Controlling Cooling Water Quality by Hydrodynamic Cavitation

W. A. Gaines, B. R. Kim, A. R. Drews, C. Bailey, T. Loch
Ford Motor Company, Dearborn, MI

S. Frenette
Sali Group, Ann Arbor, MI

D. Koontz, W. Wang
VRTX Technologies, LLC
5850 Corridor Parkway
Schertz, TX 78154

ABSTRACT

An independent field study was conducted on a cooling tower system at an automotive manufacturing facility to evaluate the performance of a VRTX hydrodynamic cavitation device for disinfection, scaling, corrosion and heat transfer efficiency. The VRTX treatment enabled the cooling tower system to operate at higher cycles of concentration than those obtained while on the chemical program without adversely affecting scaling, corrosion and heat-transfer efficiency. On average, water consumption was reduced ~ 10% and blowdown was reduced over 30%. The test results also showed that the VRTX treatment performed as well as the chemical treatment program that it replaced with regard to bacteria control without adding any chemicals. The bacteria population was maintained at equal to or less than bacterial levels obtained while on chemical treatment. No *Legionella* was detected during the study period.

KEYWORDS

Cooling water treatment, cooling tower, hydrodynamic cavitation, bacteria control, Legionella, corrosion, scaling, heat transfer, water conservation, water saving

INTRODUCTION

Cooling water must be treated to control microbial growth, to prevent scale formation and to limit corrosion of the system components. Due to performance issues at some facilities and increasingly stringent environmental regulations, Ford Motor Company decided to evaluate non-chemical devices for cooling water treatment. After extensive investigation of applications at non-Ford facilities, the VRTX system was selected as one of the non-chemical technologies to be evaluated. The evaluation team consisted of an independent consultant from the Sali Group and engineers with wide ranges of expertise from different Ford divisions, such as the Environmental Quality Office, Research & Advanced Engineering, Powertrain Operations, and Manufacturing Executive Office. The performance of VRTX treatment on the bacterial activity, corrosion, scale, heat transfer and water consumption was closed monitored during the evaluation period.

BACKGROUND INFORMATION

1. Overview of Test Cooling System

The test site was located at a Ford facility near Detroit, MI. This facility provides prototype assembly, tooling, and testing analysis of transmissions under development. Test stands and machines are cooled by three closed loop systems. One of the loops was selected for this study.

The test cooling system removes heat from the closed loop system through two plate and frame heat exchangers to an open loop cooling system. It consists of a 5,000 gallon cold well, two parallel heat exchangers, and a cooling tower. The total system volume is ~ 11,000 gallons. The cooling tower is a Marley NC series counter-flow two-cell with PVC honeycomb film fill, designed to cool 1,400-gal/min recirculation from 105 ^oF to 85 ^oF at 78 ^oF ambient wet bulb temperature. The heat exchangers are Type A15-BFL plate heat exchangers manufactured by Alfa-Laval Thermal Co. with total heat transfer surface area of 1,792 ft^2. Cooling water flowrate, temperature and pressure across the heat exchangers are continuously displayed and recorded.

Detroit city water is used as makeup for this cooling system. The water quality is summarized in Table 1. Blowdown is regulated via a conductivity controller connected to a solenoid valve.

Table 1. Summary of Makeup Water Quality

pH	7.6
Alkalinity (mg/L as $CaCO_3$)	75
Total Hardness (mg/L as $CaCO_3$)	108
Ca Hardness (mg/L as $CaCO_3$)	75
Mg Hardness (mg/L as $CaCO_3$)	33
Chloride (mg/L)	15
Conductivity (µS/cm)	220

2. Chemical Treatment Program

The chemical treatment program for the cooling water system consisted of an oxidizing biocide (12.5% sodium hypochlorite solution), a non-oxidizing biocide (Isothiazolinone), and a proprietary scale/corrosion inhibitor from the vendor. Each chemical was dosed independently to deliver timed dosing of chemicals via LMI metering pumps in a side-stream loop. Bacteria population was manually monitored by ATP analyzer and the timer set-points for biocides were adjusted based on these readings. The upper limit for bacteria count was set at 100,000 cfu/mL.

