



## Monitoring scale deposits by using a sensor-based on electrical measurements

Arley A. Cruz<sup>1\*</sup>, Fábio A. Dossi<sup>2</sup>, Giancarlo R. S. Banda<sup>3</sup>, Cláudio Dariva<sup>4</sup>

<sup>1</sup>NUESC – Instituto de Tecnologia e Pesquisa, Universidade Tiradentes, Brazil, arley\_alles@hotmail.com

<sup>2</sup>NUESC – Instituto de Tecnologia e Pesquisa, Universidade Tiradentes, Brazil

<sup>3</sup>LEN – Instituto de Tecnologia e Pesquisa, Universidade Tiradentes, Brazil

<sup>4</sup>NUESC - Instituto de Tecnologia e Pesquisa, Universidade Tiradentes, Brazil

### Abstract

Scales are known to impose a considerable challenge on the oil and gas industry due to recurrent equipment damage that negatively impacts oil productivity. The development of cutting-edge technology to monitor scale formation in the most diverse areas of oil and gas facilities is highly desirable. The goal of this research was to develop a smart sensor to measure the formation of scales in solutions using electrical measurements. The formation and deposition of scales were monitored on a real-time basis in synthetic water, which is very similar to the water found in the pre-salt oilfield. Our results showed that the equipment effectively detected scales during all deposition stages. The stages analyzed were composed of three batches in a sequence adopted to accelerate the fouling process until the complete covering of the electrode surface. In addition, this fouling behavior was validated through SEM image analysis of the electrode surface covering among the batches. Image analyses revealed a strong relationship between the output signal and the electrode surface coverage. The data suggest that the sensor was efficient for detecting scales, regardless of the type of inorganic deposit. Also, we have noticed that a clear relationship exists between the output signals and physical properties (thickness and electrode surface coverage), which may contribute to future research on scale formation.

### Keywords

Sensor development; scales; monitoring; pre-salt oilfield

### Introduction

The formation of scales continues to be a challenge to the oil industry. Studies have been focused on monitoring the scale process formation as a way to reduce the costs caused by such a phenomenon. Many analytical techniques have been used in monitoring approaches, such as TBT (Dynamic Tube Blocking Test), ultrasound, and near-infrared (NIR) spectroscopy. Additionally, the advent of computers and simulation software has enabled the construction of mathematical models to predict the fouling process [1–3]. However, serious limitations concerning fouling identification remain. TBT analysis is carried out in a capillary tube, which deviates from the real flow process of hydrocarbons. NIR technology needs a probe that might induce undesired scale formation due to local turbulence in the flow system. Regarding prediction methods, the process of inorganic

deposition is complicated in a way that mathematical models, non-rare, provide a poor description of the phenomena [4,5].

In this context, electrical measurements can be helpful for extracting information about inorganic deposits in solutions. Such an idea was encouraged by Rostron [6] in a critical review focused on scale measurements because of the possibility of their implementation in real pipeline measurements at a relatively low cost. Furthermore, some results about wax detection in oil systems have already been obtained by electrical capacitance tomography [7].

Despite the importance of monitoring scale formation, the available technology and equipment pose many limitations. Thus, here, we propose the development of a sensor based on electrical measurements to improve the detection of scale formation and its evolution over time.

## Methodology

The main idea of the sensor developed consisted in monitoring the electric current that passes through the sample, once an alternating electric potential is applied. This procedure was accomplished with the development of three stages: the input signal generation, the conversion circuit, and the output signal measurement. For the first stage, the input signal generation means an alternating electrical potential with a low amplitude to create an output signal of the sample. Such a stage was made in the frequency of 10kHz and 1V of amplitude using the wave generation function from multifunctional Digilent Analog Discovery 2™. Once the signals were generated, they passed through the sample by a pair of electrodes immersed in the solution. According to Ohm's law in Eq. (1), such an input signal is responsible for generating an alternating current as an output signal that is proportional to the resistance of the medium.

$$U = R * I \quad (1)$$

The second stage involves the conversion of the output signal (electrical current) into a proportional electrical potential. This strategy is adopted because the electrical potential is more straightforward to measure than the electrical current. This conversion was accomplished by the operational amplifier NE5532 using an inverting amplifier configuration as presented by Eq. (2).

$$U_{out} = -\frac{R_2}{R_x} * U_{in} \quad (2)$$

where  $R_2$  is referred to as the resistor gain (220 Ohms) to amplify the output signal,  $R_x$  represents the sample's resistance and  $U_{in}$  is the input signal generated by Digilent Analog Discovery 2™. Finally, the converted output signal was digitized and sent to the computer to monitor the formation of deposits. It was performed by the same analog discovery 2 using the oscilloscope function.

## Experimental Procedure

Initially, an aqueous synthetic solution was prepared to evaluate the performance of the sensor. In this study, two brines with the same composition as a Brazilian pre-salt oilfield were used and are presented in Table 1.

