POWELL ELECTROCOAGULATION

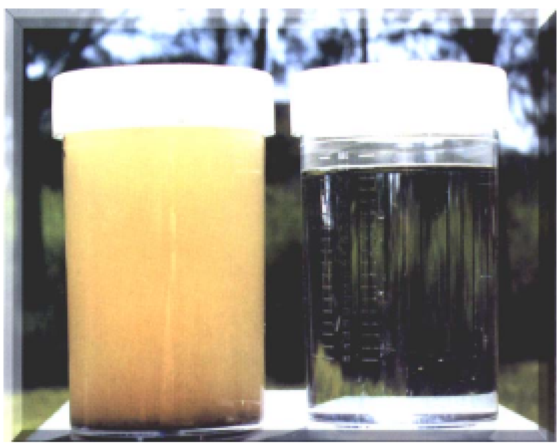
Sustainable Technology For The Future

“NEW TIMES DEMAND MORE EFFECTIVE TECHNOLOGY”

Electrocoagulation is the distinct economical and environmental choice for meeting water treatment discharge standards and compliance requirements. Recover capital and operating costs by eliminating discharge fees and fines, harvesting resources, and significantly reducing water replacement costs.

Contaminants Removed	Percentage of Removal
a) BOD	90%+
TSS (Clay, coal, silt, silica, etc.)	99%+
Fats, Oils, Grease	93-99%+
Water From Sludge	50-80%+
Heavy Metals	95-99%+
Phosphates	93%+
Total Coliform	99.99%+

30-GPM EC System



Wastewaters can be treated for as low as $0.24 per 1,000 gallons

System Capabilities

- Removes heavy metals as oxides that pass TCLP.
- Removes suspended and colloidal solids
- Breaks oil emulsions in water
- Removes fats, oil, and grease
- Removes complex organics
- Destroys & removes bacteria, viruses, and cysts
- Processes multiple contaminants

Benefits

- Low capital costs
- Low operating costs
- Low power requirements
- No chemical additions
- Low maintenance
- Minimal operator attention
- Handles a wide variation in the waste stream
- Consistent and reliable results
- Sludge minimization
- Treats multiple contaminants
- Water reuse- resulting in zero discharge

3 GPM EC System

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Article I. <u>INTRODUCTION</u>

Powell Water Systems, Inc. was formed by Scott Wade Powell to develop and market a functional operating water treatment system utilizing electrocoagulation and supporting equipment. Patent or patents pending in the United States of America and many other nations around the world enable Powell Water Systems, Inc. to control and protect the quality of electrocoagulation equipment. Quality and functional equipment, delivered at a fair price creates satisfied customers, which is one real measure of success.

The fundamental design requirements of Powell Water Systems, Inc. include quality electrocoagulation equipment, that is operator friendly, utilizing readily available components, coupled with energy efficiency. The quality product insures many years of reliable service, resulting in satisfied customers. The ease of operation invites the continued use of the equipment, which protects our environment. The use of readily available components encourages regular maintenance, which sustains on going quality treatment. The energy efficient design allows the economic benefits of clean drinking water, or industrial process water to insure the continued use of Powell Water Systems, Inc., equipment for many years to come.

The Powell Water Systems, Inc. technology efficiently removes a wide range of contaminants with a single system. Traditional water treatment would require a different type of equipment to remove bacteria, silt, pesticides, heavy metals, and oil from water. The broad-spectrum treatment effect allows one system to remove multiple contaminates at the single contaminant equipment cost, space, and time. The result is better health, wiser use of financial resources, and a cleaner world to enjoy for our children, grandchildren and our selves.

US & WORLD WIDE PATENTS & PATENTS PENDING
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Article II. <u>ELECTROCOAGULATION: AN OVERVIEW</u>

Electrocoagulation (EC), the passing of electrical current through water, has proven very effective in the removal of contaminants from water. Electrocoagulation systems have been in existence for many years (Dietrich, patented 1906), using a variety of anode and cathode geometries, including plates, balls, fluidized bed spheres, wire mesh, rods, and tubes. Scott Wade Powell of Powell Water Systems Inc. has taken a quantum leap in refining the EC process to increase removal rates and to lower capital and operating costs.

> *The electrocoagulation process is based on valid scientific principles involving responses of water contaminants to strong electric fields and electrically induced oxidation and reduction reactions. This process is able to take out over 99 percent of some heavy metal cations and also appears to be able to electrocute microorganisms in the water. It is also able to precipitate charged colloids and remove significant amounts of other ions, colloids, and emulsions. When the system is in place, the operating costs including electric power, replacement of electrodes, pump maintenance, and labor can be less than $1 per thousand gallons for some 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.*[1]

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.

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, 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.*[2]

Electrocoagulation can often neutralize ion and particle charges, thereby allowing contaminants to precipitate, reducing the concentration below that possible with chemical precipitation, and can replace and / or reduce the use of expensive chemical agents (metal salts, polymer).

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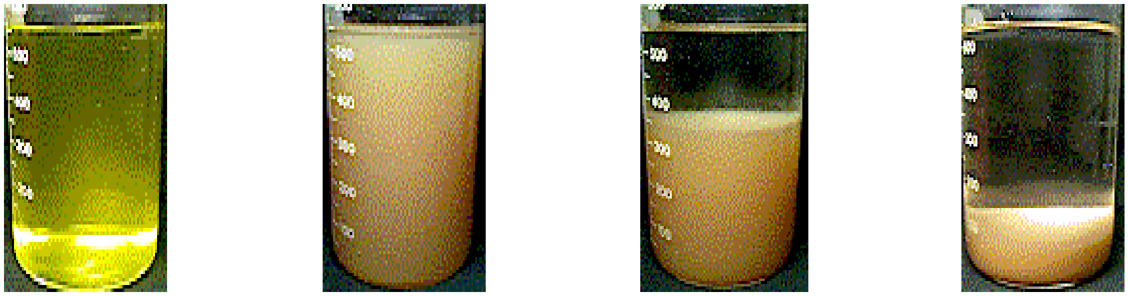
[1] United States Department of Agriculture (USDA), Agricultural Research Service: 12/18/95

[2] EPA, a SITE Superfund Innovative Technology Evaluation: EPA/640/S-937504. EPA, a SITE Superfund



Before | EC Treated | 5 Min. | 10 Min.

