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Water detection in gas/condensate flows by SeCaP technology

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ABSTRACT

Safe and controlled operation of subsea gas/condensate flow lines depends on adequate monitoring capabilities of free water in the well stream. Accurate knowledge on the amount of water present directly determines the requirement for hydrate inhibitor injection.

Free water originates from two sources; condensed water from the produced gas phase and the possible amount of formation water from the reservoir. The gas production should ideally be single phase from the reservoir, but as the temperature and the pressure are reduced in the well and flow line, both a liquid hydrocarbon phase and water will condense from the gas. Normally there is less water than condensate present, and the water cut can be lower than 10%. This means that the water often is dispersed as droplets in the condensate phase due to high velocities.

The paper presents tests on a 3” Sentech WCM (WaterCutMeter), based on the Single Electrode Capacitance Probe (SeCaP) technology. These experiments were conducted at 78 bar and 0 °C in the Norsk Hydro multiphase flow loop in Porsgrunn, with the primary objective to see if this instrument was able to detect the small changes in the amount of water present at such realistic operating conditions. The results show that the SeCaP WCM was able to detect changes in water content smaller than 0.01 vol%, but the meter needs a thorough temperature correction as the signal is strongly influenced by temperature changes.

1. Introduction

Natural gas production ideally starts out as single phase flow in the well. But as the temperature and the pressure are reduced in the well and flow line, both a liquid hydrocarbon phase and water will condense from the gas as the thermodynamic equilibrium is altered. The condensed liquids will slowly accumulate in the inclined parts of the pipeline upon reaching steady state conditions. At steady state the accumulated liquids may be major contributors to the total pressure loss in the pipeline due to the static head. In addition to the condensed liquids due to pressure and temperature decrease, the possibility to produce both hydrocarbon liquids and saline water (formation water) from the reservoir is present.

Apart from the increased pressure loss due to liquid accumulation, the water phase causes additional challenges due to the possibility of hydrate formation when the multiphase mixture reaches temperatures below 15–20 °C. Hydrates are ice-like structures formed from light hydrocarbon gases and water. To inhibit the system, usually thermodynamic inhibitors, such as methanol or glycols, are used and injected volumetrically based on the total water produced in the pipeline. If formation water is produced, there may be a need to inhibit for scale, or salt, formation as the solubility of the salts are altered due to pressure and temperature changes. For both hydrate and scale inhibition, the injection strategy is based on total amount of water produced, and the need for accurate water monitoring capabilities at the wellhead location are eminent.

The amount of liquid at the wellhead location, where the pressure and temperature still are relatively high, can be as low as 0.1 vol% based on the total volume flow rate; Elseth and Schüller [1]; Elseth and Schüller [2]. Normally there is less water than condensate present, and the water cut can be lower than 10% based on the total liquid fraction. In most cases this means that the water is dispersed as droplets in the condensate phase due to relatively high velocities and the geometrical design of the wellhead piping.

Prior to start up of such gas production, the water saturation of the system and the probability of formation water production have been tested through laboratory experiments and reservoir simulations. However, usually these experiments and simulations may have severe limitations depending on the fluid samples available and reservoir complexity. In other words, the expected amounts of water in the production system may have to be adjusted based on the initial phases of production.

For safe and controlled operations of such systems it is of crucial importance to have the correct chemical inhibition concentration. As the inhibition concentration is a pure function of the total amount of water present, the ability to quantify these tiny amounts