Table 1: Ion concentrations (ppm) for the brines used to evaluate the behavior of the sensor

Cation solution	
<i>Ions</i>	<i>Concentration (ppm)</i>
Na <sup>+</sup>	50496
Sr <sup>2+</sup>	252

Ba <sup>2+</sup>	284
Ca <sup>2+</sup>	792
Mg <sup>2+</sup>	305
K <sup>+</sup>	391
Cl <sup>-</sup>	79229

Anion solution	
<i>Ions</i>	<i>Concentration (ppm)</i>
HCO <sub>3</sub> <sup>-</sup>	1544
SO <sub>4</sub> <sup>-</sup>	46
C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup>	138
Br <sup>-</sup>	0

70 mL of each solution were mixed inside the reactor only at the measurement moment, simulating the formation of scales due to the incompatibility of the two brines. After preparing the solutions, the sensor was connected to the power supply (using a symmetric value of 15 V for the operational amplifier) and the pair of electrodes. The brines were inserted into the reactor, and an agitation system was used and set to 450 rpm to induce the precipitation process. The temperature of the solution in the reactor was maintained at 43°C by a thermostatic bath. Once the solution was introduced into the reactor, the electrodes were partially submerged in the solution, and the measurement was accomplished at the initial moment of the insertion of the electrodes. Once the initial measurement was performed, the electrodes were left inside the reactor for 2 h to accumulate an amount of scale on their surfaces. After the removal of electrodes from the reactor, they were dried for 12 h at a temperature of 100°C. Scanning Electron Microscopy (SEM) micrographs (JEOL JSM -IT200) of the electrodes were taken in each step (i.e., batch) of the procedure to monitor the presence of inorganic deposits, the degree of coverage, and the thickness of the scales. The electrodes from a previous batch were submitted to the next experiment until completing four batches. The entire procedure was repeated four times in order to evaluate the fouling evolution in each batch and until completely electrode surface coverage. The schematic diagram of the apparatus used in this work is presented in Fig. 1.

## Results and Discussion

In each experiment, the value of the output potential signal was gathered and plotted to the respective batch as a form to evaluate the process of scale formation in the electrodes. This behavior is evidenced in Figure 2.

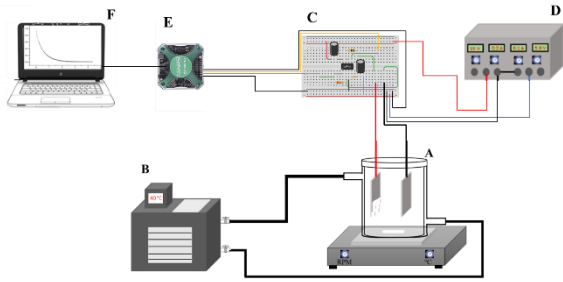


Figure 1. Schematic of the experimental apparatus: reactor with electromagnetic stirring system (A), thermostatic bath (B), injection and conversion circuits (C), power supply (D), multifunctional analog discovery 2 (E), computer (F).

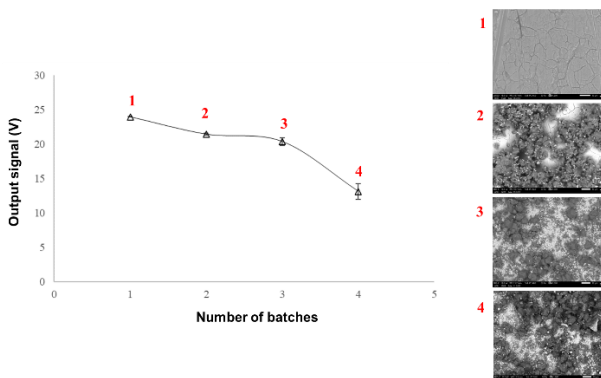


Figure 2. Observed output signal measured throughout all fouling batches. Scanning electron microscopy (SEM) analysis showing the development of scale along the batches. Each experimental point was performed in duplicate. Scale bars = 10  $\mu\text{m}$ .

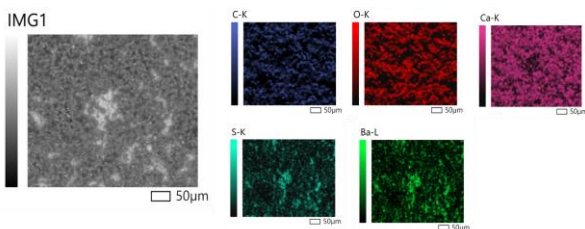


Figure 3. Map from energy dispersive spectroscopy (EDS) analysis on the electrode surface after it has been used on the second batch.

