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Sensor system for detecting gas hydrate formation and deposition in multiphase flow

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ABSTRACT

Long multiphase transport distances and development of deepwater reservoirs call for flow assurance technologies that expand the current operational envelope into the hydrate regime. Operators and research groups are developing better risk assessment tools that enable operation with lower thermodynamic safety margins and less use of chemicals without risk for hydrate plugging. However, there is currently a lack of metering technologies that can monitor the multiphase transport and provide early warning of hydrate formation and deposition. In this paper, we present a sensor system that detects and characterizes hydrate formation and deposition by measuring and analyzing the permittivity spectrum of the multiphase flow. The sensor system has been adapted to hydrate monitoring in multiphase flow by CMR in close cooperation with Equinor in projects funded by Norwegian Deepwater Programme, and verified in high pressure flow loop studies with support from DeepStar and Chevron. Example results from a high pressure multiphase flow loop experiment is presented in this paper.

1 INTRODUCTION

The oil industry is moving into more challenging environments due to the depletion of the conventional onshore and shallow water sources of hydrocarbon. The subsea environment involves low temperatures as well as high pressures, high water cuts and long transfer times. Multiphase transport of oil and gas in pipelines in this kind of environment provides conditions that are ideal for gas hydrate formation, leading to high risk for hydrate plugging. Formation of hydrate plugs is normally avoided through thermodynamic means, by keeping the entire flowline outside the hydrate stability zone. However, the costs associated with thermodynamic hydrate inhibition are considerable and alternative strategies are needed. The two last decades it has become increasingly common to operate oil-dominated flowlines inside the hydrate domain. In order to operate safely inside the hydrate domain without risk for hydrate deposition and subsequently plugging, there is a need for surveillance technologies that can give early warnings if hydrates are formed.

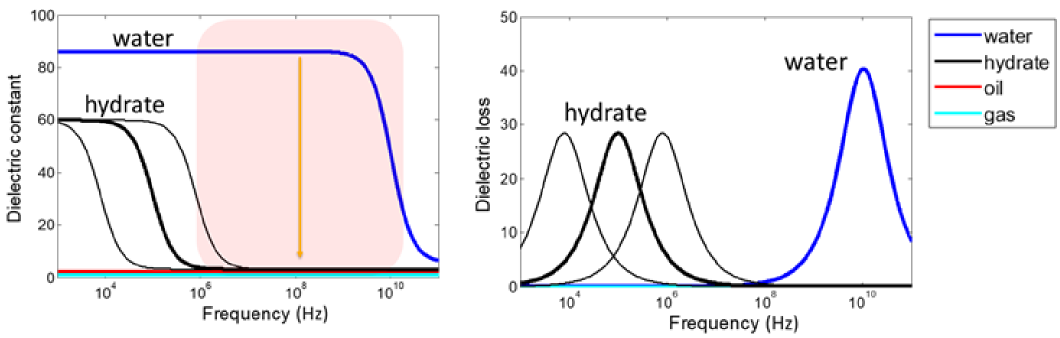

Figure 1 Complex permittivity of water, hydrates, oil and gas.

In this paper, we present a sensor system that detects and characterizes hydrate deposits by measuring the changes in permittivity spectrum in the multiphase flow when water is converted to gas hydrates. As illustrated in Figure 1, the dielectric spectrum of hydrates is significantly different from those of the other fluids present in a multiphase flow, and thereby information about hydrate formation can be determined from the measured complex permittivity spectrum. By applying adequate dielectric models, quantitative information about the composition of hydrate deposition layers and bulk flow can be achieved. The use of dielectric spectroscopy for measurement of hydrate formation was first suggested by University of Bergen and Christian Michelsen Research in the late 1990s [1], and the technology and models have been further developed and optimized in later projects [2]-[7]. This has been done in close cooperation with Equinor in development projects funded by Norwegian Deepwater Programme and in high pressure flow loop studies with support from DeepStar and Chevron.

2 SENSOR SYSTEM

The sensor system is based on broad-band permittivity measurement of the multiphase flow. During the hydrate formation process, water is transformed into solid hydrate, and thereby giving a change in the permittivity spectrum (see Figure 1). In order to detect hydrate deposition, the sensor is mounted flush with the inner pipe wall (non-intrusive) as shown in Figure 2. The formation of gas hydrates in multiphase transport pipelines typically starts near or at the wall of the pipe, as this is the coldest spot (see Figure 3). Near-wall sensing using an open-ended coaxial probe is therefore suited for early detection of hydrate formation and monitoring of build-up of hydrate deposit layers. The sensor is designed for high pressure and rough environments, and has been characterized in controlled experiments at laboratory conditions (e.g. [4]).

