System Failures Unrelated to Water Chemistry

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Abstract

Identifying the true cause(s) of building water system failures is critical to prevention, mitigation and where applicable, legal defense. Any system failure is generally the result of several, often complex, variables. Because of the specialized nature of technical knowledge required to provide successful chemical water treatment, water treaters have become an easy scapegoat for a wide variety of system failure claims. However, the origin of these problems is frequently either unrelated to water chemistry, or water chemistry is just one of several variables contributing to cause the failure.

Common causes of system failure unrelated to water treatment include: (a) Operational Issues; (b) Design Issues; and (c) and the Lack of Legacy Knowledge with respect to the system operation and maintenance practices. Operational causes of system failure may include: (1) improper commissioning; (2) inadequate cycling of the system; and (3) over-firing or under-firing. Design issues leading to system failure may include defects arising from (1) material selection; (2) inadequate hydraulic balancing; and (3) velocity related erosion/corrosion. It is the intent of the authors that understanding these possible causes will aid in identifying the root cause of the occurrence.

Introduction

Examination of the events giving rise to system failures is inherently complex and can involve highly technical analyses involving disciplines of engineering, metallurgy and chemistry. There are frequently a myriad of contributing factors to any given failure that may occur over long periods of time. In fact, certain critical events in the life of the system can occur years prior to failure.

As system failures devolve into claims and litigation, the need to properly diagnose the true root cause of system failure is critical for numerous reasons. First, the damages involved in these incidents can be significant and grossly disproportionate to the amount of money earned for work related to the system, especially in the case of the chemical water treater. Next, those seeking recovery are typically unconcerned with the true cause of their damages and will often implicate anyone involved in the design, construction, installation, commissioning, treatment and maintenance of the system regardless of their true culpability. In so doing, claimants frequently imply that the mere fact of a system-related failure necessarily means that those involved with the system were somehow the cause. Consequently, they will scour the record for any imperfections in the duties performed by any craft involved with the system. They then employ results-oriented logic and assert that the shortcomings identified were the actual cause of the failure.

Despite their limited access to the system, limited scope of work and limited pay, chemical water treaters have become favored targets in these scenarios. A system failure occurring during a water treater's term of service is often enough to result in the treater being implicated. This publication examines common causes of system failure unrelated to water treatment including: (a) Operational Issues; (b) Design Issues; and (c) Lack of Legacy Knowledge with respect to the system operation and maintenance practices.

It is the intent of the authors that understanding these possible causes will aid in identifying the root cause of the occurrence.

Failures Incident to Operational Issues

Systems may fail for reasons unrelated to their design, construction or treatment and entirely due to the manner of their operation. This section addresses common operational pitfalls including (1) improper commissioning; (2) inadequate cycling of the system; and (3) over-firing or under-firing.

Improper Commissioning

The need to timely and properly commission and passivate a building water system is critical to preserve the life of the system. Specifically, the exposed metal surface should be chemically "passivated" to ensure that the piping system metals have some reserve corrosion resistance to carry the protection forward. In the absence of proper corrosion and microbial control during this period, the addition of water jumpstarts the microbial proliferation and the ensuing corrosion acceleration which advances uninhibited.

Despite the universal recognition of the need for proper passivation, the failure to do so at initial start-up or following a seasonal layup remains a prominent cause of system failures. Case studies reflect that this step is often overlooked or deprioritized as a mere line item maintenance task. Consequently, systems are often "dead on arrival" as uninhibited water is allowed to come into contact with the inner pipe surface for extended periods. As a result, precipitated corrosion products (such as iron oxide) and microbiological depositions (such as iron and sulfate reducing bacteria which imbed themselves into iron deposits) may form on the inner wall of the pipe surface.

Depending on the nature and extent of this under deposit corrosion, subsequent chemical treatment may no longer be able to directly bathe the inner wall of the pipe but instead is in contact with the hardened corrosive layer. The result is a frequently irreversible corrosive process occurring beneath an impenetrable layer of hardened corrosive deposits that continue to feed on the pipe wall. Evidence of this corrosive process is often concealed from the bulk waters to which the treater has access for testing and treatment.

Case Study #1

A 20-story commercial building in a seasonal climate was equipped with a hydronic system that could be used for heating or cooling. The configuration included an open cooling tower system with a closed condenser loop and a hot water loop. These separate loops would mix at all times between valve exercise and mode operation. Accordingly, at any given time the water chemistry would be shared among the systems.

During the warmer summer months, the hot water loop would be "laid up" for at least 120 days. As opposed to draining, drying and cleaning the surface before start-up in the fall, the building maintenance crew would leave the hot water loop partially filled and isolated. Ultimately, the system and its attendant equipment failed. The Owner and property manager blamed the monthly water treater citing elevated bacterial levels in the water as the purported root cause of failure. It was discovered in litigation that because the hot water system was not completely drained and dried, microbiological colonies flourished during the stagnant period. This water contaminated the rest of the system.

