BIOFILM DETECTION AND MONITORING AT REAL TIME FOR COOLING WATER SYSTEM

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ABSTRACT

Cooling water systems are important part of industrial utilities systems in the pulp and paper industry. It always has been a great challenge on how to precisely measure how microbiological growth impacts in a cooling system. There are many different laboratory and field tests available for microorganism count. However, most of them only count the planktonic microorganism, in opposition to the sessile life which is important part of biofilm. This paper describes a new methodology for real time measurement of biofilm thickness utilizing ultrasound waves on a heated surface, mimicking the heat transfer equipment on field. The ability of biofilm measurement can go as low as 5 μm, which is considered very early in the biofilm formation and growth. This was applied to a large cooling system at a pulp mill which did not apply previously any biofilm monitoring.

Keywords: biofilm, heat transfer, ultrasound, real time, sessile.

1. INTRODUCTION

The definition of biofilm is a loose matrix of many kinds of microorganisms that is held together with a slimy substance called extracellular polysaccharide (EPS). A significant part of biofilm is actually water. However, its exact composition and structure will depend upon the nature and nutrient availability. The presence of biofilm in a heat transfer surface will cause loss of efficiency, microbiological influenced corrosion under the biofilm. This can lead to a heat exchanger fail or at least lower of performance. The rate of biofilm accumulation is quite fast, being able to deposit within a few hours. For this reason, biofilm monitoring in its early steps is a key performance index that can bring the best choices for a control strategy.

Some techniques may be applied to monitor biofilm growth, with advantages and disadvantages. Some equipment use electrochemical-based such as electrical resistance techniques to quantify the existence of living biofilm. Other devices apply thermal transmittance-based technologies that use heat transfer resistance to recognize biofilm. More recently a piezo crystal balance device measures the increase in weight caused by deposition and biofouling was developed. All these technologies provide measurement of biofilm growth based on indirect parameters and rely on multiple measurements to calculate coefficients such as heat transfer coefficient. A significant increase in foulant coverage in a steam surface condenser was required to yield similar fouling readings measured by a side-stream testing section [1]. Under such conditions, detection of biofouling would not be expected until a mature and uniform biofilm had developed.

The usefulness of non-invasive ultrasound to determine biofilm thickness inside potable water supply pipes [7} is due to its ability to make direct measurements of existing biofilm in the liquid phase based on the analysis of ultrasound pulse-echo behavior. This concept is applied .by? an ultrasound device which enables quick and precise biofilm thickness and loss in heat transfer measurement.

2. METHODS

The rate at which biofilm growth may occur is altered by surface temperature and water quality. Higher surface temperatures not only drive faster microbial growth cycles [6], but also enhance colonisation with higher bio-volumes, higher percent moisture and higher ratios of anaerobic to aerobic bacteria [1]. The first ultrasonic device for this purpose was developed to measure inorganic scale growth in many industrial applications [4]. . A heated stainless steel surface target, which is suitable for biofilm growth, is used in the device. The built-in variable heating element provides consistent heat output to maintain the desired surface temperature while built-in thermocouples measure temperature differences in real time. With the assistance of a pre-programmed algorithm, the heat transfer reduction sensor also reports the development of biofilm as a fouling factor and a heat transfer reduction index.

2.1 Side stream ultrasound sensor

The device shown on Figure 1 can also mimic critical heat exchanger conditions in real time. The device duplicates the shear stress and heat input so that the fouling factor can be measured continuously and can be compared to the design and operating conditions of any heat exchanger of interest. The device measures not only fouling factor, but also deposit thicknesses with an accuracy of +/- 5 microns. Ultrasound waves are used to measure the thickness of deposits. The device can differentiate between biological, organic and scale deposits. Figure 2 shows the heat transfer surface and the ultrasound sensor separately.

