ZLD – ELECTROCOAGULATION @ NUEMAN GENREATION STATION EL PASO, TX

system-design & build

APPLICATION
Turnkey EC-UF_RO Water Treatment and Recovery

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Achieving Zero Discharge at El Paso Electric Company's Newman Generating Station Using an Innovative EC–UF–RO System

JOSE C. BUSTAMANTE AND AIDA MAURICIO, El Paso Electric Company, El Paso, Texas

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KEYWORDS: Electrocoagulation, Ultrafiltration, Vacuum Clarifier and Reverse Osmosis.

ABSTRACT: As a result of growth in the El Paso, Texas area, El Paso Electric Company's Newman Generating Station was forced to evaluate options for reducing or eliminating plant discharges. An in-depth evaluation of zero liquid discharge treatment options resulted in the selection of an innovative combination of Electrocoagulation, Ultrafiltration, and Reverse Osmosis.

BACKGROUND

El Paso Electric Company's (EPEC) Newman Generating Station sits on 145 acres of land and is located approximately 20 miles north of downtown El Paso. The Newman Power Plant initiated operations in 1960 when the first generating unit was built. A fifth unit is presently under construction and is scheduled to be fully operational in 2011.

Newman utilizes a combination of groundwater and tertiary treated wastewater purchased from El Paso Water Utilities Fred Hervey Wastewater Reclamation Plant. Electric power generation produces large quantities of wastewater which requires disposal. Newman's wastewater is disposed through a combination of evaporation in two ponds and through a spray irrigation system which pumps wastewater from one of the ponds onto a property located across the facility and owned by El Paso Water Utilities.

Newman's wastewater handling activities are regulated under a permit issued by the Texas Commission on Environmental Quality (TCEQ). During the design and planning stages for construction of Unit No. 5, EPEC evaluated the historical water usage as well as the volume to be generated by the proposed Unit No. 5. Based upon these calculation it was determined that the TCEQ permit limits for the irrigation of the wastewater would be adequate for the future plant needs.

Due to the population growth of the El Paso Region, the Texas Department of Transportation had plans to construct a highway to connect Interstate Highway 10 in New Mexico to Highway 375 on the east side of El Paso. This highway is planned to cross through the area currently used by Newman to irrigate with wastewater. It is estimated that the area available for irrigation, during and after construction of the highway would be reduced by 40 to 50%. The construction of this highway would eliminate a large portion of the land available for irrigation. With a reduced acreage, Newman would not be able to irrigate without exceeding the TCEQ Permit limitations.

In order to continue providing electricity to the city and ensure the Newman facility has a means of wastewater disposal, while minimizing impacts to the surrounding community, the EPEC determined that construction of a Zero Liquid Discharge (ZLD) system to optimize water use and minimize waste was the best option for the facility.

SYSTEM DESIGN

Industry precedent at existing liquid zero discharge stations indicates that maximizing the cycles of concentration in the cooling towers is the least expensive option and should be the first step in a liquid zero discharge design. Evaporating water in the cooling towers is essentially free since the equipment and the source of heat already exist.

The first step in initiating the ZLD design was to establish a design water analysis based on the most recent data available from the Fred Hervey Water Reclamation Plant which supplies the cooling tower makeup water to the plant. That design analysis is shown Table 1.

The design water analysis was used to identify the water constituents that dictate the maximum achievable cycles of concentration under the existing operating conditions. Currently the cycles of concentration in the Newman cooling towers are limited by the irrigation discharge limitations and by the solubility limit of silica in the makeup water. Once a liquid zero discharge system is implemented at Newman, the irrigation discharge limitation of 4,000 TDS will no longer apply. However, without treatment, the silica concentration in the reclaimed makeup water supply will continue to limit the cooling tower cycles of concentration.

Table 1. Design water analysis.

CATIONS	**mg/L**
CALCIUM	79.0
MAGNESIUM	11.8
SODIUM	197.4
POTASSIUM	22.4
AMMONIA	0.0
ANIONS	
CARBONATE	0.0
BICARBONATE	221.8
HYDROXIDE	0.0
DISSOLVED CO_2	0.0
SULFATE	143.0
CHLORIDE	254.0
NITRATE	15.0
PHOSPHATE	1.0
FLUORIDE	1.0
OTHER	
SILICA as SiO_2	34
pH	7
TDS	980

The cooling towers are currently operated using a silica control limit of 125 ppm. This control limit is consistent with good operating practices that dictate that the control limit shall be set below the 150 ppm maximum solubility limit that is used as an industry standard to allow for day-to-day variations in plant operation. At the current silica concentration in the Fred Hervey water supply of 34 ppm and the control limit of 125 ppm the cooling tower cycles of concentration are limited to approximately 3.75 (125/34). The plant water balance based on the current operating conditions of the existing 4 generating units and the projections for the new 5th generating unit is shown in Figure 1.