Despite the fact that the property manager had full access to the premises 365 days a year, the monthly water treater was promptly blamed for the failure to drain and re-passivate. This was the case although the equipment manufacturer's written standards advised that "Proper cleaning and surface preparation must be completed prior to system start-up." Notably, the water treater's contract specifically provided that the "Owner will not be liable for any charges other than those described and expressly authorized." The authorized acts were limited to a single monthly service visit for the express purpose of treatment of the systems and water analysis. For that task, the treater was paid a gross sum of $300 per month. The agreement was silent regarding any shutdowns, cleaning, flushing or passivation.

Nonetheless, the owner opted not to turn to its property manager that was charging in excess of $20,000 per year. Instead, it opted to target the $300 per month water treater whose contract limited it to a single monthly visit that lasted no more than an hour each month with the chief task of water analysis. When asked where these duties appeared within its contract, the Owner stated, "We hired you guys to take care of the system. You're the experts."

It was successfully argued that the task of re-passivation was beyond the scope of the limited duties to be completed during the once per month visit of the water treater. Further evidence revealed that the hot water loop could not be independently shut down, cleaned and drained, and the chemical treater did not have the autonomy or discretion to do so.

Inadequate or Improper Cycling of the System

One of the more common root causes of failure, is caused by the improper operation of the equipment itself. It is well accepted that water treatment chemicals can only provide protection in a dynamic system when water is flowing at proper velocities. There is no chemical treatment for hydraulic or thermal stresses that can arise out of improper system cycling. Likewise, is well known that corrosion inhibition protocols for stagnant systems are completely different from those of active systems.

Case Study #2

A major internet retailer built a new data center in a desirable East Coast location. Maintaining a proper temperature of the server rooms was integral to protecting the integrity of the data, so large redundancies were built into all aspects of the cooling system. This included a 500% redundancy in the cooling tower system. Unfortunately, this consisted of 5 separate towers on individual sumps. On start-up, the commissioning engineers called for the system to rotate towers every week. This resulted in one system being on, and four being off-line at any given time. This meant that each sump, and associated piping, were stagnant for four out of every five weeks. Biological fouling and microbially influenced corrosion developed immediately. Pinhole and larger leaks began to appear within 6 months of start-up.

Initial blame fell on the water treatment company. However, the Field Service Reports and treatment plan both contained good documentation of the risks posed by stagnant water in the idle systems; along with suggestions on how to remedy these problems. As a result of this data and because the building was still in its first year of operation, the mechanical and general contractors were held liable for the repair.

Over-Firing & Under-Firing

Just as no motor oil can protect a vehicle's engine if it is consistently run above the "red line", no chemical treatment can protect a system that is being over-fired and operated outside of the manufacturer's guidelines.

Case Study #3

A group of several five-story office buildings in an office park in North Carolina was successfully treated for a number of years by a well-recognized water treatment company. The building owners brought in new management and directed them to find ways to "save money/reduce costs". The new management decreed that the heating system would be shut off overnight to "save energy". In cooler weather, the maintenance staff would arrive in the mornings and immediately put the system in "high fire" mode to get the building warmed up before tenants arrived. They failed to follow the manufacturer's guidelines that the system should never be started on high fire, but should gradually be warmed up over a minimum 4 hour period. Likewise at night, operators were instructed to simply "shut things down and leave." Again, this ignored the manufacturer's recommendation that the system should be gradually cooled down.

By the end of the heating season, nearly all of the hot water heating boilers were leaking internally. The building owners and management initially cited improper water treatment as the cause, demanding several hundred thousand dollars in damages. Examination of the failed components by a certified metallurgical lab found the failures to have been caused by creeping and stress corrosion which was due to uneven rates of expansion and contraction in the boilers. This was caused by over-firing the boilers when they were cold, and uneven cooling when they were shut off.

Failures Incident to Design Issues

The lack of a proper design can cause a litany of fatal issues in a building water system. Some of the usual suspects include improper material selection and improper hydraulic balancing. In addition, case studies reflect that the design may be properly conceived but not properly executed. Regardless of the design problem at issue, these defects are often so pervasive that otherwise perfect operations and water treatment programs cannot avail the system.

Improper Material Selection

The failure to select appropriate materials for a building water system application can prove to be a critical mistake. Despite the fact that chemical water treaters have no involvement in selecting the metallurgy of the system they are treating, they are nonetheless routinely implicated in failures for poorly designed systems. Despite the fact that water treaters are hired for a limited purpose and given limited access to the system, it is frequently alleged that they should have somehow diagnosed the improper material selection and somehow "saved the system."

