FOULING AND CLEANING MONITORING USING THE MSS – INDUSTRIAL PERSPECTIVE

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ABSTRACT

The present paper reviews the work done with the Mechatronic Surface Sensor (MSS) during the laboratorial trials and provides insights on the preliminary results obtained during field trials. The results obtained showed that the MSS is able to accurately follow the adhesion and removal of fouling layers as well as establish comparatively the type of deposit. It was also possible to monitor the fouling formation/removal and assess the efficacy of the cleaning procedures on a by-pass of an industrial cooling water system.

INTRODUCTION

Fouling is a costly problem that affects the performance of industrial processes and has also implications on the environmental quality and the human health. Many industrial operations are subjected to extensive fouling resulting from the adhesion of several fouling products (Kukulka 2005). Similarly, the cleaning of such fouling layers is another point of concern, mainly for those industries that run their processes on a daily basis. In spite of the deleterious effect of fouling it is consensual that it cannot be totally eliminated, although its understanding and mitigation is object of many research efforts.

The understanding that, for example, the indiscriminated use of chemical substances, during cleaning procedures or during water treatment in cooling water systems, can be a hazard for the environment (Cloete 2003) is changing the paradigm of water treatment programs and demanding for innovative solutions to minimize the fouling problem. The development and implementation of efficient technologies and strategies for fouling mitigation is an increasing concern to the scientific and industrial communities. Several strategies can be applied to act both on the minimization of the deposits formation or to improve their cleaning procedures. One of these strategies rely on the use of on-line, real-time monitoring techniques that provide information about the adhesion/removal of the fouling deposits.

The Mechatronic Surface Sensor (MSS) is an on-line monitoring device able to quantitatively characterize the deposit that is attached to a given surface, which results from the theoretical and experimental researches done by academia associated with the know-how gathered from industry. The basic idea behind the MSS is the fact that the attachment, growth and detachment of deposits produce changes in the vibration properties of the surface waves. It uses an actuator to excite the monitored surface and a sensor to capture its vibration. This information associated with the MSS characteristics: i) it is non-intrusive; ii) the information gathered corresponds to an integrated measurement over a significant area; iii) it can be applied to different types of surface materials, makes it quite an attractive tool for industrial application.

The present paper will summarize the laboratorial experiments performed with the MSS and their main conclusions. Furthermore, the preliminary results of the implementation of the device on the side-stream of a cooling tower system (on an open cooling water system) will also be discussed.

THE MECHATRONIC SURFACE SENSOR (MSS) – Prototype version

The present version of the MSS is composed by the monitored plate (e.g. SS, PVC or other material) that closes the open base of a semi-circular duct made of Perspex (internal diameter: 30.0 mm, equivalent diameter: 18.3 mm). An actuactor (Piezoelectric BM 70/25/200 M, from Piezomechanick GmbH) and a sensor (accelerometer ADXL-103, from Analog Devices) element are attached to the plate, on the face that is not in contact with the liquid flowing inside the duct – see Figure 1.

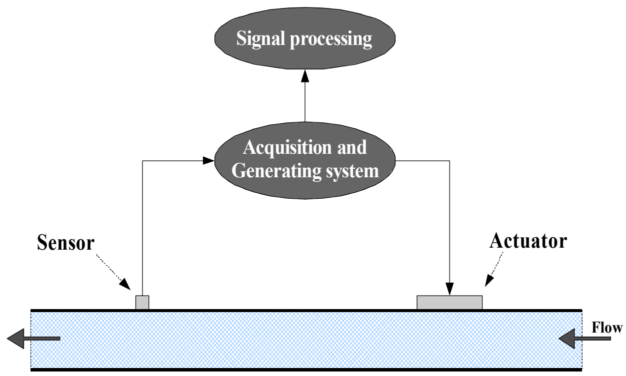

Figure 1: schematic representation of the MSS elements (actuator and sensor) and of the generating/acquisition system

Based on this common configuration, setups with different configurations have been tested. Those differences are mainly associated with: i) the existence or not of coupons; and ii) the length of the duct and of the monitored plate.

According to the schematic representation shown in Figure 1, a sinusoidal wave (the amplitude and frequency of such wave was determined for each configuration in order to match the resonant frequency of the system) was used to excite the monitored surface. The response to that excitation is then captured by the sensor and collected on the computer for signal processing. From the signal processing it was possible to determine that the FFT amplitude (or the A_{FFT}) and the damping factor (or DF) are the parameters able to respectively provide information about the amount and type/ nature of the deposit. The A_{FFT} was found to be inversely proportional to the amount of deposit attached to the surface, and was normalized (subtracting all the collected values from the initial value) in order to obtain a curve showing a direct relation between the measured variable and the amount of deposit. This normalized A_{FFT} was named 'normalized amplitude'. The DF represents the capacity that the system has to reduce the intensity of a vibration process. Higher damping factors variations were observed for more viscoelastic deposits.