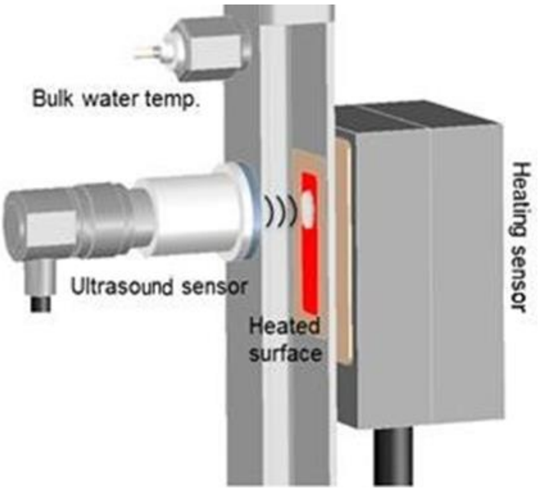

Figure 1: Side stream integrated heat transfer reduction sensor and ultrasound sensor.

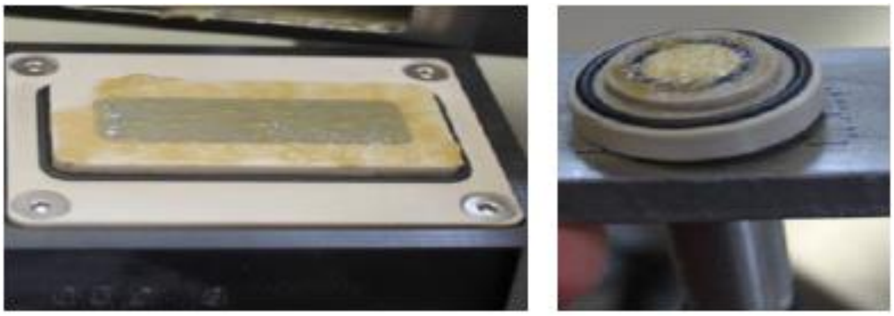

Figure 2: Heat transfer surface (left) and ultrasound sensor (right).

2.2 Measurement technique

The heat transfer surface is adjusted to a given temperature range – usually 35 – 40 °C – to enhance biofilm growth. Flowrate is also adjusted to the side stream device in order to have best velocity (lower velocity) conditions to biofilm attach on the heated surface. It is recommended to apply 15 liters per minute. The sensor sends an ultrasonic signal which goes through the water flow until it reaches the heated surface. Once it is reflected, it will reach the ultrasound sensor again. Since sound speed is known and the applied time is measured, it becomes easy to determine the extra thickness due to biofilm deposition. See Figure 3.

The biofilm thickness monitor .can detect biofilm growth in its initial formation to measurements as low as 5 µm. Depending upon the nature of the biofilm and heat exchanger characteristics, even this low thickness can represent up to 10 – 15% heat transfer loss.

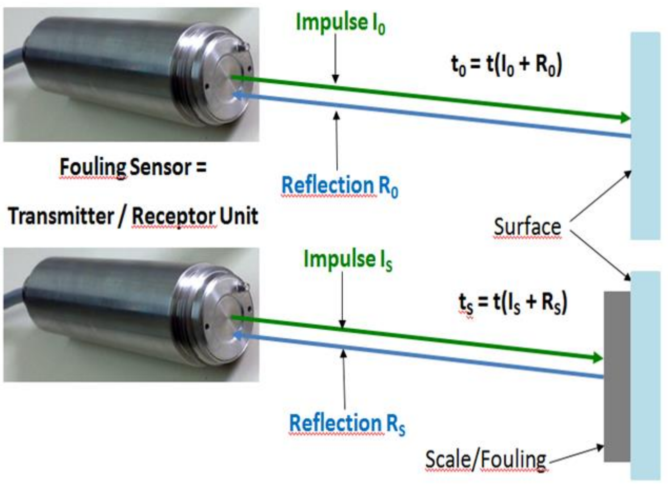

Figure 3: Ultrasound sensor biofilm thickness measurement technique.

Figure 4 shows the local field human machine interface (HMI) that the equipment has for settings and measurement results.