Case Study #4

A leading manufacturer of Personal Protective gear had a large plastics plant, where among other things, they made hard hats. They initially had 10 production lines for the manufacture of hard hats but demand was great and they added 5 more.

The plant almost immediately began to experience corrosion failures in the 5 new molds. The water treatment company was wrongfully implicated for the corrosion. Initial investigation found that stress corrosion cracking was resulting in the failure. Further investigation found that in order to "save money" the new molds were purchased from a lower cost vendor. Metallurgical analysis found that these new molds, although 420 grade stainless steel, were heat treated at a higher temperature resulting in the metal being more brittle and prone to stress corrosion cracking. When the molds were replaced with ones from the original higher priced supplier, the problem subsided. (NOTE before the remedy was implemented, the plant went through 15 molds at an approximate cost of $17,500 each. The original mold supplier's price for the molds that were deemed too expensive was approximately $2,500 per mold higher.)

Case Study #5

The closed loop piping system used at an asphalt emulsion facility failed due to leaks incident to tube fractures. The piping loop from two water tube boilers supplied steam to coils in the asphalt emulsion tanks and condensate is returned to the boiler's water feed tank from the tank coils. After a year of service, water was discovered leaking from the boiler. Investigation revealed that a water tube in the boiler's pressure vessel had fractured. The fractured tube was removed and replaced. A week later, additional tubes were fractured and leaking.

The owner's expert opined that the tubes failed due to caustic induced stress corrosion cracking. It was alleged that surface pitting and general corrosion in the tube were caused by a low pH level in the boiler's feed water and that the presence of indicators for these corrosion mechanisms suggested that appropriate water chemistry was not being maintained while the boiler was in operation. In pursuit of this theory, the Owner's expert found innocuous instances of non-compliance with the boiler manufacturer's treatment specifications and attempt to allege they were the cause of the failures. Based on the expert's report, the Owner sought damages exceeding $100,000.

Investigation revealed that the conditions leading to the fractures were not found throughout the tube surface but were localized to very specific locations. In fact, examination of the non-fractured areas of the tubes suggested no evidence of general corrosion. The boilers at issue were high capacity efficiency boilers that were represented as being able to produce extreme heat quickly such that it can go from being idle to producing steam in 5 minutes or less. It was discovered that all of the tube fractures were in locations in close proximity to the main burner. The fracture location was impinged upon by the flame from the main burner during operation.

The failed tubes were found to be made of plain low grade carbon steel. Although the steel grade met the minimum standards for a typical boiler (AISI 1010 and ASTM Standard A192) a higher grade should have been used given the exceptional heat flux involved for the boilers used.

The combination of the burner alignment which came preset from the boiler manufacturer and the use of low grade steel proved to be the actual cause of the incident. Following the last of the tube fractures, the efficiency boiler was replaced with a conventional boiler and no further issues arose.

Inadequate Hydraulic Balancing

Proper balancing of a building water system is essential for effective performance. Despite the need for a systematic approach to ensure that proper balance is achieved, it remains common to find examples of poorly balanced systems and the problems resulting therefrom.

Case Study #6

A major university in the Southwest commissioned a new campus of seven buildings to house its new Honors Program. These buildings ranged in size from 2 floors (plus basement) to 7 floors (plus basement), and were a mix of dormitories, classrooms, dining halls and activity centers. Construction and commissioning were both "rushed" at the end of the project in order to have space available for the start of the academic year. As a result of this rush, the key step of hydraulically balancing the systems was not as thorough as it should have been.

As a consequence, system flow rates were improper for many of the materials of construction. There were documented flow velocities in excess of 12 feet/second (fps) in small diameter copper piping serving all of the bathrooms in two of the dormitory buildings. Within two years, copper elbow fittings began to leak and within another 18 months, pervasive pin-hole leaks began to develop throughout the copper system in all buildings. Metallurgical analysis confirmed the root cause of the problem as erosion corrosion due to excessive water velocity in the copper pipes.

All seven buildings had to be completely replumbed. Damages were on the order of $75,000,000.

Design Specifications Not Followed

System failures relating to design issues are not exclusively based on design flaws. As reflected in the below case study, otherwise sound design choices may not effectively be communicated or executed by those responsible for construction or commissioning of the system.

Case Study #7

The condenser water system in a mixed used building in New England was designed with 10-inch closed loop piping serving the residences on the 2nd through 20th floors. After several design revisions, the first floor lobby and retail spaces were connected to a rooftop cooling tower. This open loop system was fitted with four-inch carbon steel pipe running from the rooftop mechanical room down to the first floor.

Evidence revealed that the system design experienced areas of significant "low flow" as the small bore piping had maximum design flowrates of 2.5 linear feet per second. These velocities were inadequate to push water treatment chemical through the system and insufficient to inhibit solid and microbiological depositions, thereby leading to non-uniform corrosion and under deposit corrosion.

