GOING "GREEN" UTILIZING A PRETREATMENT PROCESS FOR RECYCLED WATER USE IN COOLING TOWERS

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Introduction

Use of recycled water in cooling towers presents a unique challenge due to conflicting goals and characteristics. Ideally, cooling towers evaporate water resulting in two (2) to six (6) cycles of concentration of minerals before a significant portion (17-50%) of the recirculated water must be discharged or "blown down" to the sanitary collection system. The actual cycles of concentration that may be implemented in a given recirculating cooling tower system will vary depending on the concentration of scale-forming minerals in the make-up water and the treatment program chosen to mitigate scaling and reduce metal loss due to corrosion.

The use of lower cost recycled water, in lieu of higher priced potable water, as a make-up source in a recirculating cooling tower system has generally led to difficult operational and maintenance issues resulting from higher mineral and organic solids contained in the recycled water. These issues have traditionally resulted in fewer cycles of concentration, significant increases in chemical consumption and treatment cost, increased discharge of BOD and COD to sewers, lower cooling efficiency due to formation of bio-film and scale on heat transfer surfaces, and increased operational cost to clean and maintain the cooling system.

Amylin Pharmaceuticals Inc. (Amylin), located in San Diego, CA, recently completed recycled water retrofits at two of its facilities. The retrofits included the typical transition from the use of potable water to recycled water for irrigation and a large decorative reflecting pond. However, following the completion of an Alternative Cooling Water Treatment Evaluation by RBF Consulting (Bowdan III & Rahimian-Pour, 2011), Amylin also implemented a recycled water retrofit of its existing cooling tower utilize a newer "green" technology that employs simple filtration and softening (cation-exchange) processes to pretreat recycled make-up water. This unique pre-treatment of the recycled water addresses many of the issues traditionally inherent in recirculating cooling tower systems and results in increased operational efficiency through decreased water use, elimination of scale formation, reduction in corrosion and biological activities, and minimization of chemical use. Make-up water use and blow down to the sewer are significantly reduced by increasing the cycles of concentration within the cooling tower well above that typically permissible using a conventional cooling tower treatment regime.

The filtering and softening pretreatment process removes scale forming ions and permits the recycled water to be highly cycled within the cooling tower which increases total dissolved solids (TDS), pH, and naturally occurring silica. The high TDS and pH provide a naturally biostatic environment in which the silica forms a thin inhibition layer on metal heat exchange surfaces that enhances corrosion control. As a result of the pretreatment implementation, several benefits are derived in the cooling tower:

- ♦ The use of recycled water in cooling towers frees up valuable local potable water resources for drinking water purposes,
- ♦ High cycles of operation provides significant reduction in cooling tower water blow-down to the sanitary sewer,

- Silica, a naturally occurring constituent in the water, converts to a corrosion inhibitor in the cooling water, minimizes or eliminates the need for an additive chemical corrosion inhibitor, and significantly reduces metal corrosion rates,

- Pre-treatment utilizing softening eliminates the potential for scale formation in the cooling water system by removing scale-forming ions,

- The high TDS and pH of the highly cycled cooling water creates a natural biostatic environment, prevents bacteriological growth, and minimizes or eliminates the need for additional biocide chemicals,

- Without scale or biogrowth, efficiency of the cooling system is increased and annual cleaning costs are reduced,

- Testing and control of the water treatment program are greatly simplified, and system reliability is monitored online 24/7 for remote performance assurance and proactive response.

Most importantly, the pretreatment technology provides a significant opportunity to expand water reuse in California by increasing the retrofit and conversion of existing and proposed cooling tower systems to recycled water use. This paper discusses the implementation of the recycled water pretreatment technology on a cooling tower at an existing Amylin Pharmaceutical facility, preliminary life cycle cost analysis, and preliminary implementation considerations. Follow-up discussion of ongoing field analysis regarding water reduction, chemical use, scale control, corrosion rates, and biostatic environment at the Amylin site will be provided in a separate technical paper.

