Condenser Water Management System
Technical Description

Executive Summary

ElectroCell Systems, Inc., a Pennsylvania company, manufactures a system for commercial, industrial and institutional facilities that is applied to conventional water-cooled chilled water plants. Chiller plants are typically a facility's largest water user and also consume an average of 25% of the facility's electrical energy. The ElectroCell system significantly improves efficiency in water and energy use with paybacks in the 2.5 to 3.5 year range.

The system is not a substitute for chemical treatment; rather it is a Condenser Water Efficiency system, engineered specifically and solely to increase water and energy efficiency by addressing the uniquely challenging demands that exist only in the condenser water loop. The systems are designed to work alongside existing chemical treatment and noticeably enhance the effectiveness of the chemical treatment.

The ElectroCell system is manufactured in several standard-sized assemblies for water-cooled chiller plants and is ideal for retrofit applications. Systems can also be customized as needed. It has been in use since 2003 by dozens of Fortune 500 companies with combined duty in excess of 200 years, and reliably saves 10%-12% in chiller energy and 20%-25% in cooling plant makeup water.

Many of the ElectroCell installations are in the Northeastern U.S. and the systems are now being marketed to distributors nationally and internationally. This paper describes the system design, application and operation of the ElectroCell system for consideration by qualified organizations.

ElectroCell Condenser Water Efficiency Systems are proudly built in the United States.

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ElectroCell Systems, Inc.

1.1 Open Loop Water-Cooled Air Conditioning

In the typical open-loop cooling process diagrammed below, heat energy that is required to be removed for effective space conditioning travels through successive processes, each transferring heat from one medium to another. What is not shown is how the otherwise orderly process is dramatically challenged through the fourth medium (condenser water) due, primarily, to evaporation at the cooling tower, which is essential to complete the heat rejection cycle.

The evaporation includes exposure to atmosphere, and leads to numerous complications and requirements not found in other HVAC systems. These include concentration of unwanted solids, treatment systems, filtering with automatic self-cleaning abilities, extensive maintenance, continuous monitoring, documentation, and the potential for accelerated corrosion and biological growth with serious health risks. Additionally, the condenser loop must also reject to atmosphere the chiller's heat of compression, which represents an additional parasitic cooling load of up to 20%.

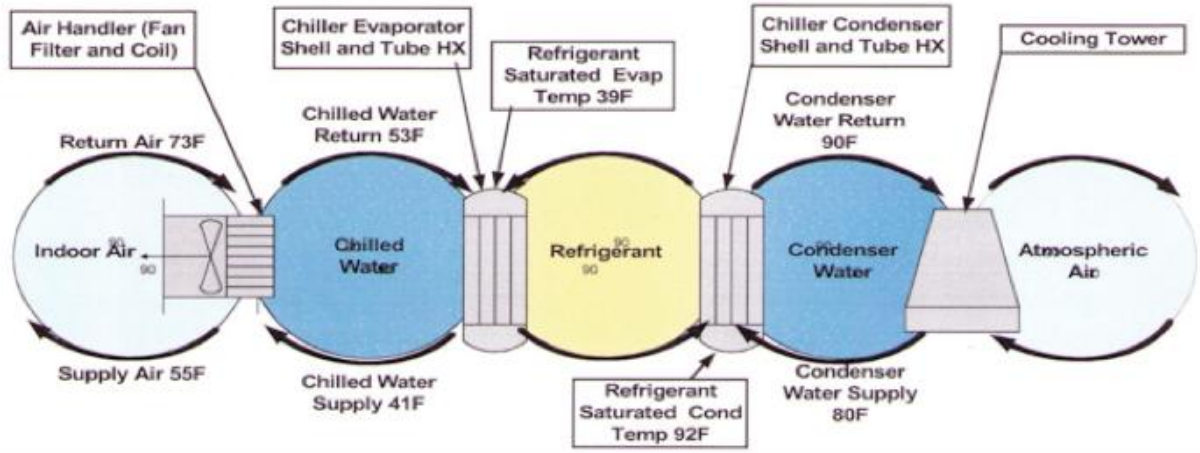

Figure 1: Air Conditioning Heat exchange Process – Water Cooled System (Riesenberger)

The continuous intake of solids into the condenser water is unavoidable; a typical 600 ton cooling tower "scrubs" airborne contaminants (dust & pollen) from the atmosphere and deposits as much as 1800 pounds of particulate matter into the condenser cooling water system each year[1]. Heavy particles settle to the tower basin, which will require manual removal. Lighter particles travel through the system to compromise performance, and large amounts of makeup water are expended in the controlling of solids concentrated in the water left behind.

Makeup water supplies vary in quality and chemistry from site to site, primarily in the amount and type of dissolved solids that, in turn, require a customized chemical selection and water treatment strategy. Makeup water characteristics can vary through the cooling season, requiring readjusted chemical treatment.

1.2 Chemical Water Treatment

[1] American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)), HVAC Systems and Equipment, "Condensers", (2012). *Effect of Fouling on Chiller Performance*. (Handbook). Atlanta, GA: ASHRAE

Condenser water treatment historically is primarily one of chemical treatment. Chemical treatment has handled this requirement over the years, but the main concern of the operators and chemical treatment specialists has been to keep the wetted surfaces clear of scale, fouling, biological growth and corrosion. This is a challenging task that depends upon the constituencies inherent in the water and requires constant attention and testing by the chemical treatment specialist.[2]

In general, very little attention has been paid to water efficiency. The main focus has been on the condition of the wetted surfaces and the effectiveness of the chemical treatment as confirmed with regular testing. Because it has been the general belief that water is an inexpensive utility, and when coupled with a lack of understanding of chemical water treatment by building system operators, the subject of water efficiency is rarely considered. Consequently, all decisions regarding water efficiency have been left to the chemical treatment specialist, who may or may not have knowledge of chilled water plant technologies, nor be expected to assume responsibility for water and energy efficiency.[3]

1.3 Physical Water Treatment

In1998 the U.S. Department of Energy's Federal Energy Management Program published a Federal Energy Alert titled 'Non-Chemical Solutions for Control of Scale, subtitled Technology for improving energy efficiency through the removal or prevention of scale'.[4] The report described the application of several physical water treatment ('PWT') technologies, including magnetic, electromagnetic, and electrostatic. The report cited field studies with positive reports (including supporting data) on effectiveness, economics, and environmental benefits on nonchemical treatment. The 'Technology Outlook' conclusion was "*Probably the most significant trend is the move away from chemical treatment technologies*".

Apparently, in response to this publication, companies emerged with systems based on various forms of PWT that were applied to cooling plants, an alternative to chemical treatment. The PWT technologies had been shown to be effective in performing various actions such as preventing precipitation, sustaining particle suspension, inhibiting scale formation, and limiting biological growth. It seems historically significant to note that the companies applying PWT technologies focused squarely on displacing chemical treatment with their various PWT-based systems. Some applications were (and are) successful and some were not.

<u>It is not the purpose of this paper to advocate for or against the use of PWT technologies as an alternative to chemical treatment.</u> Successful condenser water treatment depends on solutions that are developed custom to each site, and continuously serviced and adjusted as necessary according to water chemistry. As further described below, this paper presents <u>values and efficiency benefits in PWT applications that are additional to the value of chemical treatment</u>.

[2] Riesenberger, James, "Commercial-Industrial Cooling Water Efficiency," PBMP – Cooling Systems (Koeller and Company). Web. Nov 2015.
[3] Ibid.
[4]U.S. Department of Energy, Non-Chemical Solutions for Scale and Hardness Control. EE-0162 Pacific Northwest National Laboratory. Jan. (1998).Retrieved from http://www.magnet4less.com/FederalTechnologyReportDOEEE0162.pdf

1.4 ElectroCell Focus on Efficiency

Beginning in the 1990s, ElectroCell focused on the PWT potential for improving water and energy efficiency (which was, more or less, the intended benefit of the Federal Energy Alert). Paul McLaine, owner and founder of ElectroCell, examined additional condenser water system factors such as sidestream filtering effectiveness, heat transfer, water disposal efficiency, makeup water use, and automatic monitoring and control. It was determined with field-verified applications that use of certain PWT technologies alongside existing chemical treatment kept systems cleaner, noticeably improved water and energy efficiency, and in fact made chemical treatment more effective.

In 2003 ElectroCell developed and manufactured its first comprehensive system of condenser water efficiency using its own multiple patented PWT technologies. The system achieves and sustains significant water and energy savings and operates in harmony with chemical treatment systems.

