DOI 10.5162/SMSI2023/P44

Towards inline hydrates detection by electrical impedance measuring system

Gustavo Fraga Gehring[1], Natan S. Reginaldo[1], Jean Paulo Nakatu Longo[1], Marco José da Silva[1,2], Rigoberto E. M. Morales[1], Eduardo Nunes dos Santos[1]
[1] Multiphase Flow Research Center (NUEM) Federal University of Technology – Paraná (UTFPR), Curitiba, Brazil.
[2] Johannes Kepler Universitat, Linz, Austria.
ensantos@utfpr.edu.br

Summary:
Methane hydrates is a critical occurrence in the oil and gas industry because it can potentially interrupt the flow of pipelines. Monitoring the formation of hydrates is critical for decision-making leading to damage control of blockages. To date large safety margins are applied in hydrates management which could be optimized by proper monitoring, thus decreasing costs. Here we show that a straightforward impedance-based measuring system can detect fluctuations in conductance and capacitance and correlate them to the formation of ice in a tube. Ice has similar properties to hydrates and was therefore selected as model substance in this study.

Keywords: electrical impedance, capacitance and conductance, flow assurance, hydrates, ice formation.

Introduction

Hydrates blockages can be problematic in oil and gas facilities. The presence of hydrates can cause flow restrictions and permanent damage to pipelines. Current hydrates management strategies rely on large safety margins as well as remediation strategies such as thermal heating of pipelines of the injection of chemicals (so-called hydrated inhibitors) [1]. In that sense, detecting hydrates formation is essential for maintaining safe conditions and/or decreasing costs in oil and gas production. Since ice has similar properties to hydrates, it was therefore selected as model substance in this study.

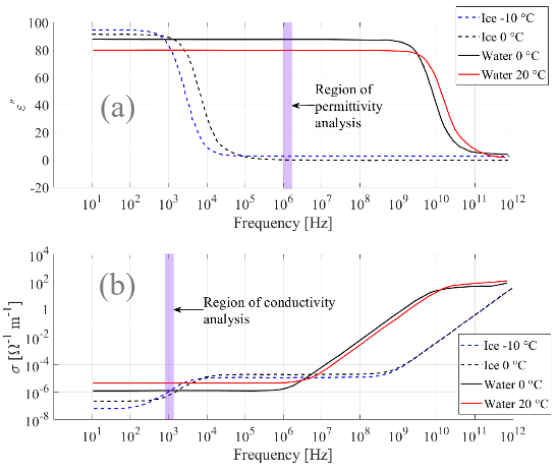

Fig. 1. Frequency-dependent (a) relative permittivity and (b) conductivity of water and ice [2].

The proposed measuring system works with the changes in conductivity and relative permittivity of water and ice to sense when solidification occurs. The frequency dependence of the relative permittivity and conductivity is shown in Fig. 1, which is generated based on the models given by [2]. Furthermore, some temperature dependencies of these electrical quantities can be seen. The region of analysis of relative permittivity was MHz, and conductivity was kHz.

Measuring system

The experimental setup depicted in Fig. 2(a) consists of a pipe section with four ring-shape sensors (1). The impedance-based measuring system (indicated by RC sensor) (3), was applied to measure the conductance and capacitance during ice formation. A computer (4) was used to monitor in real-time the electrical parameters measured by the sensor and temperature. The temperature sensor (5) was placed inside the pipe, and the control of temperature until the solidification of water was done by inserting the pipe inside a chiller (6).

A photograph of the system is shown in Fig. 2(b). The pipe was built as an apparatus consisting of a two-inch pipe (1); inside the pipe, it had two pairs of ring-shaped sensors with the same diameter. The sensors were placed to form a non-intrusive measurement. The ring-shaped is a pair of parallel electrodes with a ring geometry well-established to characterize flow patterns [3].

The electrodes support the RC sensor in sensing changes in electrical parameters (conductance and capacitance). The impedance-based measuring system has two independent circuits which determine conductance (by an opamp-based I-V method) and capacitance (by a capacitance-to-digital IC). To control and monitor the parameters of the RC sensor, a proprietary software was used (4) to display in real-time visualize the measurements. Furthermore, a temperature data logger was also applied based on the type K thermocouple. The precise temperature control was realized by the chiller.