Background

Amylin desired to reduce its potable water procurement costs and implement conservation efforts to free of potable water supply in the San Diego Region by switching from potable water to recycled water for irrigation and other non-potable use purposes. This desire was birthed from Amylin's previous conversion of another facility to recycled water use several years prior. To achieve these goals, Amylin initiated design in January 2011 for the implementation of recycled water retrofit projects at their newest facilities located at 9360 and 9390 Towne Centre Drive in San Diego, CA.

Figure 1: Photos of Amylin Building and Cooling Tower Mechanical Yard

Recycled water retrofit engineering plans were prepared by RBF Consulting, pursuant to City of San Diego (City), San Diego County Department of Environmental Health (DEH), and California Department of Public Health (CDPH) requirements. The retrofits at 9360 included conversion of the irrigation system and a large decorative reflecting pond to recycled water use. The retrofits at 9390 included conversion of the irrigation system and cooling tower system make-up water to recycled water. Due to the proposed cooling tower conversion at 9390, RBF performed an alternative treatment technology analysis for review and consideration by Amylin. Upon Amylin's approval to include the alternative treatment technology in the cooling tower retrofit design, a separate Title 22 Engineering Report was prepared for review and approval by DEH and CDPH. Construction permitting and approvals were received by early July 2011 and construction of the project commenced immediately thereafter. Project construction was completed by mid-August and cross-connection tests were performed by late-August/early September. Approval for release of the recycled water meters was received in late October 2011. Recycled water meter installation and start-up occurred on November 3, 2011.

Cooling Tower Basics

Evaporative cooling towers are used as part of a heat transfer process to remove heat generated within buildings by people and/or equipment. Considered one of the most efficient means of heat transfer, evaporative cooling towers operate on the principle of heat transference from a hot water stream to a moving air stream. A small portion of the recirculated water evaporates as it comes into contact with the air stream. The process of the water changing from a liquid state to a gaseous vapor (evaporation) requires that heat be extracted from the water stream to the air. As a result, the water stream is cooled and the air stream is heated and humidified as it is released to the atmosphere. The cooled water is then returned or recirculated back through the conditioned space or process to absorb more heat and the cycle repeats. A large volume of water is recirculated while a smaller portion is evaporated. A typical evaporative cooling tower is shown in Figure 2.

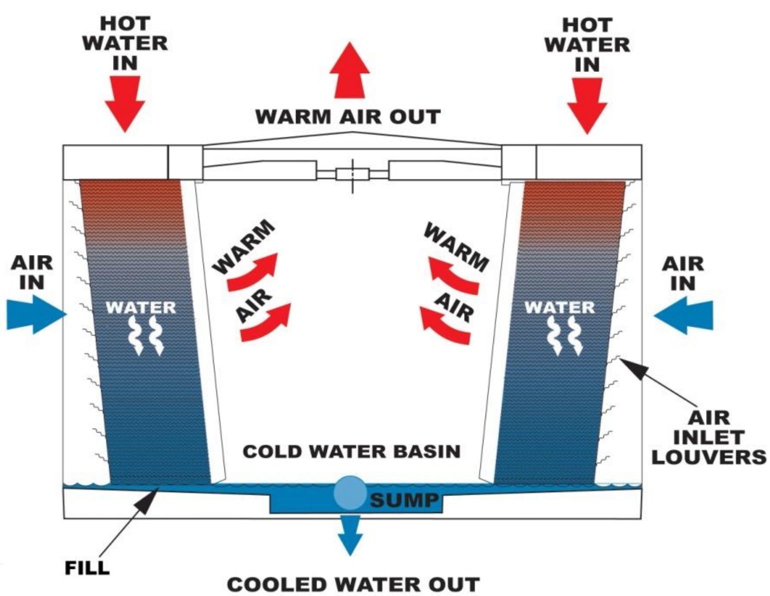

Figure 2: Typical Evaporative Cooling Tower (Courtesy of Baltimore Aircoil)

