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Catalyst-Based Nonchemical Water Treatment System Frank E. Moss US Courthouse Salt Lake City, Utah

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The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

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Table of Contents

List of Figures

List of Tables

I. Executive Summary

In 2012 and 2013, the US General Services Administration (GSA) and Oak Ridge National Laboratory conducted an evaluation of a novel nonchemical water treatment (NCWT) system at the Frank E. Moss US Courthouse in Salt Lake City, Utah. This system purports to use a proprietary metallic catalyst to change the water's chemistry such that hard calcite does not form on surfaces that are in contact with the water.

The catalyst-based NCWT system was installed on an electric domestic water heater in the courthouse.[1] This water heater had been experiencing severe calcite buildup on the heating elements. The calcite buildup impeded heat transfer from the heating elements into the domestic water, leading to the thermostat being set excessively high in an attempt to maintain the water temperature. This caused excess heat to build up on the elements, resulting in their premature failure which required frequent replacement. The buildup also required the elements to stay energized constantly to produce enough heat to maintain temperature in the domestic hot water system.

After installing the catalyst-based NCWT system, calcite buildup was dramatically reduced and failure of the elements ceased. Labor and material savings from not having to replace the elements ($1,060/year) allow for less than a two-year simple payback when compared to the installed cost of the system ($1,692) plus minimal annual maintenance ($100/year). The catalyst-based NCWT system should be considered for deployment in any heating system that is subject to calcification, including hydronic heating systems and boilers, condensing boilers, gas water heaters, and electric water heaters.

Had the catalyst-based NCWT technology not been installed on the water heater, a conventional salt-based calcite prevention system would have provided the same prevention of calcite buildup. The budget installed cost of such a system would have been $3,200 plus $350/year in chemicals and $1,500/year labor to service the chemicals. Comparing the conventional to the catalyst-based system, the latter has both a lower installed cost and annual operating cost.

The original test plan was to install the technology on both the domestic water heating system and on the site's cooling tower, which had faced calcite issues in its history. This tower has had a calcite buildup problem that is currently being addressed with a salt-based treatment system. The project's timeline did not allow for installing a system and testing it on the tower during the initial phase of this project in 2012 and 2013.

A preliminary economic analysis was performed to estimate the installed cost and potential savings on the cooling tower. If installed on the site's cooling tower, the installed cost of the catalyst-based system would be more expensive than the salt-based system ($32,380 vs. $2,700 for the salt-based). However, the salt-based system requires $900/year in chemicals and $3,900/year in labor, neither of which is needed by the catalyst-based system. This would give a simple payback of less than seven years using the technology on a cooling tower.

Background

Nearly all GSA facilities have water systems that could potentially require treatment in some capacity. There are two issues that commonly present themselves in water systems. First is the buildup of calcite on surfaces where heat is transferred into the water, or where water evaporates into air. Examples of the former include heating elements in domestic water heaters or heating surfaces in hydronic heating systems

[1] A catalyst-based NCWT device was also installed on the natural gas water heater. However, the focus of this study was the device's impact on the electric water heater and its calcification issues.

and boilers. Examples of the latter include cooling towers, evaporative cooling HVAC systems, or showerheads and faucets in bathrooms.

There are many technologies which mitigate the buildup of calcite in these conditions. Nearly all of these systems use some sort of chemical additive that prevents the calcite molecule from bonding to the surface. While effective at reducing calcite, these systems require regular maintenance and addition of chemicals to maintain their ability to prevent calcite buildup.

Other systems that are effective include pumping the water through an ultrafine membrane that captures calcite particles and prevents them from plating. These systems are commonly known as "reverse osmosis" (RO) systems. While there are no chemicals associated with RO systems, they consume substantial amounts of energy in their pumping process.

Because of the challenges associated with both the chemical-based water treatment systems and the RO systems, GSA and other owners of large numbers of buildings have been very aggressive at pursuing alternative water treatment systems. Because of this demand, many vendors have developed alternative systems, with varying degrees of effectiveness. The goal of GSA in conducting these Green Proving Ground evaluations is to determine, in a field environment with third-party subject matter experts, the effectiveness of these systems.

The second issue presented by water systems, especially those that serve a cooling tower, is the growth of moss and other biologicals. While there are many systems which purport to address the growth of biologicals, they are separate from those which address calcification. The evaluation conducted on this technology looked only at calcite buildup in a domestic water heating system. There was no attempt to evaluate its effect on the buildup of biologicals, especially since the technology was not tested on a cooling tower where biologicals are a major issue. Though the vendor claims that the technology allows for a reduction in the quantity of anti-biological chemicals in cooling towers, this claim was not tested in the domestic water heating application. Therefore, there will be no further discussions of biological mitigation in this report.

Overview of the Technology

The technology being evaluated in this project does not add chemicals to the water system, nor does it use ultrafine membranes to filter calcite molecules from the water. Instead, it uses a proprietary catalyst to reduce calcite formation.

On a very simplified level, the device's exterior looks like a section of pipe that has been painted blue, and it is inserted directly into the pipe that carries the water to be treated. Water flows through the pipe and over the catalytic insert, which causes the calcium and carbon in the water to form aragonite rather than calcite. Aragonite is chemically very similar to calcite, but it stays suspended in the water and flushes through to the drain rather than plating on heat transfer surfaces like calcite. Aragonite is an inert substance and requires no special treatment systems as it passes through the system.

Figure ES-1 shows photographs of the device's components. The image on the left shows what the exterior looks like. The image on the right shows the helical insert made out of the catalytic alloy. (Photo images were copied from the manufacturer's website.)

 

Figure ES-1. Novel Nonchemical Water Treatment System. No external energy sources are required to operate this device. Periodic maintenance issues that must be addressed are also minimal. Once installed, the system operates as a stand-alone device. The vendor reports that the system has a service life of 15–20 years.

Study Design and Objectives

This study looked directly at calcite that was forming on the heating elements of the electric domestic water heater at the courthouse. Measurements were taken during a "before" period, when no water treatment was being done on the water. After a three-month period with no water treatment, the catalyst-based NCWT system was installed, and the test was repeated to see whether there was a change in the amount of calcite being built up on the elements. The effectiveness of the device would be evaluated by looking at any change in the calcite buildup. Table ES-1 shows performance objectives

Table ES-1. Performance Objectives

Quantitative Objectives	Metrics and Data Requirements	Success Criteria	Measurement and Verification Results	Best-Case Deployment Scenario
Reduced calcite buildup on heating elements	Visual observation of elements as they are removed from the tank and compared to elements that were operated without the technology in place.	If successful, the elements operated with the technology in place will have little or no calcite buildup on them.	Elements did, in fact, show greatly reduced calcite buildup when the technology was deployed.	A facility that is experiencing problems due to calcite buildup on hydronic heating elements would benefit from this technology.

Table ES-1 (continued)

Quantitative Objectives	Metrics and Data Requirements	Success Criteria	Measurement and Verification Results	Best-Case Deployment Scenario
Reduced costs	Installation and operating costs associated with the technology will be evaluated and compared to both the site's current practice of replacing elements periodically, and the incumbent technology of a salt-based water treatment system.	If successful, the life cycle cost of the technology will be lower than current practice or the incumbent technology.	The life cycle cost did, in fact, prove lower than both alternatives.	
Qualitative Objectives				
Ease of Installation	Feedback from maintenance personnel during installation.	No major problems reported during installation.	Feedback was positive from personnel.	
Ease of use	Maintenance logs during operation.	No problems reported during use.	Customer has reported positive experiences with the technology.	

To support this test, instrumentation was installed which measured water temperature inside the system's tank, electric current to the heating elements, and flow rates of water inside the hot water system.

Project Results/Findings

The catalyst-based NCWT system showed itself to be effective at dramatically reducing calcite buildup in the system. Buildup on the elements was significantly less when the system was installed, and no heating elements failed with the technology installed.

The evaluation team had the opportunity to visit the site 18 months after the technology was installed. There continued to be very little buildup of calcite on the elements. There was some minor collection of calcite in the bottom of the water tank, but nothing that impeded the flow of heat energy into the water.

