. Rather, we provide a service similar to a “Xerox Copier” lease – a base cost plus escalators for varying use and throughput. We also finance the capital cost of the installed system, whether it is transportable or fixed base, such that the Client is only responsible for payment of treatment services, and is able to keep capital investment costs to a minimum.