An On-Line Cleaning Procedure Used to Remove Iron and Microbiological Fouling From a Critical Glycol-Contaminated Closed-Loop Cooling Water System

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Index

1) Abstract:

The objective of this paper is to outline the details of a comprehensive chemical and mechanical cleaning program that was used to remove severe iron and microbiological fouling from a critical closed-loop cooling water system at a large hospital complex. Using a combination of operational changes, side-stream filtration, and a chemical program consisting of a polymeric-based dispersant, an alkalinity and pH builder, a molybdate-based corrosion inhibitor and an oxidizing microbiocide, over a four-month period total iron concentrations in the system were reduced from 76 ppm (as Fe) to less than 2.3 ppm, and microbiological counts were lowered from over 1.5×10^6 cfu/ml to less than 100 cfu/ml. In addition, pH levels of the recirculating water were raised from 6.2 to 8.5, water clarity improved dramatically, and the pervasive rancid odor that previously characterized the system was removed entirely. Best of all, the cleaning procedure was performed “on-line”, so no downtime occurred, even during the hottest summer days.

2) Introduction:

“Out of sight, out of mind,” is a common adage that can easily be applied to most closed-loop cooling water systems. Often lurking behind sheet-rocked walls or suspended above acoustically-tiled ceilings, closed chilled water systems are almost all universally ignored by building operators and water treatment vendors alike. Time and time again, however, experience has shown that lack of attention to these systems often occurs at great risk and potential liability to all involved.

In most large modern office buildings and institutional complexes, closed-loop or chilled cooling water systems (commonly defined as any system that does not employ evaporation for cooling and has water losses less than 0.5% of its recirculation rate) play an increasingly important role in temperature and humidity control throughout critical business workspaces[1]. Working in conjunction with air-handling units, chilled water systems initially collect and remove undesired heat generated from numerous sources, including the weather, light fixtures, building occupants, and computer operations. Once collected, the undesired heat is then transferred to the open recirculating cooling water system via the chiller heat exchanger. Finally, through the process of evaporation, the heat is dissipated to the outside environment via the open cooling tower.

During the past twenty years, the expectations of workers and guests in these buildings has increased to such a level that it is now taken for granted that building air-conditioning systems will always operate as designed and without interruption. Such expectations are especially prevalent in the hospital community, where precise temperature and humidity control are deemed essential to promoting patient comfort and good health. In addition, because of their generally inaccessible nature, repair work conducted on closed-loop water system has historically been dirty, labor intensive, disruptive to facility operations and very expensive. Seeking to avoid such operational problems and liability concerns, the purpose of this technical paper is to outline in a case history format a comprehensive water management program that was used "on-line" over a period of four months to successfully clean a hospital's glycol contaminated closed-loop chilled water system. This cleaning was performed without any discomfort to the building occupants or disruption in service to this critical operating system.

3) Background Information:

Located on Boston's prestigious North Shore, a large 230-bed hospital facility previously used a 20,000 gallon closed-loop cooling water system to provide seasonal air conditioning for its multi-building complex. The chilled water loop operated in conjunction with a 1,000-ton electric centrifugal chiller and a 15,000 gallon open recirculating cooling water system utilizing a 1,500-ton Marley cross-flow cooling tower.

To prevent freezing problems during the severe New England winters, the cooling coils in the building were routinely filled with a propylene glycol solution during the late fall months. The following spring, the glycol solution was drained from the coils, and without a fresh water rinse, the units were returned to service. As sizable quantities of antifreeze were always still present in the low-lying areas of the coils, significant concentrations of propylene glycol (up to 175 ppm as active) routinely accumulated in the chilled water system.

Once introduced to the chilled water system in less than percent concentrations, propylene glycol reacts with available metallic ions in the recirculating water, such as iron (Fe) and copper (Cu) in a progressive oxidation reaction[2]. In this process, the propylene glycol is degraded to incrementally smaller organic molecules, such as aldehydes, ketones, and acids[2]. Some commonly encountered intermediate molecules formed by this process include lactic, acetic, and formic acid[2]. Once formed, these organic acids dramatically lower the pH of the recirculating water, making it extremely aggressive to the base metal of the distribution piping and the refrigeration equipment. The formation of the organic by-products also generates the putrid odor that is commonly associated with glycol contaminated chilled water systems. Most importantly, the lower molecular weight acids and other intermediate molecules provide the biologically available organic carbon needed to support microbiological growth within the system. This phenomenon is extremely important because in fresh water systems, nitrogen, phosphorous, and biologically-available carbon (BAC) are all nutrients that can limit microbiological growth if not present in sufficient concentrations[3].