3. VRTX Treatment

The hydrodynamic cavitation unit utilized in this study was supplied by VRTX Technologies LLC (Schertz, TX). The VRTX unit consists of a pressure equalizing chamber and a cavitation chamber. Inside the cavitation chamber, nozzles are positioned opposite each other at specific distances, lengths and angles. Water is pumped into the pressure-equalizing chamber at ~94 psig and then channeled into the cavitation chamber. Inside the cavitation chamber, water is forced to rotate at high velocities through the nozzles. The rotation creates a high vacuum (~ -28.5 mm Hg). The high vacuum causes micro-sized bubbles to form and grow in the water streams. The water streams in the nozzles are greatly accelerated and rotate in opposite directions. Upon exiting each nozzle, the opposing streams collide at the mid-point of the cavitation chamber where the pressure increases dramatically causing the spontaneous implosion of the micro-bubbles.

Cavitation chemistry appears to be effective against numerous strains of bacteria. Of particular note, Stout (2002) has demonstrated the efficacy of VRTX against *Legionella* pneumophila serogroup 1 of both laboratory and naturally grown cultures in a controlled laboratory setting. Cavitation can also shift the chemical reaction to form $CaCO_3$ colloidal particles. These $CaCO_3$ particles act as the growth sites for dissolved calcium ions to precipitate, instead of forming on equipment surfaces (Koestler et al., 2003). Corrosion is controlled by maintaining water at alkaline pH, controlling bacterial activity, and eliminating corrosive chemicals.

The treatment capacity of the tested VRTX unit was 60 gallons per minute. It was connected to the cold well as a side-stream treatment system. A filtration unit was also installed at the cold well in an independent side-stream. The filtration unit was designed to remove $CaCO_3$ and other suspended solids from the recirculating cooling water.

Daily monitoring and sampling commenced about 10 days before the VRTX unit was activated to obtain baseline data under chemical treatment. Then, non-oxidizing biocide and scale/ corrosion inhibitor feeds were turned off, followed by reducing conductivity blowdown set point from 1,100 to 450 µS/cm to purge residual treatment chemicals from the system. Additionally, the cold well tank was drained by one-third of its volume. After five days of excess blowdown, the VRTX unit along with the filtration unit was activated and the sodium hypochlorite feed was terminated. The blowdown valve was closed and the conductivity set point was changed back to 1,100 µS/cm two days later. Free residual chlorine measurement showed that its concentration was below the detection limit (0.1 mg/L). After a month of steady-state operation, the conductivity blowdown set point was increased to 1,250 µS/cm to determine if the cycles of concentration could be increased without adversely affecting performance. Such conductivity setting would yield cycles of concentration around 6.0.

EVALUATION METHODS

During the evaluation period, the Sali Group conducted daily visits to collect water samples and monitor the system operation, including VRTX system operation parameters, heat exchanger operation condition, and water chemistry data by on-line meters. Water samples collected were shipped overnight for analysis. Wet chemistry and bacterial enumeration were conducted by Paragon Laboratories, Inc. Wet chemistry analyses included pH, Ca, Mg, alkalinity, conductivity, residual chlorine (total and free), total suspended solids, volatile suspended solids (VSS) and total dissolved solids (TDS). *Legionella* analyses were performed by Pure Earth Environmental Lab, Inc.

Information recorded from heat exchanger monitors was used to calculate the overall heat-transfer coefficient (U_o). The overall heat-transfer coefficient is directly related to any fouling of the heat exchangers. Any scale or deposit buildup inside a heat exchanger will inhibit heat transfer and reduce the overall heat-transfer coefficient. Following formula was used for calculation:

$$U_o = Q / (A_o \Delta T_{lm}) \qquad 1$$

with Uo = overall heat-transfer coefficient (BTU/hour-ft^2-^{o}F);
Q = heat-transfer rate (BTU/hour);
A_o = heat-transfer area (ft^2);
ΔT_{lm} = log mean temperature difference (^{o}F)
$= ([T_{2in} - T_{2out}] - [T_{1in} - T_{1out}]) / \ln ([T_{2in} - T_{2out}]/[T_{1in} - T_{1out}])$;
T_{2in} = heat exchanger process water inlet temperature (^{o}F);
T_{2out} = heat exchanger tower water outlet temperature (^{o}F);
T_{1in} = heat exchanger process water outlet temperature (^{o}F);
T_{1out} = heat exchanger tower water inlet temperature (^{o}F).

