

Development of a Novel Sensor to Measure the Deposition Stress of Cooling Water Systems

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ABSTRACT

With increased usage of recycled or reclaimed water, cooling systems have become even more dynamic in nature. These sources of makeup water experience wide variability in water quality. As a result, the deposition stress seen in the cooling system heat exchangers can vary widely. This paper outlines a novel patented technology that is used to monitor deposition stress in cooling systems. The technology is able to operate at multiple temperatures simultaneously giving insight into the stress seen across a range of heat exchangers in a cooling system. Information will be provided from laboratory testing as well as applications in the field.

Key words: deposit, heat exchanger, efficiency, biofilm, scale

INTRODUCTION

Industrial cooling water systems are inherently dynamic. Conditions are constantly changing whether it be from production demands, makeup water quality and process leaks. For example, in large chemical plants the load and balance of the heat exchangers in use can be constantly changing as exchangers are taken on and offline as production demands change. Additionally, operators of these industrial systems are under increasing demand to reduce water usage and cost by either increasing cycles of concentration or using a reuse water source that often will have various water quality challenges such as variable hardness and phosphate.¹ In cases where operators are using surface water, large storm systems can stir up contaminants and turbidity into the water being used in the cooling tower. Process leaks provide nutrients for microbiological issues or lead to increased scaling stress. Finally, government

regulations are also playing a role as withdrawal and discharge limits are being put in place.²⁻³

All of these factors have placed more stress on the chemical programs used in cooling systems than ever before. Deposit on a cooling water system heat exchanger reduces heat transfer, i.e. efficiency loss, and in certain conditions enable under deposit corrosion.⁴ There is a growing need to have a performance sensor to directly measure deposit stress in the cooling system in real time. By directly measuring deposit formation in situ, deposit stress can be monitored and responded to before a substantial loss in performance or asset integrity occurs. The technologies available in the market have several limitations in operation. Many of the available technologies utilize a heated block, rod, or fluid to heat up one side of a tube or surface. The main difference between these technologies is the way the deposit is detected. Some are as simple as viewing the deposit on a tube through a viewing window. Others measure flow, inlet, and outlet temperature to calculate the heat transfer, heat transfer resistance, or u value. An instrument sold by Bridger Scientific known as a Deposit Accumulation Testing System (DATS) calculates a heat transfer resistance and outputs that to the user as well as calculating a “% clean”. It is an instrument that has been used successfully by researchers in our company to measure deposits as the performance of chemical programs are evaluated. Another approach is to use an ultrasonic sensor to measure the buildup of deposit on the surface which is indicative of potential deposit in the heat exchanger. In all of these technologies, there are two fairly large drawbacks. First the power requirements of these instruments is often quite large, ranging from hundreds to thousands of watts. Second, these devices are only capable of simulating a single temperature at a time. In many cases with the large number of heat exchangers on site, it would be beneficial to understand the deposit stress for exchangers operating at different temperature ranges.

A completely different approach to measuring deposit is the use of a quartz crystal microbalance (QCM). The QCM has a resonator that changes frequency as mass accumulates on the surface. The main downfall of QCM is that the device isn’t heated, meaning the device must be installed on the outlet of the heat exchanger. The limit on installation location raises practical implications when utilities aren’t necessarily readily available. It may not have a sample point at that specific location and may be a hazardous location such that Class I, Division II classification is required adding to system cost.

As a result of the challenges and limitations of other technologies, a novel patented⁵ technology was created and developed using resistance temperature detectors (RTDs). RTDs measure temperature through the use of a resistive element whose resistance is a function of temperature. Current is applied through the RTD causing the RTD to heat up. The current is tuned to achieve a specific surface temperature. The small size of the individual RTD’s means multiple can be integrated into a single probe and operated simultaneously. The

small RTD size also limits the amount of power required to operate. Figure 1 provides a picture of a sample probe that integrates 8 RTD's into a single device.

