The Efficacy of Ozone for the Treatment of Process Water in Evaporative Cooling Systems

A Study at Washington and Lee University

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This paper describes a comparative study conducted at Washington and Lee University to measure the effectiveness of ozone when compare to traditional chemical treatment for evaporative cooling systems.

Bacteria, Biofilm and Heat Transfer

In an evaporative cooling system, the environment is ideal for growth and reproduction of microorganisms. Limits for the amount of aerobic bacteria in bulk cooling water have been accepted universally as the norm for bacterial control with the use of mechanical and chemical interventions such as chlorine, bromine, non-oxidizing biocides and filtration. By using total colony forming units per cubic milliliter (CFU/ml) as control, an evaporative cooling water program has been considered to be satisfactory if the bacteria count is below 10^4 CFU/ml. This measurement is for planktonic bacteria, but does not measure actual impact on the major purpose of the system- heat transfer.

An evaporative cooling system exists solely for the rejection of process heat through evaporation. Heat transferred to the water via a heat exchanger is directly affected by the cleanliness of the heat transfer surface. A great deal of emphasis has been made to prevent scale formation on these surfaces. However, it has been established that biofilm on the heat transfer surface is up to 4 times as insulating as an equivalent layer of scale. Biofilm is also excellent "glue" for many of the deposits that would not precipitate in the absence of biofilm, thus directly contributing to scale formation. Therefore a renewed emphasis has been placed on keeping the heat transfer surface clean not only from scale, but especially from biofilm. Ozone has been found to be a superior choice for control of biofilm.

The Efficacy of Ozone

The goal of maintaining an evaporative cooling system heat exchanger free of biofilm formation is made increasingly difficult by EPA regulations, environmental liability, operating cost, chemical costs and worker exposure to toxic chemicals. Ozone is an excellent alternative to traditional biocide programs with benefits such as: no transportation, storage or disposal issues; on site generation based on real time organic demand of the system; fewer water discharge issues; no danger of bacterial immunity buildup; and short half-life breakdown to oxygen.

Ozone works by what could be described as "cold combustion" of organic material. Ozone coming in contact with the cell wall of bacteria results in the cell contents being exposed to oxidation, disrupting cell metabolism and eventually oxidizing remaining cell material. Since the oxidation process is nonselective, food sources for bacteria are also oxidized. In properly controlled ozone treated cooling systems, the bulk water plate counts are generally, $<10^2$ CFU/ml, the water is very clear and wetted areas of the system such as tower fill and sump are clean. During inspection of condensers, the water side tubes do not have the slippery feel associated with biofilm. Multiple sites have used eddy current testing to verify there is no detectable metal loss on these clean surfaces. Control of ozone is based on a real time feedback signal (ORP) that provides for biofilm reduction while not feeding ozone at levels that might be corrosive.

Environmentally, with the half-life of ozone at about 15 minutes in cooling water and reversion of unreacted ozone back to oxygen, many restrictions for discharge are reduced or non applicable. Additionally, since ozone does not add conductivity to the cooling water and the bacterial counts are maintained so low, it has been found that cycles of concentration can be elevated with respect to a comparable chemical program, thus achieving water conservation.

The Clean Streams™ System

The Clean Streams system is a stand-alone automated system that generates ozone on site and introduces it into the process water of evaporative cooling water systems. Feed gas is supplied from air separation units to provide clean, dry oxygen feed gas to a corona discharge ozone generator. The ozone feed gas is then introduced via a venturi into a by-pass feed line of tower basin water and the treated water is returned to the basin. The electrical field in the generator is regulated from a controller measuring the Oxidation Reduction Potential (ORP) of the bulk water and adjusts voltage applied to generate ozone. The ORP of the bulk water is maintained in the 500-600 mV range.

Background: Washington and Lee University

The Washington and Lee University operates a central chilled water plant that services the campus in Lexington, Virginia. The chiller plant has 4 electric driven chillers installed consisting of one (1) 600 ton and three (3) 1200 ton chillers. Two 1200-ton chillers are operated in the cooling season and one 1200-ton and the 600-ton chillers are on line during free cooling months when load demands are lower. Chilled water temperature is controlled by a Trane energy management system. System temperatures and flows are controlled by variable speed drives to obtain the most energy efficient use of the chillers.