4) Prior Treatment Program:

Prior to our involvement at the hospital, both the open and closed-loop cooling water systems were being treated by a local water treatment vendor. Despite knowledge of persistent glycol contamination problems in the chilled water loop, the vendor chose to use a nitrite-based corrosion control program in the system. When asked to evaluate the chilled water loop by the hospital's recently hired independent water treatment consultant, we encountered a system that was suffering from severe operating and performance problems. Water samples taken from the chilled system were tainted dark orange in color and had a very distinctive "putrid" odor. Analysis of the sample showed a pH level of 6.2, a total iron concentration of 76 ppm (as Fe), a total copper concentration of 2.7 ppm (as Cu) and a microbiological plate count of 1.5×10^6 cfu/ml. Inspection of the chiller unit also showed a substantial amount of iron fouling and corrosion on the tube sheet and significant deposition and discoloration of the copper heat exchanger tubes.

From an operations standpoint, the chiller tubes had to be "punched" clean three times in a four month period, and an independent HVAC maintenance contractor stated that the machine was operating at less than 80% of its design rating. Although no major leaks were yet encountered in the distribution piping of the chilled water system, the hospital's engineering staff was very concerned about this problem occurring in the near future, resulting in expensive and disruptive repairs to these enclosed plumbing structures.

Like many hospitals today, the facility was undergoing a major expansion of its building complex and HVAC system and wanted to complete a cleaning of the old chilled water distribution piping and refrigeration equipment before they were connected and combined into the new system. As it was just then entering the early summer months, the hospital insisted that the cleaning be completed "on-line" so that it would not interfere with the comfort and health of the facility's patients and staff.

5) Proposed Treatment Program:

The cleaning project began by first meeting with the hospital's engineering and maintenance staffs to collectively formulate a program that would both quickly correct the current problems within the chilled water system, and also prevent any future reoccurrences. Based upon these discussions, a multi-functional water management approach was recommended that consisted of changes to the hospital's operational procedures, installation of a mechanical filtration system, and the use of select chemical treatment products.

First, the procedures used to remove the propylene glycol from the cooling coils at the end of the winter season were revised. Rather than just draining the coils and returning them directly to service, maintenance personnel will now flush each unit twice with fresh water before connecting the exchanger back to the chilled water system. With this new procedure in place, it is expected that the amount of glycol entering the system will be greatly reduced in the following years. More importantly, the new procedure will significantly reduce carbon loading to the system, and also greatly reduce the concentration of acidic decomposition products in the water, thereby making future corrosion, deposit, and microbiological control goals much easier to achieve.

Next, to remove existing suspended solids from the system, it was recommended that the hospital install two 304-stainless steel, side-stream bag filtration units on the system. Plumbed in series, the bag filtration units were connected to the discharge header of the recirculating water pumps. The filters were designed to handle approximately 1.0 - 2.0% of the total recirculation rate of the chilled water system, or about 20 gpm. To maximize the pressure differential across the filter bags, the filtered water was discharged to a header located on the intake side of the same recirculating water pumps.

To accelerate sediment removal from the system and to maximize the holding capacity of the bags, the filter housings were always operated with two different micron rated bags. For instance, upon initial startup of the filtration system, we placed a 50-micron rated bag in the upstream unit, followed by a 25-micron bag in the downstream unit. As the cleaning program progressed, and the clarity of the recirculating water improved, we used increasingly smaller micron bag combinations (such as 25 and 10, and 10 and 5) until we reached our final goal of a 5.0 and 1.0 micron bag combination.