Water Loss from Cooling Towers

Over time, the recirculated cooling water is lost to the atmosphere by evaporation. This lost water must be replaced by adding additional water or "make-up water" to the cooling tower from a water source. The typical make-up water to a cooling tower is derived from a potable source; however, other sources including raw water, groundwater, and recycled water may be utilized with appropriate treatment. As water is evaporated from the cooling tower, solids (dissolved and suspended) are left behind and concentrated within the remaining cooling water. The various types of minerals, salts and organic solids present in the cooling water will determine how many times these constituents can be concentrated per unit volume of water within the cooling tower. This process of increasing or concentrating solids per unit volume of cooling water is referred to as "cycle of concentration." The cycle of concentration in a cooling tower is controlled by periodically discharging the high solids to sewer in a process called "blowdown" and replacing this lost water with lower solids concentration make-up water. Therefore, make-up water is required to replace water lost by both evaporation and blowdown. The relationship between make-up water, evaporation and blowdown is shown below in the Simplified Water Balance Diagram provided in Figure 3.

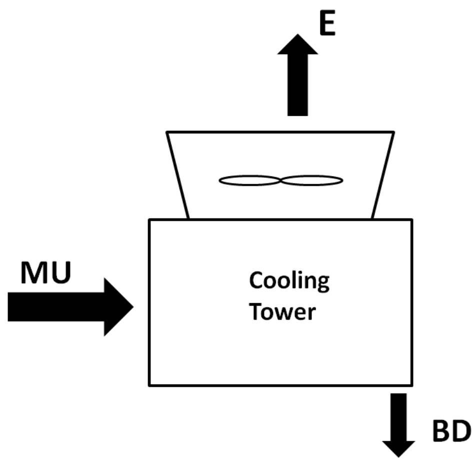

Figure 3: Simplified Cooling Tower Water Balance Diagram

From the diagram contained in Figure 3, and negating water loss associated with drift, the make-up water required (MU) is equal to the evaporation (E) plus blowdown (BD). The cycles of concentration (COC) of a cooling tower can be easily approximated by dividing the make-up water required by the blowdown.

Water Quality Considerations

The water quality of the make-up water source must be considered when evaluating the design and operation of a cooling tower. The primary concern of cooling tower operation at an increased cycle of concentration includes scale prevention, corrosion minimization, and prevention of biological activity.

Scaling of the heat transfer surfaces of a cooling system may occur due the presence of scale forming cations such as calcium and magnesium. These cations will combine with carbonate, phosphate sulfate, silicate and other anionic species to form compounds that will begin to precipitate or crystallize as their concentrations increase toward their saturation points forming scale deposits within the cooling system. Scale deposits will coat heat transfer surfaces and reduce heat transfer efficiency or clog heat transfer tubing. In addition to increasing concentrations, the saturation point of calcium based scaling compounds also tend to decrease as temperature increases which results in the potential for scale formation at higher temperatures but lower cycles of concentration. Traditional cooling tower treatment typically requires the use of a scale inhibiting chemical to prevent scale formation at high temperature while allowing increased cycles of concentration.

Corrosion within a cooling system can be caused by several mechanisms within the aqueous environment of the cooling system including oxidation, galvanic or microbial action. Cooling towers are primarily constructed of ferrous metals and may employ copper alloys and corrosion resistant materials such plastics. With metal materials such as steel, galvanized steel, stainless steel, and copper alloys, the goal of any corrosion control program is to minimize and control metal loss since corrosion prevention is difficult at best. Corrosion control of an open recirculating cooling system is typically provided by either corrosion resistant material selection, use of chemical corrosion inhibitors, or a combination of both.

Cooling towers are renowned for their ability to incubate and encourage microbial growth. This is generally caused by several factors including warm temperature, suitable pH, and nutrients or food sources contained in the water. One common microbial concern linked to cooling towers is *Legionella pneumophila* which has been shown through research to be capable of becoming airborne and traveling distances of 6 km or more. Therefore, cooling tower operation requires the use biocides or other means of microbial control to prevent the growth of bacteria and the potential spread of infectious diseases.