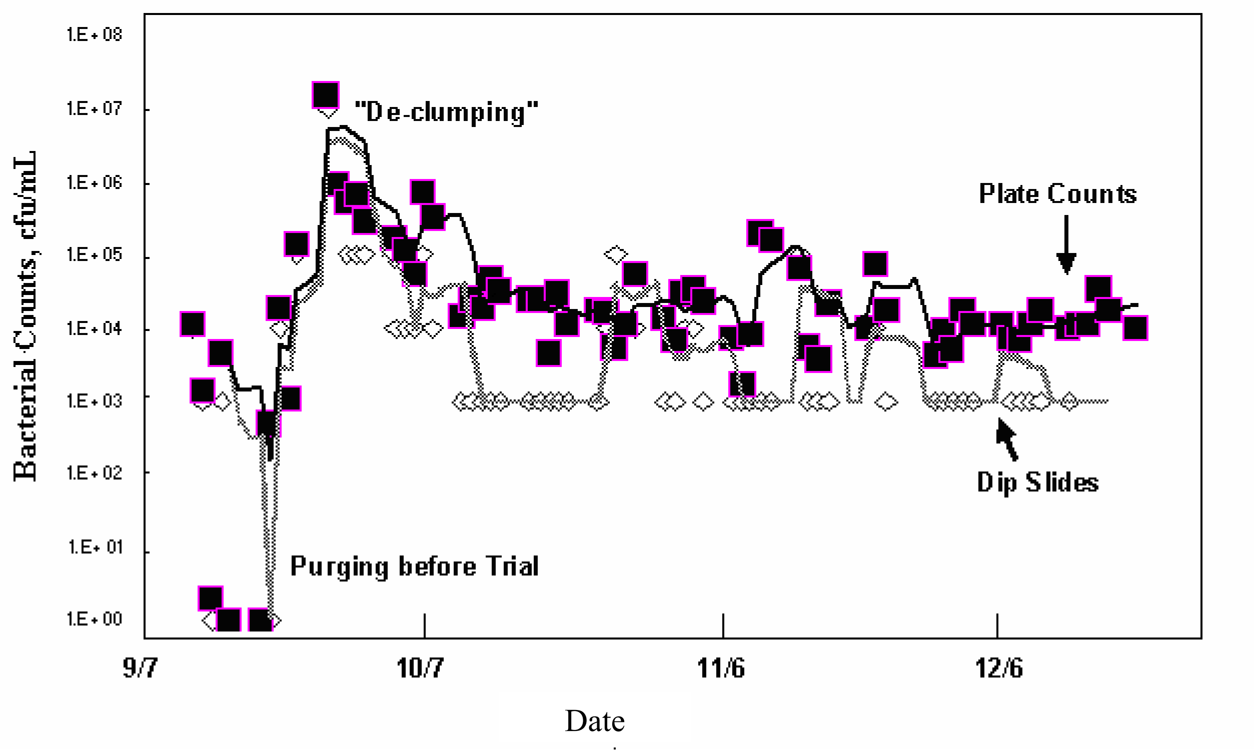
Corrosion was monitored using weight-loss coupons made of mild steel, galvanized steel, stainless steel and copper. The coupons were placed in a coupon rack following their galvanic series in seawater: galvanized steel, mild steel, stainless steel, and finally copper in the direction of flow. The coupons were exposed to the system water for 65 days and sent to Garrat-Callahan Company for metallographic analysis.