Once the operational changes were implemented, and the filtration system was installed and operating, a multi-functional chemical treatment program was implemented to further address and control corrosion, deposition, and microbiological fouling issues within the system. The chemical program consisted of a comprehensive molybdate-based corrosion inhibitor, a polymeric dispersant, a combination pH and alkalinity booster, and a chlorine dioxide releasing microbiocide. The objective of this comprehensive chemical treatment program was to quickly regain control within the system without the use of certain raw materials, such as nitrite, phosphorous and biologically-available carbon, that could further exacerbate existing problems and potentially prolong the cleanup process. In addition, the chemical treatment program needed to be accomplished "on-line", even as the chilled water system operated almost continuously throughout the hot summer months.

Using a 5-gallon by-pass feeder, all of the chemicals were slug fed to the chilled water system at dosages required to yield either a desired chemical residual level (i.e., molybdate) or specific test parameter (i.e., microbiological plate counts) within the recirculating water. Comments on the specific constituents and benefits of each of the separate treatment programs are outlined below.

A) Molybdate-Based Corrosion Inhibitor:

The inhibitor treatment program consisted of a comprehensive blend of sodium molybdate for general and pitting corrosion control of steel, sodium tolyltriazole for copper and yellow metal corrosion control, a polymeric dispersant for scale and suspended solids control, and a borate buffer for pH control. Previous studies have shown that molybdate does not act as a nutrient source for microorganisms, and provides corrosion protection in low oxygen environments and in systems previously fouled with tuberculation deposits[4]. The product was fed to the system at a rate sufficient to yield a molybdate residual of 100 – 150 ppm (as Mo) and an azole residual of 5 – 10 ppm (as active) within the recirculating water. As the pH level and the suspended solids concentration of the recirculating water was so far outside of the parameters typically encountered in a normally operated chilled water system, we also decided to supplement our standard molybdate-based corrosion control program with a polymeric dispersant and a combined pH and alkalinity builder.

B) Polymeric Dispersant:

Based upon the extremely high suspended sediment loading of the chilled water systems, we decided to supplement our program with a blended polymeric dispersant consisting of low molecular weight sulfonated styrene and polymaleic-based polymers. We specifically avoided the use of any inorganic or organic phosphates in the dispersant product, as we did not want to potentially add any additional reactive phosphate to the chilled water. Through the use of the polymaleic and sulfonated styrene molecules, we primarily sought to keep the various solid contaminants suspended and dispersed in the recirculating water until they could be easily and permanently removed from the system by the bag filtration units. A second objective of the dispersant program was to help promote the cleaning of existing deposits from piping surfaces. It was suspected that we were successful in the objective, as the recirculating water typically became much more turbid just after the addition of the dispersant program, and spool samples located in the system gradually became cleaner.

C) Microbiological Control Program:

As with all other aspects of the chemical treatment program, one of the key objectives of the microbiological control program was to use a product that would function well in a chilled water system while not contributing any limiting nutrients to the water. In the case of microbiocides, one of the most commonly added limiting nutrients is often biologically-available carbon. Although many organically-based microbiocides can provide for rapid and pronounced kill rates in chilled water systems, they often rapidly degrade to less complex and typically non-toxic molecules. Although desirable from an environmental standpoint, once degraded, these microbiocides actually provide much needed biologically-available carbon to the water. Once available, this carbon can then promote microbiological growth within the system. For this reason, it is not uncommon to see microbiological plate counts decline dramatically just after the addition of certain organic microbiocides, only to increase rapidly again after just a few days time.

Based upon such prior observations and years of accumulated experience, it was decided to implement a microbiological control program based upon a stabilized chlorite solution (SCS), a chlorine dioxide releasing product. As an inorganic product, the SCS microbiocide would not contribute any biologically-available carbon to the system. In addition, the chlorine dioxide released by the SCS has many unique attributes that make it well suited for use in chilled water systems. First, chlorine dioxide is a very weak oxidizer that will not aggressively attack iron and copper system components such as piping, tubes, and pumps. Chlorine dioxide is also a broad-spectrum microbiocide that has been shown to be particularly effective against the bacteria species incorporated in biofilm deposits. Effective as a microbiocide throughout the 3 – 10 pH range, chlorine dioxide was ideally suited for this particular cleanup program, as we worked to gradually increase the pH of the recirculating water from 6.5 to its targeted 8.5 – 9.5 range[5].