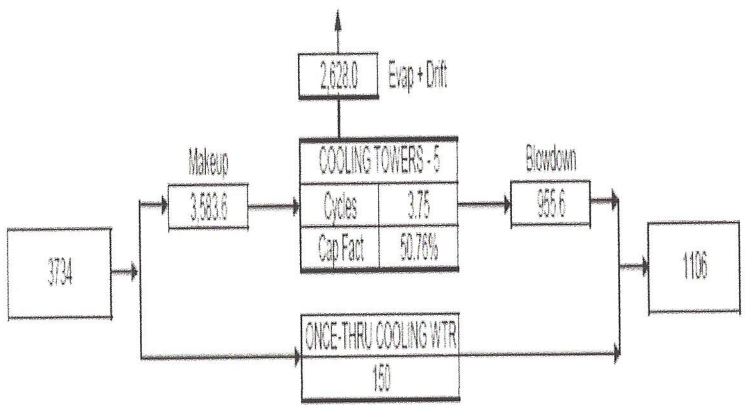


Figure 1. Plant water balance with current operating conditions with 3.75 cycles of concentration.

After review of the available treatment options for silica reduction of the cooling tower makeup, it was decided that utilizing chemical additives to sequester silica precipitation was preferable to treating the entire cooling tower makeup for silica reduction. The utilization of a silica inhibitor will permit the allowable silica concentration in the circulating water system to be increased from the current maximum recommended 150 ppm limit to 250 ppm. As with the existing 150 ppm silica limit, an actual operating control limit must be set somewhat lower that the maximum allowable limit. An actual control limit of 225 ppm was established based on the reasoning used for establishing the existing operating control limit. Under the silica-inhibited mode of operation, the cooling towers will operate at approximately 6.6 cycles of concentration (225/34). The projected plant water balance with the 6.6 cycles of concentration for the existing 4 generating units and the new 5th generating unit is shown in Figure 2.

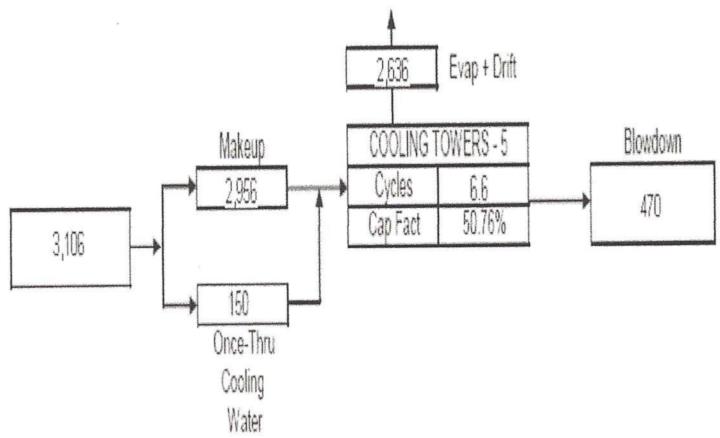


Figure 2. Projected plant water balance with 6.6 cycles of concentration.

The projected water balance shown in Figure 2 indicates that the wastewater treatment system will have to process a minimum of 470 gpm to maintain zero liquid discharge. Operating data from existing zero discharge stations indicates a design contingency of 20% to 25% is necessary to allow for plant operating variations along with maintenance outages of the ZLD equipment. This results in a final design flow rate for the ZLD treatment system of 588 gpm (470 x 1.25).

SYSTEM DESCRIPTION

A comprehensive technical and economic analysis of available cooling tower blowdown treatment options for achieving ZLD at the Newman Station was conducted. After an in-depth review of the analysis, a ZLD treatment system consisting of an Electrocoagulation (EC) system, Ultrafiltration (UF) system, Vacuum Clarifier (VC) system, and high recovery Reverse Osmosis (RO) system was selected.

The cooling tower blowdown routed to the ZLD will have a silica concentration approaching the allowable solubility limit along with high levels of phosphate and hardness. Before any further concentration of this wastewater can be accomplished, these scale-forming constituents must be reduced. The EC system (see Figure 3) will provide pretreatment for the RO system by removing most of the silica and phosphate in the wastewater stream along with a significant portion of the hardness. This will allow the RO system to concentrate the EC pretreated water at a high recovery rate to minimize the final waste stream going to a new evaporation pond.

Figure 3. EC chamber in service.

A UF system (see Figure 4) downstream of the EC system will remove suspended solids in the wastewater along with the silica, phosphate and hardness precipitates generated in the EC system. The UF system will require periodic backwash and a VC will concentrate the solids in the backwash water and allow the resultant water to be recycled.