PERFORMANCE OF VRTX TREATMENT

1. Bacterial Control

Figure 1 summarizes the heterotrophic plate counts and dip slide results from samples taken from the cooling tower bulk water. Before starting the VRTX study, the baseline bacterial concentration fluctuated daily between 1,000 to 10,000 cfu/mL, with the exception of days when the cooling water was chemically shocked. Right after the VRTX treatment, the bacterial concentration increased by several orders of magnitude to about 1,000,000 to 10,000,000 cfu/mL. This initial increase had been commonly observed during previous pilot tests. A similar phenomenon was also observed when using ultrasonic treatment on suspensions of *Bacillus subtilis* and attributed it to de-clumping which breaks up bacterial clumps into a greater number of individual bacteria in a suspension (Mason et al., 2003). Therefore, the high bacteria counts here were largely caused by the dispersion of bacteria cells, not an indication of increased bacterial activities. This was further supported by test data. The bacterial concentration declined gradually to the baseline level over the next few weeks. The total heterotrophic plate counts showed that the VRTX unit was able to maintain the bacterial concentration consistently ~10,000 cfu/mL in the absence of any disinfectant addition. The dip slides data showed even lower bacteria population. After the initial "de-clumping" period, most dip-slide data showed levels at or below the detection limit of 1,000 cfu/mL.

Figure 1. Bacteria test results using both heterotrophic plant counting (solid squares) and dip slides (open diamonds).



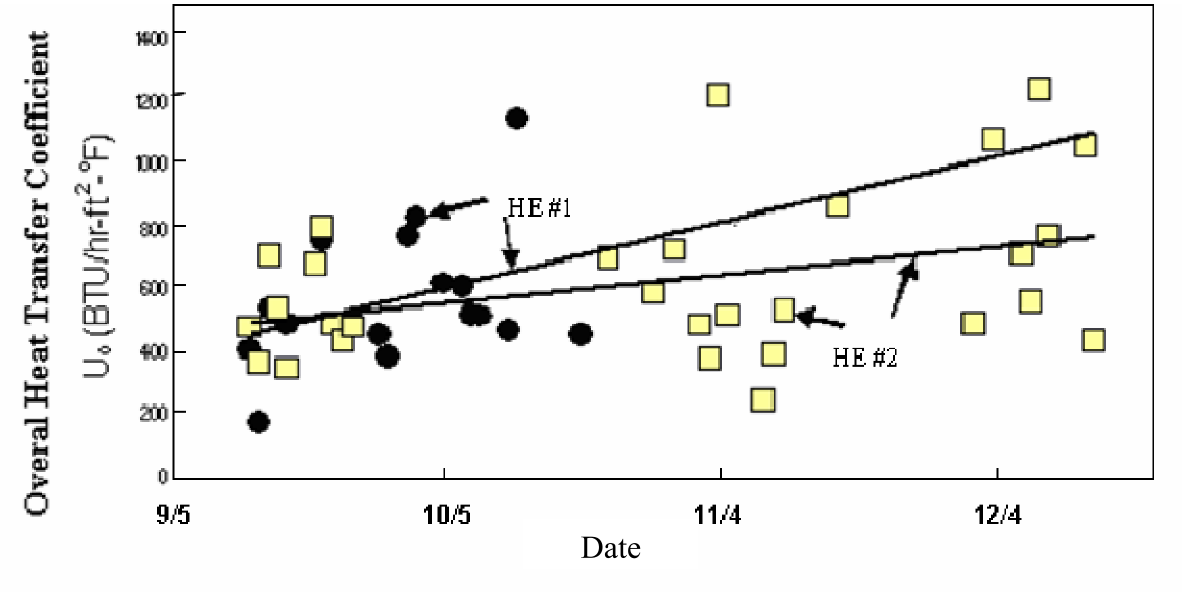
All *Legionella* tests showed that the *Legionella* population was below the method detection limit (1 cfu/mL).

2. Scaling Control

$CaCO_3$ scale predominantly forms on the heated surface in cooling water system. A very thin layer of scale deposit inside heat exchanger can significantly reduce the heat transfer rate and, consequently, reduce the overall heat transfer coefficient. For a given system, the tendency of $CaCO_3$ scaling increases with cycles of concentration.

