The STrategic Envirotechnology Partnership

Green Book Technology Summary Report

Utilizing:

VRTX Technology

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DISCLAIMER

This document is designed to assist the user in analyzing the application of specific technologies. While it provides a template for the general types of questions that you should ask when evaluating a technology, it may not include all of the questions that are relevant to your business, or which your business is legally required to ask.

This document is intended to assist envirotechnology users, developers, and investors to make informed decisions about the commercial potential, process and environmental performance of specific products or prospective products under development. This document is not intended to communicate the full market scope or competitive position of any of the underlying technologies embodied by the product, but rather to illustrate the comparative effectiveness, or potential effectiveness, of that technology in the form of one or more specific products.

Table of Contents

Introduction

This technology application analysis characterizes the main features of the VRTX technology, manufactured by A.W. Chesterton Company. The VRTX technology can effectively prevent scaling, corrosion, and biological fouling in cooling tower systems without the addition of chemicals. The use of this technology replaces a traditional chemical treatment maintenance program for cooling towers.

This report presents the results from the installation of five full-scale applications of the VRTX technology, including regulatory aspects, costs associated with implementation, environmental and performance benefits, and lessons learned from the application experiences. The performance and cost data in this report was provided by the facilities, and unless otherwise stated, no information regarding the extent of QA/QC analysis was provided in conjunction with the data. All facilities used EPA certified labs for analysis of water samples. The Pillsbury facility provided hard copies of the water quality laboratory results including chain-of–custody documentation. In large part these facilities were chosen for the preparation of this document because they had data available on the performance of the VRTX technology. In an attempt to provide the reader with as much information as possible on existing VRTX installations, in the absence of QA/QC'ed data we present non-QA/QC'ed data, and in the absence of any quantitative analyses, we present qualitative analyses provided by employees at the facilities. The authors believe the data presented in this document represents the performance of the VRTX system at each of the installations.

Description of VRTX Technology

Cooling towers traditionally require the use of a chemical treatment maintenance program to prevent scaling, corrosion, and biological fouling. The VRTX system is a mechanically induced treatment system that prevents the formation of scale deposits, corrosion, microorganisms, and slime in the water and completely eliminates the need for a chemical treatment program. No chemicals are added to the cooling tower water. The following section describes cooling towers and the VRTX system in greater detail.

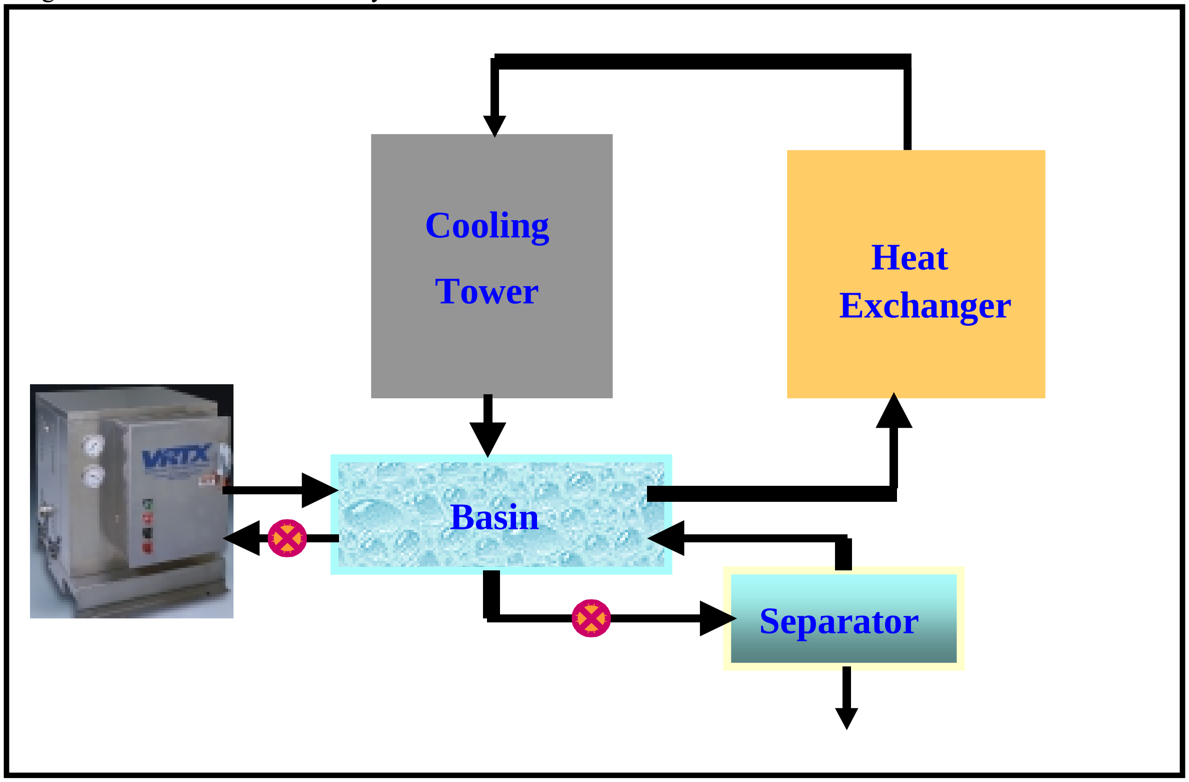
Technology Description

Cooling towers are used to remove heat from a wide range of industrial processes. In a traditional cooling tower set-up, re-circulating water is pumped from a basin into the heat exchange process (such as an air conditioning or refrigeration process). The effluent warm water from the heat exchange process is then pumped to the cooling tower. In the cooling tower, the water is sprayed onto wet decking (internal fill material designed to increase the surface area of the water), thus maximizing evaporation. Air is blown through the tower in a crossflow, counterflow, or parallel direction to the water flow. The water is cooled mainly through evaporative cooling as well as through some amount of sensible heat exchange (heat transfer from water to air). The cooled water is then pumped back to the basin, where the cycle continues. Make-up water is added to the basin to compensate for evaporation and water discharged as blowdown.

Although the circulation of water through cooling tower system saves a large amount of water, it also creates the need for an intensive maintenance system to control scaling, corrosion, and biological fouling of the cooling tower mechanism. Threshold inhibitors and acids are traditionally added to prevent scale. To prevent or slow down corrosion, anodic, cathodic, or combinatorial corrosion inhibitors are added. Both oxidizing and non-oxidizing biocides are used to kill microorganisms. All of these chemicals are traditionally added to the make-up water as it enters the basin and must be continually monitored to account for water chemistry changes.