Water from a metal plating facility treated with the Powell Electrocoagulation system.

> *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.*[3]

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 waters, a few examples of water treated by electrocoagulation include:

- The reduction of bacteria from 110,000,000 (standard plate count) in sewage waste water to 2,700 bacteria per milliliter;
- The contaminants in oily waste waters from steam cleaning operations, refineries, rendering plants, and food processors are generally reduced 95 to 99%;
- 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%.

Note: *Heavy metals processed with sufficient activation energy precipitate into acid resistant oxide sludge like $NiFe_2O_4$, that pass the Toxic Classification Leaching Procedure (TCLP) which allows the sludge to be reclassified as non hazardous (Renk, 1989; Franco, 1974; Watanabe and Nojiri, 1975; Duffey, 1983).*

Electrocoagulation through the reaction chamber developed and patented by Scott Wade Powell or Powell Water Systems Inc. produces several distinct electrochemical results independently. These observed reactions could be explained as:

A. ***Seeding*** *resulting from the anode reduction of metal ions that become new centers for larger, stable, insoluble complexes that precipitate as complex metal oxides.*

B. ***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*

[3] EPA, a SITE Superfund Innovative Technology Evaluation: EPA/640/S-937504. EPA, a SITE Superfund

C. ***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, chlorinated PCB's, etc.*

D. ***Bleaching*** *by the oxygen ions produced in the reaction chamber oxidizes dyes, cyanides, bacteria, viruses, biohazards, etc.*

E. ***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;*

F. ***Oxidation*** *- Reduction reactions are forced to their natural end point within the Powell chamber, which speeds up the natural process of nature that occurs in wet chemistry.*

G. ***EC induced pH*** *swings toward neutral.*

The Powell EC systems are optimized by controlling reaction chamber materials (iron, aluminum, titanium, graphite, etc.), amperage, voltage, flow rate, and the pH of the water. The Powell technology handles mixed waste streams (oil, metals, and bacteria), very effectively. Variables such as temperature and pressure have little effect on the process.

The electrocoagulation process has been successfully used to:

- *Harvest protein, fat, and fiber from food processor waste streams.*
- *Recycle water, allowing closed loop systems.*
- *Remove metals, and oil from wastewater.*
- *Recondition antifreeze by removing oil, dirt, and metals.*
- *Recondition brine chiller water by removing bacteria, fat, etc.*
- *Pretreatment before membrane technologies like reverse osmosis.*
- *Precondition boiler makeup water by removing silica, hardness, TSS, etc.*
- *Recondition boiler blow down by removing dissolved solids eliminating the need for boiler chemical treatment.*
- *Remove BOD, TSS, TDS, FOG, etc., from wastewater before disposal to POTW, thus reducing or eliminating discharge surcharges.*
- *De-water sewage sludge and stabilize heavy metals in sewage, lowering freight and allowing sludge to be land applied*
- *Condition and polish drinking water*
- *Remove chlorine and bacteria before water discharge or reuse*

The operating costs of electrocoagulation will vary, depending on the specific water being treated. For example, municipal sewage water was treated for $0.24/1,000 gallons, and steam cleaner water containing crude oil, dirt and heavy metals was treated for $0.05/gallon.

References:

1. Dietrich, A. E., Electric Water Purifier, United States of America Patent No. 823,671 June 19, 1906.

2. Benefield, L. D., Judkins J. F. and Weand, B. L. 1982. Process Chemistry for Water and Wastewater Treatment. Prentice Hall Inc., p. 212.

3. Woytowich D. L.; Dalrymple C. W.; Britton M. G.; 1993. Electrocoagulation (CURE) Treatment of Ship Bilgewater for the U. S. Coast Guard in Alaska. Marine Technology Society Journal, Vol. 27, No. 1 p. 62, Spring 1993.

4. Renk, R. R. 1989. Treatment of hazardous wastewaters by electrocoagulation. In: 3rd Annual Conference Proceedings (1989). Colorado Hazardous Waste Management Society.

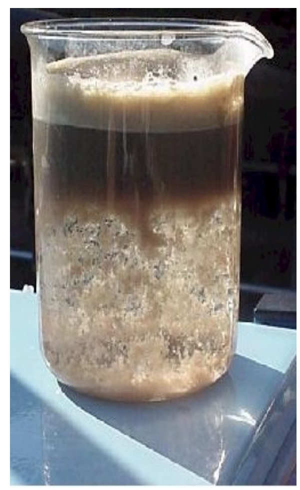
5. Duffey, J. G. 1983. Electrochemical Removal of Heavy Metals from Wastewater, Product Finishing, p. 72, August 1983

6. Franco, N. B. 1974. Electrochemical Removal of Heavy Metals from Acid Mine Drainage. Environmental Protection Agency Report EPA-670 12-74-023. May 1974

Article III. ELECTROCOAGULATION: THE TECHNOLOGY

Electrocoagulation is the process of destabilizing suspended, emulsified or dissolved contaminants in an aqueous medium by introducing an electrical current into the medium. The electrical current provides the electromotive force to drive the chemical reactions. When reactions are driven or forced, the elements or compounds will approach the most stable state. Generally, this state of stability produces a solid that is either less colloidal or less emulsified (or soluble) than the compound at equilibrium values. As this occurs, the contaminants form hydrophobic entities that precipitate and can easily be removed by a number of secondary separation techniques. Stated another way:

> *[Electrocoagulation] utilizes direct current to cause sacrificial electrode ions to remove undesirable contaminants either by chemical reaction and precipitation or by causing colloidal materials to coalesce and then be removed by electrolytic flotation. The electrochemical system has proven to be able to cope with a variety of wastewaters. These waters are paper pulp mill waste, metal plating, tanneries, canning factories, steel mill effluent, slaughterhouses, chromate, lead and mercury-laden effluents, as well as domestic sewage. These wastewaters will be reduced to clear, clean, odorless and reusable water. In most cases, more especially domestic sewage, the treated water effluent will be better than the raw water from which it had originated[4].*



1) Meat Rendering Water Processed With The Powell Electrocoagulation System

[4] Eckenfelder, W.W. and Cecil, L.K.. "Applications of New Concepts of Physical-Chemical Wastewater Treatment." Vanderbilt University; Nashville, TN: Pergamon Press, Inc.