The chilled water condensers are serviced by an evaporative cooling tower arrangement that consists of a flooded sump field-erected ceramic counter flow tower and augmented by dry sump Evapco cross flow towers. Water temperatures are maintained at lower than normal Δt of 5-7 degrees F by the energy management system.

Makeup water is supplied by a combination of the City of Lexington and two (2) auxiliary wells on campus. Makeup water chemistry varies significantly based on evaporation rate and sump level, with the lead water use from the wells and augmented water supplied by the city. In low evaporation scenarios, the bulk of the makeup water is from wells with the reverse happening during high evaporative loads.

A traditional chemical water treatment system was used on the evaporative cooling water to provide corrosion, scaling and microbiological protection.

The Study

In October of 2012 a Clean Streams ozone system was installed at Washington and Lee to evaluate the relative effectiveness of chemical and ozone treatment. Biofilm growth was monitored with biofilm coupons and an industry standard test that uses a 15-minute reaction to yield a BioMass Reading or

BMR. Corrosion was also monitored to insure the customer that corrosion rates were held to acceptable levels. Initially, cycles of concentration were to be elevated as part of the study, but were not changed to decrease the number of variables when studying the impact on biofilm.

Fouling Factor (FF) is the thermal resistance due to fouling accumulated on the heat transfer surface of a heat exchanger, and is the inverse of the actual heat transfer coefficient of the heat exchanger. Heat exchangers are designed with a maximum FF increase when first placed in service, and the American Refrigeration Institute (ARI) sets the allowance for increased fouling on condensers. After time, the formerly clean heat transfer surface FF value will increase and the resultant decrease of heat transfer can be translated into a loss of energy efficiency, or an actual increase in electrical consumption of an electric driven chiller.

Simply stated, as the heat exchanger is operated, the FF will increase due to fouling at the heat exchanger surface from deposits such as biofilm. The postulate is that the Fouling Factor is conversely improved through the removal of biofilm.

To measure Fouling Factors the Trane data monitoring system at Washington and Lee was utilized. The Trane monitoring system can calculate the real time Fouling Factor for 1200-ton chillers. It should be noted that the chillers being studied - Chiller #3 and Chiller #4 - were less than two years old. The Number 3 chiller (1200 tons) was designated the base load chiller and the Number 4 chiller (1200 tons) was set to share load when the sustained load exceeded 1200 tons. When the shared load then dropped back below 800-1000 tons, the #4 chiller was taken off line and the #3 chiller again assumed full load.

The ozone system was installed and began operation in October of 2012. In May of 2013, when the loads on the chillers increased, the condenser water was placed back on chemical treatment with the exception of the pH control where sulfuric acid was replaced with carbon dioxide. This was Phase 1 of the study. On August 13, 2013, the chemical water treatment program was secured and the ozone system was again powered up augmented by carbon dioxide pH control. This was Phase 2 of the study.

Fouling Factor and load were logged every 15 minutes for both chillers. No other changes in the chiller operation occurred and data continued to be collected every 15 minutes. Data collection commenced on June 1 and ceased on October 17th. The data was then analyzed to detect any measurable change in Fouling Factor when comparing the Phase 1 data before August 13th (chemical water treatment program) to the Phase 2 data after August 13th (ozone water treatment program).

Results and Analysis

Bioflim

Biofilm readings during the nine-month period prior to the installation of the ozone system in October 2012 indicated an average BMR of 1.16. This would be considered acceptable for traditional chemical programs and would not require additional action. Biofilm readings during the Phase 1 chemical trial indicated an average BMR of 1.29, also acceptable and requiring no additional action by traditional standards.