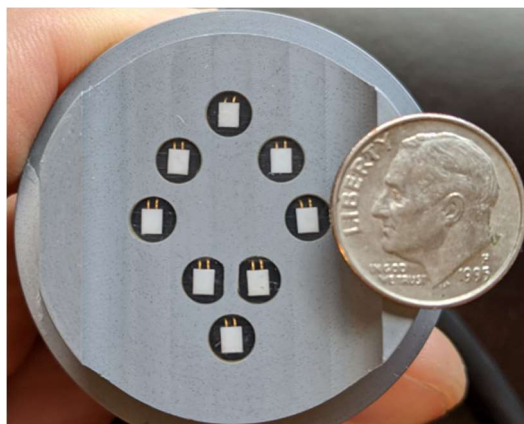


Figure 1: Sample design for a deposit sensor using RTD's as the principle means of making a deposit measurement. The probe integrates 8 RTD's into a single probe and are the white elements in the picture.

Measurements are taken by turning off power and monitoring the decay of the probe surface temperature. The decay constant is then processed, corrected for flow and temperature variations, and reported out as a Deposit Index (DI) and trended over time. Figure 2 shows an example of the decay profile and how as any type of deposit build up on the surface that the decay constant will change as a result of the deposit inhibiting heat transfer back to the fluid stream.

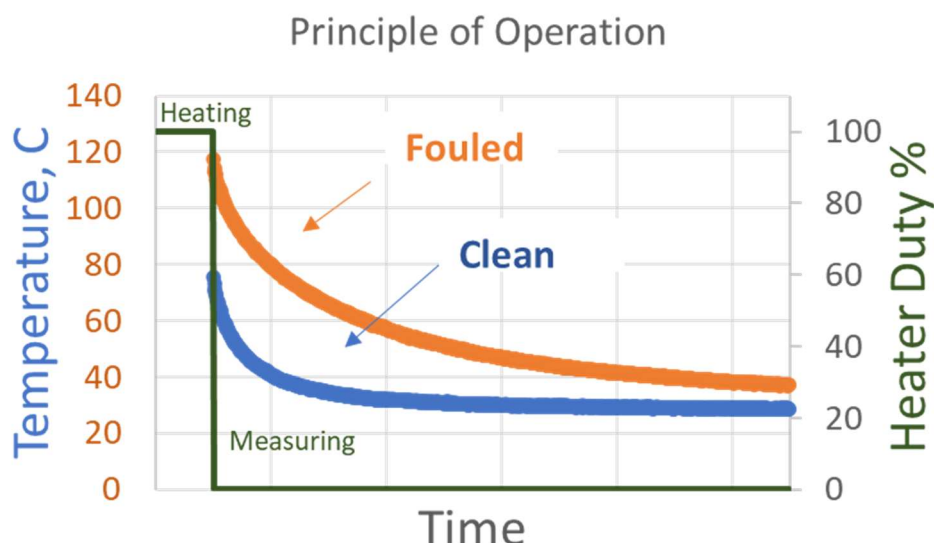


Figure 2: Principle of measurement for the deposit sensor. The temperature decay profile for the sensor changes dramatically as deposit builds on the probe surface.

LABORATORY TESTING

It is well known that the solubility of many calcium species such as calcium carbonate, calcium phosphate, and others are inversely proportional to temperature.⁶⁻⁷ These species, along with many other deposits including biofilm, have very poor heat transfer coefficients which negatively impact heat transfer efficiency in cooling water heat exchangers if not properly controlled and allowed to accumulate on the exchanger surface.⁸ With an array of customizable temperatures, the goal is to operate the sensor at and above temperatures of any critical heat exchangers in a cooling water system across the customer plant. As a result, it is believed that this technology can be a predictive indicator of scale formation as hard scale should form on the hottest temperature RTD's first and proactive measures could be taken prior to performance loss on the heat exchangers in the cooling system. To test this hypothesis, the probe was taken to our pilot cooling tower (PCT) and tested under scaling conditions using a synthetic Lake Michigan water source. The overall test setup can be seen in Figure 3. The DATS was integrated into the test procedure to act as a benchmark for the deposit sensor and will later be used in the field applications where the deposit sensor technology is evaluated. It should be noted that the two different technologies operate in fundamentally different ways and that the absolute changes in percent clean of the DATS shouldn't match that of the deposit sensor. However, overall trends and timing of deposit events should be similar when operating at the same temperature.