The ElectroCell system may be regarded as the industry's first dedicated Condenser Water Efficiency system. It has been successfully applied in medium- to large-scale chiller plants in dozens of Fortune 500 companies. Makeup water savings average 20-25% and energy savings in chiller energy average 10%-12%.

Figure 2: ElectroCell System's Xcell–6000 Assembly

ElectroCell system's means of achieving water and energy efficiency may be broadly described as:

- **Superior Solids Control**, which consists of solids removal and disposal to achieve and maintain a clean condenser water system

- **Improved Heat Transfer** in the chillers' condensers, which reduces the energy used to perform the required cooling.

1. Condenser Water Suspended Solids Control

2.1 Side Stream Filtration

The Department of Energy is a good source of information on using Side Stream Filtering (http://energy.gov/sites/prod/files/2013/10/f3/ssf_fact_sheet.pdf) Suspended solids control in condenser water systems is most commonly achieved with sidestream filtering. The following information on sidestream filtering is from U.S. Department of Energy report Side Stream Filtration for Cooling Towers.[5] The evaluation's overall objective stated as:

> "To provide information on key impacts related to energy, water, and cost savings of side stream filtration as well as key attributes on specific technology options and component specifications so that energy and facility managers can make informed decisions on which options may be most appropriate for their site."

Cooling tower systems operation is most efficient when their heat transfer surfaces are clean. However, these are dynamic systems, due to variations in the water source and their operating in the open environment. Since cooling towers are open-loop systems they are susceptible to drawing in dirt and debris, including organic matter. Birds and insects like to live in and around cooling towers due to the warm, wet environment.

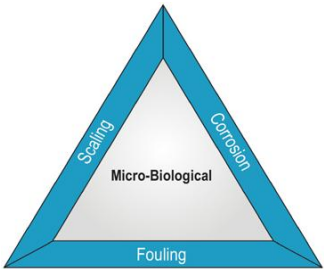

Figure 3: Cooling Tower Primary Treatment Concerns U.S. Department of Energy

The combination of process and environmental factors contribute to four primary treatment concerns: corrosion, scaling, fouling, and microbiological activity. These treatment concerns are inter-related such that reducing one can have an impact on the severity of the other three.

2.2 Side Stream Filtration Benefits

Side stream filtration systems continuously filter a portion of the cooling water to remove suspended solids, organics, and silt particles, reducing the likelihood of fouling and biological growth, which in turn helps to control other issues in the system such as scaling and corrosion.

This results in both water and energy efficiency gains due to a reduction in the amount of water discharged from the cooling system and a decrease of scale formation on the heat transfer surfaces. The figure at right shows a simplified cooling tower schematic including a sidestream filter.

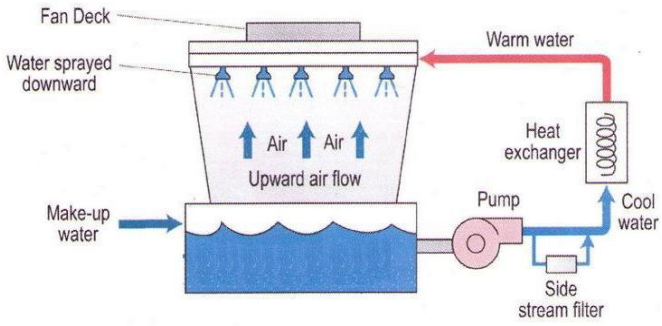

Figure 4: Cooling Tower with Side Stream Filtration Example US Dept. of Energy

[5] *Side Stream Filtration for Cooling Towers*. Washington, D.C.: United States. Department of Energy. Office of Energy Efficiency and Renewable Energy, 2012. Print.

Sidestream Filtering Benefits, (continued)

The following benefits of sidestream filtering are from U.S. Department of Energy report Side Stream Filtration for Cooling Towers.[6]

- **Reduction in water consumption**: Demand for makeup water in cooling towers is decreased with an increase in the system's cycles of concentration. Essentially, higher cycles of concentration mean that water is being recirculated through the system longer before blowdown is required. Less blowdown reduces the amount of makeup water required in the system, resulting in water savings.

- **Reduction in energy consumption**: Side stream filtration reduces the likelihood of scale and fouling on the heat exchangers. Even the smallest layer of scale or fouling on heat exchange surfaces can reduce the rate of heat exchange, forcing the system to work harder to achieve the desired cooling and in turn increases energy costs.

- **Reduction in chemical use**: Chemicals are used to bind suspended particles in the water stream and prevent scaling and corrosion. Dirty water requires more chemicals than clean water because a buildup of solid contaminants provides a buffer that reduces the effects of treatment chemicals. A side stream filtration system can remove suspended particles, reducing the need for additional chemical treatments such as dispersants and biocides.

- **Lower cooling tower maintenance cost**: Traditionally, cooling towers are cleaned by draining the tower and having the sediment removed mechanically or manually from the sump. Costs associated with the cleaning process include downtime, labor, lost water, and additional chemicals. Cooling systems that are cleaned via side stream filtration routinely provide longer periods of continuous operation before being taken off-line for required maintenance.

- **Improvement in productivity and reduction in downtime**: When a cooling system is fouled or has scale buildup, production may be slowed due to inefficient heat exchange equipment. In some cases, the cooling system and heat exchange equipment may need to be taken offline for repairs, decreasing production.

- **Control of biological growth**: Biological growth control and reduction can mitigate potential health problems, such as those caused by *Legionella*. ASHRAE Guideline 12-2000 has basic treatment recommendations for control and prevention, stating that the key to success is system cleanliness. *Legionella* thrives where there are nutrients to aid its growth and surfaces on which to live. Use of side stream filtration can minimize habitat surfaces and nutrients by maintaining lower particle levels in the water stream.

[6] *Side Stream Filtration for Cooling Towers*. Washington, D.C.: United States. Department of Energy. Office of Energy Efficiency and Renewable Energy, 2012. Print.

2.3 Sidestream Filter Types

Filters are rated by the size of particles that can be removed, measured in microns. Suspended solids in cooling towers typically range in size from 1 to 50 microns as shown in the table below.

In general, 90% of the particles in cooling towers are smaller than 10 microns.[7]

Table 1: Suspended Solids

Suspended Solids in Cooling Towers	
Particle Type	**Size (Microns)**
Sand	100 to 2,000
Pollens	10 to 1,000
Mold Spores	10 to 30
Bacteria	3

Among the side stream filter types shown below, sand filters are the most common [Ref. 3]. Sand filters direct fluid into the top of their tank(s) and onto the surface of a bed of specified sand and/or other media. As the cooling water flows through the bed of sand media, suspended solids and other particles are captured within the upper layer of media. The water moves downward, passing into a drain at the bottom of the filter tank and discharging through an outlet pipe.

Table 2: Side Stream Filtration System Characteristics (U.S. Department of Energy)

Filter Type	Particle Removal Level	Basic Filtering Mechanism	Applications	Notes
Centrifugal Separators	40-75 microns, fine to coarse inorganics with a specific gravity (1.62) or greater	High velocity water is fed in a circular pattern that moves heavier particles down and out of the system	Best for removal of large, heavy particles	Minimal maintenance is required
Automatic Screen Filter	Down to 10 microns	Water moves through a rigid screen, where large particles are trapped and sucked out of the system	Best for systems that cannot be interrupted such as industrial processes and hospitals	Self cleaning mechanism allows for no interruption in operation
Plastic Disc Filter	Down to 10 microns	Grooved, stacked plates trap particles as water moves through the discs	Appropriate where removal of both solids and organics are required	Self cleaning mechanism is automatic and requires little down time of the system
Sand Filters	Down to 10 microns for pressure sand filters; Down to 0.45 microns for high efficiency sand filters	Layers of granulated sand, trap particles as water moves through the sand layers	Best for applications that require the removal of fine and low density particles	Supplemental chlorine may be needed because sand filters can promote biological growth

Note: Adapted from U.S. Department of Energy, *Technical Evaluation of Side Stream Filtration for Cooling Towers,* p. 3, by Will Lintner, PE, 2012, Washington: Pacific Northwest National Laboratory

[7] *Side Stream Filtration for Cooling Towers*. Washington, D.C.: United States. Dept. of Energy. Office of Energy Efficiency and Renewable Energy, 2012. Print.