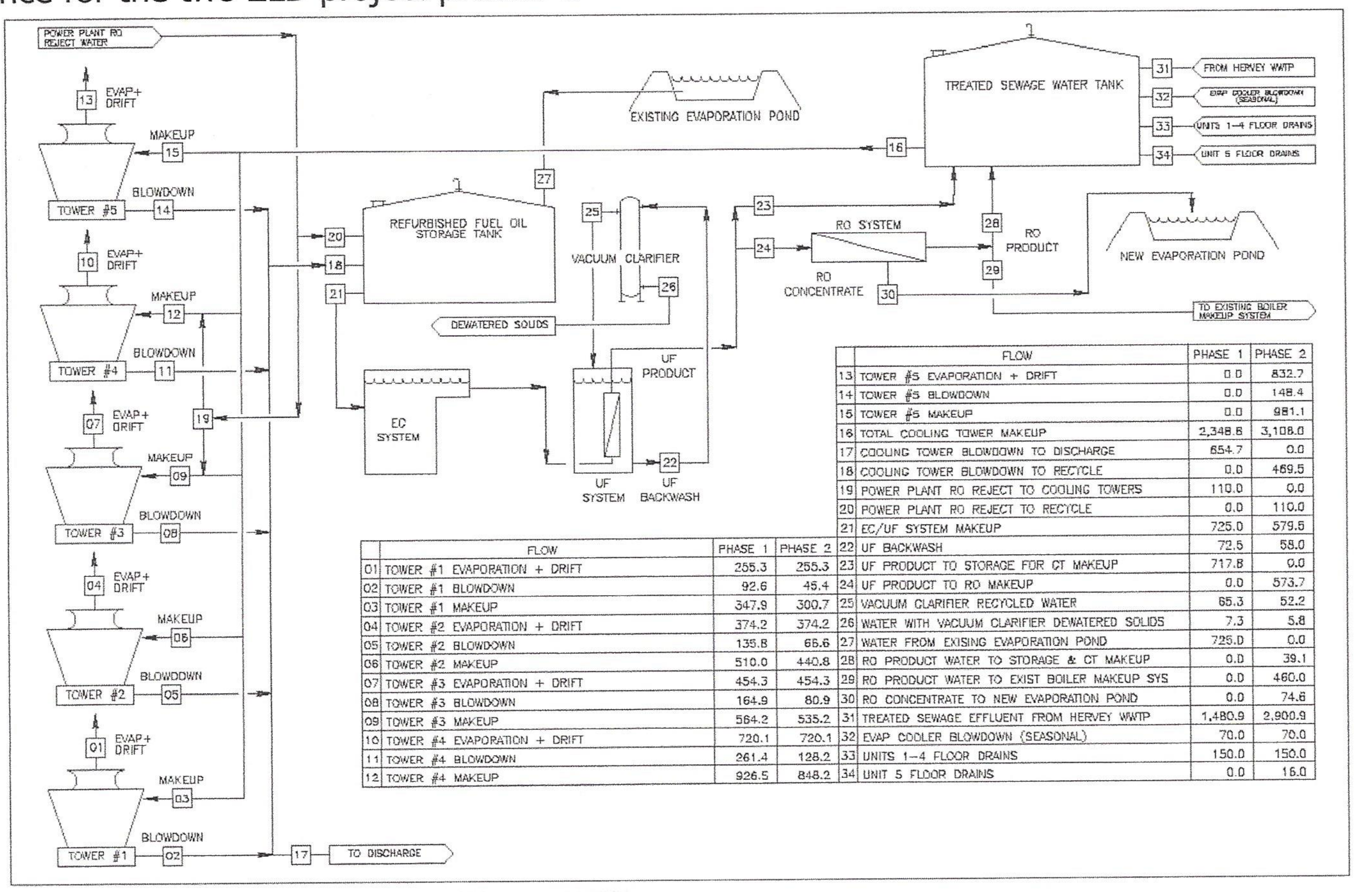
Cooling tower blowdown from the five generating units will be routed to a 1.5 MM gallon refurbished fuel oil storage tank which provides surge capacity ahead of the treatment system along with storage for periodic ZLD equipment maintenance outages.

Figure 4. UF membranes in holding tank.

Treatment of the water from the refurbished fuel oil storage tank will be initiated in the EC portion of the ZLD system. The EC system will reduce the dissolved silica, phosphate, and hardness in the wastewater by precipitating them as oxides which can then be filtered out by the UF system downstream.

The suspended solids removed in the UF system will eventually end up in the backwash water from the UF. A VC will treat the backwash water for recycle.

The overall ZLD project consists of two phases. The first phase consists of the EC, UF and VC systems initially. Although these components will be designed for integrated operation with an RO system that will be implemented during the second phase of the project, initially they will operate without the RO to dewater the existing evaporation pond. The projected water balance for the two ZLD project phases is shown in Figure 5.