Amylin Cooling System Description Prior to Retrofit

The existing Amylin cooling system is of the recirculating open cooling type employing an induced counterflow cooling tower. The design parameters of the cooling tower are provided in Table 1.

Table 1: Amylin Cooling Tower Design Parameters

Parameter	Unit	Value
Cooling Capacity	Ton	500
Delta T	Degrees F	10
Recirculation Rate	gpm	1500
Evaporation Rate[1]	gpm	12

Notes: 1. Calculated, see report discussion

Prior to retrofit, the Amylin cooling system utilized City of San Diego potable water as the make-up water supply source. Make-up water supply to the Amylin cooling tower was not separately metered from other industrial water uses. However, the cooling tower chemical feed control system utilized online conductivity monitoring to measure make-up water and cooling water conductivities to control chemical injection. Based on the ratio of cooling tower conductivity to feed water conductivity, the cycle of concentrations was calculated as 3.2. Using the cooling tower design parameters from Table 1 coupled with the known cycles of concentration, the average annual evaporation, blowdown, and make-up water rates using the following equations:

Average Evaporation (E_{avg}) = Recirculation Rate * Delta T * 0.8 / 1000
= 1,500 * 10 * 0.8 / 1000
= <u>12 gpm or 17,280 gpd</u>

Blowdown Rate (BD) = E_{avg} / (cycles of concentration – 1)
= 12 gpm / (3.2 – 1)
= <u>5.5 gpm or 7,855 gpd</u>

Make-Up Water (MU) = E_{avg} + BD
= 12 gpm + 5.5 gpm
= 17.7 gpm or 25,135 gpd

The calculated values for average evaporation (E_{avg}), blowdown (BD), and make-up (MU) water were used as the basis for the economic evaluation of traditional chemical treatment versus alternative technology treatment presented later in this technical paper. Additionally, it is noted that the existing cooling tower system appeared to be operated sub-optimally considering the fairly good quality of City of San Diego potable water. Based on an optimally operated system, it is theorized that the existing cooling tower could have been operated at up to 5.0 cycles of concentration with appropriate chemical treatment. As a result, the calculated values for average evaporation, blowdown, and make-up water rates at 5.0 cycles of concentration are 17,280 gpd, 4,320 gpd, and 21,600 gpd, respectively. These values were also considered in the economic analysis.

Recycled Water Quality

Make-up water to the Amylin cooling tower is now supplied via a connection to the existing City of San Diego recycled water distribution main located in Towne Centre Drive. The recycled water is produced at the City of San Diego North City Water Reclamation Plant (NCWRP) which is located within one mile of the Amylin facility. Table 2 presents the NCWRP annual average recycled water quality.

Table 2: City of San Diego NCWRP Average Recycled Water Quality

Parameter	Unit	Value
pH	pH Unit	7.11
Total Alkalinity	mg/L as CaCO3	109
Ortho-Phosphate	mg/L as PO4	5.8
Nitrate	mg/L as NO3	45.1
Total Organic Carbon (TOC)	mg/L	8.6
Chloride	mg/L	239
Fluoride	mg/L	0.4
Sulfate	mg/L	226
Total Dissolved Solids (TDS)	mg/L	914
Silica	mg/L	12
Aluminum	mg/L	0.12
Barium	mg/L	0.038
Calcium	mg/L	65
Magnesium	mg/L	28.1
Total Hardness	mg/L as CaCO3	278
Iron	mg/L	0.086
Copper	mg/L	0.026
Manganese	mg/L	0.066
Sodium	mg/L	187
Zinc	mg/L	0.022
Ammonia	mg/L as N	0.3