Tables ES-2 and ES-3 compare the economics of the NCWT system and a conventional salt-based water treatment system.

Table ES-2. Retrofit Economic Assessment

Cost Elements to Compare	Baseline Salt-Based Water Treatment System	Test-Bed Installation Catalyst-Based Water Treatment System
Equipment Cost[2]	$0	$1,192
Installation[3]	$0	$500
Maintenance Labor	$1,500/yr	$100/yr
Maintenance Material	$350/yr	$0/yr
Simple Payback	N/A	<1 year
Savings-to-Investment Ratio	N/A	1.0[4]

Table ES-3. End of Life Economic Assessment

Cost Elements to Compare	Baseline Salt-Based Water Treatment System	Test-Bed Installation Catalyst-Based Water Treatment System
Equipment Cost	$2,600	$1,192
Installation	$600	$500
Maintenance Labor	$1,500/yr	$100/yr
Maintenance Material	$350/yr	$0/yr
Simple Payback	N/A	Immediate
Savings-to-Investment Ratio	N/A	N/A[5]

[2] Baseline equipment cost is based on the premise that there is an existing salt-based water treatment system at the site and therefore there is no new "equipment cost."
[3] The same premise holds as with the baseline equipment cost. Therefore, there is no installation cost in this scenario.
[4] Savings-to-investment ratio (SIR) is based upon one year of saving compared to the cost of a new installation.
[5] The installed cost of the catalyst-based technology is less than the baseline technology. Therefore, the net "investment" is less than zero and an SIR cannot be calculated.

II. Introduction

A. Problem Statement

The US General Services Administration (GSA) is a leader among federal agencies in aggressively pursuing energy efficiency opportunities for its facilities and installing renewable energy systems to provide heating, cooling, and power to those facilities. The GSA Public Buildings Service has jurisdiction, custody, and control over more than 9,600 assets and is responsible for managing an inventory of diverse federal buildings totaling more than 354 million ft^2 of building stock. This includes about 400 buildings listed in or eligible for listing in the National Register of Historic Places and more than 800 buildings that are over 50 years old. GSA has an abiding interest in examining the technical performance and cost-effectiveness of different energy-efficient technologies in its existing building portfolio as well as in those buildings currently proposed for construction.

Many GSA buildings include boilers, chillers, cooling towers, domestic water heaters, and other systems impacted by the condition of water at the site. If the water is used in a cooling tower, or other equipment where it comes in contact with ambient air, fungus and moss can grow in the water. If allowed to grow unchecked, these growths (known as “biologicals” in the industry) can clog filters, impede airflows across the tower, and greatly degrade the cooling tower’s performance. There are numerous companies that make systems which purport to remove biologicals from these water systems. Many of these systems involve adding chemicals to the tower’s water system.

Another issue that can impact a facility’s water quality is high levels of calcium in the local water supply. The calcium combines with other chemicals in the water to form calcite, a hard substance which coats heat transfer surfaces of equipment. This coating can greatly reduce the efficiency of equipment and dramatically increase energy and water usage. If left untreated, the calcium coating can impede heat flow to the point where boiler tubes and heating elements get too hot and fail. This leads to further costs to replace equipment and account for lost productivity due to failed equipment.

Such being the case, there is an abundance of commercial systems that purport to reduce calcium buildup within commercial water systems. Most of the early water treatment systems relied upon adding chemicals to the building’s water system. These chemicals would react with calcium in some fashion to prevent the buildup of calcite.

It should be noted that while these chemical-based water treatment systems were generally effective at preventing calcite buildup, they present several unique challenges. First, the building owner has the added ongoing expense of purchasing chemicals to add to the water. Second, the added chemicals frequently caused issues with the wastewater disposal. Third, there are increased maintenance time and expense for upkeep and deployment of chemicals by staff.

With this being the case with chemical-based water treatment systems, identifying appropriate alternative water treatments systems has been a high priority for federal agencies and commercial entities. Based on the sheer size of the federal building portfolio, there is a huge opportunity for potential savings in chemical costs, energy costs, and waste treatment expenses.

B. Opportunity

The current field of nonchemical water treatment (NCWT) technologies can be subdivided into two main categories.

The first category uses electromagnetic energy in some form to alter the scaling behavior of the calcium carbonate and other chemicals that are native in the water system. By altering the scaling behavior, the reactions that produce calcite plating on surfaces don't happen. Various manufacturers claim that calcite stays in solution and doesn't plate, or that a different non-plating compound is produced. The common theme in all these systems is that electricity is required to produce the electromagnetic energy that is introduced into the water, therefore increasing energy consumption.

The second category of NCWT technologies uses extremely fine filter elements to trap calcium and other impurities so that they can't plate onto surfaces of building heat transfer equipment. Reverse osmosis water treatment systems, a.k.a. "RO Systems," are a common example of this category. Systems such as this tend to produce extremely pure water that does not have the chemicals which create the calcite buildup. However, these types of systems require substantial auxiliary pumping systems to push water through the extremely fine filter elements. The auxiliary pumps can consume a significant amount of electrical energy. Also, the building manager must account for the periodic cost of replacing the filter elements, which can be expensive. RO systems also lose approximately 65% of water that doesn't pass through the membrane and is flushed down the drain as a result. RO systems can produce extremely pure water, but it is a very expensive way to treat water for hardness alone.

The catalyst-based NCWT system described in this report does not fall into either one of these categories. It does not require any external source of electrical power. It also does not use any sort of ultrafine filter element with the associated need to be periodically replaced and without the loss of flushed water from the RO membrane.

On a very simplified level, the device's exterior looks like a section of pipe that has been painted blue, and it is inserted directly into the pipe which carries the water which is to be treated. Water flows through the pipe and over the catalytic insert, which causes the calcium and carbon in the water to form aragonite rather than calcite. Aragonite is chemically very similar to calcite, but it stays suspended in the water and flushes through to the drain, rather than plating on heat transfer surfaces like calcite. Aragonite is an inert substance and requires no special treatment systems as it passes through the system.

No external energy sources are required to operate this device. There are also minimal periodic maintenance issues which must be addressed. Once installed, the system operates as a stand-alone device.

A more detailed description of this technology and its operation is in the following section.

III. Methodology

A. Technology Description

Physically, from the outside this device looks like a length of pipe that's been painted blue. The device installed at the Salt Lake City facility was about two feet long and one inch in diameter, with male NPT threads on both ends. (Sizes of the unit vary widely based upon the flow rate of water to be treated.) The device is designed to be installed directly into pipe which is carrying water that needs to be treated.

Inside the pipe is a fixed, immobile helical insert that is made from a proprietary catalytic alloy. As water passes through the pipe, the helical shape causes significant turbulence, which in turn allows water molecules and their associated chemicals to brush against the catalytic insert. According to the manufacturer, as water enters the pipe it impacts with the turbulator on the front end of the alloy. This turbulation causes calcium carbonate to form from the calcium and carbon in the source water. As this calcium carbonate forms and comes in direct contact with the alloy, the properties of the alloy cause it to form in its Aragonite state, which is a state of calcium carbonate which lacks the properties to adhere to any surfaces. As the water leaves the pipe it is saturated with Aragonite crystals of calcium carbonate, thereby eliminating the possibility of scaling in the system after treatment.

Figure 1 shows photographs of the device's components. The image on the left shows what the exterior looks like. The image on the right shows the helical insert made out of the catalytic alloy. (Photo images were copied from the manufacturer's website.)

Figure 1. Novel Nonchemical Water Treatment System. No external energy sources are required to operate this device. Periodic maintenance issues that must be addressed are also minimal. Once installed, the system operates as a stand-alone device. The vendor reports that the system has a service life of 15–20 years.

No electrical energy is required by this technology. No chemicals are required to be added periodically. The manufacturer claims a 15+ year life span for the device. During this life span, the only costs associated specifically with the device is its initial purchase and installation, plus a small bi-annual cost to clean a storage tank if it is not already equipped with a continuous drain. A building owner may elect to periodically test their water quality, which is good management practice. However, this is a cost that would be associated with any water treatment system and is not specific to this technology.