	FLOW	PHASE 1	PHASE 2
01	TOWER #1 EVAPORATION + DRIFT	255.3	255.3
02	TOWER #1 BLOWDOWN	92.6	45.4
03	TOWER #1 MAKEUP	347.9	300.7
04	TOWER #2 EVAPORATION + DRIFT	374.2	374.2
05	TOWER #2 BLOWDOWN	135.8	66.6
06	TOWER #2 MAKEUP	510.0	440.8
07	TOWER #3 EVAPORATION + DRIFT	454.3	454.3
08	TOWER #3 BLOWDOWN	164.9	80.9
09	TOWER #3 MAKEUP	564.2	535.2
10	TOWER #4 EVAPORATION + DRIFT	720.1	720.1
11	TOWER #4 BLOWDOWN	261.4	128.2
12	TOWER #4 MAKEUP	926.5	848.2

	FLOW	PHASE 1	PHASE 2
13	TOWER #5 EVAPORATION + DRIFT	0.0	832.7
14	TOWER #5 BLOWDOWN	0.0	148.4
15	TOWER #5 MAKEUP	0.0	981.1
16	TOTAL COOLING TOWER MAKEUP	2,348.6	3,108.0
17	COOLING TOWER BLOWDOWN TO DISCHARGE	654.7	0.0
18	COOLING TOWER BLOWDOWN TO RECYCLE	0.0	469.5
19	POWER PLANT RO REJECT TO COOLING TOWERS	110.0	0.0
20	POWER PLANT RO REJECT TO RECYCLE	0.0	110.0
21	EC/UF SYSTEM MAKEUP	725.0	579.5
22	UF BACKWASH	72.5	58.0
23	UF PRODUCT TO STORAGE FOR CT MAKEUP	717.8	0.0
24	UF PRODUCT TO RO MAKEUP	0.0	573.7
25	VACUUM CLARIFIER RECYCLED WATER	65.3	52.2
26	WATER WITH VACUUM CLARIFIER DEWATERED SOLIDS	7.3	5.8
27	WATER FROM EXISING EVAPORATION POND	725.0	0.0
28	RO PRODUCT WATER TO STORAGE & CT MAKEUP	0.0	39.1
29	RO PRODUCT WATER TO EXIST BOILER MAKEUP SYS	0.0	460.0
30	RO CONCENTRATE TO NEW EVAPORATION POND	0.0	74.6
31	TREATED SEWAGE EFFLUENT FROM HERVEY WWTP	1,480.9	2,900.9
32	EVAP COOLER BLOWDOWN (SEASONAL)	70.0	70.0
33	UNITS 1-4 FLOOR DRAINS	150.0	150.0
34	UNIT 5 FLOOR DRAINS	0.0	16.0

Figure 5. ZLD system water balance.

Under this initial mode of operation, water from the evaporation pond will be routed to the EC, UF, and VC portions of the system to reduce silica, phosphate, hardness, and other suspended matter to a level suitable for the treated evaporation pond water to be recycled as a portion of the cooling tower makeup.

Phase 2 of the project, or the long term mode of operation, will consist of cooling tower blowdown and wastewater generated from the existing water treatment system routed to the Refurbished Fuel Oil Storage Tank for processing by the EC/UF/VC and the new RO system.

The product water from the RO in ZLD system will be preferentially recycled as makeup to the existing Newman boiler makeup system with the excess routed to the Treated Sewage Water Tank for recycle as a portion of the cooling tower makeup. Preliminary projections indicate the RO system will recovery 87% of the wastewater as very good quality product water with an estimated TDS of 42 mg/L. This water is significantly better than the current supply to the Newman boiler makeup system. As a result, the load on the existing boiler makeup system will be significantly reduced which should reduce waste volumes and regenerant chemical consumption.

TEST RESULTS

Preliminary testing of the first phase consisting of the EC/UF/VC was conducted by using cooling tower blowdown from one of the plant cooling towers. The cycles of concentration in this tower were increased to mimic the 6.6 cycles of concentrations used for the ZLD system design. The test results along with the projected treated water analysis are shown in Table 2.

Table 2. Projected and actual treated water analyses.

PPM AS ION (mg/L)	**Fred Hervey Design Analysis**	**Silica Inhibited Circulating Water @ 6.6 Cycles of Concentration**		**6.6 Cycle Cooling Tower Blowdown After EC & 11 Micron Filtration**		**Test Results (Cooling Tower Cycled Up for Test to Unknown Cycles)**		
CATIONS		No pH Adjustment	pH Adjust to 7.8	Removal Projected	Filtrate	Cooling Tower Blowdown Untreated	EC /UF Treated Blowdown Water	Removal Actual
CALCIUM	79.0	522.8	522.8	20%	418.2	170.0	140.0	17.6%
MAGNESIUM	11.8	78.1	78.1	86%	11.3	21.0	8.5	59.5%
SODIUM	197.4	1306.3	1306.3	0%	1306.3	630.0	620.0	1.6%
POTASSIUM	22.4	148.2	148.2	8%	135.9	66.0	65.0	1.5%
ANIONS								
BICARBONATE	221.8	1467.8	305.0	70%	91.5	97.6	29.3	70.0%
SULFATE	143.0	946.3	1880.0	10%	1686.4	790.0	780.0	1.3%
CHLORIDE	254.0	1680.9	1680.9	0%	1680.9	690.0	750.0	-8.7%
NITRATE	15.0	99.3	99.3	0%	99.3	82.0	0.0	100.0%
PHOSPHATE	1.0	6.6	6.6	100%	0.0			
FLUORIDE	1.0	6.6	6.6	60%	2.6			
OTHER								
SILICA as SiO2	34	225	225	98%	4.5	110	1.4	98.7%
pH	7		7.8			7.9		
TDS	980	6,583	6,354		5,437	2,752	2.394	

Silica, the principal constituent limiting the cooling tower cycles, was removed by 98.7% during the system test as shown in Table 2. This reduction percentage validated the projected silica removal rate. Similar silica reductions have been achieved during further testing of the EC, UF and VC systems.