As presented in Table 2, the presence and high concentration of ortho-phosphate (5.8 mg/L as PO4), nitrate (45.1 mg/L as NO3), and total organic carbon (8.6 mg/L) in the recycled water would significantly increase the potential for biological activity in recirculating cooling water system as these constituents provide a source of nutrients for any microorganisms that may be present in the recirculating water. In addition, high levels of ortho-phosphate in the recycled water would significantly increase scale formation due to precipitation of calcium phosphate at high cycles of concentration. Ammonia is present at a concentration of 0.3 mg/L as Nitrogen (N), which may result in the accelerated corrosion of copper and copper alloys. Existing cooling tower systems utilizing copper-based material would require periodic injection of a copper corrosion inhibitor. The Amylin cooling tower is primarily stainless steel basin construction with galvanized steel structural and upper section construction and carbon steel recirculating piping system; therefore, the elevated ammonia will not pose an additional corrosion concern.

Due to the presence of the above mentioned contaminants coupled with the elevated concentration of total dissolved solids (TDS) in the recycled water, the cooling tower system would generally need to be operated within a range of 3.0–3.5 cycles of concentration based on the use of a conventional chemical treatment program. Compared to typical potable water quality, the use of recycled water with traditional chemical treatment will generally result in an increase in the blow-down rate and make-up water requirement for the system as a result of the required lower cycles of concentration. Furthermore, the chemicals required for corrosion inhibition, scale prevention, and biological activity control will generally increase at the lower cycle of concentration to control the presence of above mentioned contaminants in the cooling water system. Therefore, pretreatment of the recycled water becomes necessary to provide optimal cooling system operation.

Alternative Green Pre-Treatment Technology

The pre-treatment process selected for the Amylin Pharmaceuticals recycled water cooling tower make-up supply is the patented green developed by Water Conservation Technology International (WCTI). A photo of the installed pre-treatment at Amylin is provided in Figure 4.

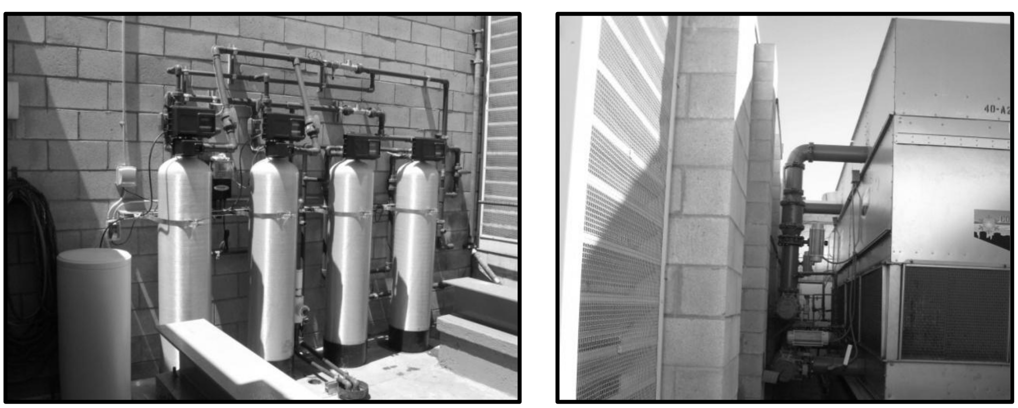

Figure 4: Alternative Technology Installation at Amylin Pharmaceuticals

The authors of this technical paper became aware of the WCTI technology upon review of a separate technical paper originally presented at the 2009 California WateReuse Annual Conference (Walters & Duke, 2009). The subject technology was employed for use at a major automotive design and manufacturing facility utilizing West Basin Municipal Water District (WBMWD) Title 22 tertiary disinfected recycled water as the cooling tower system make-up water source. Further investigation revealed several hundred installations of the subject technology using various source waters in cooling tower projects spanning the high tech data center, aerospace, commercial/institutional, and industrial market sectors. The oldest installations of the technology have now been in continuous successful operation over eight (8) years.