The amount of hydrates and the thickness of hydrate deposition layers are estimated by analysing the permittivity spectrum and its time variation, More information about the measurement method and the dielectric models used to analyse the measurements can be found in previously published work [1]-[7].

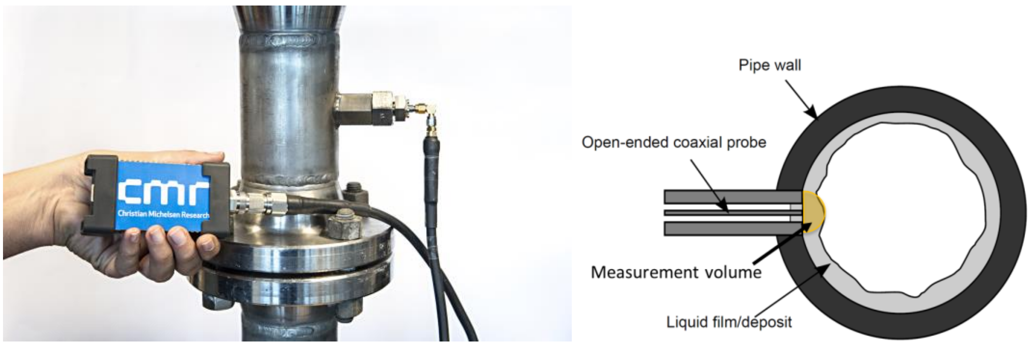

Figure 2 Sensor (open-ended coaxial permittivity probe) mounted flush with inner pipe wall.

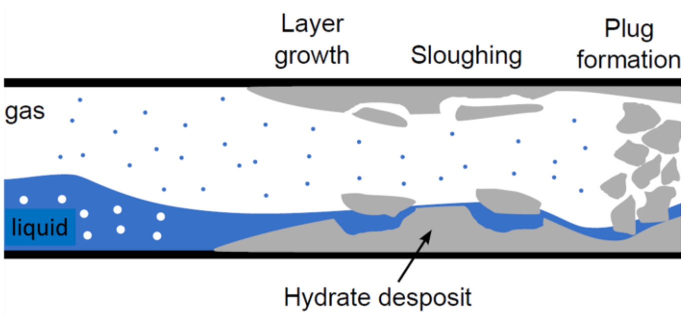

Figure 3 Typical hydrate formation process. Redrawn from [8]

3 HIGH PRESSURE FLOW LOOP EXPERIMENT

Experiments have been carried out in a high-pressure flow loop to examine the measurement system under conditions similar to those experienced at petroleum installations. The tests were carried out at Southwest Research Institute as a part of DeepStar project 11204 "Monitoring of hydrates in pipelines." A sensor was mounted at the top of a horizontal 3" pipeline. A local cooling was applied to the pipe section where the probe was mounted, in order to make the conditions favorable for hydrate formation and deposition. The operating pressure was approximately 80 bar and the local temperature was approximately 9 °C, which is significantly lower than the hydrate equilibrium temperature of approximately 15 °C. The flow consisted of a mixture of natural gas and tap water with a liquid loading of approximately 30 %. Due to the relatively high pressure and low temperature, some hydrates formed in the bulk resulting in a water/hydrate slurry flow. A slug flow consisting of large liquid slugs followed by large gas pockets was experienced. Thus, liquid slugs that filled the entire pipe cross section passed the probes regularly. The permittivity was measured every 2 seconds during the test.

Figure 4(a) shows the measured relative permittivity (real part) at 100 MHz as a function of time, and Figure 4(b) shows a detailed view over a 5 minute time period. A well-defined maximum level can be observed (illustrated by marker B), which corresponds to time intervals when liquid slugs passed the probe. The maximum level decreases with time as more hydrates were formed. The permittivity between the liquid slugs (see marker A) does not fall to the permittivity of gas (≈1), but remains at a rather high value. This shows that a slurry layer was sticking to the probes between the slugs. The measured permittivity is stable between the liquid slugs, but the permittivity level varies significantly from one stable period to the next. This can be explained by the presence of a thin stable hydrate layer at the pipe wall, backed by some remaining slurry from the liquid slug that just passed the probe. The thickness of this remaining slurry layer differs from one slug to the next. At some instances (see marker C), the measured permittivity falls between the well-defined maximum level and the typical minimum levels observed between the slugs. This is caused by smaller gas pockets inside the liquid slugs.