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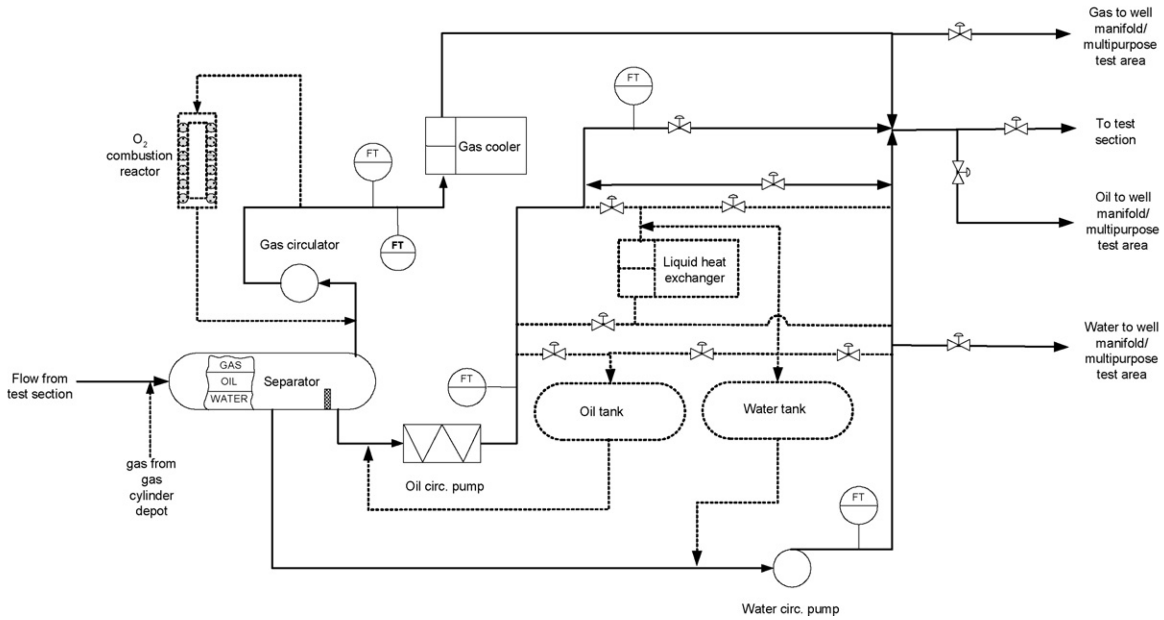

Fig. 1. Main components of the high-pressure multiphase flow loop.

of water at the wellhead is important, both at steady state and during dynamic conditions. Especially the dynamic change in water fraction is crucial to detect as this may indicate changes in the reservoir production into the well. These changes must then be compensated for with correct amount of inhibitor, or if large water production is detected, the well needs to be shut down if adequate inhibitor concentration can not be injected.

In order to do a screening test of a new water detection technique based on capacitance, a few tests were conducted as an extension of another measurement campaign. This campaign was conducted in our in-house test facility with a gas-condensate system at high pressure and low temperature.

2. Water detection measurement techniques

Several attempts have been made to accurately measure water contents at very small total water concentrations, and among these are capacitance and microwave which are frequently reported in the literature.

Traditionally capacitance measurements are performed between pairs of electrodes, and several authors have described results for either measuring water content, Chanzy et al. [3]; Fares and Alva [4]; Fares et al. [5]; Girona et al. [6]; Morgan et al. [7]; Nunez-Elisea et al. [8]; Paltineanu and Starr [9]; Rial and Han [10]; Robinson et al. [11]; Shinn et al. [12]; Starr and Paltineanu [13]; Yoder et al. [14], for detecting the position of interfaces in separated fluid systems, Hjertager et al. [15]; Jaworski and Bolton [16]; Jaworski et al. [17]; Jaworski et al. [18]; Keska et al. [19]; Thorn et al. [20]; White and Zakhari [21]; York and Williams [22], or for detection of foam drainage, Hutzler et al. [23]; Pacho and Davies [24]. The general problem with the electrode pair measurement technique is that the system short circuits in water continuous dispersions.

Microwave technology has also recently been developed for the measurement of water content in different systems, Bo and Nyfors [25]; Fischer et al. [26]; Kara et al. [27]; Mikhnev et al. [28]; Nyfors [29]; Sihvola et al. [30]. However, these measuring systems are quite different from the capacitive measuring system, based on an oscillator circuit, described in this work. More recently water content in oil–water two-phase flow was predicted by Zhang et al. [31] and composition measurements in crude oil/water emulsions has been done using ultrasonic transducers, Meng et al. [32]. A recent review of measurement techniques is given in Jaworski and Meng [33].