RESULTS AND DISCUSSION

Laboratorial trials

During its laboratorial tests the MSS showed to be able to accurately monitor different situations:

1. Biological *vs* inorganic deposits

Three deposits that can be found in drinking water systems were formed and monitored with the MSS: i) *Pseudomonas fluorescens* biofilm formed under turbulent flow; ii) *Pseudomonas fluorescens* biofilm formed under laminar flow; iii) silica deposit formed under turbulent flow. According to Pereira *et al.* (2008), the main conclusions taken from this work were that:

- the MSS can give accurate information about the amount and the physical characteristics of deposits formed on (adhered or removed) the monitored surface, respectively through the determination of the A_{FFT} and of the DF of the output wave;

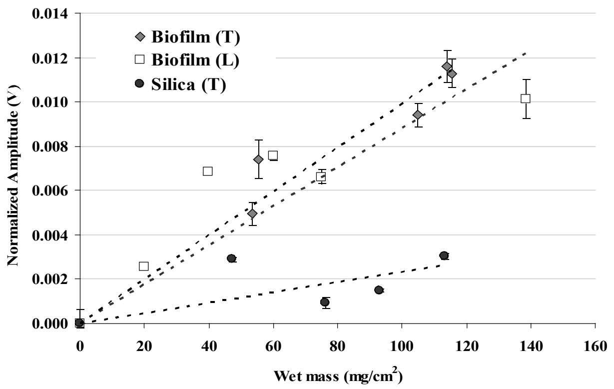

Figure 2: Variation of the MSS normalized amplitude with the wet mass per unit of area: *Pseudomonas fluorescence* biofilm under turbulent flow (♦), *Pseudomonas fluorescence* biofilm under laminar flow (☐) and silica deposit under turbulent flow (●)

- when each deposit is analysed separately it is possible to observe an increase of the normalized amplitude with the increase of the mass; a good correlation between these two parameters (normalized amplitude and wet mass) is found - see Figure 2;

- the biological layers showed a higher damping factor than the inorganic deposit, which is in accordance to the fact that it is usually accepted that biological layers are typically more viscoelastic than inorganic ones.

2. Milk fouling deposits (mineral and protein deposit)

According to Pereira *et al.* (2006), fouling caused by milk components was induced on the MSS, in order to assess its ability to follow the adhesion and removal of such deposits. The main conclusions from this study were that:

- it was possible to establish a relation between the thermal resistance (obtained from a heat flow cell) and the MSS normalized amplitude;

- the A_{FFT} and the damping factor of the vibration wave are the best parameters to characterize the vibration process, since they represent respectively changes on the mass of deposit attached to the surface, and differences in the structural properties of the fouling layer (mineral *vs* protein deposit);

- the MSS is able to follow different cleaning rates – cleaning a mineral deposit and a mixed deposit (mineral + whey protein) using an acid solution (HNO_3) results in two quite different cleaning curves, as can be seen in Figure 3.

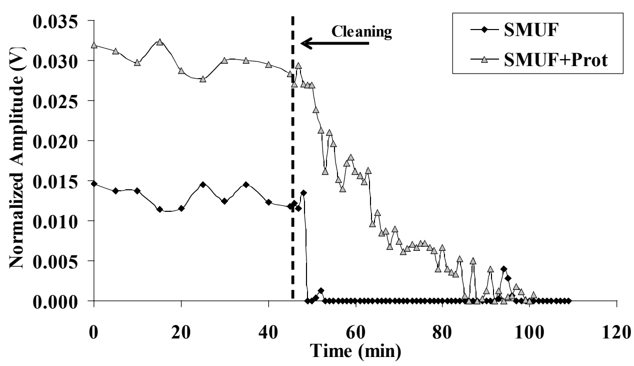

Figure 3: Cleaning of SMUF and SMUF with whey protein deposition curves assessed with the MSS

3. Shampoo films

Contrarely to what happened with the previous studies, this one deals with the use of water to remove residual (shampoo) films that stay attached to the monitored surface, rather than with solid fouling deposits. Since the shampoo physical properties (e.g. viscosity) are very different from those of water, the vibration that propagates along the tubing is affected by this property and gives rise to different A_{FFT} for shampoo and for water. The effect of different cleaning conditions, such as temperature and flow velocity on the shampoo removal (assessed through the A_{FFT}) have been determined. According to the results presented in the last edition of the present conference and the ones that can be read in Pereira *et al.* (2009), the main conclusions from these experimental trials were that:

- the MSS accurately monitored the different cleaning curves that resulted from the different cleaning conditions. It was possible to relate the amount of shampoo that stayed attached to the monitored surface to the MSS output response (A_{inv}) – Figure 4. Note that A_{inv} is a mathematical representation of the A_{FFT}, when it changes between 0 (flow cell filled with water) and 1 (flow cell filled with shampoo);

- the cleaning end-points have been positively confirmed by independent techniques (spectrophotometry and contact angle measurements).