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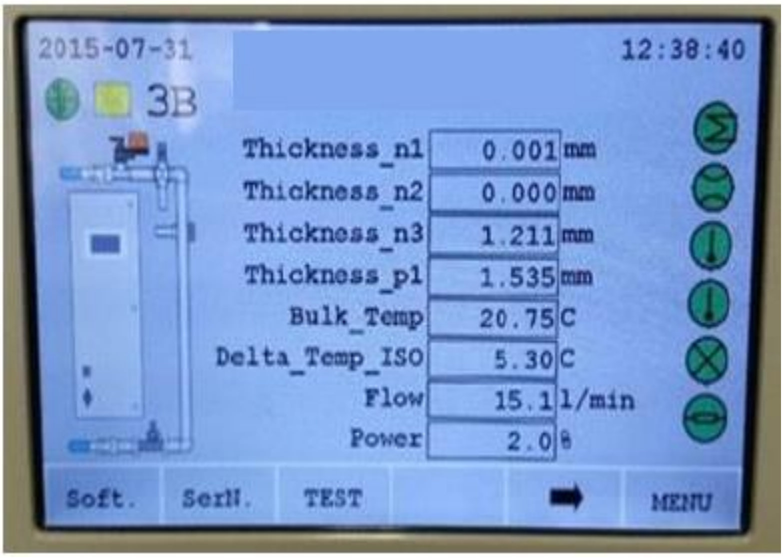

Thickness_n1 0.001 mm
Thickness_n2 0.000 mm
Thickness_n3 1.211 mm
Thickness_p1 1.535 mm
Bulk_Temp 20.75 C
Delta_Temp_ISO 5.30 C
Flow 15.1 l/min
Power 2.0

Figure 4: Human machine interface of biofilm (Thickness_n3) measurement device.

3. RESULTS AND DISCUSSION

The ultrasonic biofilm thickness measurement device was applied to assess the conditions at an existing cooling tower at a pulp mill. Table 1 summarises the operating parameters and microbiological control strategy.

Table 1. Pulp mill cooling tower parameters.

Parameter	Value
Volume	9000 m^3
Recirculation rate	35000 m^3/h
Concentration cycles	5
Turbidity	20 NTU
Suspended solids	25 ppm
Chemical Oxygen Demand	70 mg O_2/l
Total Bacterial Count	10^3 CFU/ml
Biocide	Stabilized Chloramine

It is important to notice that prior to the addition of stabilised chloramine as a microbiological control agent, the plant used to dose sodium hypochlorite. Although this is a very common biocide, many times it is not correctly applied and may generate situations where bacteria count can be at higher than desired ranges, as shown on Figure 5. It illustrates how bacteria counts significantly dropped . before and after the oxidant biocide shift.

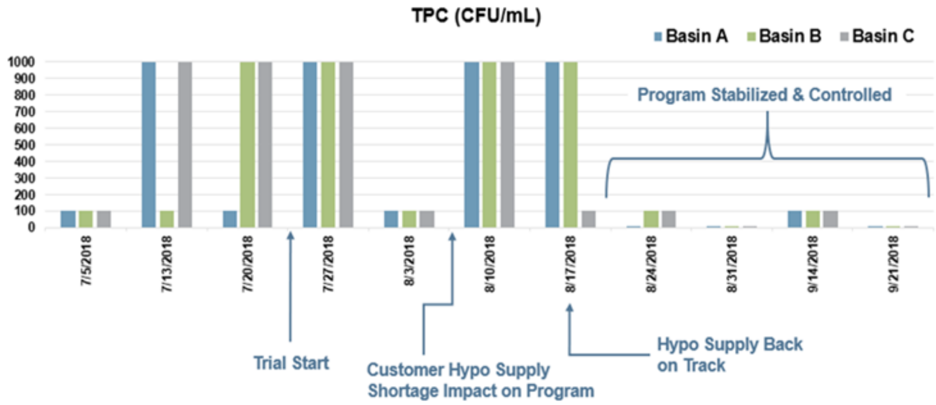

Figure 5: Total bacteria count shift between sodium hypochlorite and stabilized chloramine.