The measurement system is called SeCaP (Single electrode capacitance probe) since only one electrode is active and exposed to the measuring volume. A detailed description of the SeCaP technology is given in Schüller et al. [34]. The measuring range of SeCaP^{TM} (Single electrode capacitance probe) systems is from 0 to 100% water. Unlike traditional capacitive systems, measuring between pairs of electrodes, the SeCaP^{TM} system utilizes a single electrode for each measurement. As a consequence of this it does not “short circuit” in conducting fluids, i.e. free water or water-continuous dispersions.

3. Materials and methods

3.1. Experimental set-up

The experiments were conducted in the Norsk Hydro multiphase flow loop. The test facility is a recirculation loop facility, which is designed to handle recombined hydrocarbon fluid systems at pressures up to 110 bar and temperatures up to 140 °C. A full description of the test facility is given in Robøle et al. [35]. An overview of the main components of the test facility is shown in Fig. 1. From the three-phase separator, gas, oil and water are indi-

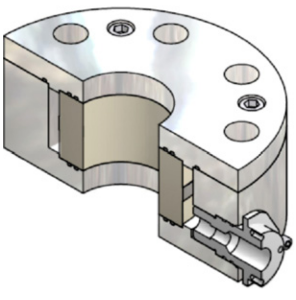

Fig. 2. Section of WCM showing ceramic ring and electrode.

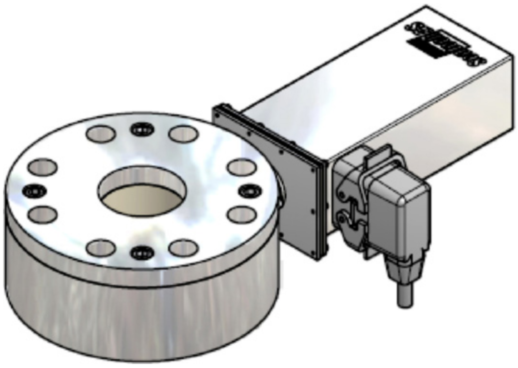

Fig. 3. Drawing of WCM.

vidually fed into the 3″ (78 mm) ID duplex steel test section via a double T-junction. Capacities of the rig are 0.002–40 m^3/h for each liquid phase and 0.3–205 Am^3/h for the gas phase. This represents a superficial gas velocity range of 0.02–11.6 m/s, and a superficial liquid velocity range of 0.0001–2.3 m/s. To cover the full range of flow rates, each phase has dual set of flow meters, all of them coriolis mass flow meters.

From the mixing point the multiphase flow enters the test section, which is totally 200 m long. This comprises a horizontal pipe of 60 m (770 D) followed by an inclinable section of 40 m (510 D), which represents the main test area. Following the main test area the pipe returns to the separator through the downstream inclinable section followed by a 60 m horizontal leg.

3.2. Water cut meter (WCM) description

A 3″ internal diameter water cut meter (WCM), (Type 3″ 900 lbs ANSI B16.5 WCM) Schüller et al. [34], was used in the experimental set-up. A section of the WCM is shown in Fig. 2 and a drawing is shown in Fig. 3.

The WCM consists of a 3″ internal diameter spool piece that has a ceramic ring in contact with the fluid. The length of the ceramic ring is 60 mm and the thickness is 30 mm. The electrode (or capacitor plate) is positioned on the external side of the ceramic material. This electrode is a 10 mm wide metal band surrounding the external periphery of the ceramic material. The metal band is fused to the ceramic material.

The function of the ceramic material is two-fold; it is hydrophobic in nature so it helps oil wetting the surface and it is as an electric insulator with a low permittivity, and this makes the instrument have a deeper “view” into the process stream.

The water cut meter is produced according to Ex standards for use in explosion hazardous environments.

The raw signal from the WCM requires temperature compensation adjustment, and the instrument should ideally operate close to steady state temperature. The changes in capacitance recorded by the meter due to changes in water volume fraction are very small (less than 0.0003 pF with a measuring time of 10 ms, Schüller et al. [36]), and the effects of uncompensated temperature effects can in the present set-up be of the same magnitude.