The VRTX system is a completely chemical-free cooling tower water treatment technology. The VRTX unit, which connects to the basin water reservoir (see Figure1), consists of a mechanical device that uses hydrodynamic cavitation to remove solids and carbon dioxide (CO_2) from cooling tower water. Typically, a side-stream of water is removed from the cooling tower basin, pumped through the VRTX unit, and returned back to the tower basin. As the water exits the VRTX unit nozzles and enters the cavitation chamber, the equilibrium of the water chemistry is shifted, resulting in the off gassing of CO_2, the precipitation of solid calcium carbonate, and the coprecipitation of several other metal carbonate solids. The water discharge from the VRTX unit is returned to the basin and a second side-stream taken from the bottom of the cooling tower basin passes through a cyclonic separator or filtration system where the solid calcium carbonate precipitate and other incidental solids can be easily separated from the water and collected. The collected solids are backflushed or siphoned from the system daily.

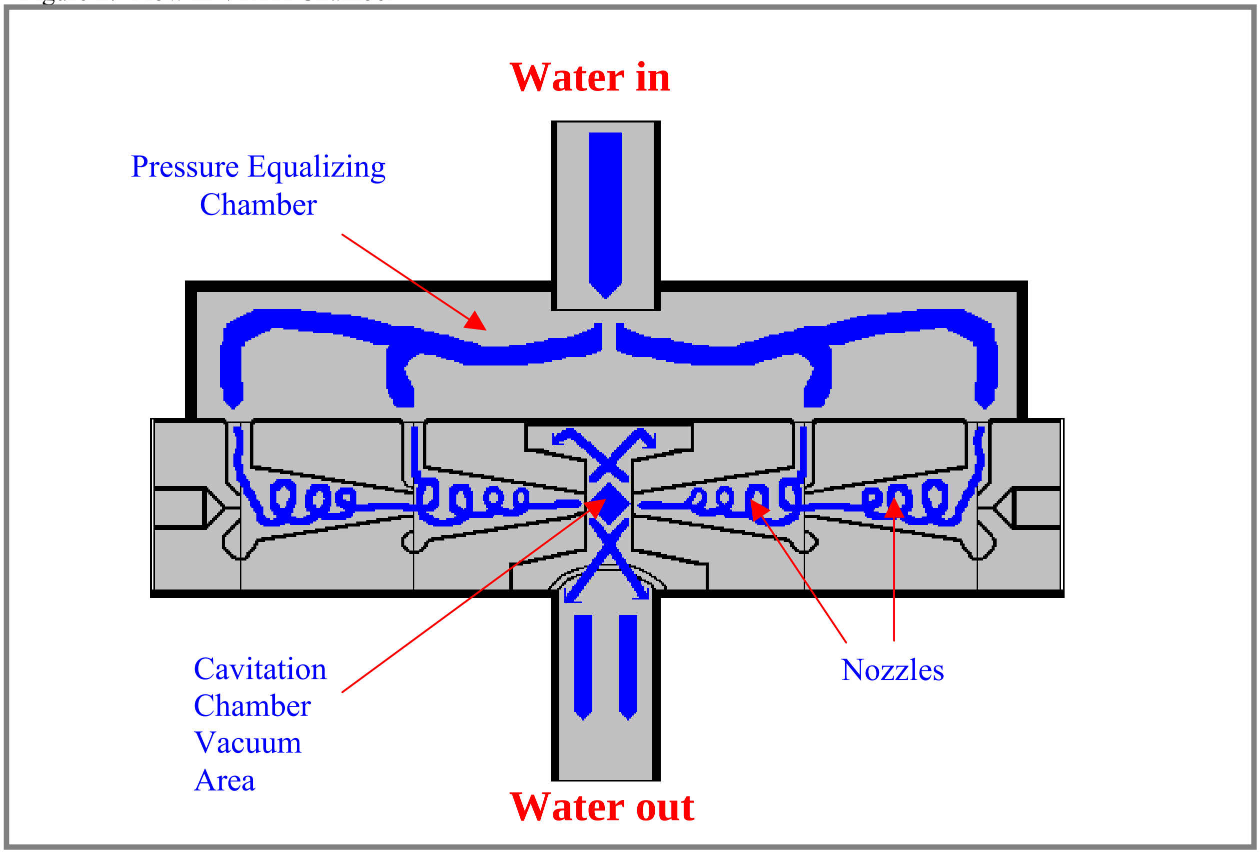
Figure 1: Placement of VRTX System



The VRTX unit consists of a pressure equalizing chamber and a cavitation chamber, as shown in Figure 2. Water is pumped from the cooling tower basin into the VRTX pressure-equalizing chamber at a pressure of approximately 70 psi. The water is then channeled into two pairs of opposing nozzles that impart a specific rotation and velocity to the water streams. The high velocity and turbulent flow generated in the nozzles creates micro-sized bubbles in the water stream. As this water exits the nozzles, the conical shaped water streams collide at specific angles in the cavitation chamber's mid-point, creating a zone of decreased pressure within the cavitation chamber. This differential pressure is metered and maintained at approximately 29 inches of vacuum by the VRTX unit. This change in pressure causes the implosive collapse of the microbubbles; a phenomenon known as hydrodynamic cavitation that causes the water chemistry equilibrium to shift. When this occurs, CO_2 and other dissolved gasses are released from the water streams and solid calcium carbonate precipitates out of solution accumulating in the cooling tower basin.

Hydrodynamic cavitation, which has been studied by researchers around the world including researchers at the Department of Chemistry at the University of Illinois at Champagne-Urbana, is the formation, growth, and implosive collapse of small gas bubbles within a liquid. Researchers at the University of Illinois have documented during the collapse of the bubbles that intense heat is generated for a very small amount of time, which can cause the formation of free radicals and other intermediate chemical species. Under these conditions, chemical reactions are forced to proceed. (For additional information on hydrodynamic cavitations and the facilitation of chemical reactions, see the American Chemical Society Article "Chemistry Induced by Hydrodynamic Cavitation" and other listings in the Reference Section at the end of this report.)

Figure 2: Flow in VRTX Chamber



Scaling

Minerals such as calcium and magnesium can form damaging scale deposits when exposed to conditions commonly found in cooling tower systems. As a result, preventing scale build-up is one of the primary objectives of a traditional cooling tower chemical treatment program. The most common type of scale is calcium carbonate, which forms on heat exchanger, piping, and cooling tower surfaces. Scaling occurs when the highly soluble and naturally occurring calcium bicarbonate decomposes into calcium carbonate and CO_2 gas. Unlike calcium bicarbonate, calcium carbonate has a very low solubility in water, approximately 15 mg/L, and unlike most compounds it tends to precipitate out of solution with increasing temperature. When the solubility limit is reached, calcium carbonate precipitates out of solution forming scale on heat exchange surfaces. The scale acts as an insulator thus reducing cooling tower efficiency and resulting in increased backpressure, higher pumping requirements, and increased energy use. A thin layer of scale can reduce heat exchange efficiency by as much as 15%.

At the cooling tower air-water interface, a portion of the water evaporates as water vapor, absorbing energy, and thus causing the remaining water to cool. The evaporated water leaves dissolved solids behind, increasing the remaining concentration of total dissolved solids (TDS), including calcium carbonate. Each time the water is recirculated the TDS concentration increases. Eventually, the water becomes saturated with calcium carbonate, resulting in precipitation and scale formation on heat transfer surfaces.