Article IV. ELECTROCOAGULATION: APPLICATIONS and BENEFITS

Electrocoagulation is the distinct economical and environmental choice for meeting water treatment discharge standards and compliance requirements. Eliminating discharge fees and fines, harvesting resources, and significantly reducing water replacement costs, generally recover capital and operating costs.

Section 4.01 SYSTEM CAPABILITIES:

- *Removes heavy metals as oxides that pass TCLP*
- *Removes suspended and colloidal solids*
- *Breaks oil emulsions in water*
- *Removes fats, oil, and grease*
- *Removes complex organics*
- *Destroys & removes bacteria, viruses & cysts*
- *Processes multiple contaminants*

Section 4.02 KEY APPLICATIONS:

- Ground water cleanup
- Process rinse and wash water
- Potable water
- Sewage treatment
- Cooling towers
- Radioactive isotope removal
- Pretreatment for reverse osmosis, ultra filtration, nanofiltration, Photocatalytics
- Water reuse resulting in zero discharge
- Metal recovery
- Influent quality water control
- Industrial waste water

Section 4.03 BENEFITS:

- Capital cost significantly less than alternative technologies
- Operating cost significantly less than alternative technologies
- Low power requirements
- Generally no chemical additions
- Metal oxide formation passing TCLP
- Low maintenance
- Minimal operator attention
- Handles a wide variation in the waste stream
- Consistent and reliable results
- Sludge minimization
- Treats multiple contaminants

Article V. ELECTROCOAGULATION: GENERAL CAPABILITIES

The following well documented lab and field tested results are routinely attained through electrocoagulation.

OPERATION	%REMOVED
BOD	90% +
TSS (Clay, coal, silt, etc.)	99% +
Fats, Oil, Grease in Water	93 to 99% +
Water in sludge	50 to 80% +
Heavy metal Removal	95 to 99% +
Phosphate Removal	93% +
Bacteria, Viruses & cysts	99.99% +

Section 5.01 SPECIFIC EXAMPLES

CONTAMINANT	SOURCE	RAW mg/l	TREATED	%REMOVAL
Aluminum	Can Mfg.	224	0.693	99.7%
Arsenic	Steam Cleaner	0.30	<0.01	96.7% +
Barium	Steam Cleaner	8.0	<0.10	98.7% +
Calcium	Cooling Tower	1,321	21.4	98.4%
Cadmium	Electroplating	31	0.338	98.9%
Chromium total	Condenser wash	139	<0.1	99.9%
Cobalt	Steam Cleaner	0.13	<0.05	62% +
Copper	Electroplating	287	0.484	99.8%
Iron	Acid Mine	151	0.57	99.6%
Lead	Manufacturing	8.21	0.23	97.2%
Magnesium	Ammunition Plt	6.7	<0.1	98.5%
Manganese	Ammunition Plt	0.28	0.047	83.2%
Mercury	Steam Cleaner	0.006	<0.002	66.6% +
Molybdenum	Steam Cleaner	0.18	0.035	80.6%
Nickel	Manufacturing	185	0.2	99.9%
Silicon	Acid Mine	21.7	0.1	99.5%
Vanadium	Steam Cleaner	0.23	<0.01	95.6% +
Zinc	Plating	221	0.14	99.9%
BOD	Fish Process	40,500	750	98.1%
TSS	Municipal POTW	5,620	25	99.6%
Fog	Food Process	18,165	28	99.9% +
Bacteria	Municipal POTW	110 MM	2,200	99.999% +

Article VI. ELECTROCOAGULATION: vs. CHEMICAL COAGULATION

Because electrocoagulation utilizes methods that precipitate out large quantities of contaminants in one operation, the technology is the distinct economical and environmental choice for industrial, commercial and municipal waste treatment. The capital and operating costs are usually significantly less than chemical coagulation. It is not unusual to recover capital costs in less than one year.

For example a 5 GPM system contrasts the advantages of electrocoagulation with a typical chemical coagulation system. This system was designed with the following requirements:

- *Reduce Ni from 8.74 to < 3 mg / l*
- *Reduce Zn from 28.0 to < 3 mg / l*
- *Reduce TSS from 657 to < 350 mg / l*
- *Reduce Oil and Grease from 27 to < 15 mg / l*
- *Reduce Phosphorus from 158.75 to < 10 mg / l*
- *Process flow rate of 5 GPM (1,500,000 GPY)*

Operating cost:	**Chemical coagulation**	**Electrocoagulation**
per gallon	$0.03	$0.001
per 1,000 gal	$30.00	$1.00
Per year	$45,000.00	$1,500.00

The estimated yearly operating cost saving using electrocoagulation in place of chemical coagulation is $43,500.00 per year. This does not include labor, sludge transportation or disposal costs.

A second example is a system with requirements to:

Reduce Ni from 25 to < 2.38 mg / l
Reduce Cr from 210 to < 1.71 mg / l
Flow rate of 100 GPM (30,000,000 GPY)

Operating cost:	**Chemical coagulation**	**Electrocoagulation**	
per 1,000 gal	$14.18		$1.69
per year	$425,400	$50,700	

The estimated yearly operating cost saving using electrocoagulation in place of chemical coagulation is $374,700.00 per year. This does not include labor, sludge transportation, or disposal costs.

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 & Eddy, Wastewater Engineering Treatment Disposal Reuse, Third Edition, page 301-303). This problem is eliminated in the electrocoagulation process. These chemicals are not only expensive, but, more importantly, the net increase in the dissolved constituents in the wastewater render it impractical or impossible to reuse.

Electrocoagulation uses electricity to precipitate the dissolved and suspended solids. The total dissolved solids in the liquid usually decrease by 27 to 60 percent. This enables the water to be reused in many applications, such as water reuse in steam cleaning operations. Reuse of the water provides a major advantage because this eliminates all EPA and POTW discharge concerns, to say nothing of the replacement costs of the water itself.