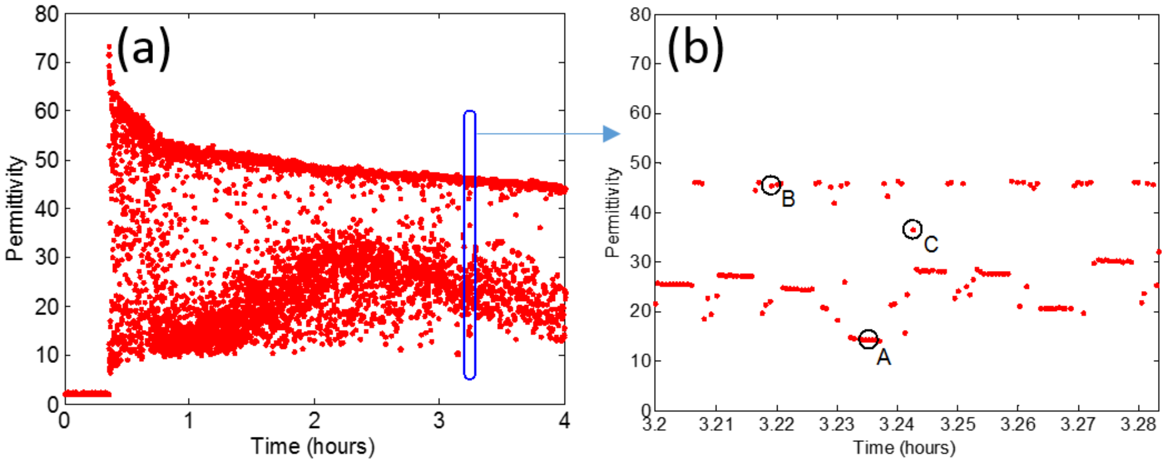

Figure 4 Time series of measured permittivity for spot frequency 100 MHz during experiment 1. (a) Probe A full time period. (b) Detailed view for Probe A. Selected period as indicated with a rectangle in (a).

Figure 5 shows the permittivity spectra for the three measurement points indicated in Figure 4(b). Spectrum B was measured during a liquid slug, and the permittivity reaches the well-defined maximum. The water dispersion is clearly observed at high frequencies in both the real and imaginary part of the permittivity. Spectrum A was measured between two slugs, when only a thin layer is present on the probes. The dispersion due to water can still be seen in the GHz range, but not as clearly as in spectrum B. The dielectric loss of spectrum A shows that the layer is water-continuous with a water conductivity of approximately 50 mS/m. Spectrum C was measured during a slug, but here the permittivity deviates from the maximum level in parts of the spectrum due to gas pockets inside the liquid slug passing the probe during the frequency sweep time.

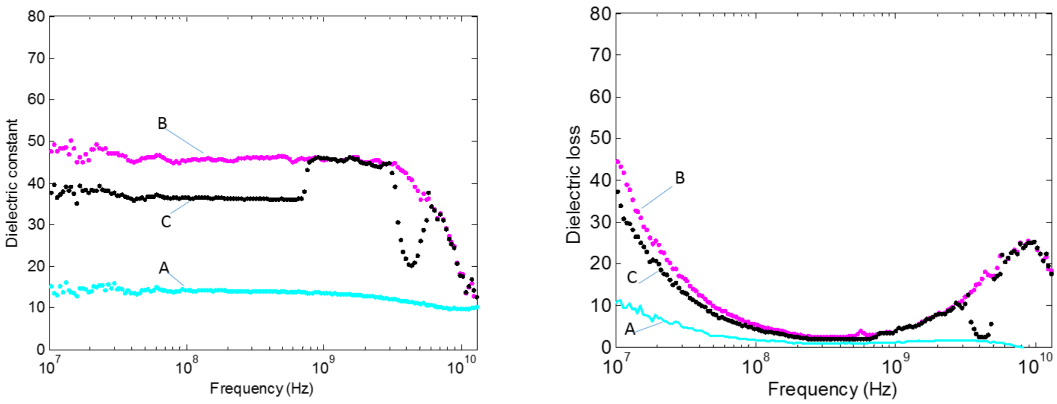

Figure 5 Measured permittivity for probe A for three selected times marked by circles in Figure 4.

Interesting information about the flowing slurry and the hydrate layers can be extracted by studying the distribution of permittivities over a slightly longer time interval (see Figure 6). The upper level is seen to be stable around 45, whereas the lower level shows a much broader distribution with permittivities from 10 to 35. This corresponds well with a thin stable hydrate layer backed by a changing slurry layer as illustrated in Figure 6. Quantitative information about the hydrate layer can be found from the permittivity spectra using adequate models [3]. For the example in Figure 6, the layer is estimated to be 0.3 mm thick and to have a 50 % hydrate volume fraction. The backing slurry was found to have a hydrate volume fraction of approximately 27 %.