Initially, the biofilm thickness was considered very low and well controlled as described on Figure 6. Most of the time the biofilm thickness was kept under 25 μm.

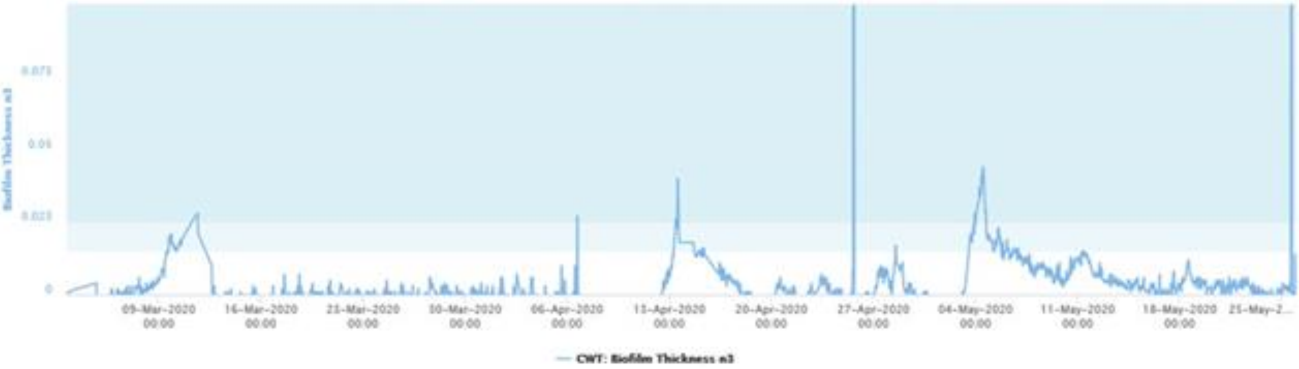

Figure 6: Biofilm thickness measurement on cooling water recirculation flow.

Even though during most of the time the biofilm thickness was below the maximum desirable limit, occasionally due to changes in water quality, airborne contaminations, process contaminations, insufficient biocide dosage and other reasons, . peaks in biofilm thickness measurements were observed. Based on this profile, a new strategy was defined to enhance this control and reduce biofilm thickness variability.

A change on stabilised chloramine dosage strategy was proposed. The total volume of biocide was kept the same. The change in strategy consisted of dividing the total dosage into small batches, allowing the system to have a minimal residual of biocide for longer periods. Figure 7 shows the ultrasonic device heating surface before and after the change in biocide dosage strategy. It is quite clear the visual difference on biofilm accumulation before and after this change.

Figure 7: Ultrasonic device heating surface before (a) and after (b) the biocide dosage strategy change.

This shift on biocide dosage strategy was performed at two different times. The online biofilm thickness measurement was used to identify the benefits of the strategy, and showed much lower thicknesses and more importantly, very low variability. Figure 8 shows the biofilm thickness drop and stability along both steps of the biocide strategy dosage change.