Electrocoagulation produces a cleaner water than either chemical precipitation or sedimentation (Wastewater Engineering, page 488). As discharge requirements become more stringent EC will become more essential.

	Percentage of removal by:		
Constituent:	**EC**	**Chemical**	**Sedimentation**
TSS	95 to 99%	80 to 90%	50 to 70%
BOD	50 to 98%	50 to 80%	25 to 40%
Bacteria	95 to 99.99%	80 to 90%	25 to 75%

The handling and disposal of the sludge resulting from chemical precipitation is one of the greatest difficulties associated with chemical treatment. Sludge is produced in great volume from most chemical precipitation operations, often reaching 0.5 percent of the volume of wastewater treated when lime is used. Waste water Engineering, Third Edition, page 489 - 491), estimated the maximal removal of TSS without chemical is up to 60 percent. With the addition of chemicals, ferrous sulfate and lime, TSS removal rates may climb up to 85 percent.

Assume that the following data apply to this situation:

1. *Wastewater flow rate = 1.0 Mgal / d*
2. *Wastewater suspended solids = 220 mg / l*
3. *Ferrous sulfate (FeSO4 * 7(H2O)) added = 70 lb / Mgal*
4. *Lime added = 600 lb / Mgal*
5. *Calcium carbonate solubility = 15 mg / l*

A. 60 percent removal of the TSS with out chemicals will produce 1,100 lb/d sludge on a dry matter basis (DMB) (Volume, 285 cubic feet / day).

B. 85 percent removal of the TSS with the chemicals will produce 3,042 lbs of sludge (Volume, 619 cubic feet / day):

1) 1,560 lb / d of sludge from the TSS
2) 27 lb / d of sludge from the Ferric Hydroxide
3) 1,455 lb / d of sludge from the Calcium carbonate

3,042 Total lbs of sludge on a dry basis.

C. 99 percent removal of the TSS with EC will produce:

1) 1,817 lb / d of sludge from the TSS
2) 8 lb / d of sludge from the aluminum chambers

1,825 Total lbs of sludge on a dry basis (Volume, 285 cubic feet / day)

The total sludge generated by electrocoagulation contains less than 0.5 percent added coagulant. Total sludge generated by Chemical precipitation contains 49 percent added coagulant. The added sludge generated by chemical precipitation effectively doubles the sludge disposal volume. The hazardous waste issue may increase the cost 20 to 30 fold.

> *"When compared with alum treatment, electrocoagulation provided approximately 83% less sludge volume and a 76% improvement in filtration rate."*

Sludge disposal costs are significant. A Class II landfill in Northern California only disposes or treats non hazardous waste. The landfill charges $18.00+ /- yard tipping fees for Class II land fill, non-leachable solids in the 20% moisture range. Non-hazardous waste recycling facilities in Northern California charge processing fees from $0.45 - $3.00 per gallon, depending on solids and / or hydrocarbon content. Hazardous waste tipping fees for F listed sludge in Northeastern Colorado range from $400 to $600 per yard.

Hauling charges are significant and may be more than the tipping fee. Hauling charges range from $55 to $70 per hour for short runs and $2.20 to $2.50 per loaded mile for runs over 100 miles for a 3,500 to 7,000 gallon (10 to 20 Yard) truck. In addition there is a $200 truck-washing fee. The hauling savings generated from electrocoagulation as compared to chemical precipitation is usually more than the cost to operate and maintain the Powell electrocoagulation system.

In example B, above, 85 percent of the TSS was removed with chemicals, producing 3,042 lbs of sludge on a Dry Matter Base (DMB). The volume of this sludge was 619 cubic feet /day, of which 49%, (1,490 lbs DMB totaling 303 cubic feet / 11 cubic yards) came from the added chemicals required to achieve the removal of the TSS. Assuming a two-hour run for a 10-yard truck at $55 per hour with a $200 truck-washing fee, the extra hauling cost for chemical added sludge is $310.

Electrocoagulation of oxygenated municipal sewerage water is summarized:

Constituent	Raw	Treated	% Removal
BOD (mg / l)	1,050	14	99% +
TSS (mg / l)	4,620	7	99% +
Bacteria (cfu)	110,000,000	2,700	99% +

> *The electrocoagulation cost was $0.24 / 1,000 gallons for electricity and chamber repair. The electrocoagulation operating cost is $240.00 per 1.0 Mgpd. That is a $70 per day savings ($310-$240) with electrocoagulation on hauling alone after deducting the electrocoagulation operating cost.*

Electrocoagulation can produce an environmentally friendly sludge in the 6 to 7 pH range. The metals in the sludge at this pH range are stabilized in a non hazardous form as Oxides, that will pass the U.S. Environmental Protection Agency (EPA) Toxic Classification Leaching Procedure (TCLP), and California Title 22 STLC & TTLC leach tests.

Chemical precipitation on the other hand, usually creates sludge in the caustic pH range above 10. The metals precipitate as hydroxides, a hazardous form because the metals will become soluble again at the natural pH range around 7.

For example chemical precipitation of phosphorus is brought about by the addition of the salts of multivalent metal ions that form precipitates of sparingly soluble phosphates. The multivalent metal ions used most commonly are calcium (Ca^{++}), Aluminum (Al^{+++}), and Iron (Fe^{+++}).

Chemical coagulation necessitates the addition of calcium, usually introduced in the form of lime. As the pH of the wastewater increases beyond 10, excess calcium ions will then react with the phosphate. The quantity of lime required to precipitate the phosphorus in wastewater is typically about 1.4 to 1.5 times the total alkalinity expressed as $CaCO_3$. Because a high pH value is required to precipitate phosphate, the pH usually requires adjustment before the subsequent treatment or disposal.

In the case of alum and iron, 1 mole will precipitate 1 mole of phosphate. These chemical precipitation reactions must be considered in light of the many competing reactions, their associated equilibrium constants, the effects of alkalinity, pH, trace elements, and ligands found in wastewater. Therefore, dosages are generally established on the basis of bench scale tests and occasionally by full-scale tests (Wastewater Engineering, page 308).