By facilitating the precipitation of calcium carbonate though the use of hydrodynamic cavitation, the VRTX system continuously removes calcium carbonate from the recirculating cooling tower water. The following equation describes the reaction that occurs within the chamber.

Degassed from system

$$Ca(HCO_3)_2 \rightleftarrows CaCO_3 \downarrow + CO_2 \uparrow + H_2O$$

Precipitate

Calcium Bicarbonate ⇄ Calcium Carbonate + Carbon Dioxide + Water

The chemical equilibrium of the carbonate species is shifted, driving the above reaction to the right. As a result, the soluble calcium bicarbonate converts into a solid calcium carbonate precipitate and carbon dioxide gas. As long as CO_2 is removed, the equilibrium tends to stay to the right side of the equation. The solid precipitate is easily removed from the water through the use of a cyclonic separator or filtration system. Carbon dioxide is degassed from the water upon leaving the VRTX unit and entering the cooling tower basin. Because both calcium bicarbonate and calcium carbonate are simultaneously removed from the water stream, the solubility limit of calcium carbonate is not reached and scaling is inhibited.

Corrosion

Corrosion, triggered by decreased pH of the process water is a common problem for cooling systems. Corrosion can be distributed throughout the cooling tower system as well as can be localized, causing severe pitting and equipment failure.

Because the circulating water in a cooling tower contains oxygen, iron is oxidized when it comes in contact with the circulating water. The following equation illustrates this anodic reaction:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$

These electrons are then consumed by the hydrogen ion (H^+) in one of the following cathodic reactions:

$$2H^+(aq) + 2e^- \rightarrow H_2(g)$$
$$4H^+(aq) + O_2(aq) + 4e^- \rightarrow 2H_2O(l)$$

Since an acidic pH indicates the presence of hydrogen ions, a decreased circulating water pH promotes greater levels of corrosion. The concentration of hydrogen ions is exponentially proportional to pH therefore a small decrease in pH will substantially increase the hydrogen concentration. This makes pH an important factor in controlling corrosion.

Other important factors that affect the rate of corrosion are the chemical composition of the water, concentration of dissolved gases, flow rate, temperature, microorganisms, and type of metal construction. Dissolved gases such as oxygen, carbon dioxide, sulfur, sulfur dioxide, and sulfur trioxide buildup in cooling tower water as a result of the continuous aeration of the tower. These gases, absorbed into the cooling tower water from the air (much like a scrubber) also contribute to the oxidation of metal as shown in the above reactions.

Prevention of Scaling and Corrosion

Traditional measures for preventing scaling and corrosion in cooling towers are complicated by the fact that as chemicals are added to address one problem, they often exacerbate the other. The addition of a buffering chemical, which raises the pH of the circulating water, to prevent corrosion can lead to increased precipitation of calcium carbonate. Conversely, chemicals added to prevent scaling lower the pH of the water, and thus increase the rate of corrosion. The challenge of a chemical treatment program is to maintain the delicate balance between these two conditions.

Because the VRTX system does not rely on chemical additions to manipulate water chemistry, this problem is avoided. While scaling is prevented through the precipitation of calcium carbonate and its subsequent removal by filtration, the VRTX system also minimizes the potential for oxidation of the cooling tower's metal surfaces by removing the oxygen, CO_2 and other dissolved gases from the water.

Biological Fouling

Biological fouling in cooling tower systems is another issue that is traditionally addressed through chemical treatment programs. Microbiological organisms are introduced to cooling towers in two ways: organisms may be present in the makeup water that enters the cooling tower, and they can also be present in the air that passes through the cooling tower.

When water and air come in contact in the tower, the "scrubbing" effect that occurs causes the organisms to pass from the air to the water. When the water recirculates, the suspended solids, nutrient, and oxygen levels in the water increase. These conditions, combined with sunlight and the warm circulating cooling tower water, provide an ideal environment for microorganism to grow and rapidly reproduce.

Bacterial growth usually occurs in the piping and heat exchangers, inhibiting heat transfer, restricting flow, and plugging water passages. There are two types of bacteria that are typically found in cooling towers – sulfur and iron reducing bacteria. Sulfur-reducing bacteria reduce the sulfate in the water, forming corrosive sulfide ions. Similarly, iron-reducing bacteria also produce corrosive agents in the water and are particularly harmful because the resultant corrosion of surfaces is often concealed under the bacterial slime itself.

In contrast to bacteria, algal and fungal formation rarely occur in piping and heat exchangers. Algae can flourish in areas of cooling tower systems that have direct exposure to sunlight and air, such as on the top of a cooling tower, specifically along the distribution deck. Fungal growth can occur on any wood portions of a cooling tower.

Prevention of Biological Fouling

Many different types of oxidizing and non-oxidizing biocides are traditionally used in cooling towers to prevent bacterial, algal, and fungal growth. The oxidizing biocides, such as chlorine and its alternatives, are stronger oxidizing agents than oxygen and as a result often contribute to corrosion within the system. In addition, these biocides generally are most effective if used with a low pH, which further contributes to the corrosive nature of the water.

Passing a portion of the circulating water through the VRTX chamber also controls biological fouling. According to the vendor, the high temperatures and changing pressures generated inside the VRTX cavitation chamber are sufficient to destroy the microorganisms that would otherwise cause bacterial, algal, and fungal blooms. No additional chemical inputs are required.

Environmental and Economic Impacts

Use of the VRTX system has many environmental and economic benefits, the most obvious is the elimination of all toxic and hazardous treatment chemicals used to control scale buildup on heat transfer surfaces and biological activity in the cooling tower. An additional benefit, both environmental and economic, is the conservation of water through the reduction in blowdown volume (and thus an increase in cycles of concentration). The need for blowdown is reduced as a result of the removal of precipitated calcium carbonate and dissolved gases by the VRTX system. Several companies using the system have reduced their blowdown water consumption by 60 to 90 percent.

The increased cycles of concentration do not necessarily result in a build-up of metal ions in the circulating water. The vendor asserts that metal ion removal is accomplished with the VRTX system through coprecipitation – the incorporation of other divalent cations (“Me^{2+}”) into the crystal lattice – as the calcium carbonate precipitate is formed. The extent of coprecipitation is determined by the solubility of the metal carbonate ($MeCO_3$). If the solubility of $MeCO_3$ is significantly greater than the solubility of $CaCO_3$, the cation may remain in solution. If the solubility of $MeCO_3$ is roughly the same or less than the solubility of $CaCO_3$, the cation will coprecipitate into the solid matrix. Because many metal carbonates are less soluble than $CaCO_3$ they will be removed from the circulating water by coprecipitation with $CaCO_3$. This claim is supported by water quality analysis performed at one of the demonstration sites for the metals magnesium, copper, zinc and lead. Table 1 below provides the solubility product constants taken from the CRC Handbook of Chemistry and Physics, 1st Student Edition, 1988 for several common metal carbonates.