2.4 Sand Filter Characteristics

Filter operation requires that particle removal and self-cleaning perform with equal success. Sand filters work less effectively with high-density sand-like materials because these materials cannot be properly removed by backwashing.[8]

Table 3: Sand Filter Characteristics (U.S. Department of Energy)

Filter Type	Particle Removal Level	Self-Cleaning Features	Maintenance and Parts Replacement	Water Loss From Back Wash
Pressure Sand Filter	Down to 10 microns	Automatic backwash, once a day or on pressure drop as needed.	Periodic inspection; sand media and electromechanical parts; periodical sand media replacement	Requires a lot of water for backwashing
High Efficiency Sand Filter	Down to 0.45 microns. Best for fine light particles. Avoid heavy coarse particle applications	Automatic backwash features, requires less time and water than other sand filters.	Sand media must be monitored and periodically disposed and replaced.	Requires more backwash water than centrifugal separators, automatic screen, and disc filters; but about eight times less water than other sand filters

Note: Adapted from U.S. Department of Energy, *Technical Evaluation of Side Stream Filtration for Cooling Towers*, p. 3, by Will Lintner, PE, 2012, Washington: Pacific Northwest National Laboratory

2.5 Sand Filter Limitations

Although sidestream sand media filtering can be effective some applications, limitations of sand filters are apparent according to the information above:

- **Limited Range of Particle Removal Effectiveness:** Depending on the sand filter type, particle removal and self-cleaning will be effective with either larger particles (> 10 microns) or smaller particles (<10 microns), but not both. Removal across the full range would therefore require two types of filters piped in series: a pressure sand filter for large particles along with a high efficiency sand filter for small particles (plus supplemental chlorine treatment).

- **High Backwashing Rates:** Particle removal from the sand media in pressure sand filters requires high amounts of backwashing (15-20 minutes) using large amounts of water, especially under high cooling load conditions.

- **Substantial Maintenance Requirements:** The sand media requires periodic replacement for continued effectiveness. Due to the size and weight of the sand media it is common for the required maintenance to be deferred or eliminated, leading to lowered effectiveness and increased backwashing.

- **Additional Biological Control:** As noted above in Filter Types table (pervious page), an additional treatment system may be needed due to the warm, moist filter environment that promotes biological growth.

[8] *Side Stream Filtration for Cooling Towers*. Washington, D.C.: United States. Dept. of Energy. Office of Energy Efficiency and Renewable Energy, 2012. Print.

3. ElectroCell System Suspended Solids Control

The ElectroCell System provides a breakthrough in sidestream filtering with highly effective removal of the full range of particle sizes without the use of a filter media. The system combines physical technologies, variable controlled flow rates, and vessel design to accomplish an average of 92%-97% particle removal through precipitation.

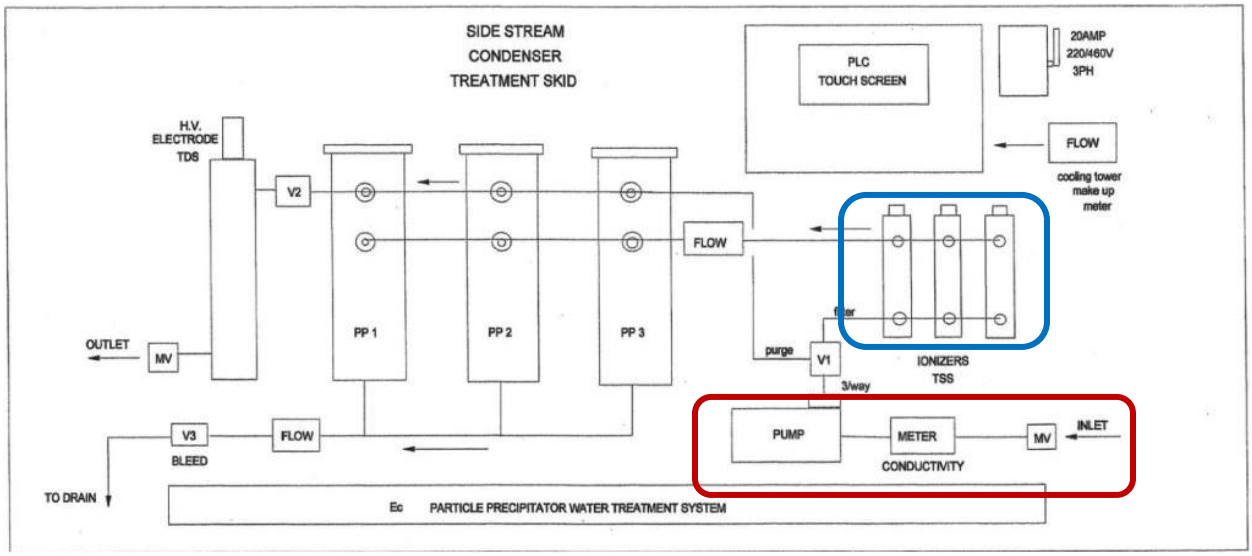

Figure 5: Xcell Assembly Particle Precipitator Equipment Schematic (ElectroCell System)

3.1 Xcell Assembly Sidestream Flow Control (enclosed in red above)

Condenser water (CDW) enters system through sidestream piping at the inlet and measured for flow and conductivity. Desired flow through the assembly is maintained with the VFD-controlled pump.

3.2 Xcell Assembly Ionizers (enclosed in blue above)

The Condenser Water passes through control valve V1 through ionizers (middle right) for pre-treatment in the precipitation of solids. These induce electrocoagulation (also known as short wave electrolysis) by means of alloyed metals with low-voltage direct current pulsing of the cathode and anode. Solids (organic and inorganic) are normally held in solution by electrical charges. The addition of ions with opposite charges destabilizes the colloids, allowing them to coagulate.

Electrocoagulation is an established PWT method used in many industries including wash water treatment, wastewater treatment, industrial processed water, and medical treatment. It has especially become a rapidly growing technology used in wastewater treatment due to its ability to remove contaminants that are generally more difficult to remove by media filtration or chemical treatment. Note that the ElectroCell System does not use copper, aluminum, or any heavy metals in the ionizers.

3.3 Xcell Assembly Solids Precipitation (enclosed in red below)

The pretreated condenser water passes into the larger, parallel-piped precipitation vessels (PP-1, 2, 3, in center) and experiences a dramatic reduction in flow rate. Suspended solids with increased mass precipitate out of solution and settle to the bottom of the pods. Condenser water flows upward through static mixers that also further retard flow rate and enhance uniform coagulation and precipitation of solids.

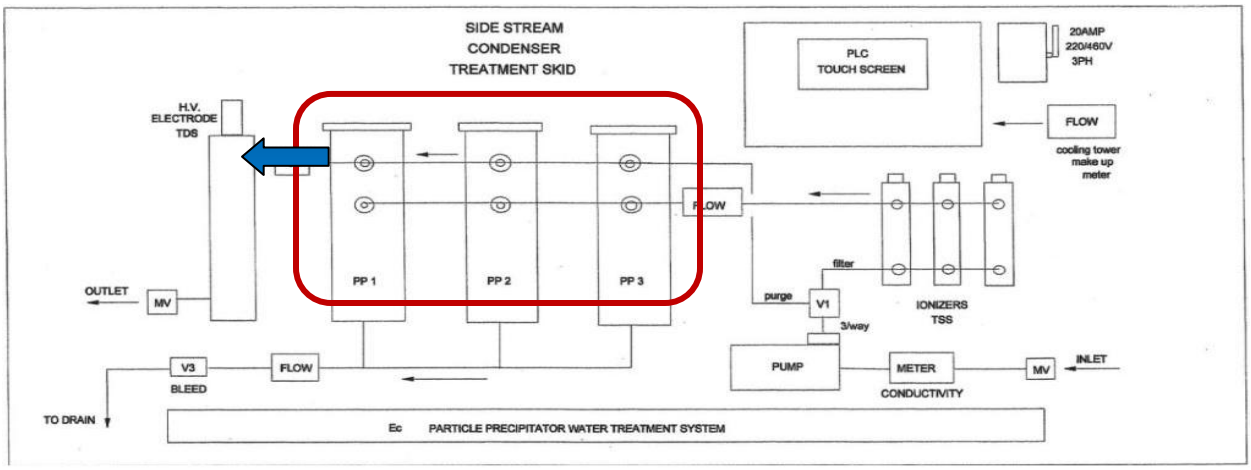

Figure 6: Xcell Assembly Particle Precipitator Equipment Schematic (ElectroCell System)

Note that the sidestream flow leaving the precipitation vessels is elevated (indicated by blue arrow) so that the returning condenser water does not come in contact with the collected solids that have settled to the base of the vessels.

3.4 XCELL ASSEMBLY Removal of Collected Solids (enclosed in blue below)

The ElectroCell system takes advantage of the blowdown process to remove solids that have accumulated in the base of the precipitator vessels. When the condenser water conductivity setpoint is exceeded, control valve V3 on the XCELL ASSEMBLY assembly opens, which diverts flow through the vessel bases and carries the solids out to drain (indicated by blue arrow). When conductivity drops to the acceptable level, Valve V3 closes and the XCELL ASSEMBLY system resumes normal operation. This strategy saves water by putting the blowdown (which normally runs straight to drain) to beneficial use in removing solids instead of having to use repeated purge cycles.