A significant drop in the signal was observed along with the batches, revealing a decrease in the conductivity between the electrodes (Fig. 2). Such a phenomenon is due to the accumulation of scales on the electrodes, making input signals more difficult to pass through the electrodes. The scale accumulation was confirmed by SEM analysis, which showed the successive increase in deposits on the surface of the electrodes throughout the batches. It is important to state a considerable reproducibility of the procedure and phenomena (Fig. 2). More detailed images of a small portion of the electrodes revealed the presence of different types of deposits with the majority of  $\text{CaCO}_3$  and

$\text{BaSO}_4$ , according to the map from energy dispersive spectroscopy (EDS) analysis (Fig. 3). The increase in scale-driven electrode surface coverage due to the large content of solutes in the solution [8] was also evidenced through SEM analysis (Figs. 2-4). Liu and co-workers [3], detected  $\text{CaCO}_3$  deposits at around 40% of surface coverage with a quartz crystal microbalance with dissipation (QCM-D). However, the measurements were accomplished at very low concentrations of ions in comparison to real oilfield conditions. Here, the thickness of the scale deposition was assessed by SEM images of the electrodes (cross-sectional view) collected after the second and fourth batches (Fig. 4).

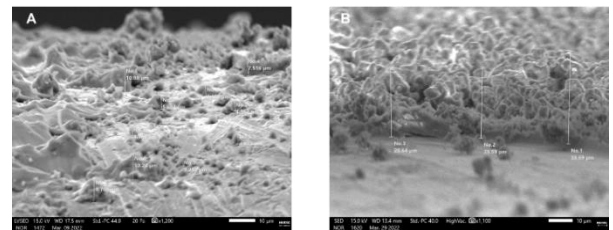


Figure 4. SEM cross-sectional view of inorganic deposits demonstrating its heightens. Images were obtained on electrodes after second (A) and fourth batches (B).

The increase in scale thickness along the experiments was conspicuous after the second batch (Fig. 4a), a step in which the thickness reached a mean value of  $8.6 \pm 2.5 \mu\text{m}$ . After the fourth batch (Fig. 4b), fouling mean thickness increased to  $29.6 \pm 5.5 \mu\text{m}$  due to successive accumulation of inorganic deposits. The preference for new inorganic crystals to accumulate onto already deposited ones was observed, thereby increasing the thickness in some regions of the electrodes [9]. Because of such a process, irregularities in the thickness of the layer contributed to considerable standard deviation values. It is essential to state that at the initial stages of deposition, the thickness is attributed to a particular grain measurement (not shown). In this sense, more reliable thickness measures are obtained when scales fully cover the electrodes.

## Conclusions

This work focused on the development of new sensors to monitor scale formation. Our data suggest that the sensor was efficient for detecting scales, regardless of the type of inorganic deposit. Furthermore, we have noticed that a relationship exists between the output signals and physical properties (thickness and electrode surface coverage) of the inorganic deposits, which may contribute to future research on scale formation.

## Acknowledgments

The authors thank to CENPES/Petrobras, CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil) - Finance Code 001 and ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis) for financial support and scholarships.

## Responsibility Notice

The authors are the only ones responsible for the paper content.

## References

- [1] A.V.A. de Souza, F. Rosário, J. Cajaiba, Evaluation of calcium carbonate inhibitors using sintered metal filter in a pressurized dynamic system, *Materials*. 12 (2019). <https://doi.org/10.3390/ma12111849>.
- [2] K. Christidis, G.P.P. Gunarathne, K. Peteineri, Intelligent instrumentation for identification of scales in petroleum pipelines in situ, *Transactions of the Institute of Measurement and Control*. 35 (2013) 457–463. <https://doi.org/10.1177/0142331212453598>.
- [3] H.A. Ohen, L.E. Williams, J.D. Lynn, L. Ali, Assessment and Diagnosis of Inorganic-Scaling Potential Using Near-Infrared Technology for Effective Treatment, 2004.
- [4] M.S. Kamal, I. Hussein, M. Mahmoud, A.S. Sultan, M.A.S. Saad, Oilfield scale formation and chemical removal: A review, *Journal of Petroleum Science and Engineering*. 171 (2018) 127–139. <https://doi.org/10.1016/j.petrol.2018.07.037>.
- [5] A.A. Olajire, A review of oilfield scale management technology for oil and gas production, *Journal of Petroleum Science and Engineering*. 135 (2015) 723–737. <https://doi.org/10.1016/j.petrol.2015.09.011>.
- [6] P. Rostron, Critical Review of Pipeline Scale Measurement Technologies Abbreviations: PMMA: Poly Methyl Methacrylate, *MOJ Mining and Metallurgy*. 1 (2018). <https://doi.org/10.15406/mojmm.2018.01.00004>.
- [7] Real-time monitoring of electrochemically induced calcium carbonate depositions\_ Kinetics and mechanisms \_ Elsevier Enhanced Reader, (n.d.).
- [8] Z. Liu, H. Onay, F. Guo, J. Chen, L. Poltorak, P. Hedayati, E.J.R. Sudhölter, Calcium Carbonate-Modified Surfaces by Electrocrystallization to Study Anionic Surfactant Adsorption, *Energy and Fuels*. 35 (2021) 1358–1370. <https://doi.org/10.1021/acs.energyfuels.0c03695>.
- [9] Z. Liu, H. Onay, F. Guo, Q. Lv, E. Sudholter, Real-time monitoring of electrochemically induced calcium carbonate depositions\_ Kinetics and mechanisms, (n.d.). <https://doi.org/10.1016/j.electacta.2021.137719>.