Table 1 Solubility Product Constant for Carbonates

Compound	Solubility Product Constant
$MgCO_3$	6.82×10^{-6}
$NiCO_3$	1.42×10^{-7}
$CaCO_3$	4.96×10^{-9}
$BaCO_3$	2.58×10^{-9}
$ZnCO_3$	1.19×10^{-10}
$FeCO_3$	3.07×10^{-11}
$MnCO_3$	2.24×10^{-11}
$PbCO_3$	1.46×10^{-13}

The solid precipitate should be analyzed to determine whether it should be disposed of as hazardous or non-hazardous waste, depending on the level of heavy metal contamination. The carbon dioxide gas can be vented to the atmosphere provided that no sulfurous or otherwise objectionable gases are present. For a discussion on environmental compliance using the VRTX technology see the “Regulatory” section of this document.

In addition to eliminating the use of treatment chemicals and reducing water consumption, the VRTX technology has many additional environmental and economic benefits. The elimination of scale on cooling tower surfaces improves cooling tower performance, allowing for more efficient heat transfer and less energy consumption. The elimination of scale also reduces the cost of cooling tower maintenance as the need for periodic production downtime associated with removing scale is eliminated. Annual descaling using mechanical methods or acids and other corrosive chemicals is also eliminated. In addition, use of the VRTX system eliminates the potential difficulty in meeting effluent discharge limits associated with a chemical treatment system, as no chemicals are added to the system and a mildly basic pH of 9 is maintained throughout the system.

Technology Applicability

This section describes the development history of the VRTX Technology.

Development / Application History

In mid-1988, research was initiated to study the commercial viability of using the colloid mill invention to treat recirculating cooling tower water. Several iterations of today's VRTX technology were designed and tested at various beta sites across the country. After these tests proved successful, a design was made commercially available in the spring of 1991. While further research was ongoing, a small sales representative group was formed and system sales began in targeted marketing areas. By 1996, approximately 75 systems had been installed, most of which are still in operation at this time.

During the period of 1996-1999, several VRTX design enhancements were made and new patents were issued. Also during this time period, the A.W. Chesterton Company formed the VRTX Technologies Division and established an R & D facility to support the development and sale of new applications for this technology. In January 2000 VRTX Technologies was established as a separate business entity of the A.W. Chesterton Company.

Applicability of Technology

VRTX systems are currently in use for cooling tower systems in industries such as food processing and storage, plastic injection molding, investment casting, electronics manufacturing, soft drink bottling, cold storage, and wire drawing. Specific applications and installations will be discussed in the following sections.

VRTX Technology Application

This section describes the use of the VRTX technology at the following sites: Pillsbury (MN), Richmond Cold Storage (VA), Lancer Corp (TX), International Paper Co. (VA), and Fujitsu Corporation (OR). General information on each of these sites is given in the table below.

Table 2: VRTX Applications

Site	Industry Sector	Date of Implementation	Results
Pillsbury (MN)	Food Processing and Storage	2000	• Eliminated use, handling, and disposal of treatment chemicals • Substantial water savings • Cycles of concentration increased from 2.9 to 6.3
Richmond Cold Storage, Inc. (VA)	Cold Storage Warehouse	3 Units Installed, 1995, 1996, 1999	• No detectable scale or corrosion problems • Substantial water savings • Cycles of concentration increased from 4 to 18.9
Lancer, Corp (TX)	Plastic Injection Molding	1998	• No system shutdown related to cooling water • Substantial water savings • Cycles of concentration increased from 2.5 to 9
International Paper Co. (VA)	Technology Center	Sept. 1999	• Hazardous chemicals eliminated • Blowdown reduced to <250 GPD from ~1000 GPD • Old scale softened and removed • Cycles of concentration increased from 2.8 to 5.3
Fujitsu Corporation (OR)	Microchip Manufacturing	2 Units Installed, 1993, 1994	• Scale under control • Substantial water savings • Cycles of concentration increased from 4.6 to 33

Pillsbury:

General Setting

A 90-day comparison between the VRTX technology and a traditional chemical treatment maintenance program was performed at a Pillsbury plant in Chanhassen, Minnesota during August, September, and October of 2000. The facility employs evaporative condensers to cool ammonia refrigerant used in the food processing operation and the finished product storage area. The evaporative condensers serve as noncontact heat exchangers, and are located in two areas designated as EC-1 and EC-2. EC-1 consists of four evaporative condensers that circulate water to a common cooling water sump. EC-2 consists of five evaporative condensers that circulate water to a second sump. The combined cooling capacity of the condensers is 1,269 tons for EC-1 and 1,552 tons for EC-2.

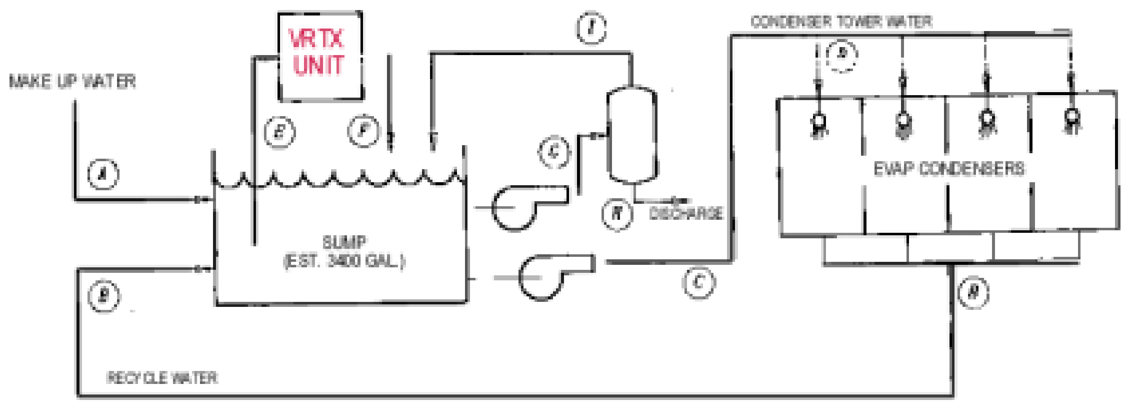
Prior to the trial, both refrigerant cooling systems used a traditional chemical treatment maintenance system to prevent scaling, corrosion, and biological fouling. During the 90-day trial, EC-1 used the VRTX system in lieu of all chemical treatment while EC-2 operated as usual using its chemical treatment maintenance program. The purpose of the trial was to compare the performance of the evaporative condenser systems using the different maintenance systems. Throughout the trial, the temperature, pH, alkalinity, calcium, magnesium, iron, zinc, suspended solids, and total dissolved solids levels in the water were measured weekly. In addition, cold-rolled steel coupons were installed in approximately sixty different places in both EC-1 and EC-2 for corrosion and biological analysis.