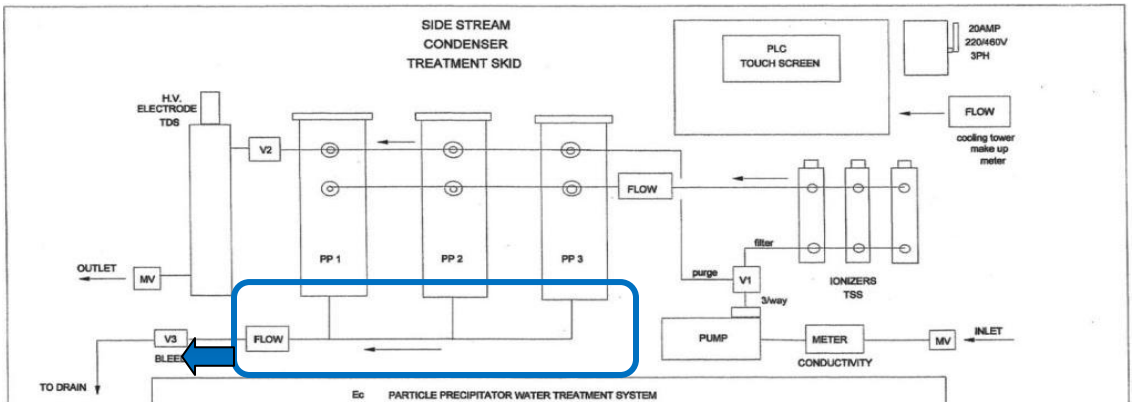

Figure 7: Xcell Assembly Collected Solids Removal Schematic (ElectroCell System)

Xcell Assembly Removal of Collected Solids, continued

Limited purge cycles are used on the Xcell Assembly to perform 'top-down' cleaning of the precipitation vessels and static mixers once or twice per day, according to conditions. In the purge sequence, diverting valves V1 and V2 are actuated to reverse flow direction through the precipitators, sending flow downward through the vessels to cleanse any particles that may be in the system. Purge cycles run according to time schedules.

The Xcell Assembly purge cycle requires far less water than sand filters since there is no media to be cleaned. Unlike pressure sand filters that typically have a 15-20 minute purge cycle to flush the media, the Xcell Assembly cycle runs a timed cycle of only 4-6 minutes. Although there are pressure controls that will allow the system to purge automatically at any time if necessary, the purge cycle normally does not need to run, even under heavy cooling loads, except once or twice a day.

3.5 Water Savings

The sum effect of the Xcell Assembly precipitation and the electrostatic treatment is to enable tremendous water savings[9]. This is accomplished without any change in the conductivity setpoint. Note that in the example below the system achieved 23.5% annual savings in makeup water.

The COC is established by the chemical treatment supplier, who determines the best ratio of makeup water volume to blowdown water volume. Higher cycles use less water, and lower cycles are required with lower quality water. Conductivity is the quality measure and blowdown is initiated when is rises above setpoint.

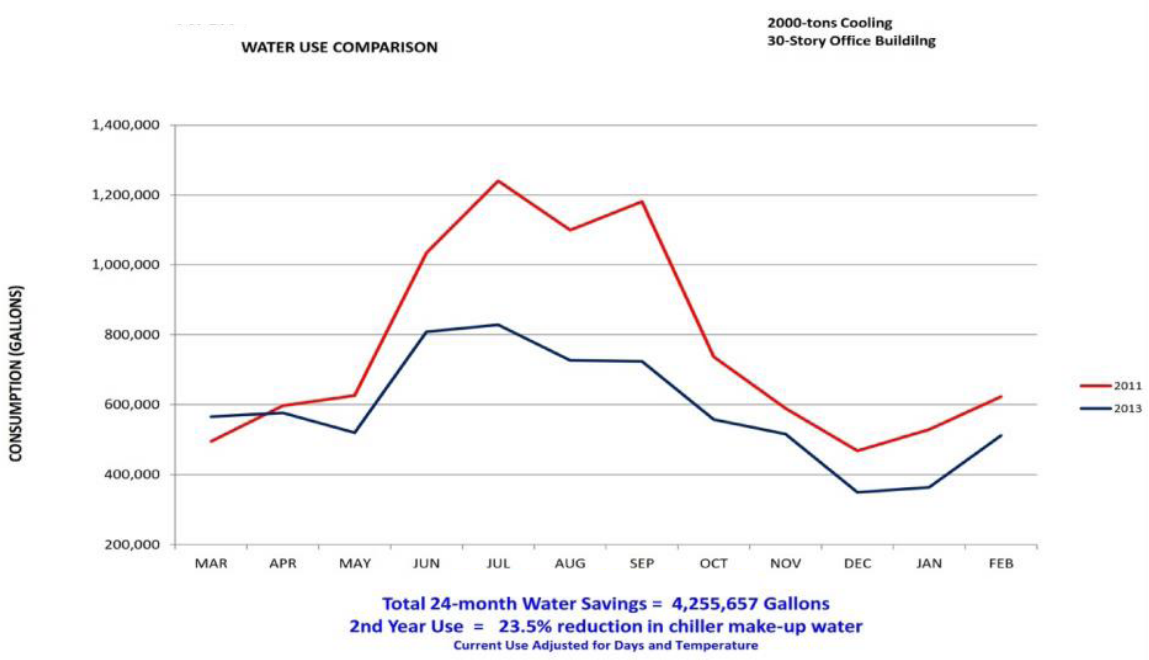

Figure 8: ElectroCell System (installed Feb 2012) Typical Water Savings

[9] McLachlan, D.R. Dr., and A. Wilson, "The Design and Implementation of Physical Water Treatment Technology in Large Flow Industrial Applications", Cooling Tower Institute Annual Conference. 2009.

3.6 Xcell Assembly Precipitation Performance (Example #1)

Particle removal rates are confirmed by a certified independent laboratory using light scattering measurement technology. This confirms effective removal for larger particles (above 25 micron) down to the smallest particles (down to 1 micron or lower). At the site shown below, the ElectroCell System removed 93% of the all particles (by count) and 99% of the solids (by volume) that were present in the baseline condition using sand filters. The left columns were the existing condition and the right columns were the improved condition after three months of operation.

Table 4: Particle removal rates before and after ElectroCell System installation

Source: CT Basin Water

Test Method Sample analyzed by electro-optical particle analyzer employing the light scattering principle of operation in a dilute ratio 1:800 with filtered water and particle data corrected Stirring was continuous.

Baseline prior to Xcell Application			After 3 Months with Xcell Application		
PARTICLE COUNTS PER 100mL TEST PORTION			**PARTICLE COUNTS PER 100mL TEST PORTION**		
1 - 3 micron:	8,352,320		1 - 3 micron:	835,508	
3 - 5 micron:	1,568,520		3 - 5 micron:	23,090	
5 - 10 micron:	1,708,520		5 - 10 micron:	48,440	
10 - 15 micron:	572,480		10 - 15 micron:	18,706	
15 - 25 micron:	776,640		15 - 25 micron:	6,570	
Over 25 micron:	431,680		Over 25 micron:	5,648	
TOTAL/100mL:	**13,410,160**		**TOTAL/100mL:**	**937,962**	
SOLIDS PER 100 LITERS OF SYSTEM VOLUME (mm^3)			**SOLIDS PER 100 LITERS OF SYSTEM VOLUME (mm^3)**		
1 - 5 micron:	167.20		1 - 5 micron:	8.16	
5 - 10 micron:	721.00		5 - 10 micron:	20.44	
Over 10 micron:	295,516.85		Over 10 micron:	3,839.93	
TOTAL/100 Liters:	**296,405.05**	**2,964 ppm**	**TOTAL/100 Liters:**	**3,868.53**	**39 ppm**

3.6 Xcell Assembly Precipitation Performance (Example #2)

The system's precipitation is highly effective in under extremely demanding conditions. The chart below shows particle counts from a brewery with a 6,000 ton cooling plant running 24/7/365 and utilizing well water for makeup with very high amounts of suspended solids (763,463 particles per 100mL). Baseline filtering was sidestream pressure sand filtering. Data was tallied from four tests (makeup water, baseline condenser water with pressure sand filters, and condenser water with the Xcell Assembly application after 3-month of use, and again after 7 months of use). Solids removal over the baseline (using sand filters) with the ElectroCell system was 91.3% after three months, and improved to 97.7% removal after seven months. Note the solids removal effectiveness throughout the entire range of particle sizes with the ElectroCell system.