The second phase of the project involving the RO system is currently being installed. It is anticipated that the commissioning of the second phase will take place at the beginning of August 2010. The goal is to have the entire ZLD system fully operational by the end of 2010.

CONCLUSION

In response to external factors, El Paso Electric Company decided to implement a ZLD system at its Newman Generating Station. The ZLD consists of an innovative combination of Electrocoagulation, Ultrafiltration, and Reverse Osmosis. Silica, the key limiting factor in the cooling tower water, has been reduced by approximately 98% during the testing of the EC/UF/VC equipment. The RO portion is currently being installed and is scheduled to be commission at the beginning of August 2010.

AKNOWLEDGENTS

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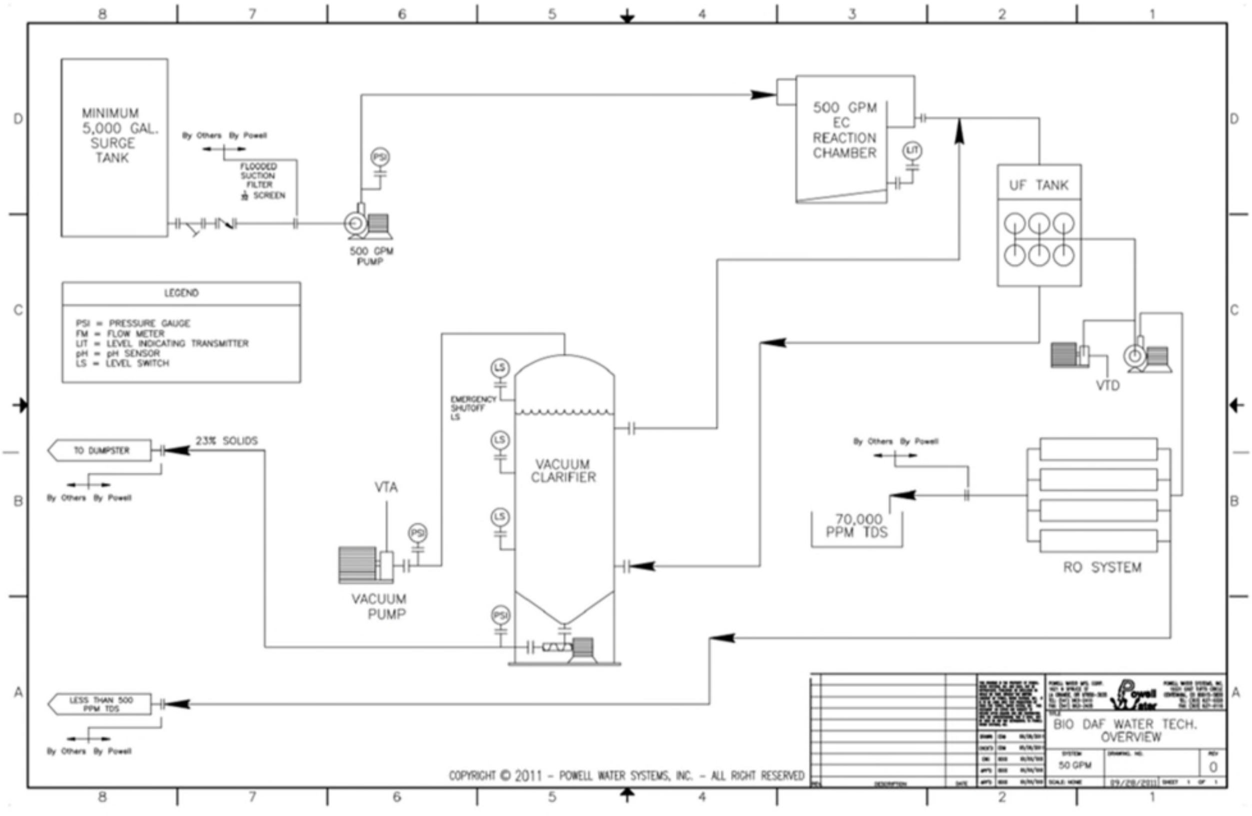
EC Treatment Train El Paso Electric

Tertiary Treated Sewerage Water
2 @ 500 GPM EC machines; 1-minute residency,
Ultra Filter
2 Stage Reverse Osmosis (RO) = (ZLD)