3.3. Experimental fluids and conditions

The test fluids were fresh water including 34.7 wt% methanol, a hydrocarbon condensate and gas mixture from an onshore terminal. Pure aqueous phase through the test section, showed 96% of full scale reading on the WCM. A 100% reading would indicate only fresh water present, so the presence of methanol lowers the signal strength. A fluid description is given in Table 1.

The molar composition of the gas was approximately 1.2% N_2, 1.1% CO_2, 82.5% CH_4, 13.8% C_2H_6, 1.3% C_3H_8 and 0.12% C_4H_{10}. The gas was in contact with the water phase in the system separator, so the gas phase was saturated with water at 0 °C with a saturation pressure of approximately 0.006 bar. The mole fraction water vapour in the gas phase was therefore approximately 8×10^{-5}.

The experiments were performed at a pressure of 78 bar and a temperature close to 0 °C in the facility. The flow loop was in the horizontal position, and the WCM meter was located at the end of the main test area, just upstream of the 180° bend returning the fluids to the separator.

Two sets of experiments were conducted, both with a constant gas velocity of approx. 9.5 m/s. One set with a gas–liquid ratio (GLR) of approximate 150 with a water cut range of approximately 1–6%, and one with a GLR of approximately 4000 with a water cuts of 15 and 85%. Both sets of conditions are within expected wellhead conditions for different gas-condensate fields, and the flow pattern is expected to be annular/mist flow with water dispersed in condensate at low water cuts, and vice versa at high water cut.

The experiments were intended to screen the instruments' ability to detect changes in water loading and the sensitivity to such changes. It is important to clarify that the experimental and instrument set-up was not specially designed for these tests, as they were only intended to give indications of the potential for water detection at realistic conditions with respect to GLR and water cut. The WCM used was not the latest version, and Sentech AS informs that significant improvements to the sensitivity and temperature compensation have been made in the latest versions of the instrument.

4. Results

The variations in liquid flow rates are shown in Figs. 4 and 5 as a function of time for the two set of experiments, GLR ≈ 150 and GLR ≈ 4000, respectively. The condensate flow rate was kept constant at approximately 1000 L/h (0.66 vol%) for the GLR ≈ 150 experiments, while the water rate was varied in step as follows: 0, 9, 17, 38 and 62 L/hour. A period of no water was then deployed to the system before the water rate again was set to 9 L/h and subsequently increased to 60 L/h. Then the water was shut off and back on again to 60 L/h. The experimental set with GLR ≈ 4000 had approximately constant total liquid flow rate of 40 L/h with two water cut levels, 15 and 85%. Similar as for the first set of experiments the initial conditions were with no water before the 15% water cut was initiated directly followed by the 85% water cut test. The test set finally had a period of pure condensate flow. As seen in Fig. 5 there was initial problems to adjust correct liquid flow rates both for the 15 and 85% water cut experiments.

The response from the WCM raw signal is shown in Figs. 6 and 7, along with the input volume fraction of water. From Fig. 6 we can observe that the WCM signal is initially a bit unstable when no

Table 1
Measured properties of MeOH fluids system at 0 °C and 75 bar.

Fluid	Density (kg/m^3)	Viscosity (mPas)	Surface tension (mN/m)	Interfacial tension (mN/m)
Gas	78	0.014	$\sigma_{GC} = 8.5$	
Condensate	692	0.57	$\sigma_{GW} = 21.8$	$\sigma_{CW} = 5.4$
Water/MeOH	933	3.10		

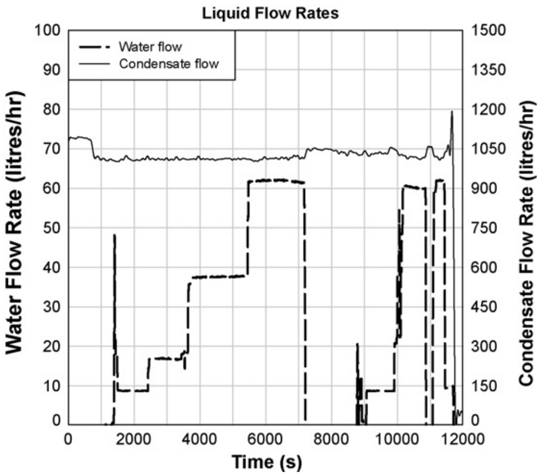

Fig. 4. Flow rates at first time interval.