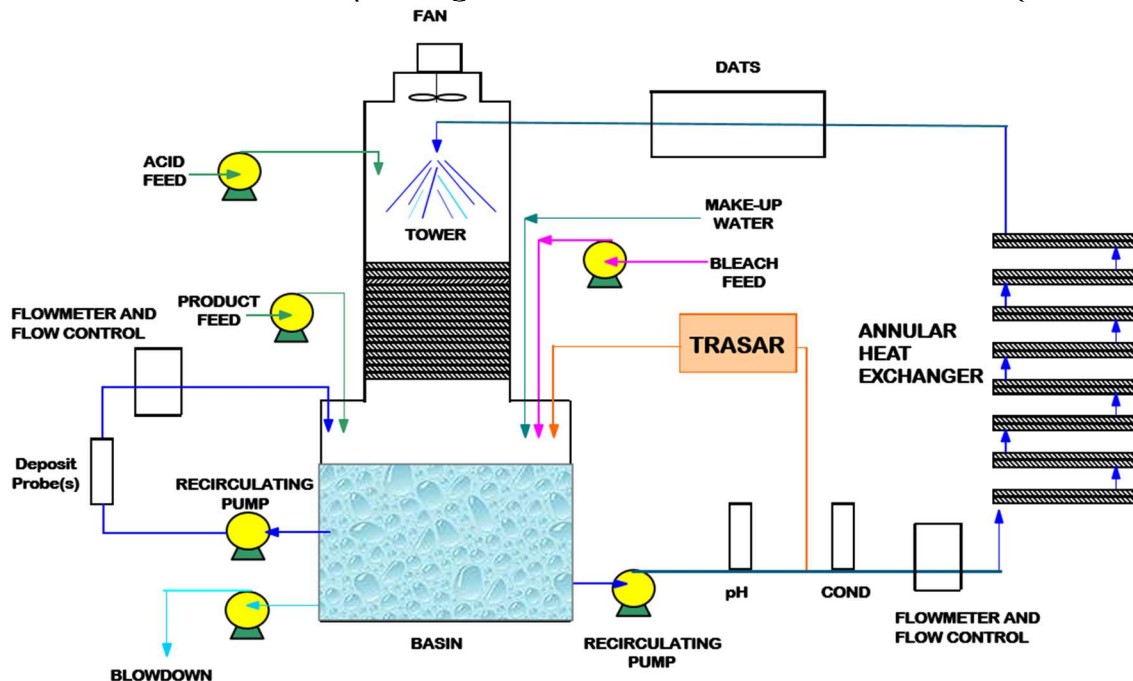


Figure 3: Pilot Cooling Tower (PCT) experimental setup. The setup includes a DATS as a benchmark technology to compare the new novel deposit sensor which was installed in a separate flow loop and controlled to the same flow rate.