WINWERKS & POWELL ELECTROCOAGULATION

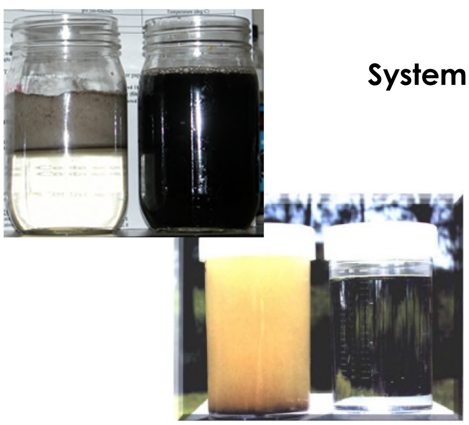
"30 Years of EFFECTIVE, RELIABLE, SAFE Wastewater Applications"

Treating Cooling Tower make-up and blowdown water with Electrocoagulation (electrocuting wastewater streams) offers a very safe, economical and environmentally qualified water treatment for meeting discharge standards and compliance requirements. Recover water, capital and operating costs by eliminating discharge fees, increasing cycles of concentration to conserve water, and significantly reducing water replacement costs. No maintenance chemicals needed. Send treated wastewater to storm drains and capture NaCl for industrial reuse.

Design Build & P3 Delivery

Contaminants Removed	**Percentage of Removal**
TSS (Clay, silt, silica, etc.)	**99%+**
Bacteria	**99%**
BOD 5	**98%+**
Viruses like Legionnaires	**99%+**
Fats, Oils, Grease	**93-99%+**
Heavy Metals	**95-99%+**
Phosphates	**99%+**
Water from Sludge	**50-80%+**

1.5 GPM to 60 M+ GPD



System Capabilities

Removes heavy metals and pass TCLP
Removes suspended and colloidal solids & silicas
Destroys & removes bacteria, viruses, and cysts
Breaks oil emulsions in water
Removes fats, oil, and grease
Increase Cycles of Concentration, up to 15 times
Processes multiple contaminants, simultaneously
Flexible to meet changing influent water
Designed to meet discharge standards
Recycled water enhances overall water use efficiency

Facts & Benefits

- Turnkey delivery, single point of responsibility
- Extend cooling tower life, substantially
- Recognized green building practice
- Over 150 electrocoagulation installs: consistent and reliable results
- Proven; University & Case Studies, White Papers
- Low operating and maintenance costs
- Low power requirements & minimal operator attention
- No chemical or biocides
- Handles a wide variation in the waste streams
- Sustainability; reduce sludge, energy and landfill use
- Treats multiple contaminants & concentrates NaCL (salts)
- Water reuse- resulting in near zero liquid discharge

Kurt A. Tetzlaff
President
O 858-350-1358
C 858-342-2659
ktetzlaff@winwerksipd.com
www.winwerksipd.com

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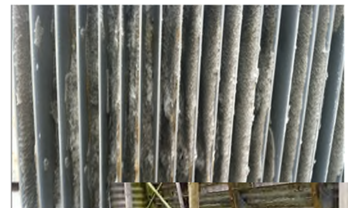
WINWERKS & POWELL ELECTROCOAGULATION

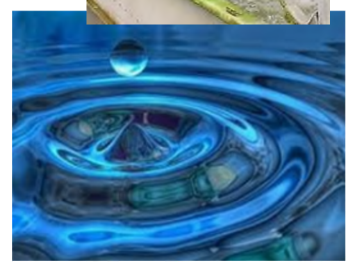
Cooling Tower Makeup and Blowdown Water Technology Process

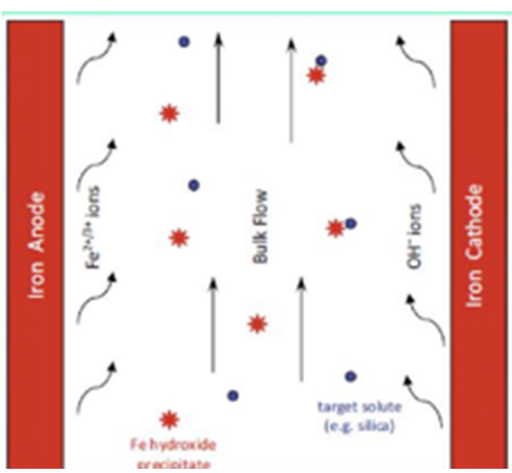
www.winwerksipd.com/electrocoagulation-facts

Electrocoagulation (EC) has been in existence for decades with the first patent issued in 1906. However, only during the past 30 years has the process been fully commercialized as a result of Powell Water technological advancements to overcome the deficiencies of previous systems. Treating cooling tower (CT) makeup water and blowdown water with Powell electrocoagulation prevents scaling by separating the silica, phosphate, calcium carbonate, and magnesium carbonate as coagulated solids before going through the cooling tower. Cooling tower cycles of concentration can increase from 3 or 4 to 5 -10 times more cycles. Salts can be concentrated to 35,000 ppm and eventually sent down storm drains to the sea. Kills legionella bacteria, the cause of Legionnaires' disease. Extends Cooling Tower life increases cooling efficiency and lowers maintenance costs.