Technology Implementation

The well water in Chanhassen, Minnesota is typically hard water with high levels of both calcium (typically 65-75 mg/L) and magnesium (typically 30-40 mg/L). Because the VRTX system is designed to work adequately without additional water softening, the make-up water for EC-1 was not softened. The make-up water for EC-2 required softening for scale prevention, as it was part of the traditional chemical treatment maintenance program for this facility.

The VRTX system, a VRTX unit and separator system, was connected to the EC-1 collection sump basin. A side stream from the sump water was continuously circulated through a 60 gpm VRTX unit utilizing a 7.5 hp pump. A filter system utilizing an additional 1.5 hp pump was connected to the opposite side of the sump basin to separate and remove the precipitated solids from the water stream. (See Figure 3 for a process flow diagram of the cooling operation.)

Figure 3: Pillsbury cooling process



Richmond Cold Storage:

General Setting/Technology Implementation

Richmond Cold Storage (RCS) operates several facilities in Virginia and North Carolina. The company installed VRTX units at several facilities during the early to mid 1990's, and currently includes VRTX units in the specifications for any new cooling tower installations. The data presented in the following section is from two different facilities containing cooling towers rated at 1200 tons and 900 tons of cooling, respectively. The operations at the facilities consist of blast freezing chilled food from a nearby food processor in a room with air circulating at ¯40° F. The ammonia refrigeration units extract heat which is removed by rooftop cooling towers. The facility has a soft water supply.

A 40 gpm VRTX unit was originally installed on each of the two cooling towers. Later, a second 40 gpm VRTX unit was installed on the 900 ton cooling tower. The addition of the second VRTX unit on the 900 ton cooling tower is discussed further in the "Lessons Learned/Implementation Issues" section of this document.

Lancer Corp:

General Setting/Technology Implementation

Lancer uses water to cool hydraulic oil used on plastic injection molding machines. The facility is located near San Antonio, Texas, where the water supply is hard. The facility has two 15 year old, 350 ton cooling towers that operate in parallel. The facility, which had a history of needing to clean and remove scale from the cooling towers every two weeks, installed a 40 gpm VRTX unit in 1998. This initiated a series of changes that have greatly improved the reliability of the company's cooling tower system that now requires scale removal only as part of the annual maintenance routine.

International Paper:

General Setting/Technology Implementation

International Paper, located near the Cincinnati metropolitan area, operates test laboratories and pilot processes. Cooling is required for temperature and humidity control. The facility's water supply is perhaps the poorest quality of the facilities discussed here, with a TDS level of nearly 900 mg/L and chlorides greater than 200 mg/L. A 60 gpm VRTX system was installed in 1999 on the facility's combined cooling capacity of 1000 tons (divided among five units: 2x400 + 2x100 + 25). The facility is satisfied with the results.

Fujitsu Corporation:

General Setting/Technology Implementation

Fujitsu is a microelectronics facility in the Portland, Oregon area, with a soft water supply. Cooling is required to maintain control of humidity in the facility's clean rooms. One building is equipped with an older, forced draft tower, and a second building has two newer towers installed. Each of the three towers is rated at 300 tons of cooling, and they are all ground installed. The facility operates 24 hours per day, 7 days per week.

Fujitsu installed a VRTX unit on the older tower in 1993. Two years later, an additional unit was installed on the new towers. The older tower has a small V-shaped sump and required some trial-and-error repiping to get the VRTX to allow sufficient degassing and settling of solids. There were no such problems with the installation on the newer towers that had larger sumps and bottom drainage for periodic solids removal.

VTRX Technology Performance

This section presents VRTX technology performance data for the previously described application sites.

Performance Goals

The VRTX technology eliminates the need for chemical treatment of cooling towers. Use of this technology can:

- Prevent scaling, corrosion, and biological fouling
- Decrease water consumption
- Decrease blowdown
- Increase cycles of concentration
- Eliminate chemical use
- Result in cost savings from elimination of treatment chemicals and reduced water consumption

Technology Application Results

Pillsbury:

During the 90-day side-by-side demonstration at Pillsbury, scaling, corrosion, and biological fouling were closely monitored by an independent, environmental consulting service for both the VRTX system and the traditional chemical treatment maintenance system. The following table summarizes the results of the 90-day trial period.

Table 3: Scaling, Corrosion, and Biological Fouling Data

<table>
<tr><th colspan="3">Parameters</th><th>VRTX Technology</th><th>Traditional</th></tr>
<tr><td colspan="3">pH [90-day mean value]</td><td>9.08</td><td>9.17</td></tr>
<tr><td rowspan="4">Scaling</td><td rowspan="2">Calcium (mg/L)
[90-day mean value]</td><td>Make-up</td><td>73</td><td>1.0*</td></tr>
<tr><td>Sump</td><td>28</td><td>9</td></tr>
<tr><td rowspan="2">Magnesium (mg/L)
[90-day mean value]</td><td>Make-up</td><td>34</td><td>0.57*</td></tr>
<tr><td>Sump</td><td>403</td><td>29.9</td></tr>
<tr><td>Biological Fouling</td><td colspan="2">Total Plate Count (CFU/ml)**
[90-day mean value]</td><td>96,061</td><td>38,345</td></tr>
<tr><td rowspan="3">Corrosion Rate</td><td rowspan="3">Carbon Steel Coupon Analysis (mpy)***</td><td>One Month</td><td>1.33</td><td>0.37</td></tr>
<tr><td>Two Months</td><td>0.71</td><td>0.58</td></tr>
<tr><td>Three Months</td><td>0.45</td><td>0.37</td></tr>
</table>

*Low values are due to softening the water in traditional set-up.
**CFU/ml = Colony Forming Unit per 1 milliliter of water.
***mpy = mils (one-thousandth [10^{-3}] of an inch) per year.

Scaling Prevention

Because the water used for the VRTX technology application was not softened, the calcium level of the VRTX make-up water was high, at 73 mg/L (see Table 3). Weekly measurements of the sump water indicated average calcium levels of 28 mg/L, demonstrating the continuous removal of calcium during the 90-day trial. As a result, no scale formation occurred within the evaporative condensers. In addition, Pillsbury employees observed several 2-5 pound chucks of existing scale were dislodged from the evaporative condenser shortly after the installation of the VRTX system. The VRTX system also rendered any of the remaining scale easily removable from heat exchange surfaces without the use of acid, which was normally required for scale removal prior to VRTX installation. While the removal of existing scale initially caused some pipe blockage throughout the system, it resulted in increased heat transfer efficiency once the scale was removed from the water stream. The VRTX system ultimately removed hundreds of pounds of calcium and magnesium scale from the cooling tower system. (See Lessons Learned/Implementation Issues Section.)

During the trial period, the solids filter associated with the VRTX system had limited success removing the magnesium solid precipitate from the sump, as indicated by the discrepancy in magnesium levels between the make-up water and the sump water provided in Table 3. Pillsbury attributes this problem to the significant turbulence in the cooling tower basin and the need for a filtration system designed for turbulent flow and the smaller diameter (smaller diameter than calcium carbonate precipitate) magnesium carbonate precipitate. (See Lessons Learned/Implementation Issues Section.)