When chemical precipitation is used, anaerobic digestion for sludge stabilization may not be possible because of the toxicity of the precipitated heavy metals. (Wastewater Engineering, page 756). For land application of sludge, concentrations of heavy metals often limit the sludge application rate and the useful life of the application site to which it is applied (Wastewater Engineering, page 772).

Land application of sludge has been practiced successfully for decades. Sludge may be applied to **(1)** Agricultural land, **(2)** Forest land, **(3)** Disturbed land, and **(4)** Dedicated land disposal sites. Sludge acts as a soil conditioner to facilitate nutrient transport, increase water retention, and improve soil tilth. Sludge also serves as a partial replacement for expensive chemical fertilizers. Characteristics of sludge that affect its suitability for land application or affect the design of land application systems include organic content (usually measured as volatile solids), nutrients, pathogens, metals, and toxic organics. (Wastewater Engineering, page 903). Electrocoagulation can eliminate the concerns regarding pathogens, and metals.

Metals are a major concern in sludge as shown in the following table (Wastewater Engineering, page 772). Typical metal content in wastewater sludge:

Dry sludge, mg / kg

Metal	Range	Median
Arsenic (As)	1.1 - 230	10
Cadmium (Cd)	1 - 3, 410	10
Chromium (Cr)	10 - 99,000	500
Cobalt (Co)	11.3 - 2,490	30
Copper (Cu)	84 - 17,000	800
Iron (Fe)	1,000 - 154,000	17,000
Lead (Pb)	13 - 26,000	500
Manganese (Mn)	32-9, 870	260
Mercury (Hg)	0.6 - 56	6
Molybdenum (Mo)	0.1 - 214	4
Nickel (Ni)	2 - 5,300	80
Selenium (Se)	1.7 - 17.2	5
Tin (Sn)	2.6 - 329	14
Zinc (Zn)	101 - 49,000	1,700

EPA concerns about toxic leach-able metal build up in soils may cause a majority of sludge to be deposited in hazardous waste landfills. This not only increases the disposal cost several fold, it eliminates the beneficial soil additive effect discussed earlier.

The reality of the Hazardous waste limits can be illustrated by acceptable disposal limits at non-hazardous disposal facilities like Forward, Inc. Stockton, CA. Forward, Inc. can only accept waste for disposal with levels of metals below the following leachability listed limits:

Element	**Title 22 STLC**	**Title 22 TTLC**
	(Mg / l)	**(Mg / kg)**
Antimony (Sb)	15.00	500
Arsenic (As)	5.00	500
Barium (Ba)	100.00	10,000
Beryllium (Be)	0.75	75
Cadmium (Cd)	1.00	100
Chromium (Cr)	560.00	2500
Hexavalent (Cr+6)	5.00	500
Cobalt (Co)	80.00	8,000
Copper (Cu)	25.00	2,500
Lead (Pb)	5.00	1,000
Mercury (Hg)	0.20	20
Molybdenum (Mo)	350.00	3,500
Nickel (Ni)	20.00	2,000
Selenium (Se)	1.00	100
Silver (Ag)	5.00	500
Thallium (Tl)	7.00	700
Vanadium (V)	24.00	2,400
Zinc (Zn)	250.00	5,000

Forward has no fixed limit for petroleum hydrocarbons except Benzene at 0.5 mg / l (TCLP).

Electrocoagulation may soon move from the optional treatment method to the essential treatment method as the US EPA begins to enforce the laws protecting the environment from toxic wastes, including heavy metals. Electrocoagulation cleans most wastewater streams better, with less operating cost, producing less sludge, with the sludge being a better quality than chemical precipitation. The reuse opportunities for the water is increased because dissolved solids are not added to the waste water stream; and usable products are harvested because the metal oxides pass leachability tests, allowing the sludge to be utilized as a soil additive.

Portable bench scale Powell electrocoagulation units are available to demonstrate the advantages of electrocoagulation. If you would like additional information or a demonstration of the electrocoagulation process please contact a Powell Water Systems Inc. representative to arrange a demonstration.

Article VII. ELECTROCOAGULATION: WATER REUSE &RECYCLING

The Powell EC system is an extremely effective wastewater treatment system, reclaiming water for reuse and the harvesting of valuable by-products. Examples of possible water reuse come from treating waste streams generated from steam cleaners, pressure washers, textile manufacturing, metal platters, meat and poultry processors, commercial laundry, mining operations and municipal sewage system plants. The following examples document the positive effects of electrocoagulation in a wide variety of industrial and municipal applications:

Section 7.01 Steam Cleaners:

Steam cleaners are used in many industrial applications to clean parts and equipment. Some major users of steam cleaning equipment include truck and bus washing, engine cleaning, and all types of repair facilities. Treating the waste streams generated from steam cleaner units operating in California has proven effective in separating the oil and water and removing metals and dirt from the water so the water can be reused.

One example is the wastewater from a steam cleaner used to clean oil field service equipment which contains 8 ppm of chrome, lead, and zinc with lesser amounts of the other 17 metals on the states standard test along with a few ppm of oil and grease. At these concentrations the water is considered a hazardous waste with disposal costs ranging from $0.60 to $2.30 per gallon.

After treatment by electrocoagulation, the clear water met all federal secondary drinking water standards with the exception of surfactants. This was not a concern because the water was recycled through the steam cleaner and the recycled surfactants reduced the need to add soap to the steam cleaner system. It should be noted that charcoal could be used in conjunction with the EC process to make the water meet secondary drinking water standards. The sludge from the EC process contained 90 mg/kg oil and grease. The heavy metals were converted into oxides and the sludge passed the states TTLC and STLC as required by CAC title 22. As a result the State Health Board approved the EC processed sludge as a non hazardous waste.

Section 7.02 Pressure Washers:

Pressure washers are used for cleaning operations such as cleaning floors, parking lots, equipment, and parts. The wash water contains heavy metals, oil, grease, and suspended solids. The EC unit separates and removes the metals, oil, grease, and suspended solids from the wash water. The water can then be returned directly to the pressure washer to be reused. The removed metals, oil, grease, and suspended solids can be disposed of in traditional landfills.

Section 7.03 Textile Dye:

Textile dye water can be cost effectively treated using EC to separate the die from the water. By removing the color, suspended solids and silica, the water is of sufficient quality for reuse.