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 removed by electrolytic flotation. Powell's patented and proven electrochemical system copes with a variety of wastewaters. These waters can originate from cooling towers, coal utility plants, paper pulp mill waste, metal plating, tanneries, canning factories, steel mill effluent, slaughterhouses, or PWWTP. Silicas, sand, chromate, boron, arsenic, lead and mercury laden effluents, as well as domestic sewage are treated. These wastewaters become clear, clean, odorless and reusable water, often better than the raw water."[1]





In the Electrocoagulation process, the electrical current is introduced into water via parallel plates constructed of various metals that are selected to optimize the removal process. The two most common plate materials are iron and aluminum. In accordance with Faraday's Law, metal ions will be split off or sacrificed into the liquid medium. 'these metal ions tend to form metal oxides that electromechanically attract to the contaminants that have been destabilized. The unit also contains an air purge system to fluidize precipitates, polarity reversing to extend blade life and prevent contaminants from coating the blades, and an automated clean-in–place system. The acid solution used in the automated cleaning cycle is recycled and, when exhausted, it is routed through the EC system for final disposal. Frequency, every 4-6 hours, 20-minute cycle or less.

No chemicals are required for the treatment process. Solids are removed by filters or clarifiers with water available for reuse or discharge.

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

Powell Water Systems Installations
WinWerks IPD Contact Development Services

EC Efficacy: Metals, Ions, Solids, Hardness, Bacteria, Radioisotopes, and Turbidity

Contaminant	Before (mg/l)	After (mg/l)	Removal Rate %
Aldrin (pesticide)	0.063	ND (0.001)	**98**
Aluminium	224	ND (0.7)	**99+**
Ammonia	49	19.4	**60**
Arsenic	0.076	ND (<0.002)	**97**
Barium	0.014	ND (<0.001)	**93**
Benzene	90.1	0.36	**99+**
BOD5	1,050	14	**98**
Boron	4.86	1.41	**70**
Cadmium	0.125	ND (<0.004)	**96**
Calcium	1,321	21.4	**98**
Chlorpyriphos	5.87	ND (0.03)	**99+**
Chromium	139	ND (<0.1)	**99+**
Cobalt	0.1238	0.0214	**82**
Copper	0.7984	ND (<0.0020)	**99+**
Cyanide (free)	723	ND (<0.02)	**99+**
Cypermethrin	1.3	0.07	**94**
DDT	0.261	0.002	**99+**
Diazinon	34	0.21	**99+**
Ethyl Benzene	428	0.372	**99+**
Fluoride	1.1	0.415	**62**
Gold	5.72	1.38	**75**
Iron	68.34	0.19	**99+**
Lead	0.59	0.0032	**99+**
Lindane	0.143	ND (0.001)	**99+**
Magnesium	13.15	0.04	**99+**
Manganese	1.061	0.018	**98**
Mercury	0.72	ND (<0.003)	**98**
Molybdenum	0.35	0.029	**91**
MP-Xylene	41.6	0.057	**99+**
MTBE	21.58	0.0462	**99+**
Nickel	183	0.07	**99+**
Nitrate	11.7	2.6	**77**
Nitrite	21	12	**42**
Nitrogen TKN	1,118	59	**94**
NTU	35.38	0.32	**99**
O-Xylene	191	0.416	**99+**
PCB	0.0007	ND (<0.0001)	**85**
Petro Hydrocarbons	72.5	ND (<0.2)	**99+**

Contaminant	Before (mg/l)	After (mg/l)	Removal Rate %
Phosphate	28	ND (0.2)	**99+**
Platinum	4.4	0.68	**84**
Potassium	200	110	**45**
Propetamphos	80.87	0.36	**99+**
Selenium	68	38	**44**
Silicon	21.07	ND (0.10)	**99+**
Sulfate	104	68	**34**
Silver	0.0081	0.0006	**92**
Tin	0.213	ND (<0.020)	**90**
Toluene	28,480	0.227	**99+**
TSS	1,560	8	**99+**
Vanadium	0.262	ND (<0.002)	**99+**
Zinc	221	0.140	**99+**

Bacteria	Before (cfu)	After (cfu)	Removal Rate %
Bacteria	110,000,000 cfu	2,700 cfu	**99+**
Coliform	318,000,000 cfu	ND (<1) cfu	**99+**
E. coli	>2,419.2 mpn	ND (<0.01) mpn	**99+**
Enterococcus	83 mpn	ND (<10.) mpn	**82**
Total Coliform	>2,419.2 mpn	ND (<0.1) mpn	**99+**

Radioisotopes	Before (pCi/L)	After (pCi/L)	Removal Rate %
Americium-241	71.99 pCi/L	0.57 pCi/L	**99+**
Plutonium-239	29.85 pCi/L	0.29 pCi/L	**99+**
Radium	1093.pCi/L	0.10 pCi/L	**99+**
	Before mg/L	**After mg/L**	
Uranium	0.13 mg/L	0.0002 mg/L	**99+**