Corrosion Prevention
Carbon steel corrosion coupons were placed in the sump to monitor the corrosion potential (tendency) of the circulating water. As shown in Table 3, corrosion rates ranged from 0.45 mpy (mils per year) to 1.33 mpy for the VRTX technology. Although the corrosion levels were slightly higher for the VRTX technology application than for the traditional system, all of the readings were within the 0 mpy to 2 mpy range – indicating excellent corrosion control, according to the Handbook of Air Conditioning System Design standards. In addition, there was no observable rust on the coupons in the VRTX system, while those in the traditional chemical maintenance system had observable swelling and rust.

Biological Fouling Prevention
Total plate counts were higher for the VRTX system than for the traditional system, as shown in Table 3, although no bacteria or algae was observed on the VRTX evaporative condensers when dismantled. The higher plate counts for the VRTX system may be attributed to start-up issues, and are discussed in the "Lessons Learned/Installation Issues" section of this document. These start-up issues have since been resolved (old scale build-up removed), and recent total plate counts since the end of the 90 day trial have been consistently lower than 20,000 CFU/ml., which is better than the chemical treatment program on the EC-2 cooling tower.

Environmental Impacts
The following table summarizes the chemicals used for both systems during the 90-day trial period.

Table 4: Chemical Consumption During 90-day Trial

Chemical Consumed	VRTX Technology (gallons)	Traditional (gallons)	Traditional (pounds)
CWT-350	0	17	431
CWT-30	0	21	207
CWT-525	0	720	6,155

As shown in Table 4, no treatment chemicals were added to the VRTX system during the 90-day trial period. CWT-525, the chemical used in the highest quantities for the traditional system, is an anti-scaling and corrosion polymer treatment containing sodium hydroxide, a CERCLA listed chemical. CWT-30 and CWT-350 are both biocides; CWT-30 has two EPCRA Section 313 reportable chemicals, disodium ethylenebisdithiocarbamate and sodium dimethyldithiocarbamate, and CWT-350 contains sodium hypochlorite, a CERCLA listed chemical. Elimination of these chemicals offers a significant reduction in regulatory burden.

Table 5: Water Consumption During 90-day Trial

Chemical	VRTX Technology	Traditional
Water Use (gallons)	1,413,000	2,420,000
Cycles of Concentration	6	2.9
% Blowdown	3.4 %	32.6 %

As shown in Table 5, the evaporative condenser system equipped with the VRTX technology saved approximately 1,000,000 gallons in water consumption during the 90-day trial period due to significant reductions in blowdown. Blowdown percentage[1] for the VRTX system was calculated to be approximately 3.4%, compared to 32.6% for the traditional system. The cycles of concentration shown in Table 5 are based on the total dissolved solids (TDS) of the blowdown versus the TDS of the make-up water. These values were calculated using an average of the TDS measurements that were taken weekly over the entire 90-day trial period. The cycles of concentration and the blowdown for the VRTX system are not proportional because of the removal of precipitated solids by the VRTX unit.

Pillsbury has since purchased a second VRTX system for use in EC-2 and will install the unit by the end of the year 2001.

Other VRTX Application Results:

Table 6 summarizes the performance results of the VRTX technology at Richmond Cold Storage, Lancer Corporation, International Paper, Fujitsu Corporation and Pillsbury.

[1] Percent blowdown for the two systems was measured using different methods. The percent blowdown of the system equipped with the VRTX technology was determined as a ratio of total volume of water removed through blowdown per total volume of make-up water. A flow meter malfunction limited measurements to the first 65 days of the trial. For the traditional cooling system, blowdown was measured during a one-week period using conductivity readings. Conductivity readings were used because a flowmeter failed on the traditional blowdown stream. Currently, flow meters are installed on both cooling towers and the flow rates presented in this report are supported by current flow measurements on both towers.

Table 6: VRTX Application Results

Operational Parameters		Richmond Cold Stor.	Lancer	Internat'l Paper	Fujitsu	Pillsbury
Cooling Tower Capacity		1200 Ton + 900 Ton	2x350 Ton	1000 Ton	3x300 Ton	~ 1300 Ton
Material of Construction		Galvanized Steel	Galv. Steel	Galv. Steel	Galv. Steel	Galv. Steel
Corrosion Rate		2.0 mpy (mild steel)	Acceptable**	Acceptable**	Acceptable**	0.89 mpy
Function/Duty		Refrigeration	Hydraulic Oil	Test Lab A/C	Mfg. A/C	Refrigeration
Water Source		County Wells	City Wells	County Wells	City-Surface	City-Well
Sump Water Temperatures		Not Measured	90	82	88	75
Size of VRTX unit		3x40 gpm	40 gpm	60 gpm	3x30 gpm	60 gpm
Duration of Water Samples		6 months	13 months	24 months	12 months	3 months
Number of Water Samples		3	> 30	> 30	6	48
pH	Make-up	6.8	7.3	8.2	7.1	8
	Sump	9.3	8.8	9.2	8.9	9.08
Alkalinity (mg/L)	Make-up	24	198	326	38	350
	Sump	374	330	1498	454	1329
TDS (mg/L)	Make-up	34	364	866	68	400
	Sump	1377	1076	4531	2588	1600
Calcium (mg/L)	Make-up	4	174	142	22	73
	Sump	50	201	76	48	28
Magnesium (mg/L)	Make-up	2	72	48	4	34
	Sump	29	503	456	202	403
Chloride (mg/L)	Make-up	6	25	210	12	22
	Sump	113	226	1102	446	100
Cycle of Concentration - VRTX (Prior to VRTX Installation) *		18.9 (4)	9 (2.5)	5.3 (2.8)	33 (4.6)	6.3 (2.9)
Annual water savings (%)		20%	29%	17%	19%	41%
Annual Blowdown Water Savings	%	83%	82%	67%	88%	94%
	gallons	5.0 million	3.3 million	3.5 million	1.5 million	1.5 million

*The number of times non-volatile constituents in makeup water are concentrated by the evaporative cooling tower is the "Cycles of Concentration" (COC) for the cooling tower. If the COC factor is 3, the non-volatile constituents in the blowdown water are three times the concentrations of the makeup water. The blowdown volume (including any drift or leaks) is one third (33%) of the makeup water volume. If the COC increases to 10, then only one tenth (10%) of the makeup water is discharged as blowdown – a "calculated" water savings of 23% (33% - 10%).

**Acceptable: Not measured quantitatively by facility; however, no corrosion prevention chemicals have been added to date.

During 1999, tower water samples were taken at the four facilities and analyzed. Lancer tower samples were taken through the following year (2000) as well. A phone survey of these facilities was conducted in the spring and summer 2001.

Richmond Cold Storage provided limited data (3 bimonthly samples), as did Fujitsu (6 bimonthly samples). Greater than 30 water samples were taken from International Paper and Lancer over 13 month and 24 month periods, respectively. Only one or two fresh water make-up water analyses were provided from each facility, which could potentially inflate the cycles of concentration numbers since samples were obtained during the late fall/early winter season.