Catalyst-based NCWT is a proprietary technology. Only one manufacturer currently produces it.[6] The technology was developed in the United Kingdom and has been commercially available in Europe and Asia since 1973. The technology was brought to the United States in 2010 and is gaining acceptance in various applications including food production, household uses, cooling towers, and hydronic heating systems. Within the context of the Department of Energy's Technology Readiness Levels (TRLs), this technology would be considered one step beyond TRL9. Not only is it "System Proven and Ready for Full Commercial Deployment,"[7] it is actually deployed on a commercial basis.

The claimed benefits of the catalyst-based NCWT technology are as follows.

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[6] Fluid Dynamics NA, LLC, 4900 Airport Parkway #1005, Addison, TX 75001-1005.
[7] See DOE Advanced Manufacturing Office Home.

- It reduces or eliminates the buildup of calcite on heat transfer surfaces such as boiler tubes, domestic water heater heating elements, cooling towers, and chiller tubes.

- It requires no maintenance after it is installed. There is no filter element or similar component which needs periodic replacement.

- No external energy is needed to operate the device. No electricity is consumed during its operation.

- There are no chemical additions which need to be periodically added like with a salt-based water treatment system.

Currently, the GSA extensively uses water treatment systems, both chemical based and those that are nonchemical based, to combat scale buildup in their building water systems.

The catalytic technology studied here delivers energy savings in two ways. First, like with all effective water treatment systems, it reduces calcite scale buildup on heat transfer surfaces. Calcite acts as an insulating surface that prevents heat from moving in ways that it is supposed to move. For example, calcite on the heating element of an electric domestic water heater would impede heat energy from transferring to the water. This causes extra electrical energy to be needed by the element to raise the water temperature to the same desired setpoint. It also will cause heat energy to concentrate on the element, which will raise its temperature and eventually lead to premature element failure.

The second way that the catalyst-based NCWT technology saves energy is by not requiring any energy to operate. All other NCWT systems use some form of electrical energy to do what they do; either to operate the system's controls or to produce the electromagnetic field that reduces calcite. The catalyst-based system requires no external energy source.

The catalyst-based NCWT system reduces water consumption relative to chemical-based water treatment systems. Because the catalyst-based system adds no chemicals to the site's water system, there is no need for extra "flushing" of chemical-laden water to the drain.

In preparing for this field evaluation, Oak Ridge National Laboratory (ORNL) researchers read several case studies that were provided by the manufacturer. A link to the manufacturer's webpage can be found in Appendix A. All case studies indicate the ability for the technology to reduce scale buildup in applications that were similar to the situation being faced in GSA facilities. However, they were read in the context of having been provided by the manufacturer.

There were no other federal installations with this technology with whom ORNL could collaborate.

There were no special "barriers" presented when looking at this technology. There is no special energy source that needs installed for the system to work. Also, because there are no added chemicals related with this technology, there are no special waste permitting issues present.

The technology is certified by the National Sanitation Foundation (NSF), which further reduces perceived barriers when it is installed on a potable water system.

There is almost no risk associated with installation of this technology. In an absolute worst-case scenario where the technology totally fails to mitigate the buildup of calcite in a system, the building owner simply has to switch to an existing and proven method of treating the water system. The "proven" system will not have the claimed benefits purported by the catalyst-based NCWT system, but that is a small issue in that the "proven" system will actually work should the catalyst-based system totally fail.

B. Technical Objectives and Demonstration Project Locations

The search for several possible sites focused on GSA facilities in Colorado and Utah. These areas have a history of high calcium content in their groundwater supplies that presents challenges to facility operations. After looking at a number of facilities in Denver, Ogden, and Salt Lake City, the project team settled on the Frank E. Moss US Courthouse in Salt Lake City, Utah, as its site for evaluation. This facility's water supply has a high calcium content which impacts its various water systems. Specifically, there are issues of excess scale buildup on a relatively new electric domestic water heater and on the building's cooling tower.

On the domestic water heater, calcium has been building up on the electric heating elements. The calcium builds up so quickly and thickly that the elements were overheating and failing, often within two months of installing new elements. At the time when the Green Proving Ground was looking for a test site, operating personnel at the courthouse had not yet implemented any sort of water treatment system for the water heater. They were still replacing elements as they failed while seeking a permanent solution.

The situation at the domestic water heater gave the project the opportunity to evaluate a system which heretofore had no effective water treatment. The "before" condition evaluation would include looking at the amount of calcite buildup on the heating elements, the material and labor costs of replacing the elements so frequently, and the added energy costs of maintaining the water system's temperature while the elements were coated with calcite. The "after" condition would look at these same items, and see how they might have changed with the addition of the catalyst-based water treatment system.

As for the cooling tower, in 2012 calcite had built up on the fill material to the point where water and air flows were being impeded. Site operations personnel had to thoroughly clean the calcite using chemical and physical means, including replacing some fill elements. They then installed a salt-based water treatment system. To date, the salt-based system has effectively controlled calcite buildup on the fill material.

The evaluation plan on the cooling tower was to document the cost of installing the salt-based system, the buildup of calcite (or more accurately the lack of calcite due to the system's effectiveness), the cost of labor to periodically re-fill the system with salt, the cost of energy to operate the system, the cost of extra water to flush the system, and the cost of chemicals itself. To document the "after" condition, the project was to look at the cost of installing the catalyst-based NCWT system, the level of calcite buildup, and the absence of cost for chemicals/labor/energy to operate the system. The "before" and "after" situation would be compared to determine the overall effectiveness of the catalyst-based NCWT system.

IV. Measurement and Verification Evaluation Plan

A. Facility Description

As described above, the Frank E. Moss US Courthouse in Salt Lake City, Utah, provided two opportunities to test the new technology. The electric domestic water heater had heretofore no effective water treatment system and was suffering significant issues due to calcite buildup on its heating elements. The cooling tower had been experiencing ill effects from calcite buildup on the fill material, but these were being addressed by a salt-based water treatment system. (Note: For reasons detailed in the "Results" section, the catalyst-based NCWT system was ultimately not tested on the cooling tower. For that reason, the focus from here forward will be on the electric water heater.)

The electric domestic water heater had been suffering calcite buildup on the heating elements. The calcite would build up, which would impede heat energy from transferring from the element to the water. This caused the heating elements to stay energized much longer than they should have in order to maintain water temperatures in the tank, resulting in excess energy consumption. The calcite buildup also caused the elements' temperature to rise to the point where they would fail on a regular basis and need replacement.

Figure 2 is a photograph of the electric water heater where the test was conducted. The insulated line on the right side is where the system's cold and recirculating water enters the tank.

Figure 2. Electric Water Heater Where Test Was Conducted.

Figure 3 is a photograph of one of the heating elements that was removed. Please note the extensive buildup of calcium, the warped shape due to overheating, and the burn-through near the base of the element that caused it to fail.

Figure 3. One of the Heating Elements Removed from the Electric Water Heater.

Figure 4 is another photo of a heating element taken at the moment it was removed from the tank. Please note the thickness of the calcite coating. It appears green in this photo due to it still being wet. This buildup was caused after just two months of operation in the tank.

Figure 4. Heating Element Removed from the Electric Water Heater.

Figure 5 shows all six heating elements, which were removed by site operations personnel during one of the repair sessions. Three elements had failed, and all were severely coated with calcite.

Figure 5. All Six Heating Elements Removed from the Electric Water Heater During a Repair Session.

B. Technology Specification

The catalyst-based NCWT system is a single technology. In fact, it is a single piece of simple equipment that can best be described as looking like a length of pipe with a helical insert through the middle.

The size of these “pipe sections” varies widely based upon the flow rate of the system being treated. The smallest is three-eighths of an inch in diameter, which will treat 0.4 to 1.9 gpm. It is targeted for an individual ice maker or small appliance. The technology is available in larger standard sizes up to 12 in. nominal, which treats 2,200–3,800 gpm. On a custom basis, the vendor can produce units up to 72 in. in diameter.