In less than two years, the small bore open loop experienced leaks incident to massive tuberculation and corrosion completely eating through the pipe wall. The building owner filed a lawsuit seeking more than $2,500,000 in damages naming the design engineer, general contractor, mechanical subcontractor, construction phase water treater and the ongoing monthly water treater.

During litigation, documents were discovered reflecting that the design engineer did not intend for the open loop design to be utilized. These documents, which predated substantial completion, indicated that the mechanical subcontractor was to "revise the retail loop to be on the closed side of the heat exchanger." During one inspection, the design engineer indicated that he was "disturbed" by the system layout and that he "thought the retail loop was going to receive closed water."

These documents lead to cross-examination of the design engineer who conceded that the open loop design was the cheapest of the available options, the riskiest for corrosion related failure and that a closed loop system could have worked but was more expensive. After the incident, the open loop was converted to a closed loop design and no further issues occurred.

Erosion Corrosion

Erosion Corrosion refers to "acceleration in the rate of corrosion attack in metal due to the relative motion of a corrosive fluid and a metal surface. The increased turbulence caused by pitting on the internal surfaces of a tube can result in rapidly increasing erosion rates and eventually a leak." This phenomenon is often associated with systems with high flow velocities, small pipe diameters and piping run designs that create abrupt changes in flow direction.

Case Study #8

During the warmer summer months in Colorado, a hot water loop servicing a 14-story building would be "laid up" for at least 3 months. As opposed to draining, drying and cleaning the surface before start-up in the fall, the building maintenance crew would leave the hot water loop partially filled and isolated. Despite this practice, the system operated without incident for over 10 years before the pumping configuration was changed and the pumps upgraded. After the Summer layup in the first full season following the pump upgrades, the building water system and its attendant aluminum heat exchangers failed.

The manufacturer of the heat exchanger denied the warranty and concluded that improper water treatment chemistry was the cause of the failures. The Owner and property manager likewise blamed the monthly water treater citing elevated bacterial levels in the water as the purported root cause of failure.

However, metallurgical graphing of the pipe walls revealed evidence of erosion secondary to turbulent water flow. Specifically, it was confirmed that foreign debris and dissolved solids were allowed to stagnate in the system during the Summer layup. Because the hot water system was not completely drained and dried, microbiological colonies flourished during the stagnant period.

The foreign debris that was allowed to accumulate combined with turbulent water flow and caused the resulting damage to the system.

Failures Incident to Lack of Legacy Knowledge

Increasingly, veteran and experienced maintenance staff and system operators are retiring and leaving the work force. In decades past, the replacement for these veterans would be hired 6 months to a year ahead of their retirement, allowing for a significant amount of site and system specific on-the-job-training. However, current hiring and staffing practices are being dictated by short term financial considerations. As a result, a substantial amount of site and system specific legacy knowledge is being lost; often with expensive consequences.

Case Study #9

An older multi-story office building in New England used a direct contact fluid cooler to provide cooling during the summer months. The system was not difficult to treat and operated without incident for many years. As often happens, the initial building manager retired and was replaced by an experienced manager who was new to this property. About the same time, the veteran head of the maintenance staff also retired.

The new maintenance personnel did not take the time to read all of the operational manuals for what they perceived was a relatively simple cooling system. As a result, the new maintenance staff failed to properly drain the cooling water loop during winter months resulting in cracks due to freezing in the fluid cooler heat exchanger on the roof.

Once again, the new building manager was quick to put the initial blame on the water treatment program. However, metallurgical analysis and review by a Registered Professional Engineer confirmed that the damage was caused by freezing due to improper/incomplete draining of the system at the end of the cooling season.

Conclusion

There is a high degree of risk in disputes arising from complex system failures where the ultimate decision makers (Judges, Jurors and Arbitrators) are frequently unfamiliar with the technical principles at issue. The conflation of flaws, which are mere imperfections that did not cause the failure, and defects which are those deficiencies that actually caused the harm, can serve to inflame an already perilous litigation for those wrongfully implicated.

In light of these factors, the ability to properly identify the actual root cause of a system failure can be critical. This is especially true for chemical water treaters. Despite their limited access, scope of work and pay, treaters have become a "catch-all" target for any ill that befalls a system. Most water treaters possess a high degree of technical competence in the discipline of water chemistry. This level of proficiency in their respective field is often exploited by opportunistic claimants who will allege that the treater is a complete systems expert who should somehow save the system from engineering, operation and design failures.

As shown in the aforementioned case studies, water chemistry is frequently targeted as the culpable cause despite compelling facts demonstrating that issues arising from defective system design, improper operations and the lack of legacy knowledge are the true culprits.