WCTI's patented green process uses well known general water chemistry principles, which have been separately employed in various segments of the water treatment industry to provide a unique, natural, and proven method for using recycled water, reducing overall water use, and minimizing chemical requirements specifically for cooling towers. The technology utilizes the natural minerals present in a typical recycled water source to provide corrosion inhibition, scale prevention, and biological control within the cooling water system. The process utilizes multi-media filtration system to ensure a recycled water turbidity of less than 1.0 NTU followed by a high efficiency softening (HES) system. Additionally the filtration system prevents fouling of the resins in the softening process and reduces the suspended solids concentration in the cooling water as the cycle of concentration is increased.

Scale and Corrosion Control
After softening of the water, the remaining natural chemistry in the source water used beneficially by the WCTI process includes silica, alkalinity, and total dissolved solids, which perform productive roles when concentrated in the cooling water system. Simple evaporative concentration of these source water minerals results in the polymerization of silica to amorphous polysilicates that provide corrosion inhibition of metal surfaces at saturation concentrations. Excess silica in the cooling water will form soluble and meta-stable silica colloids that do not form heat transfer inhibiting deposits since low solubility salt scales that result from calcium or magnesium have been removed by the high efficiency softening process.

Water Use Reduction
Based on the NCWRP recycled water quality presented in Table 2, the Amylin cooling tower will be ramped up to fifty (50) cycle of concentration using the alternative WCTI pre-treatment technology. This high cycle of concentration is a direct result of the removal of scale-forming cations (calcium and magnesium). The high cycle of concentration in the cooling tower is further based on the need to maintain silica and total dissolved solids within a desirable and easily maintainable concentration and pH range. This high cycle of concentration significantly reduces the blow-down rate and makeup water requirement, and also eliminates the addition of corrosion inhibitor, scale inhibitor, and biocides. Based on 50 cycles of concentration and utilizing the cooling tower design parameters of Table 1, the total make-up water requirement and blowdown are reduced to 17,633 gpd and 353 gpd respectively resulting in water savings of about 30% when compared to the prior tower operation at 3.2 cycle of concentration.

Biological Control
The high cycles of concentration in the Amylin cooling tower result in high concentrations of TDS and alkalinity which also causes an increase in the pH of the circulated cooling water. High TDS (Heller, Holler, & others, 1998) and pH (States, Conley, & others, 1987) are prohibitive to biological activity including *Legionella pneumophila*; therefore the cooling water becomes naturally bio-static at the high cycle of concentration attained with reduction in blow-down. This bio-static chemistry is a natural process that also appears to mitigate pathogen risk and endocrine chemistry contaminant issues. Coliform testing, conducted as part of other projects by third party organizations, has shown bacterial colonies to be non-existent (10^0 CFU/ml at 48 hours). Ongoing testing at the Amylin cooling tower is expected to confirm the results of others.

Simplified Operation
High concentration of TDS also provides increased natural solubility of calcium and magnesium salts due to the "non-common ion effect" (an example of this is seawater). This provides very forgiving

tower water chemistry in the event of hardness upset, precluding scale deposition. Furthermore, with tower control at high TDS and soft water control ranges, calcium and magnesium deposits will be removed from prior scaled systems. This process simplifies the complexities of tower water chemistry control, hazards for storage and handling of chemicals, and increases reliability with reduced testing and control actions. Minimization of chemical use is afforded by use of the naturally occurring chemistry of the water. The softening step requires only the procurement of high quality salt for regeneration.

Economic Analysis Results

An economic analysis was performed prior to the start of design for the Amylin recycled water retrofits. The purpose of the analysis was to determine the expected cost savings of converting to recycled water use and implementing the alternative WCTI pre-treatment technology. The analysis compared the former cooling tower operation on potable water using traditional chemical treatment at the suboptimal (typical) 3.2 cycle of concentration and optimal 5.0 cycle of concentration to that of the revised operation using recycled water at 50 cycles of operation. The results of the analysis are summarized in Table 3.