For the domestic water heater test site, a 1.25 in. device was initially selected based upon design flow data for the domestic hot water circulating pumps that were found in the original design documents. Note: Please see the “Results” section for details about the results of this selection.

Installation of this technology is very straight forward. A section of the cold water and recirculating line was removed, appropriate pipe fittings were installed, and the technology was installed just as any pipe spool piece would be installed. Labor to install the device was only $500 (10 person-hours at $50/hr).

Figure 6 shows the device in its final configuration. It is the silver section of pipe on the right side of the black panel box. This is the cold water inlet to the water heater tank.

Figure 6. Final Configuration for the Nonchemical Water Treatment System (silver section of pipe on the cold water inlet to the water heater tank).

C. Technology Deployment

On the electric water heater, there was no incumbent technology being used at the time of this test. The "before" condition was to document the effects of calcite buildup within the system and its associated costs. The "after" condition was looking at any calcite reduction and the cost of operating the catalyst-based NCWT system.

D. Test Plan

Due to the nature of the situation at the electric water heater, a qualitative evaluation was selected versus a quantitative evaluation. The following items were tracked in the "before" condition.

1. Quantity of calcium that would build up on the elements while installed in the tank.

2. Time between failure of the elements due to overheating from the calcite buildup.

3. Labor and material costs associated with replacing the elements.

4. Electricity consumed by the heating elements.

The above items would be recorded for a three-month period from August to November 2012.

In November the technology would be installed and the same items recorded for another three-month period.

There are no standard protocols (e.g., ASHRAE or NSF) for measuring the items in this study.

Installation of the new technology would be performed by a plumbing contractor hired by GSA.

In the event of heating element failure, replacement would be done by the building contract operations personnel. All elements removed would be kept for evaluation by ORNL researchers.

Electrical consumption would be measured by a current meter that was already in place. GSA would download data and send it to ORNL.

ORNL would have overall responsibility for conducting this test. The primary investigator, Dan Howett, has extensive experience working with water treatment systems of various types while he worked in the private industrial sector prior to joining the laboratory.

E. Instrumentation Plan

Other than the electric current meter, there are no specific instruments associated with this test.

Condition of the heating elements was to be documented with digital photographs.

Labor to replace heating elements was to be documented with work orders.

Labor to install the new technology was to be documented with the work order to the contractor.

V. Results

In August of 2012, new heating elements were installed in the water heater to begin the "before" phase of the technology evaluation. At this time, the technology was not installed as the goal was to see, in a controlled fashion, how the heating elements would respond under the existing conditions of excessive calcification. They were to remain in place until October when ORNL was to return to the site and the technology would be installed.

Within six weeks of being installed, all three heating elements had failed. Building operations personnel replaced the elements, documented their condition, and saved them for ORNL. The mode of failure was the same in all three elements: excess calcium buildup led to overheating and failure.

The three new elements that were used to replace the three failed elements lasted until ORNL's return trip in November. The three elements were removed from the tank and all showed excess calcium, though no failure yet.

The technology was installed and three new elements were installed in the tank to begin the "after" period of the evaluation. This evaluation period was to run until February 2013, at which time the elements would be removed and evaluated to determine the technology's effectiveness.

In December 2012, the GSA building manager contacted ORNL to say that it appeared that all three elements had again failed and ask for further guidance on what to do. After consultation with the project team, the elements were removed and their condition documented. Figure 7 shows two of the three failed elements.

Figure 7. Two of the Three Failed Heating Elements from December 2012.

The failure mode was the same as during the “before” test. Excess calcium buildup caused overheating and premature failure of the elements.

At this point in the test, it appeared that the technology was not working properly. Several decisions were made which affected that test going forward.

1. The team elected to not test the technology on the cooling tower. The cooling tower calcite condition was being successfully mitigated by a salt-based water treatment system. If the salt-based system were replaced by the catalyst-based NCWT system and calcium buildup was no longer mitigated, there was significant risk of damage to the tower fill or damage to the chiller condenser tubes. Because of this risk, the cooling tower test was removed from the technology evaluation.

2. If the technology were eventually to prove itself effective on the water heater, ORNL would conduct a “hypothetical” economic analysis of the cost and savings of using the catalyst-based NCWT system on the cooling tower. This would meet the goal of looking at the potential economics of using the technology on a cooling tower but without putting the current tower at risk. It should be noted that even if the device proved effective on the water heater, there would not be sufficient time to run a risk-free test on the cooling tower during the summer of 2014.

3. The vendor was consulted and given an opportunity to evaluate all findings to date and asked to provide input as to what might be causing the technology to not work as promised. This was done so that the project team would have the opportunity to learn whether there was a parameter that the technology needed for proper operation that was not currently being met. If that parameter could be learned, and

then adjusted to allow for proper operation, then this parameter could be documented in the final report for use by potential future users of the technology.

Over the next several months, the situation was evaluated by GSA personnel, ORNL researchers, the technology vendor, and the water heater manufacturer. Additional flow meters were installed on the hot water system's recirculating line and makeup water line. After compiling all data and expert advice, the following conclusions were reached about conditions with the water heater system.

1. The flow rate in the recirculating line, where the catalyst-based NCWT system was installed, was actually 6–11 gpm, not the 20 gpm indicated in the design documents. The lowest effective flow rate of the 1.25 in. device was 20 gpm. The manufacturer indicated that having the device properly sized to match the flow rate is critical to proper performance. For this reason, a 0.75 in. device, with flow rates of 6–12 gpm, was recommended for the next round of testing.

2. The water heater vendor noticed that the electric heating elements being used by the building operation team were actually designed for residential use. They were not built as robustly as for a commercial unit. For the next round of testing elements for a commercial system would be used.

3. During the period when ORNL and GSA were evaluating the situation, taking flow measurements, and developing a new course of action, building operations personnel, working without guidance from ORNL or the project technical team, modified the heater so that it used six heating elements instead of three like when it was originally shipped. They believed that six elements might mitigate the ongoing calcification issue and reduce the element failure rate. After learning about this action, the technical team evaluated the situation and determined that the six elements were still showing calcification and failure. Thus, even though this was an unexpected twist in the project and it would have been preferred to not happen, it did not impact the overall findings of the report.

On April 3, 2013, the team again convened at the courthouse to start a second round of testing that incorporated the above findings. Because the project was beginning anew with a "before" period, the technology was removed from its location and a blank spool piece of pipe was put back in place.

The six heating elements were all replaced with models that were designed for commercial service. It should be noted that in January 2013, as soon as the water heater manufacturer noted the residential elements, building operations personnel installed commercial grade elements. When these elements were evaluated during the April visit after three months of operational time, none of them had totally failed. There was still substantial buildup of calcite on the elements, to a thickness that normally takes years to develop. The elements also showed some signs of overheating and slight warpage. These observations indicate that the elements still would have failed within a few months, but not within the frequency that the site had been experiencing.

On June 11, 2013, the team convened in Salt Lake City to remove the elements from the "before" period and to install the 0.75 in. device where the previous 1.25 in. device had been. At this point the "after" period of the test would begin.

The heating elements that were removed all showed severe buildup of calcite, and this was after only two months of operation. They also showed signs of overheating and bending, which are precursors of failure (Figure 8).

Figure 8. Heating Elements Removed June 2013.

Figure 9 shows the 0.75 in. device installed where the 1.25 in. device had been located.

Figure 9. Electric Water Heater Showing the 0.75 in. Device (blue) Installed on the Cold Water Inlet Pipe.

In early July 2013, site operations personnel observed that the temperature of the domestic water heating system had risen to almost 150°F. At this point they felt that it was too hot for safe use in the facility, so on July 12 they adjusted the thermostat to its next lowest setting. After checking the temperature trends of the system, personnel determined from the data that the temperature rise began at the same time that the catalyst-based NCWT device had been installed (Figure 10). It should be noted that the electric heating elements, in their efforts to maintain the temperature set point, remained energized 24 hours a day, even over weekends. This constant state of being energized was required because the elements were so caked with calcite, which was acting as an insulator and impeding heat energy from easily transferring from the element to the water.