Section 7.04 Metal Plating:

Metal platers use electrocoagulation to remove metals from the plating rinse water tank, enabling them to reuse the remediated water as process water. With no water discharge, they avoid potential liability, save on sewer cost, monitoring, and testing fees, as well as the cost of make-up water. The removal of 90%± metals is sufficient reduction to achieve quality plating results.

Section 7.05 Meat And Poultry Processing:

Meat and poultry processors use electrocoagulation to harvest protein and fat previously discharged into municipal sewage systems. In one case, the recovered protein and fat had an animal feed value of $0.13 per pound and saved the sewage surcharge of $0.25 per pound of BOD and $0.20 per pound of TSS, a combined savings of over $0.58 per pound..

Recycling brine chiller water is another major application. The electrocoagulation process destroys the fecal Coliform by 99.9999%, and separates the fat, protein, and suspended solids, thus enabling the brine chiller water to be reused as opposed to being discharged. There is an economic benefit from the recovery of the fat and protein, and a major savings in disposal costs, since the brine water is very difficult to deal with in a sewage treatment facility.

Section 7.06 Commercial Laundries:

Commercial laundries are able to facilitate the reuse of their wash water using electrocoagulation. The EC process effectively removes both suspended solids and complex organics. An additional benefit is that the water will retain the heat during the EC process, thereby saving energy.

Section 7.07 Mining:

Mining operators use electrocoagulation to remove suspended particles of clay and coal finds from mine process water. The untreated water could not be used to cool mine equipment, nor could it be discharged into the local watershed due to environmental regulations. The EC water removed 99%+ of the particles allowing the water to be reused in the mining operation, which saved trucking in fresh water.

Section 7.08 Coal:

High moisture (30% moisture) coal was heated to drive off the moisture. The moisture condensate was then Electrocoagulated and separated into burnable solids and clear liquid usable to inject into the oil field strata to facilitate crude oil recovery.

Section 7.09 Domestic Sewage:

After electrocoagulation, treated domestic sewage water will, in most cases, " be better than the raw water from which it had originated."[5]

[5] United States Department of Agriculture (USDA), Agricultural Research Service: 12/18/95

Article VIII. ELECTROCOAGULATION: DOCUMENTED LAB RESULTS

Section 8.01 Food processing industry:

(a) Pork slaughter, processing, and packaging plant (006 - 605):

	Raw (mg / l)	Treated	% Removal
TKN	1,118.88	59.08	94.72%
Nitrate	21.00	12.00	42.86%
Nitrite	0.35	0.47	
T-Phos	120.00	2.50	97.92%
Ammonia	49.00	19.40	60.41%
TSS	4,040.00	60.00	99.57%
BOD	1,580.00	397.40	96.57%
PH	6.81 SU	10.17 SU	

(b) Beef rendering plant (002 - 83):

	Raw (mg / l)	Treated	% Removal
BOD	5,700	590	89.6%
TSS	4,540	260	94.3%
FOG	3,050	150	95.1%

(c) Chicken processing plant (006-863):

	Raw (mg / l)	Treated	%Removal
BOD (Total)	4,328 ppm	480 ppm	89%
BOD (Soluble)	303 ppm	39 ppm	87%
TSS	3,367 ppm	83 ppm	97%

(d) Fish processing and packaging plant (005 - 516):

	Raw (mg / l)	Treated	% Removal
BOD	40,500	750.0	98.1%
TSS	33,667	107.0	99.7%
FOG	3,047	12.1	99.7%

Section 8.02 Salad dressing production plant water (002 - 163):

	Raw (mg / l)	Treated	% Removal
BOD	8,223	752	91.0%
TSS	14,528	86	99.4%
FOG	18,165	28	99.8%

Section 8.03 Salad oil production plant water (002 - 133):

	Raw (mg / l)	Treated	% Removal
COD	10,000	1,250	87.5%
TSS	1,074	12	98.9%
FOG	833	14	98.3%

Section 8.04 Electroplating Industry:
Plating sample (006-552):

Element	Raw / ppm	EC treated / ppm	%Removal
Cr	210	0.0216	99.99%
Ni	25	0.0731	99.97%
Zn		0.0065	
Ag			<0.0030

Section 8.05 Metal harvester:
EC Treatment of tank 5040 (006-556):

	Raw	pH 5.3	% Removal	PH 8.3	% Removal	pH 9.4	% Removal
Al	4.365	0.5577	87.22%	0.378	91.34%	0.4312	90.12%
As	0.1018	<0.05	>50.88%	0.4011	-	<0.05	>50.80
Ba	0.0145	<0.0010	>93.10%	<0.0010	>93.1%	<0.0010	>93.10%
Ca	19.59	2.656	86.40%	3.257	83.4%	2.500	87.20%
Cd	0.1252	<0.0040	>96.81%	0.0151	87.94%	0.0126	89.94%
Co	0.1238	0.0214	82.71%	0.0515	58.40%	0.0451	63.57%
Cr	0.3952	0.0168	95.97%	0.0252	93.62%	0.0246	93.78%
Cu	0.7984	<0.0020	>99.75%	<0.0020	>99.75%	<00.20	>99.70%
Fe	68.34	0.6054	99.11%	0.4136	99.39%	0.1939	99.72%
Mg	13.15	0.3606	97.26%	0.0444	99.66%	0.0766	99.42%
Mn	1.061	0.0568	94.65%	0.0452	95.74%	0.0184	98.27%
Ni	1.683	0.4177	75.18%	0.5520	67.20%	0.5213	69.03%
P	605.3	286.7	52.60%	437.7	27.7	13.3	31.7%
Pb	0.3497	<0.0250	>92.85%	<0.0250	>92.85%	0.0278	92.05%
Se	0.0763	<0.0500	>34.47%	0.1909	-	0.1049	-
Sn	0.2130	0.0735	65.49%	<0.0200	>90.61%	0.0960	54.93%
V	0.2621	<0.0020	>99.24%	0.0023	99.12	0.0035	98.66%
Zn	3.674	0.0419	98.86%	0.0520	98.58%	0.0422	98.85%

Section 8.06 Hydrocarbon Condensate:

30% moisture coal was heated to drive off the moisture. The moisture condensate was then Electrocoagulated, Lab analyses (006-597):

Constituent	Concentration Incoming (mg / l)	Electrocoagulated Water (mg / l)	% Removal
Aluminum	1.9	0.5	73.7%
Ammonia	46.6	22.3	50%
Arsenic	0.067	0.042	37.3
Barium	0.5	<0.1	80% +
Beryllium	<0.001	<0.001	
Boron	2.7	1.7	37.0%
Cadmium	<0.001	<0.001	
Chloride	12	29	(241.7%)
Chromium	0.02	<0.01	50% +
Cobalt	<0.01	<0.01	
Copper	0.17	<0.01	94.1%
Cyanide	0.009	0.006	33.3%
Fluoride	0.59	0.18	69.5%
Iron	29.1	3.13	89.2
Lead	1.88	<0.01	99.5% +
Lithium	<0.1	<0.1	
Manganese	0.24	0.80	(333%)
Mercury	0.010	0.004	60%
Nickel	0.05	0.02	60%
Nitrate	<0.05	0.05	
Nitrite	<0.05	<0.05	
Total Oil & Grease	1,610	47.0	97.1%
Phenol	520	145.0	72.1%
Selenium	<0.005	<0.005	
Silver	<0.005	0.010	
Sulfate	104	68.0	34.6%
TDS	1,060	470.0	55.7%
Uranium	<0.0003	0.001	
Vanadium	<0.10	<0.10	
Zinc	0.27	<0.01	96.3% +
Ph	6.6 SU	7.2 SU	

The following lab analyses (006-597) is for the sludge created in the electrocoagulation process. This sludge can be burned.

Sludge	As Received	DMB
% Moisture	69.88%	-
% Ash	2.34	7.76
% Volatile	22.67	75.25
% Fixed Carbon	5.11	16.99
Total	**100.00**	**100.00**

BTU / lb.	4,429	14,704
% Sulfur	0.69%	2.30%
MAF BTU	N/T	15,943
Lb. SO2/MBTU	3.13	3.13

Section 8.07 Water Wash Recycling from a Steam Cleaner:

Recycling of Steam cleaner wash water (004-263).

Constituent	Wastewater ppm	EC water ppm	% Removal
Antimony	<0.01	0.014	
Arsenic	0.30	<0.01	96.7% +
Barium	8.0	<0.10	98.7% +
Beryllium	<0.01	<0.01	
Cadmium	0.141	0.031	78.0%
Chromium	7.98	0.05	99.4%
Cobalt	0.13	<0.05	61.5% +
Copper	6.96	<0.05	99.3% +
Lead	7.4	1.74	76.5%
Mercury	0.003	<0.001	66.7% +
Molybdenum	0.18	0.035	80.7%
Nickel	0.4	<0.05	87.5%
Selenium	<0.005	<0.005	
Silver	<0.01	<0.01	
Thalliums	<0.10	<0.10	
Vanadium	0.23	<0.01	95.7% +
Zinc	19.4	1.20	93.8%

Dry sludge separated from the Steam cleaner wastewater listed above (005-462).

Element	TTLC Raw mg / kg	Max State	STLC Raw mg / l	Max State
Antimony	2.4	500		
Arsenic	3.85	500		
Barium	307	10,000		
Beryllium	nd	75		
Cadmium	nd	100		
Chromium	59.2	2,500		
Cobalt	10.4	8,000		
Copper	498	2,500	3.8	25
Lead	790	1,000		
Mercury	0.15	20		
Molybdenum	21.3	3,500		
Nickel	25.5	2,000		
Selenium	nd	100		
Silver	2.7	500		
Thalliums	14.2	700		
Vanadium	42.1	2,400		
Zinc	1,798	5,000	60	250
Oil & Grease	89,780			

Note: *Carol Carollo of the California Waste Extraction Unit required that a TTLC element that was 10 times the STLC limit be tested for the STLC. That is why Copper and Zinc was tested. As a result of these tests this sludge is acceptable for landfill disposal.*

Section 8.08 Municipal sewage from POTW discharge water:

(002-156)	**Raw**	**Treated**	**% Removal**
BOD (mg / l)	1,050	14	99% +
TSS (mg / l)	4,620	7	99% +
Bacteria (cfu)	110,000,000	2,700	99% +
(002-179)	**Raw**	**Treated**	**% Removal**
BOD (mg / l)	79	0	99% +
TSS (mg / l)	12	6	99% +
(002-187)	**Raw**	**Treated**	**% Removal**
BOD (mg / l)	500	19	96%
TSS (mg / l)	3,245	14	99% +
(006-646)	**Raw**	**Treated**	**% Removal**
BOD (mg / l)	3,345	510	84%
TSS (mg / l)	16,500	165	99%
Volatile Solids	12,300	126	99%
TSS (mg / l)	12	6	50%
Vanderbilt Study	**Raw**	**Treated**	**% Removal**
COD	490	26	94.7%
Total Solids	602	401	43.4%
Suspended Solids	73	7	90.4%
Settleable Solids	21	5	76.2%
Total Hardness	127	11	91.3%
Alkalinity	267	11	95.8%
pH	6.88	7.02	
IOD	0.98	<0.1	89.8%
BOD	220	9	95.9%
Coliform	318,000/ml	0	99% +
Phosphates	38	0	99% +

Section 8.09 Textile and Dye Industry: Color Removal

Source	**Raw**	**Treated**	**% Removal**
Ref. 006-691	125.1 NTU	12.1 NTU	90.0%
Ref. 006-692	129.4 NTU	2.2 NTU	98.3%
Ref. 006-854	68.3 NTU	0.68 NTU	99.0%
Ref. 006-854	2,340.0 NTU	4.5 NTU	99.8%

Section 8.10 Pesticide Treatment (Halogenated Hydrocarbons) (006-864):

	Raw	**Treated**	**Sludge**	**% Removed From Water**
% Solids	0.969	0.391	13.799	59.6%
% Total Grease	0.215	0.016	3.799	92.6%
% Suint	0.506	0.297	0.456	41.3%
Dirt	0.248	0.078	9.544	68.5%
COD Value (mg/l)	9,688	1,340	-	86.2%
PH	5.88	4.63	-	
Sulphate Value (mg/l)	1,600	1,075	-	32.8%
Suspended Solids (mg/l)	2,930	545	-	88.2%