Dyes	Before (NTU)	After (NTU)	Removal Rate %
Ref. 006-691	125.1	12.1	**90**
Ref. 006-692	129.4	2.2	**98**
Ref. 006-854	68.30	0.68	**99+**
Ref. 006-851	2,340	4.5	**99+**

Notes: ND = Not Detected at the Reporting Limit mg/l = milligram per liter or part per million pCi/L = picocuries per liter

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Alcan–Canada • Alcan International Limited–Canada • Alfa Appliance Service–Colorado • Anadarko Petroleum–Wyoming • Apex Processing Systems–Australia • Aquamanzi–California • Associated Plating–California • AWES–Colorado • BacTee Systems–North Dakota • Barreto Manufacturing–Oregon • BASX Systems–Colorado • Beckley Water Company–West Virginia • Beijing Wall Investment–China • Ben Gerker Company–Missouri • Boeing–Arizona • Brian Collins–United Kingdom • Burlington Engineering–California • Carige Water Technology–Puerto Rico • Chautauqua Hardware–New York • Chevron Energy Technology Company–California • Christ Water USA–Intel–Washington • CleanWaters LTD–Korea • Colorado Energy Management–New Mexico • Compañía Chilena de Tabacos S.A.–Chile • Conoco Phillips–Oklahoma • Consolidated Meats Group–Australia • Dong Lim Industrial–Korea • Doosan Industrial Development–Korea • E.A.R.T.H / I.M.S.E (Division) - Kingdom of Saudi Arabia • Ethan Allen Coachworks–Vermont • EC System (Thailand) Co–Bangkok • EC&P–Korea • Eco Dewell International–Arizona • EcoGeo International–South Korea • El Paso Electric Company–Texas • Electro Chemical Finishing–Michigan • Emerald Performance Materials–Wyoming • Environmental Solutions & Products–Indiana • ES3–Utah • Fontaniva Bonifico –Italy • Flagship Ecosystems Pte Ltd–Singapore • George A. Bull, Jr–Illinois • Gerber Pumps International–Florida • Golden Star Technology–California • Golder Associates Inc – Colorado • Hyannis Car Wash–Massachusetts • I G B Vetsch AG–Switzerland • Ilen Seafoods–Ireland • Indland Empire Oilseeds–Washington • Integralsa SA–Mexico • Intel–Oregon • International Dehydrated Foods–Missouri • J C Engineering Consultant–Taiwan • Joe's Plating–California • Joyner's Die Casting & Plating–Minnesota • Kent Troup–New York • KVF–Quad–Illinois • Lawrence Livermore National Labs–California • LIG–Korea • Metal Preparations Co–New York • Natural Environmental Systems–Missouri • Natural Systems–California • NEAT Environmental Inc–Canada • New Century Water–California • New China Limited–Texas • Newalta Corporation–Canada • Office of Naval Research–Virginia • Peagasus Environmental Group–Washington • Piedras Negras–Mexico • Production Plating–Washington • Quantum Ionics–Florida • RAK Gas Commission–UAE • REW Nukem–South Carolina • Rhapsody Environmental–California • Rich–Aqua Environmental–Taiwan • Sam–Chang Foundry–Korea • Sammis Oil and Gas–Canada • Samsung SDI Cheonan–Korea • Samsung SDI Pusan–Korea • San Antonio Trade Group–Texas • Santa Clara Waste Water–California • Separation Process Technologies–Japan • Shihlin Electric & Engineering Corp–Taiwan • Southern California Water Company– California • Spence Electro Plating–California • SUMCO Oregon Corp–Oregon • Sumco USA Cincinnati Division– Ohio • Sustainable Industrial Development–Pakistan • Tecprosol International C. A. • Ted Bozarth–Texas • Terra–Magic–Oregon • The Art Alliance–Florida • Tom Beckwith International–California • Troop Environmental Alternatives–New York • TSS Filtration Services–Texas • Tyson Fresh Meats–South Dakota • U S Army Research–Pennsylvania • UCO–California • Ultra Wheel Company–California • United States Navy–California • Universal Systems–Oregon • Uxmal–Mexico • Vermont Organics Reclamation–Vermont • Wastech International–New Hampshire • Wastewater Treatment Associates–Colorado • Water & Power Technologies Inc–Utah • Water Solutions–Oregon • Water Systems Integrators–Colorado • Western Finance & Lease–North Dakota • William Long Sales–Michigan • WMC Corp–Ontario • World Water Works–New York

Developer, Turnkey	Technology and Product Engineering
WinWerks IPD	Powell Water Systems Inc
3741 Overpark Rd.	19331 East Tufts Circle
San Diego, CA	Centennial, Colorado
92130 USA	80015-5820 USA
Telephone 858-350-1358	Telephone 303 627 0320
Fax 858-350-1359	Fax 303 627 0116
Cell 858-342-2659	Cell 303 241 2489
ktetzlaff@winwerksipd.com	Skype: powellwater
www.winwerksipd.com	www.powellwater.com