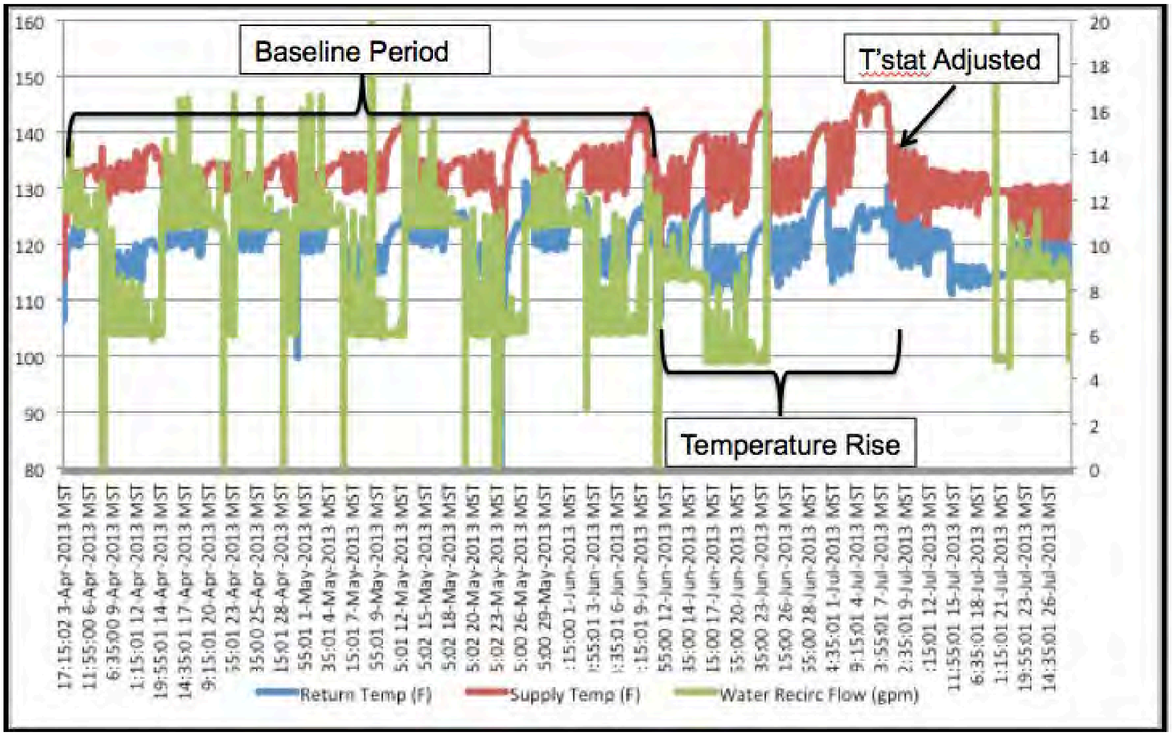


Figure 10. Graph Showing Water Heating System Temperature Trends Over Time.

After the thermostat was adjusted, temperature in the system went back down to around 130°F, where it was supposed to be. Data from the electrical meter on the heater noted that at this point the heating elements began to cycle off when the temperature reached its set point. Figure 11 is a graph of the electric current showing it cycling off during the night and on weekends when usage is low.

According to manufacturer's guidance, the 0.75 in. device that was installed has an optimal flow range of 6.0–11.9 gpm, with the ability to address flow rates as high as 16 gpm. The vendor's design chart of optimal and maximum flow ranges is included in Appendix A of this report.

The manufacturer's recommended flow rates are consistent with what was measured in the above graph. Please note that the step changes in flow rates are caused when the two circulating pumps alternate between each other. One pumps at about 6 gpm, the other around 11 gpm (Figure 10). It should be noted that a set of flow rate data was lost due to meter failure. However, discussions with site operations personnel plus analysis of data before and after the meter failure gave the evaluation team confidence that there were no variations in the building operating characteristics during the gap in data.

After scrutinizing the data, ORNL researchers concluded that it appeared that more heat was being transferred from the heating element into the water. The only thing that could have allowed this to happen is a reduced buildup of calcium on the heating elements.

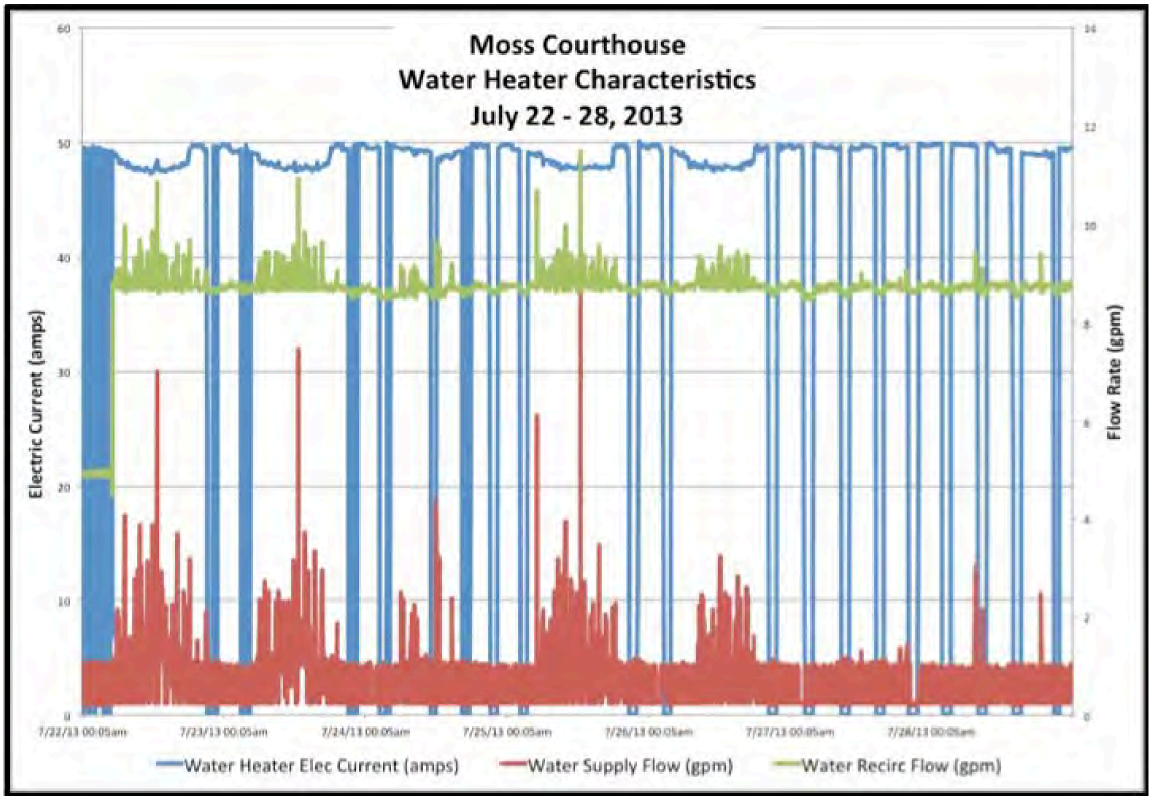


Figure 11. Graph Showing Electric Current and Water Flow Rates.

On August 20, 2013, the team met in Salt Lake City to examine the elements for calcium buildup. The six elements were removed, and they were indeed dramatically cleaner than had been seen in the past. Most of each element was bare metal with no buildup whatsoever. What calcium was found on the elements was in the form of very thin flakes. Also, there was no evidence of overheating or warping, which indicates there is no reason to fear impending failure of these elements (Figure 12).

The water temperature rise after installation of the catalyst-based water treatment system, the lack of severe calcium buildup, and the lack of evidence of overheating all indicate that the non-catalyst NCWT system was effective at preventing the buildup of calcite scale in the water heater.

On November 20, 2014, the project team had the opportunity to reconvene at the site to evaluate the technology's long-term effectiveness after 17 months of continuous operation. During this period, no heating elements had failed.