Table 3: Economic Analysis Summary

Description	**Previous Chemical Treatment Program**	**Revised Chemical Treatment Program**	**Alternative WCTI Technology**
Operational Data			
Make-up Water Source	100% Potable Water	100% Potable	100% Recycled Water
Annual Average Evaporation, gpd	17,280	17,280	17,280
Annual Average Blow-Down Rate, gpd	7,855	4,320	353
Annual Average Make-up Water Rate, gpd	25,135	21,600	17,633
Cycle of Concentration	3.2	5.0	50
Annual O&M Cost Comparison			
Annual Make-up Water Cost [1]	$44,645	$38,366	$6,883
Annual Blow-Down Cost [2]	$28,747	$15,810	$1,291
Annual Chemical Cost[3]	$8,000	$10,000	$0
Annual Salt Cost for Softening System	$0	$0	$2,300
WCTI Service/Patent Program Cost	$0	$0	$9,600
Total Annual O&M Costs	**$81,392**	**$64,176**	**$20,074**
Annual Cost Savings of Alternative WCTI Technology with Recycled Water	**$61,318**	**$44,102**	**$0**
WCTI Equipment Cost			$14,050
WCTI Equipment Installation Cost			$7,300
Total WCTI Capital Cost[4]			**$21,350**
Return on Investment (ROI), Months	**4.2**	**5.8**	

Notes:

[1] Make-up water cost is calculated based on the recycled water @ $0.80/HCF and potable water @ $3.64/HCF.

[2] Blow-down cost is calculated based on the sewer discharge cost @ $7.50/HCF.

[3] Chemical cost was provided by estimated by RBF based on part year consumption data.

[4] Equipment and installation costs provided by WCTI.

As shown in Table 3, implementation of the alternative WCTI pre-treatment technology with recycled water at Amylin will result in annual savings ranging from $44,000 to $61,000 when compared to previous optimized and non-optimized operation on potable water with traditional chemical treatment. The analysis results will be verified against actual operation and maintenance data to be generated as the Amylin site continues to ramp up to the desired operating regime of 50 cycle of concentration. The results of this continued data collection will be presented in a future technical paper.

System Reporting and Monitoring

The Amylin pre-treatment system is equipped with a remote monitoring system which allows real-time monitoring of the system function and advanced alarming for any events that could result in cooling tower upset. Daily graphs containing information including hourly softened water flow, make-up water feed pressure, and regeneration conductivity provide sufficient data to verify proper operation of the pretreatment system and cooling tower. An example of a recent chart providing specific operational data for the Amylin cooling tower and pre-treatment system is provided in Figure 5.