Table 5: Data Assembled by Dan Wheatley. Example of Particle Counts from Data Tests

Particle Counts per 100mL by size; Test Portion	MAKEUP WATER		CONDENSER WATER							
			Baseline Condition with Sand Fliters		After 3 months with ElectroCell			After 7 months with ElectroCell		
	August 2012		August 2012		April 2013		Reduction from Baseline	July 2013		Reduction from Baseline
1-3 Micron	576,043	75.4%	4,472,490	83.4%	633,057	94.1%	85.8%	139,224	77.5%	96.9%
3-5 Micron	84,183	11.0%	663,970	8.6%	22,860	3.4%	96.6%	2,516	1.4%	99.6%
5-10 Micron	59,618	7.8%	357,140	4.6%	9,189	1.4%	97.4%	19,788	11.0%	94.5%
10-15 Micron	14,218	1.9%	94,380	1.2%	1,642	0.2%	98.3%	6,704	3.7%	92.9%
15-25 Micron	17,954	2.4%	113,000	1.5%	2,612	0.4%	97.7%	7,030	3.9%	93.8%
>25 Micron	11,630	1.5%	60,280	0.8%	3,635	0.5%	94.0%	4,404	2.5%	92.7%
TOTALS	**763,646**	**100.0%**	**7,761,260**	**100.0%**	**672,995**	**100.0%**	**91.3%**	**179,666**	**100.0%**	**97.7%**

4. Condenser Water Heat Transfer Overview

4.1 Cooling Tower Tons with Heat of Compression

Heat energy being removed is commonly quantified as tons of cooling, with a ton being equal to 12,000 BTU. Specifically, the 12,000 BTU is a Refrigeration Ton, and 12,000 BTU plus the additional heat of compression BTU defines a Cooling Tower Ton. The Heat of Compression (HOC) is the heat energy added to the refrigerant by the compression. An older 'rule of thumb' in the industry is to estimate 3,000 BTU for HOC, which would then equal 15,000 per cooling tower ton. This, however, equates to HOC of .88 kW per ton, which is unreasonably high, even for older chillers.

A more reasonable average HOC for existing chillers may be .62 kW/Ton, which equates to an HOC of 2,116, for a cooling tower ton of 14,116 BTU. It is not uncommon to encounter older existing chillers designed for this performance that are averaging .7 kW/Ton due to conditions that compromise efficiency. This equates to 2,389 HOC BTU, which results on a cooling tower ton of 14,389 BTU.

4.2 Condenser Tube Fouling

There are several factors that increase kW/Ton over design, namely, (1) Non-condensable gases (i.e. air) in the refrigerant, (2) Low condenser water flow rate, (3) high condenser inlet water temperature, and (4) excessive fouling or scaling of the condenser tubes.[10] Items 1, 2, and 3 should be confirmed even though fouling or scaling (Item 4) may most often be the cause of chiller inefficiency.

Some fouling/scaling is expected even at design efficiency; the Air Conditioning, Heating and Refrigeration Institute (AHRI) establishes chiller efficiency for design purposes based an expected continuous condenser fouling factor of .00025[11].

As shown in the ASHRAE Handbook 'Systems and Equipment' at right, this expected fouling factor of .00025 decreases chiller performance 3%, and performance linearly degrades an additional 3%, approximately, with each .00025 increase in fouling.[12] Note also that efficiency would increase 3% over design with no fouling.

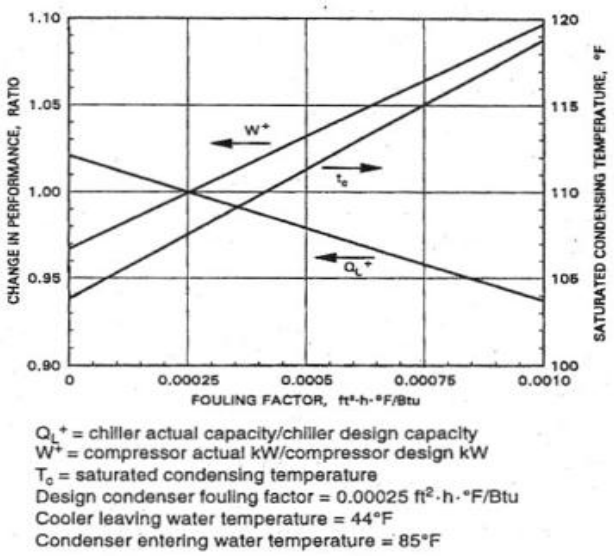

Figure 9: Effect on Fouling on Chiller Performance

[10] Chem-Aqua, Inc. (2011). *Monitoring and Troubleshooting Chiller Efficiency*. Bulletin. Retrieved from http://www.chemaqua.com/downloads/cases/catb2-043_9-10.pdf

11 Ibid.

[12] American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)), HVAC Systems and Equipment, "Condensers", (2012). *Effect of Fouling on Chiller Performance*. (Handbook). Atlanta, GA: ASHRAE

4.2 Condenser Tube Fouling, continued

Various published efficiency losses due to fouling differ slightly and are sometimes characterized as 2.75% loss per .00025 fouling (slightly less than the 3% above). Variations may be due to allowances for biological fouling that is known to have up to four times more insulating effect than that of inorganic fouling or scaling.

The chart at right, using the 2.75% rate, shows linear increases in power with increased fouling, along the corresponding fouling thickness (in inches). Note that a .00025 fouling factor (designated with the blue arrow) is the design allowance.

Table 6: Linear increase with increase fouling

Condenser Fouling Factor	Thickness (Inches)	Additional Power Required
0.0000	0.000	0%
0.0001	0.001	1.1%
0.00025	0.003	2.8%
0.00050	0.006	5.5%
0.00075	0.009	8.3%
0.00100	0.012	11.0%
0.00125	0.015	13.8%
0.00150	0.018	16.5%
0.00175	0.021	19.3%

An indicator of the effects of fouling on a running chiller is the approach temperature, which shows heat transfer effectiveness in the condenser. The approach temperature of a condenser is the temperature difference between the leaving condenser water and the leaving liquid (condensed) refrigerant.

An approach temperature of 1°F indicates excellent heat transfer and efficient operation. In the illustration below[13] the approach temperature is 3°F, indicating less efficient operation. In a 600 ton chiller running 1800 GPM (3 GPM per ton), the difference between a 1°F and a 3°F approach temperature is 1,800,000 fewer BTUs transferred to the condenser water.

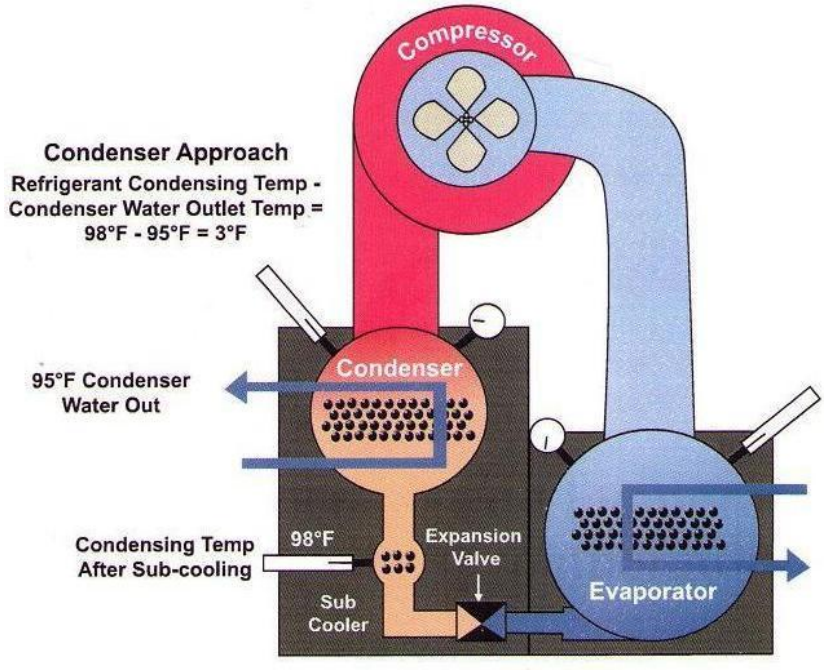

Figure 10: Condenser and Evaporator Approach Temperature
Chem-Aqua, Inc. (2011). *Monitoring and Troubleshooting Chiller Efficiency*. Bulletin. Retrieved from http://www.chemaqua.com/downloads/cases/catb2-043_9-10.pdf