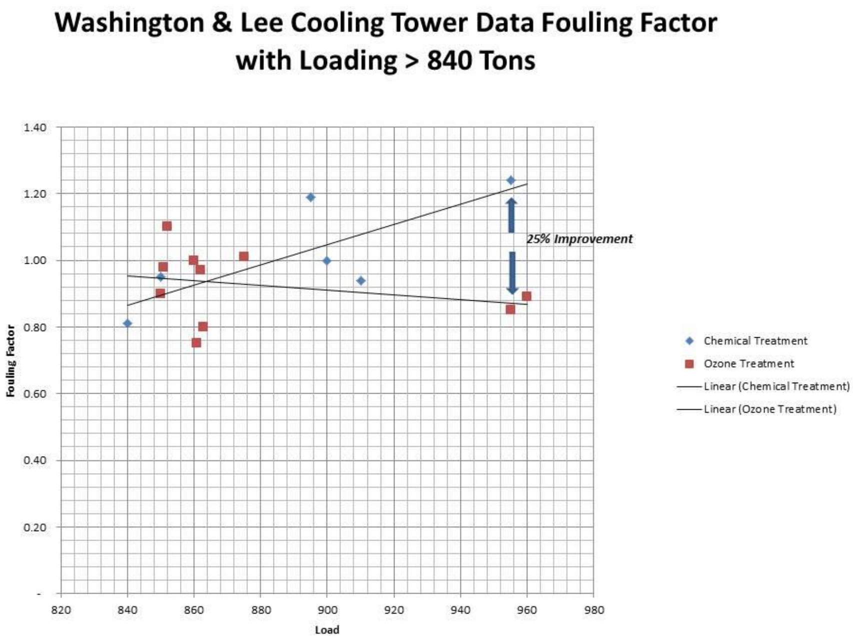
Biofilm readings from the commencement of ozone operations in October of 2012 to the beginning of the study period, indicated an average BMR of 0.29. Anything below 0.30 is considered no growth. During Phase 2 of the study, we saw an average BMR of 0.33. Even though we were seeing good control using chemical treatment, we experienced significant improvement with the ozone treatment, which we believe correlates directly with the improved FF seen.

Fouling Factor

Fouling Factor is calculated based on heat exchanger design and real time pressures, flows and temperatures. Thus, a change in FF will also indicate a change in heat transfer efficiency that directly impacts electrical efficiency. In multiple manufacturers' literature, a relationship of percent efficiency to FF is found to be a constant of approximately 108.52. Thus, a decrease in FF can be directly related to an increase in electrical efficiency, which converts to reduced electrical consumption.

During low load periods there was no detectable trend difference in the Fouling Factors. However, when the system was under sustained high loads above 800 tons there was an observed trending decrease in the measured Fouling Factor. When the chemical program Fouling Factor was compared to the ozone program Fouling Factor, the ozone showed marked improvement over the chemical program. The Trane Energy Management program recorded all data. Fouling Factors during the "high load" periods of the Phase 2 ozone treatment were 13 to 20 percent lower than those measured during the Phase 1 chemical treatment. For all data recorded for both Phases, the difference averaged to approximately a 3.58 percent decrease in energy consumption for the ozone treated Phase.

Overall Data forPhase I Vs. Phase II Fouling Factors		
Time period	**Chemicals**	**Average FF**
June 2013		0.001006932
July 2013		0.000863926
Aug 1-13, 2013		0.000760535
	Chem AVG	***0.000877131***
Time period	**Ozone**	**Average FF**
Aug 13-31, 2013		0.000716787
Sept 2013		0.000733132
	Ozone AVG	***0.000724959***
% Improvement in FF =		**17%**
Translated to Elecrical Savings=		**3.58%**



Corrosion

Corrosion rates, as measured with both corrator readings and corrosion coupons remained static and low during all portions of the study. There appeared to be no significant corrosion occurring during either the chemical treatment or the ozone treatment portions of the study. After the trial, Chiller #3 was eddy current tested and results indicated no noticeable corrosion or reduction in tube condition or performance. These were the first such corrator and eddy current tests performed since the commencement of operation of the ozone system in October of 2012.

Conclusions

The study demonstrated a significant improvement in the reduction of biofilm on the heat transfer surfaces when ozone was used versus traditional chemical treatment. The BMR levels and measured fouling factor when the evaporative cooling water system was under significant loads appear to be correlated. The overall improvement in the Fouling Factor translates to energy saving in the range of approximately 3.7 percent. This was achieved on one-year-old chillers with relatively clean heat transfer surfaces as the starting point. The Washington and Lee system was treated with ozone for more than one year and there is no evidence of corrosion or metal loss.

The findings support the use of ozone as an effective and more efficient means of treating process water in evaporative cooling water systems. Further work need to be done to accurately measure the fouling factors under different load scenarios and resultant improvements in energy usage.