As a weak oxidizer, chlorine dioxide will also not react with either glycol or many of its degradation by-products, such as ketones, aldehydes, or organic acids. By not being consumed and deactivated by these background organic contaminants, the chlorine dioxide remains available for its primary intended purpose, that of a microbiocide. However, chlorine dioxide will react with soluble ferrous iron in the system, quickly oxidizing it to the insoluble ferric state. In this case, it is believed that the oxidation of iron in the chilled water is actually beneficial to the overall objectives of the cleanup program, as the precipitated ferric iron can then be more easily and permanently removed from the system by the bag filtration unit.

D) Alkalinity and pH Builder:

As the final step in the chemical treatment program, we elected to add a combination alkalinity and pH builder to the system. The product, a liquid blend of sodium borate, sodium bicarbonate, and sodium hydroxide, was slowly added to the system over the course of several weeks. The product was designed to reduce the corrosive nature of the recirculating water by gradually increasing the pH level of the recirculation water from 6.5 to our desired range of 8.5 – 9.5.

6) Program Results:

Beginning in July of 2005, and continuing over the course of the entire four month cleaning procedure, Jamestown representatives visited the hospital on a weekly basis to check chemical residual levels and other key water treatment parameters within the chilled water system. During these visits, the representatives also added required treatment chemicals, changed filter bags, and consulted with the hospital's maintenance and engineering staffs on the progress of the cleaning program.

Throughout the cleaning procedure, a steady improvement in all key water treatment parameters was noticed, including total iron and copper concentrations, alkalinity and pH levels, and molybdate and azole residuals. Within several weeks time, molybdate residuals were consistently being maintained between 100 – 150 ppm (as Mo), while azole concentrations were being controlled between 5 – 10 ppm (as azole). Slowly and steadily, pH levels in the system were raised from a starting level of 6.5 to a final range of 8.5 – 9.5. After several months, total iron concentrations in the system declined from 76.0 ppm to 2.34 ppm (as Fe). Copper concentrations also declined, from a high of 2.7 ppm to a final value of 0.4 ppm (as Cu). Similarly, microbiological plate counts in the system declined from a high of 1.5×10^6 cfu/ml to less than 100 cfu/ml. There was also a marked improvement in the appearance and turbidity of the recirculating water, as it now approached near swimming pool clarity. There was also a welcome disappearance of the distinctive rancid odor that had previously characterized the system.

From an operational standpoint, no leaks occurred in the chilled water system during the entire cleaning procedure, and the refrigeration equipment also soon returned to its rated operating efficiency. Best of all, these results were obtained while the chilled water system remained in constant operation throughout the brutal summer months of 2005, which was one of the hottest on record for the northeastern United States. In fact, the hospital's engineering staff and HVAC contractor were so pleased with the progress of the cleaning program, that they decided to connect the new chilled water system to the older refrigeration equipment and distribution piping several months ahead of schedule.

Once connected, on the approval of the hospital's engineering staff, the cleaning of the older system was discontinued. Chilled waters from the old and new systems were then commingled, and combined system was then treated for the following year in a traditional manner by the HVAC contractor's own water treatment vendor.

7) Summary:

Historically, closed-loop recirculating water systems have been overlooked by all concerned parties, including maintenance staffs, building owners and water treatment vendors. This is particularly true for chilled water systems that have the potential to be fouled by glycol-based anti-freeze products. However, considering the sizable economic costs and potential liability issues associated with repairs to these types of systems, it is now imperative that more attention be placed upon the proper operation of chilled water systems.

In the event that a chilled water system has become contaminated, it is now important that the situation be detected quickly so that proper corrective actions can be taken before potential corrosion, deposition and microbiological control problems cause irreversible damage. Only by fully understanding and appreciating the unique operating parameters of chilled water systems, however, can the seasoned water treatment professional hope to develop a cleaning program that will properly address each of these interconnected problems. As outlined in this paper, through the use of a comprehensive water management program that incorporates proper operational procedures, installation of mechanical filtration, and the use of select chemical products, just such an objective can be successfully achieved. We are confident that these basic procedures, once modified to the site-specific demands of a facility, can be used as a guideline by other water treatment professionals to successfully treat similarly fouled chilled water systems.

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