Figure 2 illustrates the changes in overall heat-transfer coefficient of heat exchanger during the study period. Despite increased cycles of concentration, the calculated heat transfer efficiencies show marginal improvement trends with VRTX treatment. More data points are needed to see if such change was statistically significant. Nonetheless, these results suggest that the VRTX treatment, at least, is as effective as the previous chemical treatment in deposit control, even at increased cycles of concentration.

Figure 2. Calculated overall heat transfer coefficient for heat exchangers #1 (circles) and #2 (squares)



3. Corrosion Control

Table 2 lists the coupon test results along with data from two prior tests during the chemical program for comparison. The corrosion rate of copper was equivalent to those obtained during the chemical program; and the corrosion rate of mild steel was much better. The corrosion rates observed under VRTX program fall into the "Negligible or Excellent" category commonly used in industry (Boffardi, 2000). Corrosion rate for galvanized steel was high, as expected, because coupon was not pre-treated. Fresh zinc metal usually has high corrosion rate at pH > 8.5. VRTX recommends all new galvanized systems should be passivated initially.

All coupons showed uniform general corrosion. No localized corrosion was observed (see Photo 1).

4. Water Consumption

During the first half of the study period, the average makeup water consumption was reduced ~ 25% compared to chemical treatment. The water consumption was reduced another ~30% during the second half of study period when the blowdown conductivity set point was further increased. Part of the reduction in water consumption was contributed by changes in evaporation rate due to changes in heat load and weather condition. The estimates based on cycles of concentration show ~ 10% reduction in makeup consumption and ~ 40% reduction in blow-down discharge during test period.

Table 2. Results of the Corrosion Coupons Test

Date Coupon Retrieved	Days Exposed	Corrosion Rate (mils per year)			
		Stainless Steel	Copper	Galvanized Steel	Mild Steel
03/2000	23		<0.1		1.3
06/2004	61		<0.1		0.5*
12/2004	65	<0.1	<0.1	4.3	0.3

* Coupon was pre-treated.

Photo 1. Coupons retrieved after a 65-day exposure (From top to bottom: mild steel, copper, galvanized steel, and 316L stainless steel).

Before Cleaning

After Cleaning

DISCUSSION

It is known that microorganisms in cooling water can become resistant over time when subjected to a single biocide. Periodic alternating of biocides is often used to attempt to mitigate this. However, it is difficult to determine the optimum product/dosage/frequency to alternate within a given system. Resistance is often first noted by a failure of the process – namely elevated bacterial levels following routine disinfection. VRTX treatment eliminates the potential for this resistance to develop.

Eliminating biocides also improves morale, health, and safety of working environment. Exposed over extended time periods to biocides, some employees develop hypersensitivity and exhibit "flare-up" dermal reactions. VRTX treatment eliminates the potential for sensitizing to occur. In addition, it eliminates inventory control, ordering, material handling, storage, and training associated with hazardous chemicals. Applying VRTX treatment simplifies plant operation. While biocides must be managed by federally licensed applicators that generally perform testing and instrument calibration, any skilled individual can maintain VRTX system. Moreover, reducing water consumption and wastewater discharge improve corporate image by supporting “green” and sustainable manufacturing.

VRTX treatment is also cost effective. Cost analysis indicated the total annual saving was over $15,000 for this tested cooling system.

CONCLUSIONS

The field study was conducted to evaluate the performance of VRTX treatment with respect to disinfection, corrosion and scaling control. With respect to disinfection, the VRTX unit performed as well as the chemical program that it replaced in terms of total heterotrophic plate count without adding any chemicals. With respect to scaling control, the heat transfer efficiency of heat exchangers was not adversely affected by VRTX treatment even at increased cycles of concentration; in fact, there was evidence of a marginal improvement. With respect to corrosion control, results from weight-loss coupon tests revealed very low corrosion rates except for un-passivated fresh galvanized steel. The observed corrosion rates of copper and mild steel were either equivalent or better than those obtained during the chemical program.

Besides eliminating hazardous chemicals and simplifying operation, VRTX treatment can reduce water consumption and waste discharge. Additionally, the blowdown water could be captured and further used for other applications, such as irrigation and urinal flushing, because there are no toxic chemicals in it. The use of VRTX technology can also aid in attaining LEED certification.

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