[13] Chem-Aqua, Inc. (2011). *Monitoring and Troubleshooting Chiller Efficiency*. Bulletin. Retrieved from http://www.chemaqua.com/downloads/cases/catb2-043_9-10.pdf

4.3 Laminar Flow with Boundary Layer

Most condensers are designed for heat exchange as shell-and-tube, with refrigerant in the shell and condenser water flowing through the tubes. Water (including condenser water) at rest as well as in motion normally experiences surface tension due to existing weak static charges that are approximately evenly divided between negative and positive, therefore causing common attraction and resistance to dispersion. This surface tension causes water flowing through a pipe to naturally develop laminar flow. Laminar flow is characterized by straight, ordered flow with a parabolic profile.[14]

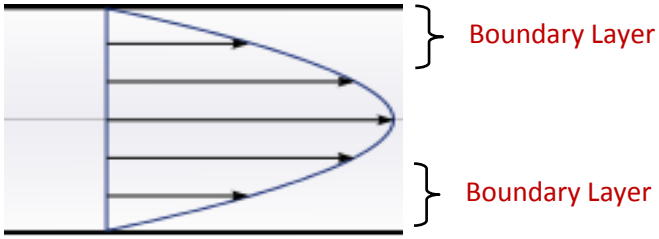

Figure 11: Laminar Condenser Water Flow

Highest flow velocity is in the center of a pipe and diminishes away from the center towards a thermal boundary layer between the flowing water and the pipe wall. Contact for heat exchange is at the pipe wall (where all heat exchange must occur), and as shown at right, contact in the fully developed laminar flow region is reduced by the laminar flow profile.

4.4 Turbulent Flow

The alternate condition to laminar flow is described as turbulent flow. In turbulent flow, water flowing away from the pipe center does not follow straight, uniform flow; rather, the lack of surface tension allows it to disperse away from the pipe center and flow with a more flattened profile as shown at right. This eliminates much of the boundary layer, creating more contact with the pipe wall and increasing heat transfer opportunity.

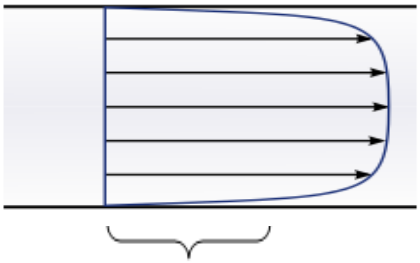

Figure 12: Turbulent Condenser Water Flow with increased pipe wall contact and decreased boundary laver

There are various established methods for inducing turbulence that may be classified as either passive or active. Passive methods include extended condenser tube surfaces, condenser inserts, coiled or twisted tubes, condenser pipe wall surface treatments, and additives.[15] Some chiller manufacturers have enhanced tubes to induce turbulent flow with tube grooving or rifling.

Active techniques include surface vibration, injection, suction, and electrostatic fields. The electrostatic field, used by the ElectroCell system, causes turbulence by imposing a uniform negative charge on the flowing water which breaks the surface tension of the water.

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[14] Lundsford, Kevin M. (1998). *Increasing Heat Exchanger Performance*. Bryan Research & Engineering, Inc., Bryan, TX. Retrieved from http://www.bre.com/portals/0/technicalarticles/increasing%20heat%20exchanger%20performance.pdf

[15] Ibid.

5. ElectroCell Heat Transfer Efficiency

Use of the ElectroCell system results in an average of 10%-12% chiller energy savings due to improved heat transfer in the condensers. Savings are in the compressor energy (through reduced heat of compressions) as the result of improved heat transfer, which requires less heat of compression. This heat transfer improvement is the result of the electrostatic treatment causing turbulence and shear force de-fouling as described below.

5.1 Increased Thermal Transfer

ElectroCell applies patented electrostatic treatment in the Xcell Assembly primarily to induce turbulent flow, break down the thermal boundary layer, and enable enhanced heat exchange in the condenser. As the sidestream condenser water flows out of the precipitation vessels, it is combined into a single pipe and flows through the high voltage (20-24 kVDC) electrostatic treatment vessel (enclosed in red below). Larger systems have multiple vessels, each equipped with an electrode.

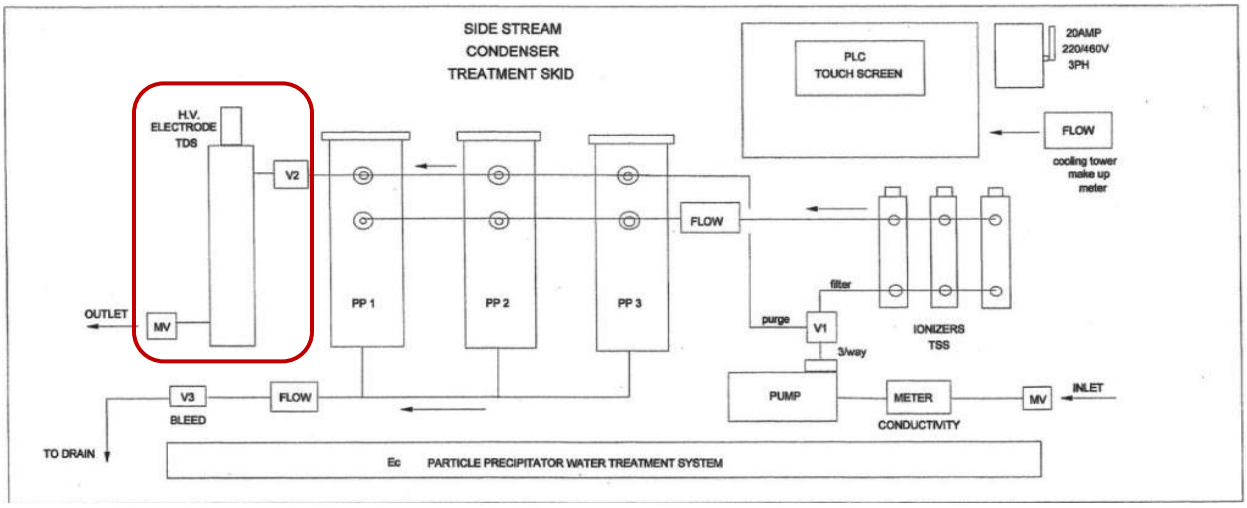

Figure 13: Xcell Assembly Electrostatic Treatment

The cylindrical vessel houses the patented ElectroCell high-voltage electrode that is mounted in the center of the vessel. Condenser water flows in parallel with the electrode and in contact with the dielectric.

Characteristic of a capacitor, there is virtually no electrical current flowing across or through the dielectric into the water. The electrode maintains a strong static field and imposes a negative charge on the water, as well as on the dissolved solids and suspended solids.

30" patented electrode for electrostatic field generation

Figure 14: ElectroCell Patented Electrode

5.2 Shear Force De-Fouling and De-Scaling

In addition to primary benefit of improved heat transfer, the secondary benefit of breaking down the boundary layer is to introduce the shear force of the flowing condenser water against the pipe surfaces to naturally clean away fouling and scaling that inhibits heat transfer (and can also cause corrosion).

Although it is not the ideal application, ElectroCell systems can be applied to condenser water systems with significant fouling or scaling systems and will cause them to become clean over time.

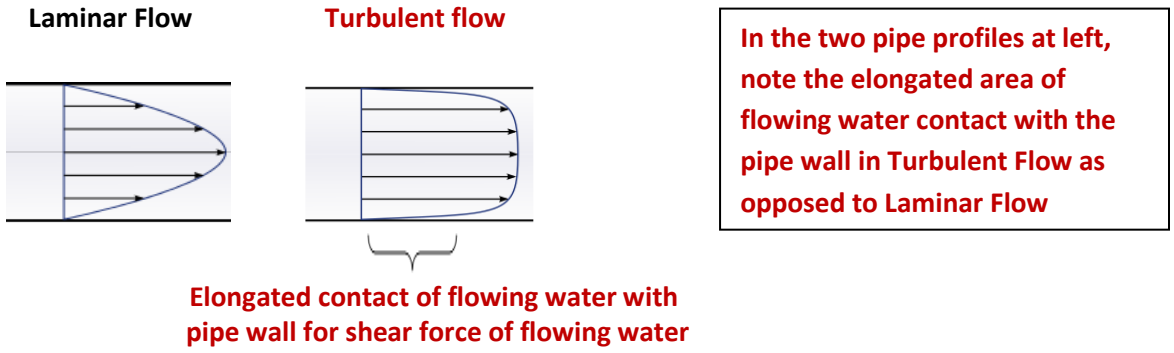

Figure 15: Laminar Flow versus Turbulent Flow

5.3 Maintaining Solids in Suspension for Removal by the Xcell Assembly

The high-voltage electrostatic treatment also contributes to the solids removal process. Solids are prevented from settling out in the condenser and piping, as well as preventing the unwanted precipitation of dissolved solids in the condenser and piping. The uniform negative charges imposed causes solids to repel one another, as well as repel the pipe surfaces, which are also negative. The effect is to keep solids in suspension until they are removed by the Xcell Assembly precipitation process.