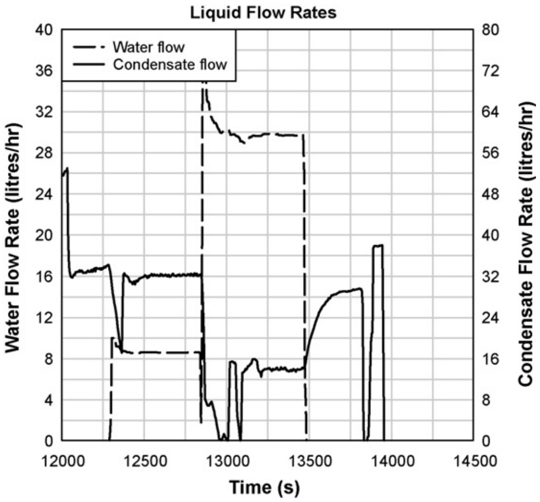

Fig. 5. Flow rates at second time interval.

water is injected. The first injection of water was transient, maximizing briefly just below 50 L/h, before stabilizing at 9 L/h. The response to the injection of water is seen as an initial rapid increase, which levels off with time. Next step in water flow also causes an initial rapid increase, which levels off and decreases with time.

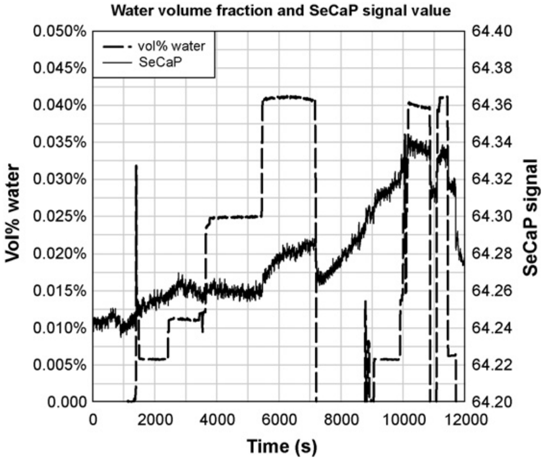

Fig. 6. Vol% water and SeCaP signal at first time interval.

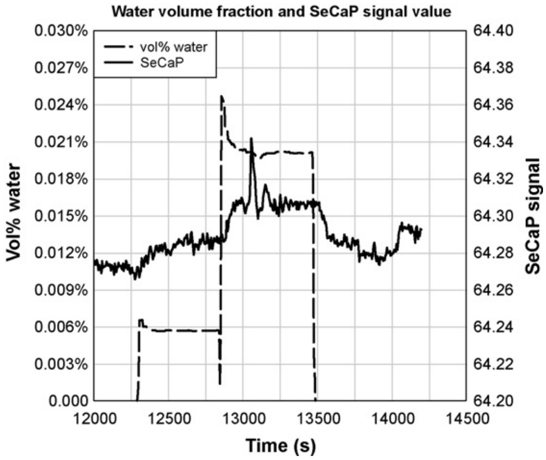

Fig. 7. Vol% water and SeCaP signal at second time interval.

Increasing the water volume from 0.011 to 0.025% just causes an initial signal increase before the signal is seen to decrease and levels off. The first real indication from the WCM that there is an increase in water fraction is seen when increasing the water fraction up to 0.041%. The signal is seen to have a steady increase in strength and also indicate an asymptotic trend. A similar well-defined signal indication is seen when the water is shut off after the experiment with 0.041%. In the following period with pure gas-condensate flow, the WCM signal is steadily increasing, but the signal trend is seen to be altered by the following injection of water, especially when increasing it up to 0.040% again and when water is shut off and on.

For the GLR $\approx$ 150 experiments the WCM signal is shown in Fig. 7. We observe from the figure that both changes in water fraction levels are recognized by the WCM signal in terms of an increase or a decrease.