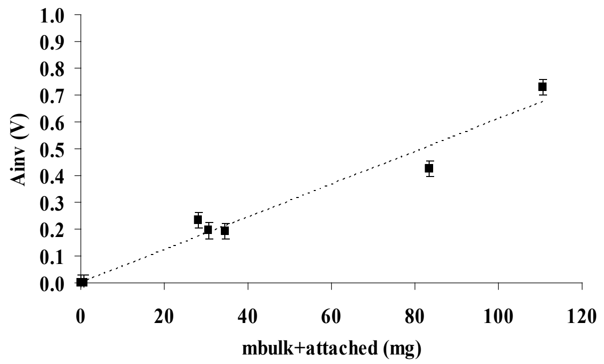

Figure 4: Relation between the A_{inv} and the mass of shampoo that remains in the flow cell after the cleaning procedure (R^2=0.9633)

<u>Field trial</u> – Side stream of a Cooling Water System

The laboratorial results seems to indicate that the MSS has a significant potential for laboratorial applications, regarding the monitoring of the fouling formation and removal and the optimization of the cleaning procedures. Being so, the MSS is being tested on side-stream of a cooling tower on an open cooling water system. The system was actuated with a sinusoidal wave with 4500 Hz and 5 V and the MSS response (normalized amplitude) along time is shown on Figure 5.

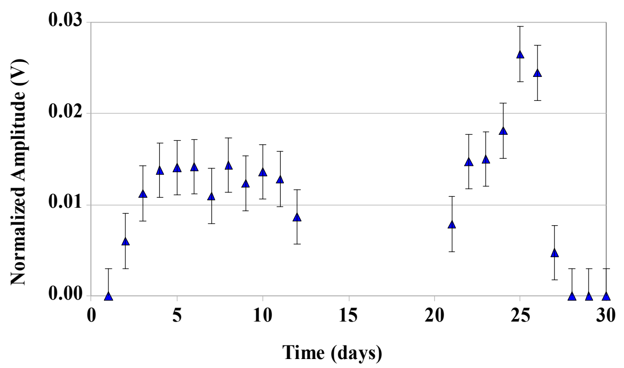

Figure 5: variation of the MSS normalized amplitude with time

Figure 5, shows that the MSS normalized amplitude increased on the first two days and then reached a stabilization plateau (aproximately from day 3 to days 12). It was possible to visually observe a similar trend since on the first two days a very thin deposit was formed on the MSS inner surface (this fouling is a result of environmental dirtyness rather than scaling or corrosion products). Due to technical problems in the plant it was not possible to evaluate the MSS information between days 13 and 22.

On day 20, the water on the basin of the cooling tower showed a brown coloration (this coloration was a result of a process contamination) which demanded the implementation of a serie of actions to fullface that problem. Those actions included the increase of the blowdown, the addition of extra dosis of biocide and of dispersant. Figure 5 shows that apart from the increase observed between days 24 and 26, the MSS normalized amplitude reached zero – indicating that there is no deposit attached to monitored surface (this cleaning condition was also visually confirmed). The increase between days 24 and 26 is possibly due to the swelling of the fouling layer. The swelling is widely reported in literature as a physical response of the interactions between the cleaning agents and the fouling layer. This phenomenom was, for example, found during the study of cleaning procedures of ultra filtration membrane (Zondervan et al., 2007) or during the cleaning of protein layers with alkali solutions (e.g. Sahoo et al, 2008).

The increase on the strict regulations associated with chemical substances discharges or with green-house gas emissions, the social concerns with the environment and the economic losses associated with the deposits formation and/ or removal are examples of how important the implementation of new procedures and new strategies are. The industrial implementation of the MSS would be a contribute to minimize the fouling effect by providing on-line, real-time information about the adhesion/removal of the fouling layers. The monitoring approach can be used simultaneaously as a way to: i) help in the understanding of the mechanisms behind fouling and cleaning; ii) monitor fouling extent and apply timely counter-measures; iii) evaluate the efficacy of those applied counter-measures, as well as to detect the cleaning end-points (which is of the utmost importance during cleaning procedures).

Regarding the MSS, significant efforts are being done in order to industrially test the features observed under laboratory conditions, but also to re-design its physical configuration in order to make it more close to what industrial facilities demand – robust, easy to implement and easy to operate.

CONCLUSIONS

The MSS device, an on-line monitoring device based on the vibration propagation along a monitored surface, was tested in the laboratory with several fluids that produce different deposits. The results obtained in these tests indicated that the MSS is able to:

- quantitatively assess the amount of layer attached to the surface;

- produce semi-quantitative information that enables to distinguish different types of attached layers;

- monitor cleaning operations and determine the respective end-point in real time;

- monitor distinct processes, from milk pasteurization to cooling water systems and shampoo cleaning procedures.

Additionally, the MSS is being field tested, showing results that confirm its suitability for industrial applications.

NOMENCLATURE

A_{FFT} – Amplitude after Fast Fourier Transform procedure
A_{inv} – Inverse Amplitude
DF – Damping Factor
L – Laminar flow
MSS – Mechatronic surface Sensor
Prot – Whey Protein
SMUF – Simulated Milk Ultrafiltrate
T – Turbulent flow

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