Particles in suspension also act as nucleation sites for homogeneous nucleation of scale in bulk solution.

It is this reaction in the bulk solution of the water stream that lessens the tendency to form scale on the heat transfer surface and the other surfaces of the condenser water system.[16]

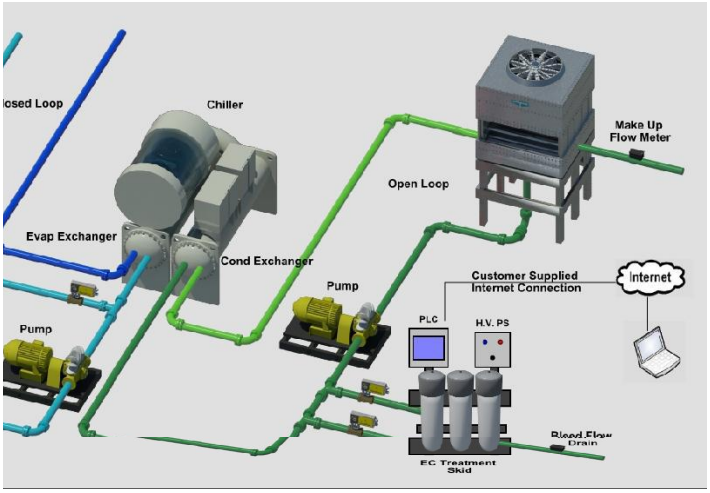

Figure 16: Solids removal process with continuous monitoring

[16] Riesenberger, James, "Commercial-Industrial Cooling Water Efficiency," PBMP – Cooling Systems (Koeller and Company)

5.4 Electrohydrodynamic ('EHD') Effect

An ElectroCell application of electrostatic treatment for control of suspended solids control in 2001 also showed substantial chiller savings (shown below) from data collected by the client at a pharmaceutical site.

The condensers were known to be completely clean and investigation of the source of the additional efficiency led to ElectroCell personnel meeting with Michael M. Ohadi, University of Maryland at College Park, Center for Environmental Energy Engineering, Department of Mechanical Engineering.

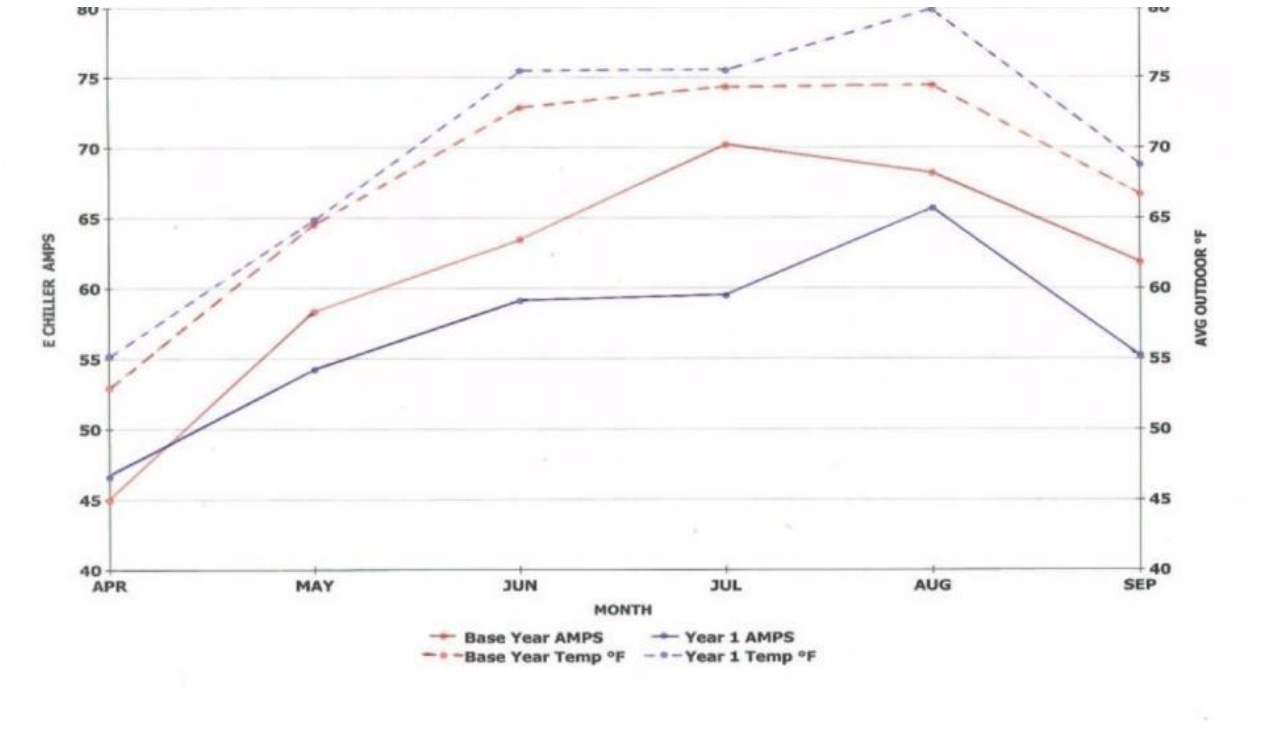

Figure 17: ElectroCell Customer Energy Savings Results

Dr. Ohadi and his fellow researchers had extensively studied the effects of electrostatic treatment and confirmed the scientific basis for substantially improved heat transfer with the ElectroCell application.[17]

The Electrohydrodynamic ('EHD') effect refers to the coupling of an electric field with the fluid flow in a dielectric fluid medium. The net effect is the production of secondary motions that destabilize the thermal boundary layer near the heat transfer surface, leading to heat transfer coefficients that are substantially higher than those achievable by the conventional enhancement techniques.[18]

Dr. Ohadi's 2004 report describes several dozen EHD research projects and results as well as the introductory comments on the following page.

[17] Ohadi, M.M., Darabi, J., Roget, B., *Electrode Design, Fabrication, and Materials Science for EHD-Enhanced Heat and Mass Transport.* Department of Mechanical Engineering, University of MD, College Park, MD. Meeting 2001.

[18] Wu, J., Ohadi, M.M., Dessiatoum, S., Starner, K.E., *An EHD- Enhanced Tube bundle Condenser.* AHX/EHD Consortium, MD, (2001)

Electrode Design, Fabrication, and Materials Science for EHD-Enhanced Heat and Mass Transport

M. M. Ohadi, J. Darabi, B. Roget
Advanced Heat Exchangers/EHD Laboratory
Department of Mechanical Engineering
University of Maryland, College Park, MD 20742

"Research in the past two decades by a number of independent researchers has clearly established the significant potential of the EHD technique for heat transfer enhancement of industrially significant fluids such as air, liquids, refrigerants, aviation fuels, oils, etc. The work has included successful design and testing of laboratory-scale heat exchangers with active participation of industrial sponsors. With the rapid advancement and expansion of the electronics and computers into new applications, the prospects for electronically controllable heat transfer surfaces utilizing electric fields are finally very encouraging".

"The EHD technique has high payoff potential and promising applications for energy systems in defense applications as well as non military industries. The commercial applications of the EHD technique are extensive and include industrial heat exchanger equipment for waste heat recovery, refrigeration and air conditioning, electronic cooling, cryogenic and process industry applications, laser medical and industrial cooling, and microelectromechanical systems (MEMS)-based technologies."