The tower was cycled up to 4 cycles of concentration with a Ca/Mg hardness of 600 and 300 ppm respectively. Alkalinity was 250 ppm and pH controlled at 8.5. The deposit sensor was operating at multiple temperatures during the test which included the bulk water, medium, and high temperatures which were 108°F (42°C), 140°F (60°C), and 162°F (72°C) respectively. Flow was controlled across the probe to give a water linear velocity of ~ 2.4 ft/s. Bleach was fed to maintain an ORP value of 350mV which resulted in a free residual chlorine level of ~0.2 ppm to reduce the potential for biofilm growth in the system. Polymer based scale inhibitor was fed to specifically control any calcium phosphate scaling stress in the system but was gradually reduced to induce calcium phosphate scale in the system. In addition to slowly reducing the polymer dose, additional phosphate was spiked into the system on 12/18 as well as on 12/19 to provide additional deposit stress. The probe response over the course of the experiment can be seen in Figure 4. It can be seen in the data that the 162°F (72°C) sensor started to respond on 12/17 with a downward trend and the additional stress caused by the phosphate spike on 12/18 caused a drop of 8.5 in the deposit index. The downward slope (-2.5) shows continued deposit stress potential after the phosphate event occurred at that elevated temperature.

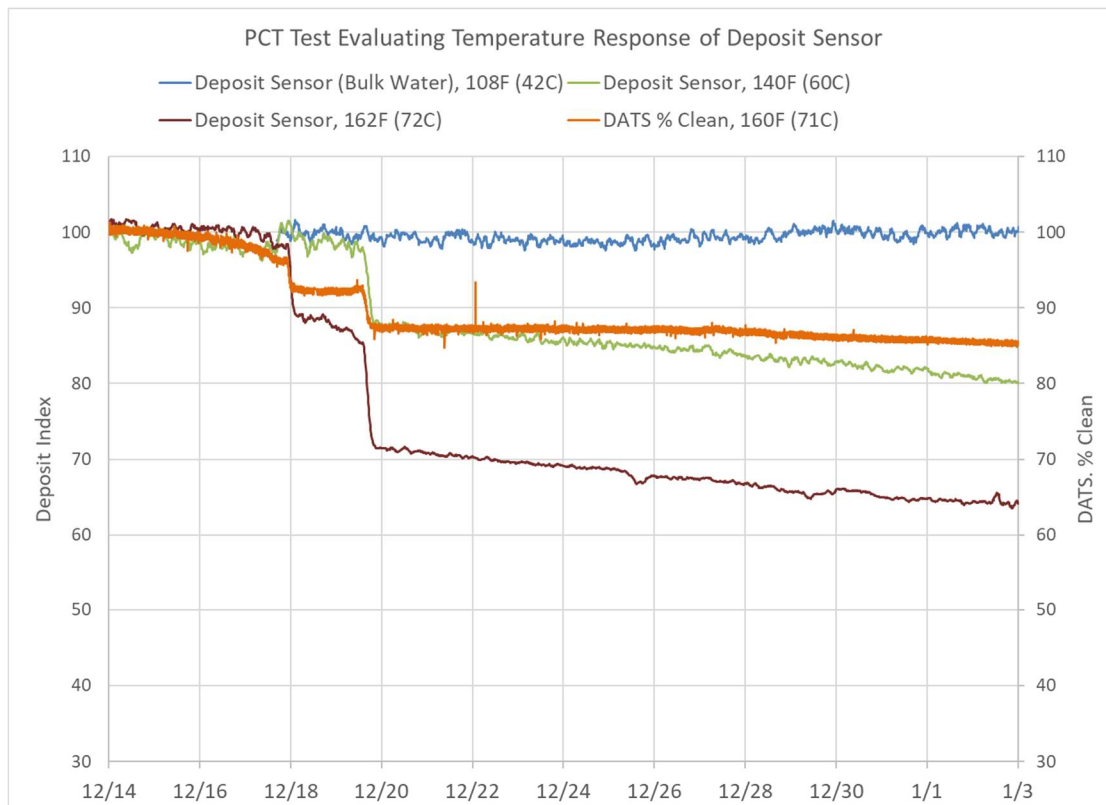


Figure 4: Deposit probe response on the PCT as polymer dosage was reduced into a regime to cause scaling while excess phosphate was occasionally spiked into the system to cause additional stress on the water chemistry.