The tank was drained and heating elements removed for evaluation. There was some calcite on each element, similar to what was found in the July 2013 evaluation. However, the elements were mostly clean and in good condition. Figure 13 shows a typical element.

Figure 12. One of the Six Elements Examined August 20, 2013.

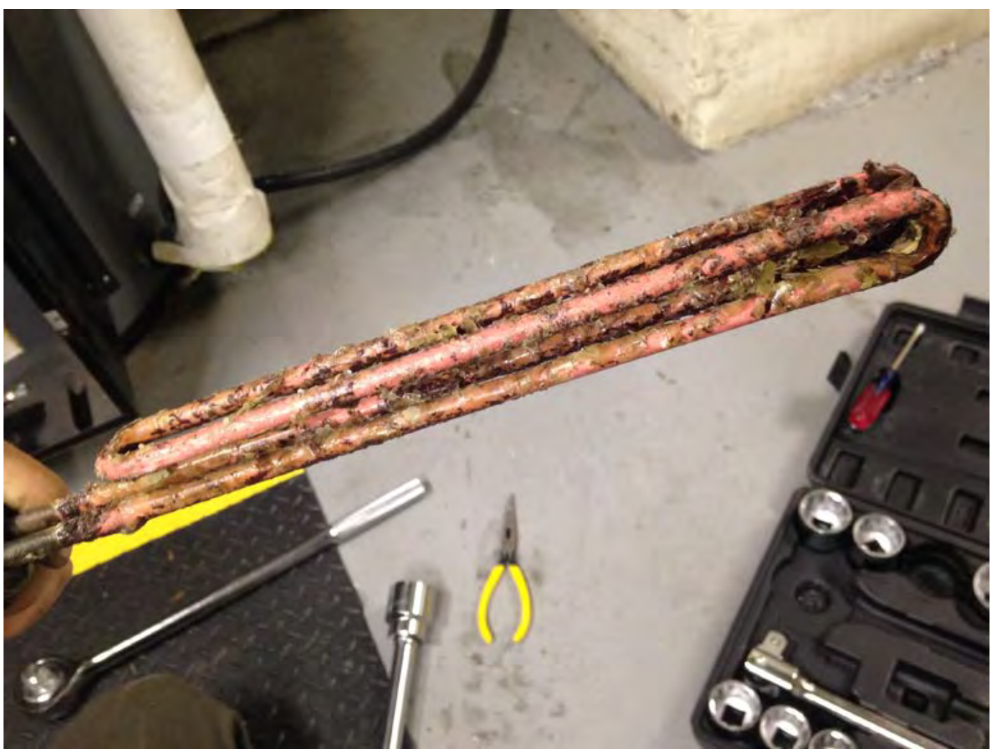


Figure 13. One of the Six Elements Examined in November 2014.

The team did note that there was a small collection of soft material that looked like calcite in the tank's bottom. The technology's vendor was contacted and asked about this observation. The vendor's response follows.

01 December 2014

Ref: Moss Court House water conditioning

To whom it may concern,

Following the recent review of the above we can confirm that the deposition that is being experienced is normal in water heaters where there is a sump that does not have a periodic bleed program in place. As water heats and cools some treated calcium will come out of solution and precipitate as a soft sludge. This sludge will usually exit the system when the water flows out the drain however in systems where there is no available drain it is suggested that the sludge is removed manually either using a scoop or if possible a wet & dry vac can be inserted into the heater via the elements maintenance hatch and sucked out.

The frequency of this cleaning regime depends on water quality and the volume of water that is being processed through the heating system, generally in applications such as this it will be required between every 18–24 months.

Evidence from this trip indicates that the technology is capable of maintaining clean heating elements over a long period, but labor must be accounted for approximately every two years to clean the buildup from the bottom of the tank.

Financials of mitigating failures of heating elements in Salt Lake City

Material cost of 0.75 in. catalyst-based NCWT device: $1,142
Material cost of parts to install device: $50
Labor cost to install device: $500
Total installed cost: $1,692
Biannual labor to clean bottom of the tank: $200

Material cost of replacing one failed heating element: $30
Labor cost to replace failed element: $400
Total cost of replacing six commercial-grade failed elements: $580

Simple payback if failure of heating elements requires the tank to be repaired two times per year: $1,692 ÷ [(2 * $580) − $100] = less than two years.

Financials of comparing the catalyst-based NCWT technology to a salt-based water treatment system commonly used to treat calcite buildup

The most common current method of addressing calcification issues in domestic water equipment is with a salt-based water treatment system. These are commonly called "water softeners."

A local water softener vendor was contacted and provided with the operating parameters (flow rate, total flow, and water hardness) at the test site. The vendor provided the following cost estimate for installed cost and annual cost of salt to operate the salt-based system.

Material cost of the water softening equipment: \$2,600
Labor cost to install the device: \$600
Total cost to install the water softening equipment: \$3,200
Annual cost of salt: \$350/year
Annual labor to replace salt within the equipment: \$1,500

Table 1 directly compares the cost of the catalyst-based and salt-based water treatment systems.

Table 1. Comparison of Catalyst-Based Nonchemical Water Treatment System and Salt-Based Water Treatment System

Description of Cost	Catalyst-Based System	Salt-Based System
Purchase price of equipment and material for installation	\$1,192	\$2,600
Labor to install	\$500	\$600
Annual cost of chemicals	\$0	\$350
Annual labor to service chemical	\$0	\$1,500
Biannual labor to clean tank	\$200 (average \$100/year)	\$0

Simple payback = less than one year {([\$2,600 + \$600] − [\$1,192 + \$500]) ÷ ([\$350 + \$1,500] − \$100)}.

Evaluation of results associated with installing the catalyst-based NCWT system on the site's cooling tower

As mentioned previously in this report, the original measurement and verification plan for this project included installing a catalyst-based NCWT system on the site's cooling tower and evaluating its effectiveness. The tower had long been suffering from excess calcification on its fill material. To mitigate the situation, the site had installed a salt-based water treatment system that has proven effective at preventing calcite buildup.

The original plan was to install the catalyst-based NCWT system on the tower, measure its effectiveness at calcite prevention, and then compare the economics of the two systems. Because of circumstances discussed previously, the catalyst-based NCWT system was not installed on the tower. However, because of the effectiveness that the technology showed on the domestic water heating system, the project team elected to conduct a hypothetical economic analysis from the premise that it would show similar effectiveness on the cooling tower.

Figure 14 is a flow diagram that illustrates how the catalyst-based NCWT system would be installed on a cooling tower. Two devices are required; one on the makeup water line and one on the recirculating water line. Please note that this diagram comes from literature produced by the manufacturer.