The measured permittivity during the complete flow loop experiment example is shown in Figure 7(a). By analyzing the measured permittivity spectra versus time as described above, the build-up of the hydrate layer and the change of water fraction in the layer and the bulk during the complete experiment can be estimated. Figure 7(b) shows the estimated results versus time. Differential pressure measurements and borescope images taken during the flow test show that the estimated values are reasonable.

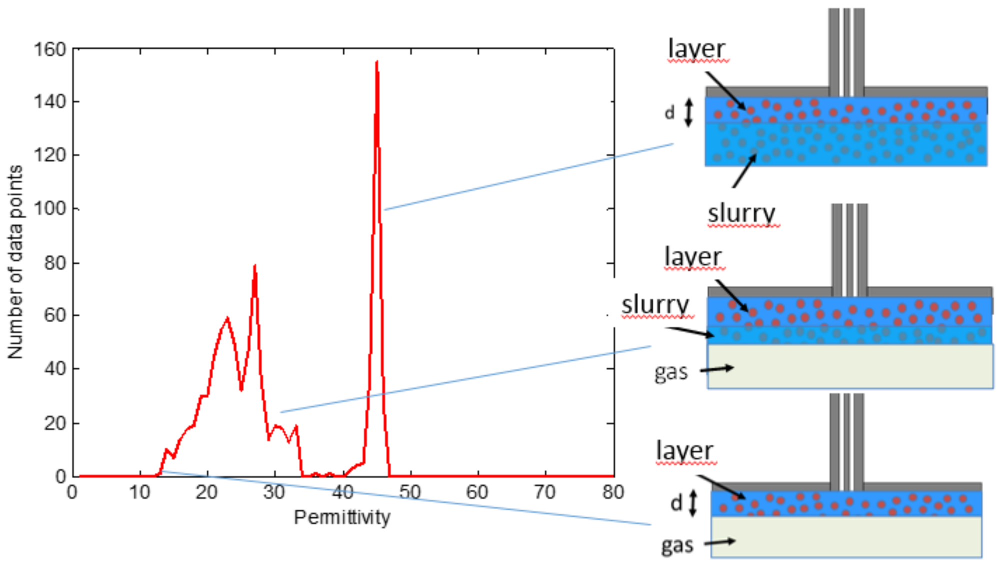

Figure 6 Distribution of permittivity (real part, 100 MHz) in a 30 minute time interval.

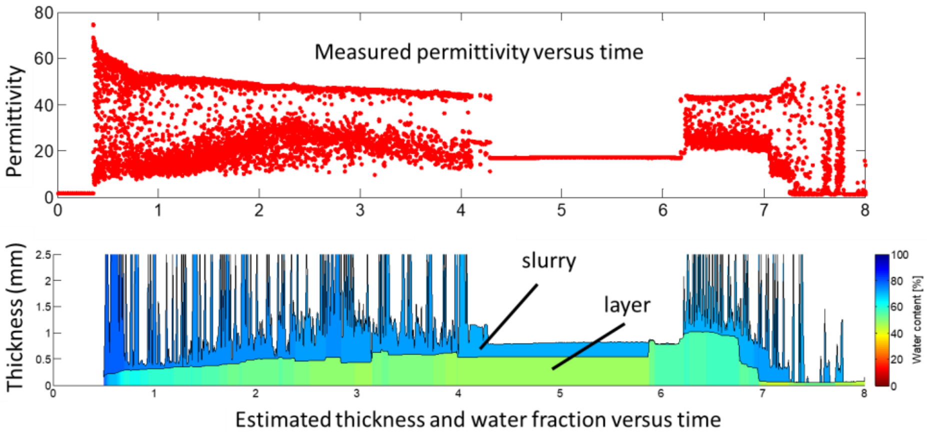

Figure 7 (a) Measures permittivity and (b) estimated thickness and water content of hydrate deposition layer versus time during hydrate formation at top of a multiphase pipeline. Note that the multiphase pump was stopped between approximately 4 and 6 h.

4 CONCLUSION

The results from the flow loop experiments show that hydrate formation in the bulk flow and hydrate deposition on the pipe wall can be detected and characterized using a permittivity measurement system. Very thin hydrate layers can be detected, and the build-up of thicker deposits can be followed. By using appropriate models, deposition thickness, local water content and water conductivity can be estimated.

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