The water analysis data (temperature, pH, alkalinity, TDS, calcium, magnesium, and chloride) shown in Table 5 represent the mean values for water samples taken during the sampling period. Standard deviations were typically plus or minus 25% – less for Richmond Cold Storage (~15%) and greater for International Paper (~40%). There were no apparent seasonal trends in the data with the exception of a second year decline in calcium levels and an increase in alkalinity, TDS, magnesium, and chloride during the summer months for Lancer.

Richmond Cold Storage

Richmond Cold Storage operates cooling towers in conjunction with their evaporative condenser units. The facility has a water supply with relatively low levels of TDS, calcium, and magnesium. Blowdown is conducted once per day, and accumulated sediment is back flushed to drain twice daily.

The cycles of concentration increased from 4 to approximately 19 after the installation of the VRTX unit, representing a 20% water savings. Some initial corrosion and rust problems were eliminated after an additional VRTX unit was added (see the "Lessons Learned/Implementation Issues" section of this document for further discussion). Richmond Cold Storage staff maintain that the VRTX technology has reduced blowdown requirements and controlled algae and bacteria.

Lancer

Before installing the VRTX technology, Lancer would rotate weekly between its two cooling towers, using one while cleaning the other. Since the installation of the VRTX system, the towers are used simultaneously and operate reliably most of the time. Scaling, line blockage, and corrosion are reduced, and maintenance needs are eased, allowing the towers to be run simultaneously. A small amount of algal growth still occurs on a corner of the tower, but not enough to warrant chemical treatment. The facility's cycles of concentration has increased from 2.5 to 9, resulting in a calculated water savings of 29%. The VRTX system has allowed the facility to completely eliminate their chemical treatment program. Recently, Lancer has begun using the VRTX treated cooling water for cooling their plastic injection molds, eliminating the use of costly DI water for this process.

International Paper

International Paper uses 20,000-45,000 gal/day of makeup water depending upon the season. Blowdown is 2,000-5,000 gal/day. The facility operates at greater than 5 cycles of concentration with the VRTX system compared to less than 3 with the previous chemical treatment program. The VRTX system has yielded nearly 20% in water savings, eliminated the use of scaling and corrosion treatment chemicals, and reduced the number of shutdowns required for cleaning. Because two of the three towers are exposed to the sun, they must still be treated with algaecide.

Fujitsu

Of the four companies, Fujitsu's cooling operations operate at the highest cycles of concentration (>30) and at the second highest TDS concentration. The facility previously operated at less than five cycles of concentration, amounting to a calculated percent water savings of 19%. Fujitsu reports that there is no blowdown from these cooling towers and no significant drift losses, though solids are periodically siphoned from the bottom of the sumps to sand filters. The make-up water is the best of the four facilities with a combined calcium and magnesium level in the makeup water of only 6 mg/L.

The facility reports that the VRTX system works very well on their new towers. The older tower, constructed of galvanized steel and after some period of service coated with epoxy, was refurbished last year (after 15 years). This cooling tower does get some scaling at the edges where the media is not consistently wetted by the drip-pan distributors, while the two newer towers still require some algaecide to address biological growth stemming from sunlight exposure. Despite these factors, the facility has eliminated their formal chemical treatment program and reports that the cooling towers now require very little maintenance, which is advantageous for Fujitsu's relatively tight staffing.

Cost Information

Pillsbury:

Table 7 details the cost savings achieved at Pillsbury during the 90-day comparison.

Table 7: Cost Savings during Pillsbury 90-day Trial

Item	Savings
Water & Sewer Savings	$4,128.70
Sewer Availability Charge Savings (one-time)	$17,976.79
Chemicals from Water Softening Savings	$912.48
Chemical Treatment Savings	$16,997.29
TOTAL SAVINGS	**$40,015.26**

Pillsbury's VRTX unit, which has a flow rate of 60 gpm, was purchased for approximately $60,000 (including the cost of installation). The company did not provide any specific energy consumption information beyond that used by the system's two pumps (7.5 hp and 1.5 hp, as mentioned previously). Cost savings from water conservation documented in the previous section are listed in Table 7, as are cost savings stemming from the elimination of water softening and treatment chemicals. The Sewer Availability Charge is a one-time savings from the local sewer authority that resulted from Pillsbury's reduced water consumption. Based on these figures, first year savings were in excess of $60,000, indicating a pay back period of less than one year.

Other Applications:

Limited specific cost information was provided from each of the four facilities using the technology. Annual savings on chemical purchases due to the use of the VRTX system ranged from $7,200 to $20,000 per year. In addition, International Paper calculated an estimated payback period of three years for the equipment. Table 8 summarizes the cost saving realized at the four installations.

Table 8. Cost Savings from Other Applications.

Facility	Richmond Cold Storage	Lancer	International Paper	Fujitsu
Approximate Annual Chemical Savings	$ 8,000	$ 7,200	$ 8,000	$ 20,000

Regulatory/Safety Requirements

This section provides information on regulatory requirements relevant to the VRTX system.

Applicable Regulations and Permit Requirements

Water Discharge

Water discharge regulations are the primary permitting area anticipated for the VRTX non-contact cooling water system. Depending on the nature of discharge and the disposal route selected, different regulatory requirements may apply. This section reviews the state and federal water discharge regulations that typically apply to VRTX systems, as well as conventional non-contact cooling water systems. Local water discharge regulations may also apply in some areas and the local authority should be contacted for applicable permits and regulations. The water-related permitting requirements noted here do not trigger any air or hazardous waste requirements.

If a facility uses a VRTX system to replace a traditional non-contact cooling water treatment system, then its existing permits (local, state and/or federal) are adequate, because the VRTX system will not increase the volume or contamination of the discharge. This regulatory assessment is based on test results indicating that discharges from the VRTX system are similar to or cleaner than ordinary non-contact cooling water discharges.

For new installations, or those expanding their existing cooling tower capacity, new permits or changes to existing permits may be required depending on the quantity discharged and the disposal route. We recommend that a facility considering the purchase of the VRTX system contact the Massachusetts Department of Environmental Protection (DEP) Infoline (1-800-462-0444) for current applicable permitting information. Permit requirements for non-contact cooling water will also be part of a pre-permitting conference offered by DEP Regional Service Centers for new industrial facilities; the Info-line will assist in a referral to the appropriate regional office.

There are four disposal routes for non-contact cooling water:

1) Holding Tanks, for shipment off-site to a treatment facility
2) Sewer discharges
3) Surface Water discharges
4) Groundwater discharges

Each of these disposal routes has different regulatory requirements from different jurisdictions. They are discussed below in order from least regulated to most regulated.

Holding Tanks for Shipment Off-Site to a Treatment Facility

While this is the least regulated from an environmental point of view, due to the transfer of treatment responsibilities to another facility, it is also the least common because of the generally high costs of transportation. It is usually selected by operations without access to other disposal options.