(a) Organochlorine Pesticides (mg / l)

	Raw	**Treated**	**Sludge**	**% Removal from Water**
a' – HCH	0.091	<0.001	0.061	98.9%
b' – HCH	0.100	0.001	0.116	99.0%
lindane (y' - HCH)	0.143	0.001	0.113	99.3%
Aldrin	0.063	0.001	0.040	98.4%
p.p. DDT	0.261	0.002	0.236	99.2%
TOTAL OC's:	**0.712**	**0.006**	**0.666**	**99.2%**

(b) Organobopphoporus Pesticides (mg / kg):

	Raw	**Treated**	**Sludge**	**% Removal from Water**
Propetamphos	80.87	0.36	14.51	99.6%
Diazinon	34.00	0.21	14.14	99.4%
Chlorieviphos	5.87	0.03	0.70	99.5%
TOTAL OP's:	**120.73**	**0.62**	**28.78**	**99.5%**

(c) Synthetic Pyrethroid Pesticides (mg / kg):

	Raw	**Treated**	**Sludge**	**% Removal from Water**
Cypermethrin	1.30	0.07	7.80	94.6%
TOTAL Pyrethroid:	**1.30**	**0.08**	**8.22**	**93.8%**

Section 8.11 Radioactive Nucleotide Removal (7-213/11-41):

	Raw	**Treated**	**Sludge**	**% Removal from Water**
Uranium	**14.6**	**0.6**		**95.9%**

Article IX. ELECTROCOAGULATION: ADDITIONAL APPLICATIONS

Section 9.01 Ground Water Cleanup

Electrocoagulation is extremely effective in the removal of naturally occurring salts in well water, as well as the separation of iron, magnesium, calcium, metals, nitrates and sulfur. Electrocoagulation is also well suited for the reclamation of ground water that has been contaminated with heavy metals, high molecular weight hydrocarbons and Halogenated hydrocarbons.

Section 9.02 Surface Water Cleanup

Electrocoagulation is used to remove bacteria, viruses and cysts from surface water, thereby rendering contaminated waste streams into potable water. Electrocoagulation is particularly effective in the removal of life threatening contaminants such as giardia and cryptosporidium.

Section 9.03 Process Rinse Water and Wash Water

Electrocoagulation routinely treats process and rinse water from the electroplating, computer board manufactures, textile industry, paint rinse water, steel production, mining industry, automotive industry, equipment repair industry, stack wash water, and pulp and paper. In most cases, the treated water can be recycled and reused.

Section 9.04 Sewage Treatment

Electrocoagulation has proven effective in treating sewage water, sewage sludge concentrations, and sewage sludge metal fixation sufficiently to enable land application.

Section 9.05 Cooling Towers

Electrocoagulation is used to pre-treat water entering towers as well as blow down water to remove algae, suspended solids, calcium, and magnesium buildup, thereby eliminating costly replacement water.

Section 9.06 Radioactive Isotope Removal

Metal ion isotope removal from cooling water at a nuclear power plant site demonstrates another effective application of electrocoagulation.

Section 9.07 Water Pretreatment

Water pretreatment with Electrocoagulation has proven effective in removing bacteria, silica and TSS prior to subsequent polishing with reverse osmosis, ultra filtration, nanofiltration, and photocatalytics.

Section 9.08 Food Processing Industry

Meat, Poultry, Fish, total plant effluent to harvest additional protein and fat for sale, Salad oil, beverage, potato processing, vegetable washing, equipment washing.

Section 9.09 Antifreeze Regeneration

The removal of metals, oils, and dirt, form the antifreeze. Large fleet users include governments, mining company, bus company, trucking company, service stations, auto dealerships, etc.

11.0 SAMPLE PROFILE SHEET

(Please complete ONE Water Sample Profile per sample of water)

Company Supplying Sample: ____

Discharge Concern – Analytical Data:

Parameter	Concentration		Required Discharge Concentration (mg/l)
	Maximum	Minimum	
Example: TSS	70 PPM	40 PPM	<2 PPM allowing reuse

Sample Composition:

Constituents	Approximate Percentages
Example: Hydraulic Fluid	**50 %**

Water Accumulation:

Generation Cycle: ☐ Constant ☐ Batch

Batch Volume: ____________________________

Average Volume generated:__________ ☐ GPM ☐ GPD ☐ GPW

Peak Flow Rates:____________________________

re there any spikes in this? ☐ No ☐ Yes

Water Storage Method: ☐ Tank ☐ Pond ☐ Pit ☐ Other:______________

Total Volume of Storage:____

* GPM – Gallons per minute GPD – Gallons per Day GPW – Gallons per Week

Sample Information:

(It is important that the sample is at normal high operating levels. This means it should be the worst case found normally.)

Date Sample Collected: ____________ Time Sample Collected: __________________

Water Name (As designated by Sample Agent): ______________________________

Temperature Storage Instructions: ☐ Frozen ☐ Ambient ☐ Refrigerated

DOT Shipping Name: ______________________________ Hazard Class: ____________

Hazardous (defined by RCRA*)? ☐ No ☐ Yes

Hazardous (defined by State Regulation)? ☐ No ☐ Yes

Hazardous Waste Number (s): ____

If Hazardous Waste Number(s) unavailable list characteristics:

Describe the water source:

Discharge Information:

Is recycling of water feasible in this industry? ☐ No ☐ Yes

Is the company being charged for discharge at this time? ☐ No ☐ Yes

If Yes, at what rate?____

Can these discharge rates be eliminated? ☐ No ☐ Yes

Instructions:

It is important that the sample is at normal high operating levels. This means it should be the worst case found NORMALLY. Send liquid samples only. Solids content MUST be less than 1%. If the solid content of your water exceeds 1% please call for preliminary consultation and instructions.

The water sample should be placed in a non-breakable container with a waterproof seal. The container should be new or recently emptied of contents to avoid contaminating the sample. Plastic distilled water jugs, new plastic gasoline containers, etc., work well.