5. Discussion

The raw data signal of the WCM instrument is observed to detect changes in water fractions in the multiphase flow. However, the data presented in Figs. 6 and 7 also indicate periods of significant signal drifting. The reason for the observed drift is thought to be two-folded: the temperature compensation of the raw data signal and the dynamics of the experimental facility.

A plot showing the variations in process temperature and WCM temperature during the tests is shown in Fig. 8. The process flow temperature was close to $-1\,^{\circ}\mathrm{C}$ for the whole test period, but the temperature in the WCM instrument was varying from 7 to $5\,^{\circ}\mathrm{C}$. The WCM temperature was especially unsteady in the time period 2400 s to 7800 s. From Fig. 8 it is observed that the WCM temperature exhibits some periods with relatively large gradients, coinciding with changes in SeCaP signal. During these time periods, the WCM signal is more difficult to correlate to the changes in vol% water. See for instance the test with a water vol% of 0.011 in Fig. 6, where the raw data signal initially increases before decreasing. From Fig. 8 this is seen to coincide with a large drop in the WCM temperature. Similar behaviour can also be observed for the next experiment with 0.025 vol% water.

From Fig. 8 we also observe a slow transient shift in the zero level of the SeCaP signal during the test period, which also is believed to be related with the uncompensated temperature effects. The shift in zero level is clearly observed in Fig. 6 at times between 7500 s and 9000 s where there is zero water flow, and an increase in WCM signal is observed with time. This coincides with a sudden increase in the WCM temperature as seen in Fig. 8.

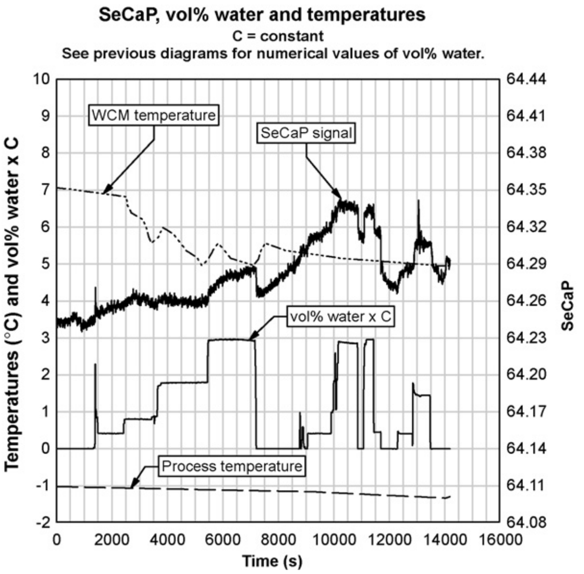

Fig. 8. Temperatures and SeCaP signal.

The experimental facility comprises a 100 m long test section upstream of the installed WCM instrument. At conditions with high GLR the dynamic response at the position of the WCM instrument may in some cases be significant. As most of the liquid moves as a relatively slow film at the pipe wall, there may be liquid remains long after the flow meter registers changes. Such slow dynamic changes may alter the actual recorded data signal significantly in the experiments presented here. Ideally the pipe should have been "dried" with hot gas prior to the tests with water. This would initially have given a much better base line for the raw data signal.

6. Conclusions

The purpose of the present study was to document that the SeCaP WCM instrument has a high sensitivity to variations in water flow rate, even when the water is dispersed in an oil phase. The tests were run at low water cuts, so at least a proportion of the water phase was dispersed in the oil phase. The SeCaP measuring system is much more sensitive to water than to oil, and the signal would have been much stronger if the water phase had wetted the wall of the WCM.The conclusions from this study can be summarized as follows:

- The SeCaP WCM system has a very high sensitivity to variations in water flow rate. It is able to detect variations in water concentrations of the order 0.01 vol%.
- The system was not able to compensate for the temperature transients occurring during the test period, which introduced uncertainties in quantifying the results.
- The conducted experiments indicate that the SeCaP technology has the potential to quantitatively determine very low water concentrations if the temperature compensation becomes good enough.

The absolute accuracy of the instrument has not been addressed in this work, but this is an issue that also has to be addressed in the development of a high sensitivity WCM application.

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