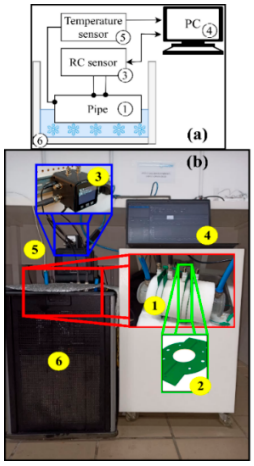

Fig. 2. Measurement system. (a) Experimental setup (b) photograph of the system.

Ice formation

The ice formation process (Fig. 3), with the pipe full of water, started when (t = 0 s) with setting the bath to -10 °C. At this time, the temperature inside the pipe was 7 °C (the thermocouple has a nominal uncertainty 1 °C tolerance). As the temperature of the water inside the pipe is higher than the temperature of the bath, heat is transferred from the water inside the pipe to the fluid in the bath; for that reason, the temperature inside the pipe starts to fall. As temperature decreases, changes in normalized conductance and normalized capacitance occur – this was expected for the dependency of these electrical parameters over temperature (see [4, 5]). The conductivity of water decreases with the temperature; this change in this parameter causes a decrease in the conductance measured.

On the other hand, the permittivity of the water increases as the temperature decay – as noted in Fig. 1(a). These higher permittivity values increase the capacitance measured. These behaviors are in good agreement with [2]. The temperature inside the pipe decreases until -3 °C. Although the freezing temperature of the water is close to 0 °C, the water rarely freezes when it hits this temperature; that is the well-known supercooling principle [5]. At the time t = 01:15:00, the temperature abruptly changes from -3 °C to 0 °C. This is when nucleation occurs, and that ice begins to form. A rising in temperature characterizes this stage due to latent heat being released by the ice crystal absorbed by water. When ice is formed, steep fluctuations in conductance and capacitance are noticed. Both normalized conductance and capacitance decrease due to the conductivity and relative permittivity of ice is lower than water, thus being a good indicator for ice formation.

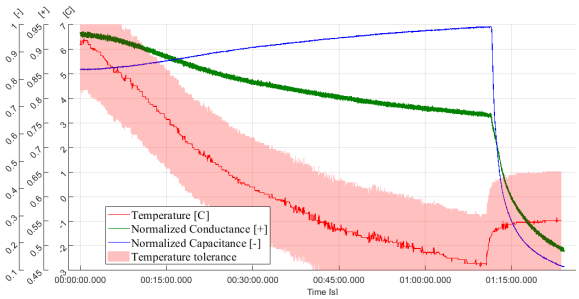

Fig. 3. Ice formation from fresh water.

Conclusion

An impedance-based measuring system was developed and tested to monitor the ice formation process. The system was capable of detecting conductance and capacitance variations that were correlated to the solidification of water. Hydrates is expected to behave similarly and will be studied in the next research phase.

References

[1] Makogon, T. Y. (2019). Handbook of multiphase flow assurance. Gulf Professional Publishing.

[2] Artemov, V. G., Ryzhkin, I. A., & Sinitsyn, V. V. (2015). Similarity of the dielectric relaxation processes and transport characteristics in water and ice. JETP Letters, 102(1), 41-45; doi:10.1134/S0021364015130020

[3] Shi, X., Tan, C., Dong, F., dos Santos, E. N., & da Silva, M. J. (2020). Conductance sensors for multiphase flow measurement: A review. IEEE Sensors Journal, 21(11), 12913-12925; doi: 10.1109/JSEN.2020.3042206

[4] Felsberger, R., Schweighofer, B., Flatscher, M., Rath, M., Grubmüller, M., & Wegleiter, H. (2018, June). Low power ice detection with capacitive and impedance spectroscopy-based measurements. In 2018 IEEE 27th international symposium on industrial electronics (ISIE) (pp. 809-813). IEEE; doi: 10.1109/ISIE.2018.8433765

[5] Gordon, J. R. (1996). An investigation into freezing and bursting water pipes in residential construction. Building Research Council. School of Architecture. College of Fine and Applied Arts. University of Illinois at Urbana-Champaign.