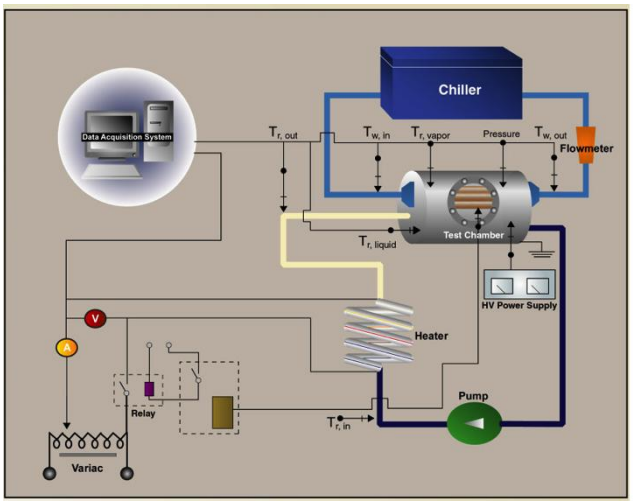

Figure 18: Diagram of test setup for Electrohydrodynamic (EHD) enhanced heat exchanger, M. Ohadi, Advanced HX Consortium/S2TS, January 2004

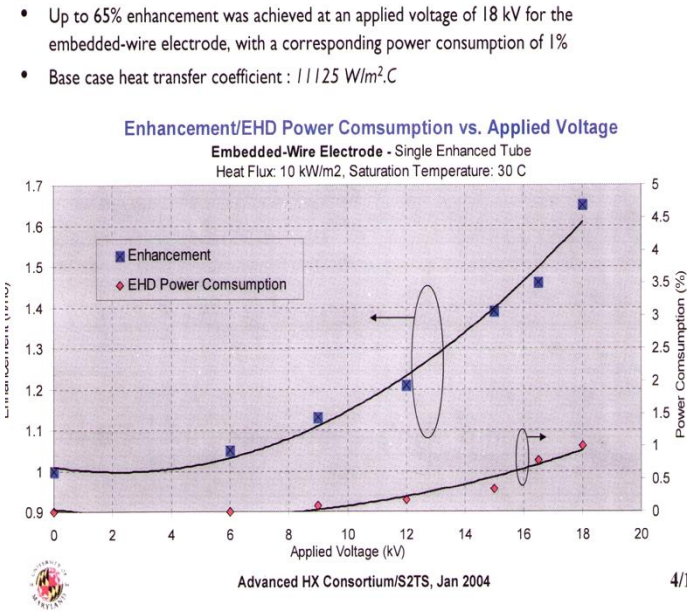

Figure 19: Test results showing Electohydrodynamic heat transfer enhancement up to 65% at 18 kVDC

6. ElectroCell System Automation

The Xcell Assembly system is fully automated with a control enclosure, touch screen for color graphic display and setpoint entry, programmable logic controller ('PLC') for fully automatic control and connection to building automation systems (enclosed in red below). All controls, power supplies, control devices and sensors are fully prepiped and prewired, ready for automatic operation. All systems are fully tested at the ElectroCell assembly plant prior to shipping.

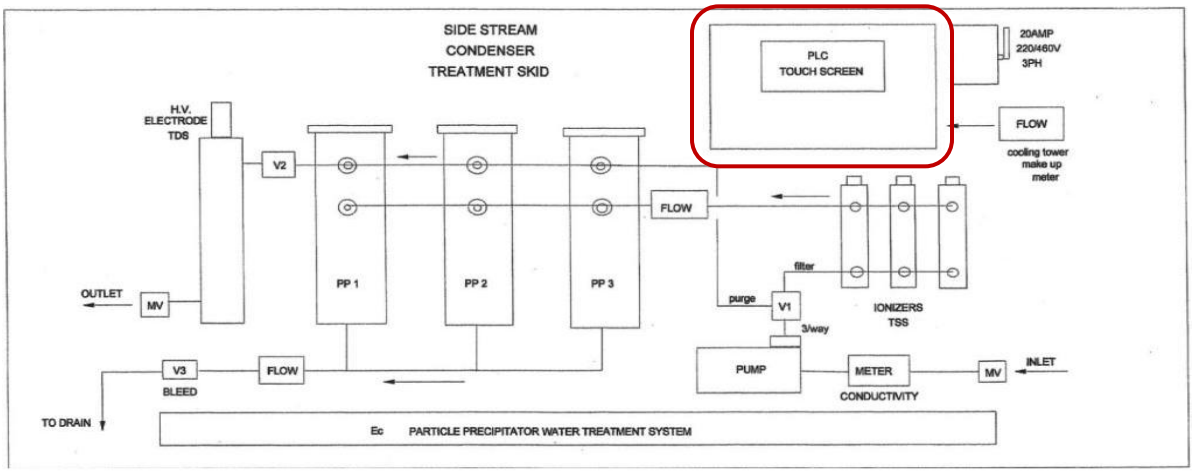

Figure 20: Xcell Assembly Automation and Control System

6.1 Automatic Control Sequences

- Pump Speed control via variable frequency drive
- Conductivity Control via bleed cycle
- Timed Purge Cycle
- Electrode Power Fault, shutdown with audible alarm

6.2 Monitoring with Colorgraphic Display

- Pump Speed %
- System Water Pressure (PSIG)
- Conductivity (µ mho)
- Filtered Flow Rate - GPM and Accumulated gallons
- Bleed Flow - GPM and Accumulated gallons
- Makeup Water - Accumulated gallons
- Bleed/Purge Status

6.3 Building Automation Connectivity

The system may be connected to building automation systems for remote connectivity via BACnet or Modbus.

7. ElectroCell Performance Claims

ElectroCell Systems Inc. lists the following claims for capabilities and performance of the Condenser Water Management Systems as applied to open-loop chilled water plants with average seasonal load of 500 refrigeration tons or higher and which also meet the following minimum criteria:

- ✓ Chillers, pumps, cooling towers, and piping are in reasonable working order
- ✓ Plants are reasonably supported, maintained, and monitored with professional facility personnel
- ✓ Plants have a successful chemical treatment system in place

ElectroCell Claims:

Chiller Energy – Improved chiller efficiency

- Improvement of 10% more in chiller efficiency (in kW/Ton)
- Improved heat exchange in the condensers
- Fouling eliminated or reduced to design minimum

Makeup Water – Improves makeup water efficiency

- With 92% to 97% solids removal
- 20% less makeup water required
- Blowdown will reduce accordingly

Maintenance – Reduced maintenance efforts and costs

- Reduced or eliminated tube punching in condensers
- Reduced of pump seals and replacement of bearings
- Eliminated filter media replacement

Chemical Treatment – Improves chemical treatment effectiveness

- With 20% or more reduction in water use, less chemical required
- With removal of suspended solids down to 1 micron, less halogen/biocide required

8. Partial Client Reference List

JOHNSON & JOHNSON HEADQUARTERS
New Brunswick, NJ
(Chillers, Cooling Towers, Boilers, DHW, Filter)

JOHNSON HALL
New Brunswick, NJ
(Chillers, Cooling Towers, Boilers, DHW, Filter)

MERCK
Summit, NJ
(Chillers, Cooling Towers, Indoor Fountains)

MERCK
Rahway, NJ
(Chillers, Filter)

BRISTOL-MYERS SQUIBB
New Brunswick, NJ
(Chillers, Cooling Towers, Vacuum Pumps)

ROBERT WOODS JOHNSON FOUNDATION
Princeton, NJ
(Chiller, Cooling Towers, Filter)

JANSSEN PHARMACEUTICAL
Raritan, NJ
(Cooling Tower, Atlas Copco Air Compressors)

PPL (Pennsylvania Power & Light)
Allentown, PA
(Chillers, Cooling Towers, Lobby Water Falls/Fountain)

CHRISTIAN HEALTH CARE CENTER
Wyckoff, NJ
(Chillers, Cooling Towers, Filter, Heat Pumps)

PALL LIFE SCIENCE
Fajardo, Puerto Rico
(Chillers, Cooling Towers, Filter)

JANSSEN PHARMACEUTICAL
Gurabo, Puerto Rico
(Chillers, Cooling Towers)

ANHEUSER BUSCH
Merrimack, NH
(600-ton Ammonia System w/Cooling Tower)

AT&T CITY CENTER
Birmingham, AL
(Chillers, Cooling Towers, Filter)

AT&T MAIN
New Orleans, LA
(Chillers, Cooling Towers, Filter)

AT&T
Wayne, PA
(Chillers, Cooling Towers, Filter)

AT&T
Norfolk, VA
(Chillers, Cooling Towers, Filter)

PECO (Philadelphia Electric Company)
Headquarters Bldg., Philadelphia, PA
(Chillers, Cooling Towers, Filter)

PECO (Philadelphia Electric Company)
Market Street Bldg., Philadelphia, PA
(Chillers, Cooling Towers, Filter)

PECO (Philadelphia Electric Company)
Service Center Bldg., Philadelphia, PA
(Chillers, Cooling Towers, Filter)

PECO (Philadelphia Electric Company)
Plymouth Meeting, PA
(Chillers, Cooling Towers, Filter)

HYATT REGENCY
New Brunswick, NJ
(Chillers, Cooling Towers)

BAYSIDE CONSULTING GROUP
Gwynedd, PA
Engineering Group

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