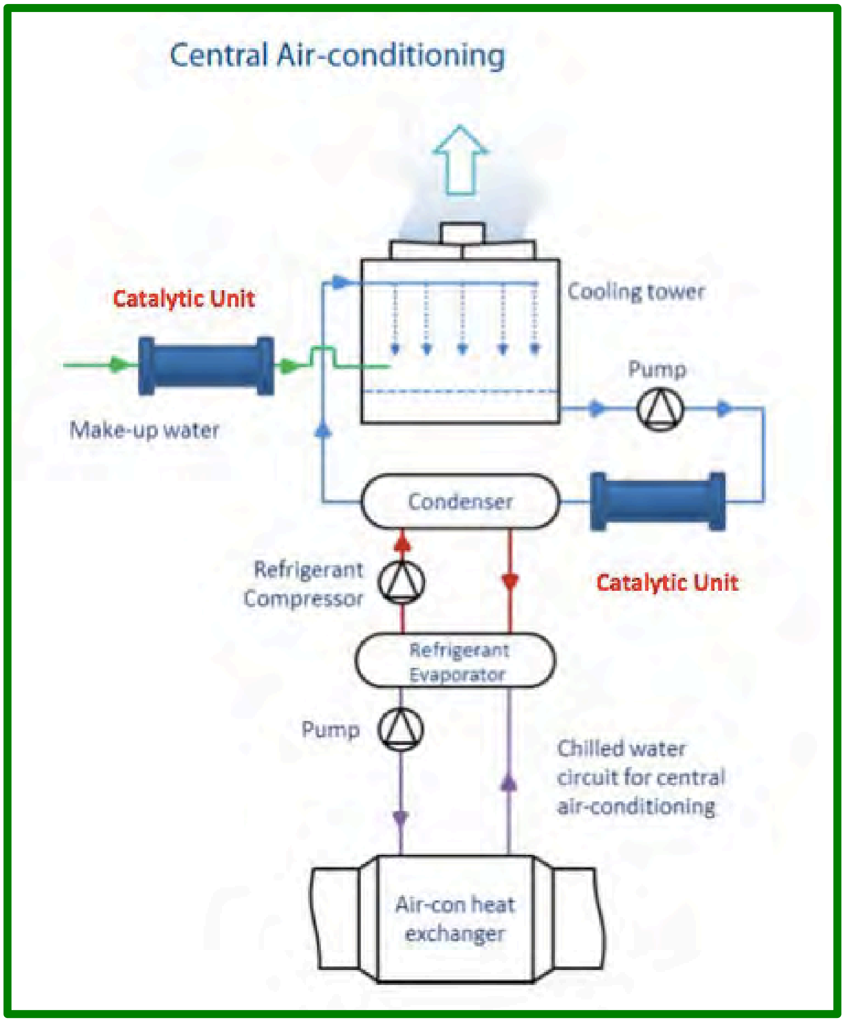


Figure 14. Manufacturer's Flow Diagram Showing the Nonchemical Water Treatment System Installed on a Cooling Tower.

Based on the premise that the catalyst-based NCWT system would be just as effective at preventing calcite buildup on a cooling tower as it was on the domestic water heater, it is a straightforward exercise to document and compare the financials of the existing salt-based system and the proposed catalyst-based system. It should be noted that the site's cooling tower only operates about seven months out of the year. All operating costs in the following analysis have been normalized to present the costs of operating the tower 12 months each year as most cooling towers are.

Financials of the existing salt-based water treatment system

Installation cost of the system, including labor and material:	$2,700[8]
Cost of salt for 12 months/year operation:	$900/year
Average labor to check system daily and fill as needed:	15 minutes/day

[8] Note: When using a salt-based water treatment system, only the makeup water line must be treated. This line's flow rate is relatively small compared to the flow through the large tower recirculating line. Flow through the makeup water line is similar to that found in the domestic water heater.

Annual labor cost at 260 days/year and $60/hour: $3,900/year
Electricity cost for the existing unit is not metered: $100/year (estimated)
Water lost due to blowdown is not metered: $unknown

Financials of the proposed catalyst-based water treatment system if retrofitted into the existing tower piping

Estimated Cost of Installing and Operating Catalyst-Based Water Treatment System

Equipment cost of the two catalyst-based devices: $29,380[9]
Labor cost estimate to install devices in a retrofit installation: $ 3,000

Note: If this were a new installation, there would be zero marginal labor cost associated with installing this system. The catalyst-based devices are installed in the exact same manner as pipe spool pieces. Given that the contractor would be installing either spool pieces or NCWT devices, the marginal labor cost becomes zero.

Cost of salt or other chemicals for twelve months/year operation: $zero/year
Average labor to check system daily and fill as needed: zero minutes/day
Annual labor cost at 260 days/year and $60/hour: $zero/year
Electricity cost: $zero/year
Water lost due to blowdown: $unknown (see discussion below)

The simple payback period (SPP) for using the NCWT technology on a cooling tower that operates 12 months per year is **less than seven years**.

When looking at the economics of the hypothetical application on the cooling tower at the courthouse in Salt Lake City, several items become noteworthy.

First, the catalyst-based NCWT technology does show economic promise from the perspective that it has zero operating cost for additional chemicals (salt, etc.), labor to maintain chemicals, and energy used by the water treatment system compared to a typical salt-based system. At the Salt Lake City courthouse, where the cooling tower operates seven months per year, the economics of a hypothetical installation would have less than about an eleven-year simple payback compared to the existing water treatment system. At other sites, the existing cost of these elements would have to be evaluated on an individual basis to determine economic viability.

Second, the vendor of the catalyst-based NCWT technology claims that the system allows for the use of biocides in a cooling tower to be reduced by 50%, but that claim has not been tested at a GSA site. This claim should be tested within any follow-on evaluation of the technology on a cooling tower.

VI. Summary Findings and Conclusions

A. Overall Technology Assessment at Demonstration Facility

This assessment was successful in evaluating the value propositions put forward by the vendor. The technology showed itself to be effective at preventing the buildup of calcite scale on heating element surfaces in a domestic water system. Further, the buildup prevention was accomplished by the technology

[9] Note: The significant increase in cost over the similar technology installed on the domestic water heater is due to the fact that the vendor recommends installing its system on the large recirculating line as well as the smaller tower makeup water line. The recirculating line is a 10 in. pipe that carries significant water flow from the tower to the chiller. The domestic water heater line carried less than 20 gpm through its 2 in. diameter.

and it consumed no energy whatsoever. Also, it added no chemicals to the water stream such as with a salt-based water softening system. The technology was cost effective when its initial installation cost was compared to labor and operational savings over the life of the product. In some cases, the simple payback was immediate as both the installed and operating costs were less than a comparably performing salt-based water treatment system.

The major barrier identified with this technology is that its effectiveness is sensitive to being installed in a system where the water flow rate is within the optimum operating range of the size of unit installed. This barrier can be mitigated by measuring the flow prior to installing the device, and then working with the vendor to install a unit that is sized properly for the measured flow. Experience in this evaluation has shown that simply using the flow rate given in the design data (from pump curves or other sources) is not an accurate way of determining the actual flow rate within the system.

If a facility's flow rate is measured and the rate is shown to have a wide operating range, it will be important to consult with the vendor to develop a design that incorporates the technology so that it is effective over the wide range of flow rates.

The technology has demonstrated its effectiveness in this study, and it is recommended that it be considered for adoption by GSA facilities that are experiencing scaling issues in water heating systems.

B. Best Practice

When installing this technology, it is imperative that the facility manager conduct a flow test using ultrasonic meters to determine the actual water flow rates at the point where the device will be installed. This best practice was learned very clearly based upon lessons learned during this test where manufacturers' pump curves and design data were used to estimate the flow rate, rather than relying on actual measurements. This technology demonstrated a sensitivity to its operating flow rate that must be accounted for when installing it.

Based on the study results, this technology demonstrates the ability to support meeting the performance standards for water treatment systems described in Section 5.3.5 of GSA's Facility Standards for the Public Buildings Service (P-100).

C. Barriers and Enablers to Adoption

There are only two apparent barriers that need to be overcome in order for this technology to have a widespread adoption.

First, there will be a certain amount of hesitancy within the audience of building managers to adopt a catalyst-based technology such as this. The water treatment system market has historically been dominated by systems which use either mechanical means (ex: RO systems) or active chemical means (ex: salt-based systems) to reduce scaling. The technology is unlike either of these systems, and thus will have a certain hurdle to climb to reach customer acceptance. Third party evaluations such as GSA's Green Proving Ground program will go a long way to overcoming this barrier.

Second, the technology can have higher first costs than other water treatment systems. However, because it uses no energy or chemicals, and potentially reduces water consumption and biocide use on cooling tower applications, there are substantial operating savings to be gained by its use. Each facility owner will have to evaluate their own situation to determine if the higher first cost is still economically viable at their facility.

D. Market Potential Within the GSA Portfolio

Given the ubiquity of domestic water heating within GSA facilities, any buildings that are experiencing a calcite scale issue have potential to be helped by this technology. Also, most larger GSA facilities use cooling towers and hydronic heating systems to meeting HVAC needs. These also would benefit from this technology.