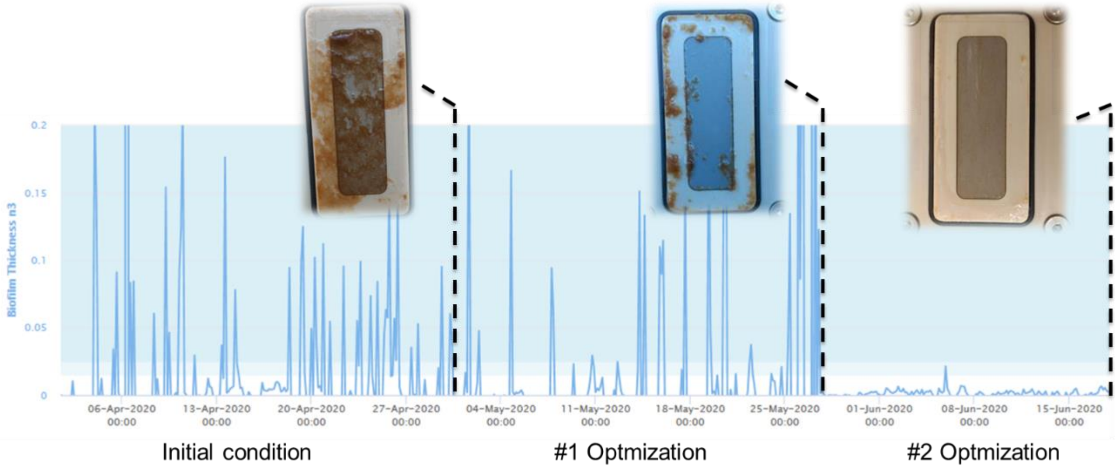

Figure 8: Biofilm thickness measurements throughout the biocide dosage strategy change.

The corresponding heat transfer loss due to excessive biofilm accumulation was calculated for these three different periods and is illustrated in Figure 9 below. It was possible to identify a progressive change of over six times less heat transfer loss due to almost no biofilm deposition on the biofilm thickness sensor.

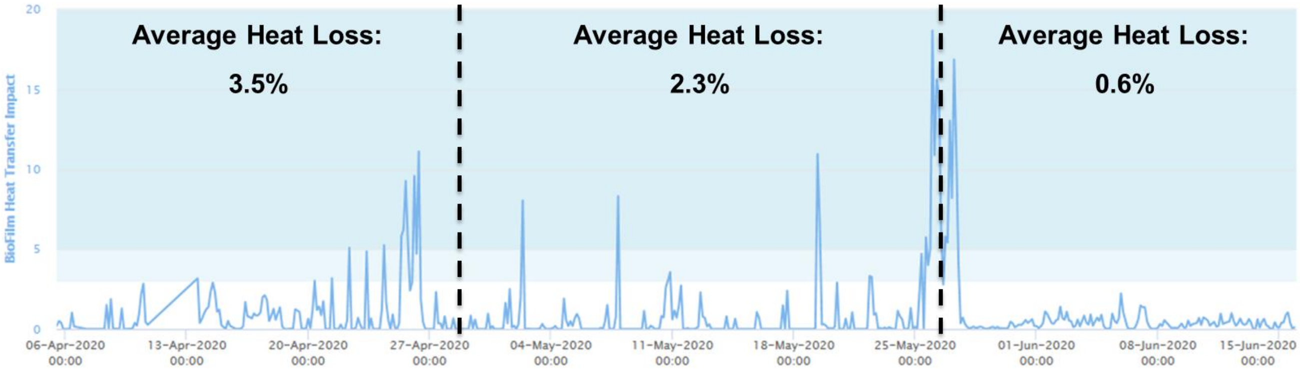

Figure 9: Heat transfer loss due to biofilm deposition throughout the biocide dosage strategy change.

During a plant outage it was possible to inspect one of the main heat exchangers that use cooling water. Figure 10 is the internal area of this heat exchanger in its water circulation side. It is absolutely biofilm and sludge free, duplicating in practice exactly what was being observed with the online monitoring..

Figure 10: Heat exchanger inspection during plant outage after several months of real time biofilm monitoring.

4. CONCLUSIONS

The ultrasonic biofilm thickness measurement device fulfilled its purposes and provided a true, reliable, and helpful objective that allowed for the first time, an identification of the real sessile bacteria population on this cooling tower. In fact, this trial was the very first one of a series applying this new technology.

After the period of trial, the system was kept up until today and continues to measure and alarm whenever and action is needed to address a water treatment challenge.

In summary, the biofilm thickness measurement device facilitated. :

→ Measurements of biofilm thickness < 5 – 10 µm
→ Investigation on best biocide dosage strategy with no change on total consumption
→ Reduction of heat transfer loss from 3.5% to 0.6%
→ Fewer bacteria count tests on field
→ Fewer chemical tests on field
→ Real time biofilm and slime formation
→ Cleaner and biofilm free heat exchanger surfaces observed during plant outage

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