Industrial wastewater holding tanks (IWHTs) are regulated under statutory authority from the Massachusetts Clean Waters Act (Massachusetts General Laws 21, Chapter 21, sections 26 to 53). Presently, IWHTs must get DEP one-time plan approvals. There are, however, new regulations under development that will require one-time certifications to replace the plan approval (they will be located in 314 CMR 10.00). These new regulations should be promulgated by the end of 2001. The certification covers structural standards for in-ground and above-ground IWHTs, wastewater management provisions, and record keeping requirements.

Sewer Discharges

The two regulatory levels for sewer dischargers are the local and state discharge permits. These permits are generally less stringent than surface water or groundwater discharge permits because their discharges are processed through the sewage treatment plant prior to discharge to the environment. There is often some duplication between the local and state sewer discharge permits.

Federal permits for surface water discharging from sewage treatment plants mandate local sewer discharge permit issuance. The local sewer discharge permits' specific provisions vary depending on the size of the sewage treatment plant, the size and nature of the receiving water body, and the sewage treatment plant service area's industrial profile. However, most sewage treatment plants are trying to conserve available treatment capacity and prohibit, or at least discourage, non-contact cooling water discharges to their sewers. The local POTW should be contacted for its regulations and permit requirements.

Currently, the state sewer discharge permit program is under revision primarily due to the overlap with locally issued permits. DEP should promulgate new regulations by the middle of 2002, which will eliminate permit duplication by replacing the state permit with an annual certification.

Until the new regulations are complete, the existing state regulations apply to environmentally significant sewer dischargers (see 314 CMR 7.00 and 12.00), and generally, non-contact cooling water is not environmentally significant.

Surface Water Discharges

While both federal and state laws require permits for surface water discharges, they are virtually the same in most cases. Non-contact cooling water can be classified as polluted water due to heat or other contaminants contained in it. Massachusetts is not delegated under the federal surface water discharge permit program, formally known as the National Pollutant Discharge Elimination System (NPDES). Massachusetts plays a key role in issuing the federal permit by certifying that the proposed permit meets state water quality classifications (under 314 CMR 4.00). During the certification process, the DEP also reviews the discharge and usually uses the federal permit to meet the state permit requirements. If the DEP finds that it has additional concerns, it will add special conditions, but will basically use the federal permit as a foundation. Besides the federal and state regulation, the local authority may have additional surface water discharge regulation for some specific areas. The local authority should be contacted for its regulations and permit requirements.

Groundwater Discharges

The Massachusetts DEP regulates non-contact cooling water discharges to groundwater over 2,000 gallons per day under 314 CMR 5.00. Typically, groundwater discharge permits are the most stringent water discharge permit since they require a basic hydro-geological assessment, effluent limitations and one-time or ongoing monitoring of the discharge.

Facilities with non-contact cooling water discharges to groundwater under 2,000 gallons per day are exempted from discharge permit requirement, and the DEP only requires the facility to register in the Underground Injection Control (UIC) program. By increasing the cycles of circulation, the VRTX system may allow additional facilities to come under this threshold, thereby eliminating state water discharge permit requirements.

Precipitate Disposal

Based on information provided about the VRTX system and the low levels of metals typically present in cooling water influent, it is unlikely that the solid precipitate generated from VRTX system will be hazardous waste. As with any waste generated by a facility, the generator is responsible for ensuring that it is handled appropriately. If a facility has questions about the potential for concentrating metals in the precipitate in quantities that would qualify as hazardous waste, they should use the TCLP test (as described in 310 CMR 30.102 and 30.120 through 30.125) as the performance measure.

Lessons Learned/Implementation Issues

This section discusses lessons learned and implementation issues associated with the VRTX system applications profiled earlier in this report.

Design Issues

During the 90-day trial at Pillsbury, magnesium levels in the water were consistently high, indicating that magnesium was not being removed from the water stream. The company believes that the magnesium carbonate solids were accumulating in the sump and redisolving into solution after precipitation, rather than being removed. Pillsbury has since replaced the original strainer with a turbodisc filter that removes solids to less than 5 microns and has relocated the filter to a less turbulent section of the cooling tower basin. This has resulted in effective magnesium solids removal, and since the installation magnesium levels in the cooling tower basin have consistently been in the 50mg/L range.

At Fujitsu, the first VRTX installation encountered some difficulties with degassing. Rerouting the VRTX unit return water from the lower region of the sump to the top of the sump allowed more opportunity for degassing. Fujitsu has found that the VRTX technology works best on their two newer towers that have larger sumps and are induced draft rather than forced draft.

Richmond Cold Storage determined that different makeup water sources required specific ratios of VRTX unit size to tower size. At two of its North Carolina facilities, the company installed three VRTX units with similar tower sizes but different well sources. At the first location, a single 40 gpm VRTX unit was satisfactory for treatment. At the second location, rusting and corrosion problems prompted the company to add an additional 40 gpm VRTX unit. The facility attributed the need for an additional VRTX unit to the differences in iron and mineral content of the make-up water at the two facilities.

Implementation Considerations

The most significant start up issue at Pillsbury concerned the removal of existing scale within the evaporative condensers. Some of the pipes in the cooling system experienced clogging when existing scale broke off from heat exchange surfaces and entered the water stream. This scale also interfered with the flow through the VRTX chamber, affecting the vacuum and the unit’s overall performance.

High bacterial counts during the 90-day trial were also attributed to the dislodging of the existing scale. Several layers of bacteria slime within the dislodged scale were identified. The company believes that as the chunks broke off and became entrained in the cooling tower water the layers of bacteria flourish, raising bacteria counts. Once all the old scale was removed the bacteria counts returned to 20,000 CFU or less, which is consistently half the number of colonies measured on the chemical treatment side.

The company determined that if scale is not removed from the water stream, it can impact the ability of the VRTX system to pull a vacuum. This reduced the system effectiveness at killing bacteria, removing calcium carbonate, and increasing the cycles of concentration. For this reason, the manufacturer recommends purging the system periodically during the first 2-4 weeks following installation. Alternatively, the cooling tower system could be cleaned prior to VRTX installation to eliminate the need to purge the system.

Pillsbury also found that while VRTX maintenance demands are much less than what is required for a traditional chemical treatment program, it is important to follow the unit's required maintenance schedule to ensure its proper operation. This includes monitoring the vacuum and other settings within the chamber, monitoring the solids separator to ensure proper separation, periodically cleaning strainer baskets, and tracking calcium, magnesium, total plate counts, and corrosion levels within the system.

Both Fujitsu and International Paper noted that the addition of some algaecide is still necessary for the cooling towers exposed to a significant amount of sunlight.

At this time it remains uncertain whether the use of the VRTX system results in energy savings. Potential energy savings would likely result from the elimination of scale on the heat transfer surfaces as well as through reduced water consumption. Whether these savings would be offset by the energy consumption of the VRTX system itself (to our knowledge) has yet to be determined by any VRTX users.

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