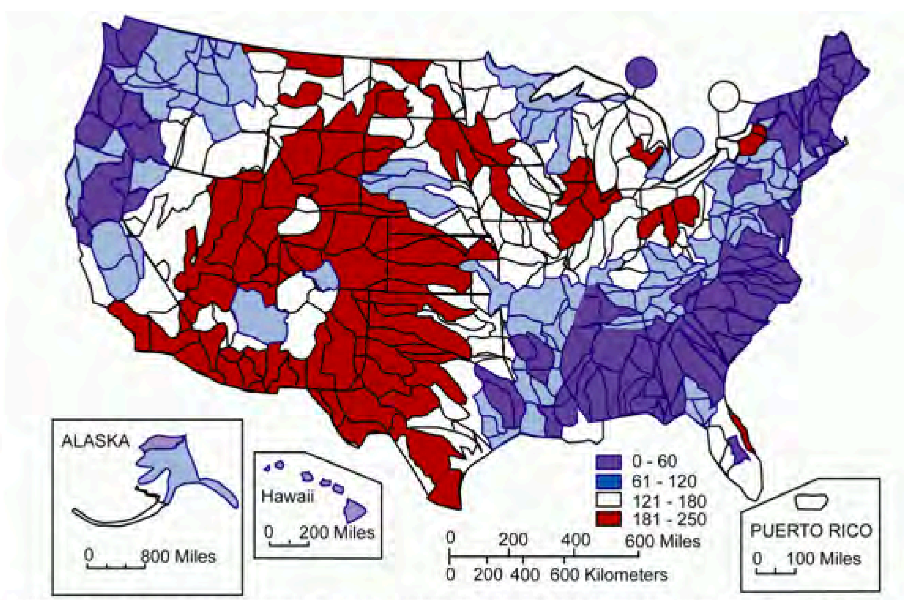
Based on this study, SPPs on a cooling tower that that operates year-round would be less than seven years compared to other water treatment systems.

This technology would be most cost effective if used in new construction due to the lower marginal cost compared to installing it in a retrofit application. This technology installs in a system as if it were a spool piece of pipe. In new construction, the flanged or threaded fittings into which the technology connects can be planned and installed during initial construction. This approach would cost significantly less than a retrofit application where the water system would have to be taken out of service, the existing piping cut into with pieces then requiring disposal, flanged or threaded fitting being installed into the piping system, and then installing the device and bringing the system back into service.

In both new construction and retrofit applications the technology would provide the same descaling service, but the cost of installing it would be much less if it were designed into a new system from the beginning.

This technology requires no added wiring or plumbing connections, which would be found with conventional water treatment systems.

The harder the water, the more likely that the catalyst-based NCWT system will be cost-effective. Figure 15, from the USGS (USGS Water-Quality Information), shows water hardnesses that are found across the country. However, local water conditions should be measured for hardness as these can vary significantly from the averages shown in the figure based upon local geologic conditions.



Mean hardness as calcium carbonate at NASQAN water-monitoring sites during the 1975 water year. Colors represent streamflow from the hydrologic-unit area. Mape edited by USEPA, 2005. Modified from Briggs and others, 1977.

Figure 15. Average Water Hardness Across the United States as Calcium Carbonate (in milligrams per liter).

E. Recommendations for Installation, Commissioning, Training, and Change Management

The vendor claims a service life of 15 years for this product. This claim has not been verified.

Because there are no moving parts, no chemicals to be added, and no periodic maintenance to be performed on this technology, no training is needed for site maintenance personnel.

Installation of the technology should be executed within the design guidance provided by the manufacturer.

This technology should be considered at any GSA facility with calcification issues. The economics of the installation at each facility would have to be individually evaluated based upon local construction labor rates, local costs of alternative technologies, and the cost of issues being caused by excess hardness in the local water supply. In general, the harder the water, the more likely the catalyst-based NCWT technology will be cost-effective.

Because this technology is currently available from only one manufacturer, GSA's purchasing department will have to determine the appropriate vehicle through which the technology could be purchased for use in GSA facilities.

VII. Appendices

A. Detailed Technology Specification and Technology Case Studies

In preparing for this field evaluation, ORNL read several case studies that were provided by the manufacturer and found at Scaletron Case Studies.

The page linked below contains a selection from the vendor's specification sheet that shows optimal flow ranges for the various sizes of their technologies.

More information can be found at http://www.fluiddynamicsna.com/files/1014/2137/3743/Scaletron_Specification_SheetNCD.pdf.

SELECTION GUIDANCE:

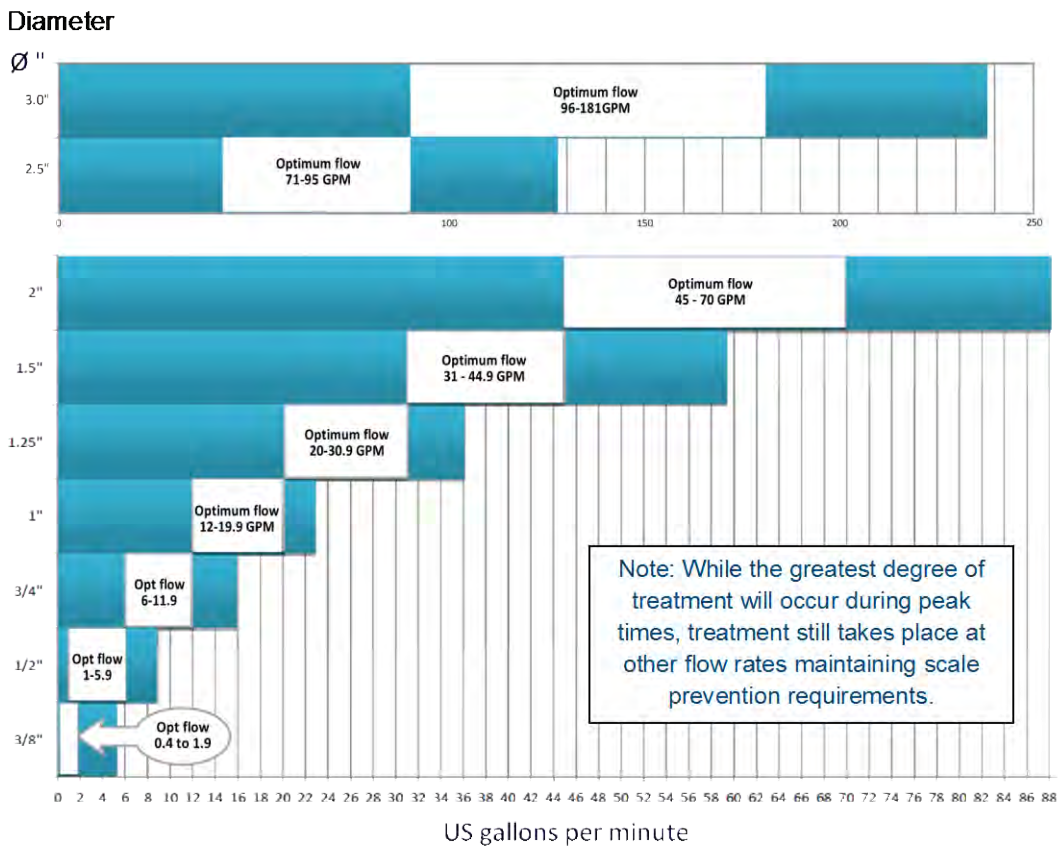
Peak and average flow rates should be considered when selecting the correct Scaletron for a system.

Once the flow has been determined the "Product Selection Guidance Chart" shown below will provide assistance in selecting the diameter suited to the application.

The goal is to determine and select the minimum diameter unit that can be used without incurring unacceptable pressure losses at peak demand periods.

For example: A hotel on city water is found to have peak consumption between 6 and 8 am in the morning. The minimum sized diameter unit capable of supplying the peak time flow without unacceptable pressure losses should be selected.

PRODUCT SELECTION GUIDANCE CHART:



Actual maximum throughput (GPM) will vary according to system pressure.

Fluid Dynamics NA, LLC | P.O. Box 1005 | Addison, Texas 75001-1005 | (855) 228 8766 (toll free) | www.fluiddynamicsna.com

B. Enlarged Flow Rate and Temperature Graph

The following is an enlarged image of Figure 10 from the main body of the report. It is being shown here for clarity's sake.