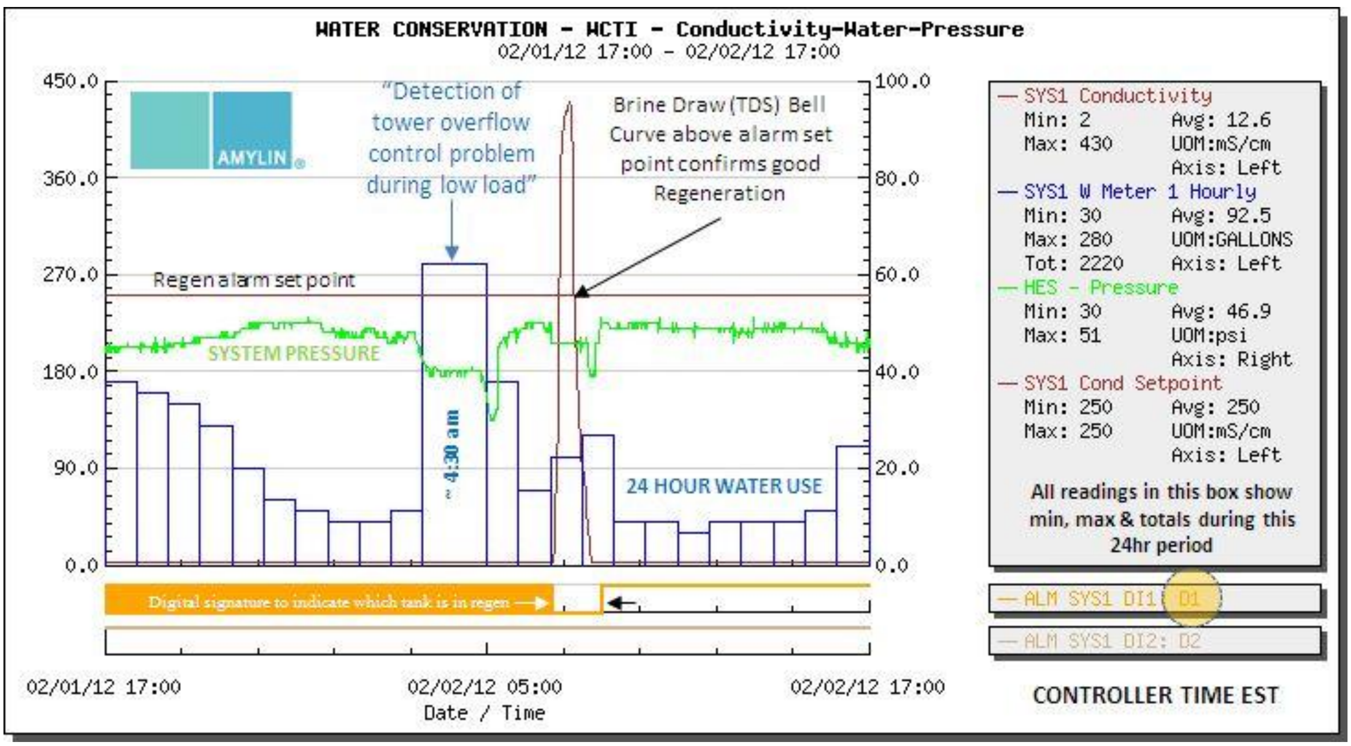

Figure 5: Amylin Remote Monitoring Data Graph (February 2, 2012)

The remote monitoring graph above provides several key pieces of information concerning system operation on February 2, 2012. A cooling tower basin overflow situation occurred at about 4:30 a.m. resulting in excess make-up water being supplied to the tower. The basin overflow to drain was caused by a leaking make-up water valve that requires replacement. Later in the morning, HES No. 1 executed a regeneration cycle. This was a normal event and was confirmed by the data showing successful regeneration. Cooling systems that are considering implementing the alternative WCTI pre-treatment technology should consider the addition of remote monitoring capabilities for regular data reporting of system operating conditions and alarms.

Conclusion

The Amylin cooling tower recently began operating on recycled water utilizing the green alternative pre-treatment technology supplied by WCTI. The use of the alternative technology provides for the potential of greater implementation of cooling tower retrofits by existing and proposed recycled water customers. The alternative technology provides the benefits of lower cost recycled water, reduced water use, minimization of treatment chemicals, and microbial control. Furthermore, the natural chemistry created by removing scale-forming ions and high cycling the process provides natural scale prevention and corrosion control. While the technology is not suitable for every cooling system environment, it provides a means to address most difficult applications including recycled water use while providing the afore-mentioned benefits.

Like any other cooling tower treatment technology, successful operation will require regular testing and data collection to verify system operational performance. The remote monitoring feature of the WCTI system has allowed Amylin to discover prior operating inefficiencies caused by faulty make-up and cooling water loop valves which were previously masked by tower operation at lower cycles of concentration. The monitoring system allows the cooling system operator to provide proactive management of the cooling tower environment while benefitting from lower operational costs.

The Amylin site is currently being ramped up to the desired high cycle of concentration range of operation as the prior cooling tower inefficiencies are corrected. A separate technical paper will present detailed operational data confirming the performance of the Amylin cooling tower to the preliminary data and information provided in this technical paper.

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