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Impact of Wax on Hydrate crystallization in flow loop

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Abstract
In the oil and gas industry, the coexistence of wax and hydrate precipitation poses significant challenges for production and transportation systems. By addressing the combined effects of wax and hydrates, operators can enhance flow assurance and minimize operational disruptions in oil and gas production systems. Understanding the impact of wax on hydrate formation is crucial for optimizing operational parameters, chemical inhibitor dosing, and heat tracing.Both wax and hydrates are solid deposits that can form in pipelines, flowlines, and equipment, leading to reduced flow rates, increased pressure drops, and potential blockages. This study investigates the impact of wax precipitation on hydrate formation through loop tests. The experimental setup involved flowing a hydrocarbon mixture (representative of oil and gas production) through a closed-loop system. The loop was subjected to varying temperatures and pressures to induce wax and hydrate crystallisation. Results indicate that wax precipitation significantly affects the hydrodynamic properties of the fluid, particularly its viscosity. This modified rheological behavior influences the kinetics of hydrate nucleation and growth.

Keywords
Wax, Hydrate, co-crystalisation

Introduction
In the oil and gas industry, the simultaneous occurrence of wax and hydrate precipitation poses significant challenges for production and transportation systems. Both wax and hydrates are solid deposits that can form in pipelines, flowlines, and equipment, leading to reduced flow rates, increased pressure drops, and potential blockages. The simultaneous occurrence of wax and hydrate precipitation exacerbates the challenges faced by operators. When both wax and hydrates coexist, their combined effects can lead to more severe blockages and operational risks.
The interplay between wax and hydrates is complex, as they can interact and influence each other's deposition behavior. For instance, wax deposits can provide nucleation sites for hydrate crystals.
Managing comingle precipitation requires a holistic approach, considering both chemical inhibitors and operational strategies. As a result, managing this comingle precipitation requires a holistic approach that considers both chemical inhibitors and operational strategies.
This study aims to assess the impact of wax precipitation on the hydrate formation in different flow regime.

Methodology
Experiments were carried out in a high-pressure flow loop, schematically represented in Figure 1. The flow loop is 56 meters long and has an inner diameter equal to 10.2 mm at the horizontal sections and 15.7 mm at the vertical sections. It is equipped with several different measurement systems, such as: temperature probes, differential pressure probes, absolute pressure probe, Coriolis flowmeter and densimeter, Focused Beam Reflectance Measurement (FBRM), Particle Vision Microscope (PVM), acoustic emission, permittivity and a high-speed camera. Flow is induced by a progressive cavity pump, which does not break the particles. The temperature is controlled by several heat exchangers along the pipeline.
The fluids used were: Kerdane oil, composed mainly by paraffinic and cyclic hydrocarbons ranging from C_{11} – C_{14}, furnished by Mieuxa, deionized water with 30 g/L of NaCl, wax, composed by hydrocarbons ranging from C_{20} – C_{32} furnished by Sigma Aldrich, and a synthetic natural gas, furnished by Air Products where the composition is shown in Table 1.
The wax was dissolved into the oil prior to its injection in the flow loop. The wax content of 2 wt %, in relation to the mass of oil, results in a wax

appearance temperature (WAT) of 10 °C (measured by Differential Scanning Calorimetry).

Table 1. Composition of the natural gas

Component	Mole fraction
Methane	91.7
Ethane	5.9
Nitrogen	0.8
Carbon Dioxide	0.8
Propane	0.6
Butane	0.1
Isobutane	0.1

The water cut used was 10 %. Under shear, this mixture of fluids results in a water-in-oil emulsion. One should note that the gas is injected in the separator (Fig. 1) and dissolves in the oil phase. Therefore, in the flow line, there is no free gas phase.

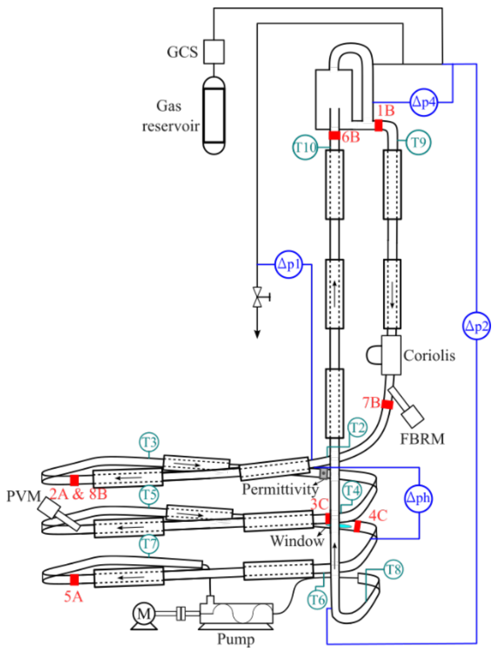

Figure 1. Flow loop scheme

The experimental protocol applied consists in first decrease the temperature, under shear, to 8 °C. As soon as the temperature is constant, pressurize to 8 bar with natural gas using the GPC. Then the temperature is controlled to 4 °C. After stabilization of pressure and temperature the system is pressurized to 75 bar. At this moment, the system enters the hydrate domain and the time is set as zero. This protocol was elaborated by De Almeida et al. [1] in order to enhance reproducibility and reduce the effect of external temperature.
After the pressurization to 75 bar, the pressure is kept constant by means of a gas compensation system (GPC). This system allows to measure the flow rate of gas being injected, and therefore the gas consumption due to hydrate formation. A model implemented by De Almeida et al. [1] is used to calculate the hydrate fraction.

Results and Discussion

Figure 2 illustrates the signals of density, absolute energy and dielectric before hydrate formation (region 1), the first few minutes after the onset (region 2) and when the signal stabilize (region 3). The first few minutes after hydrate onset, the signals shows that hydrates are forming and agglomerating, represented by the peaks seen in density, absolute energy and dielectric in region 2 of Fig. 2. After a few minutes, the agglomerates start to accumulate in certain restrictions of the flow loop. Moreover, if the particles grow to a certain size where the apparent weight (weight minus buoyancy) over comes the lift forces provided by the flow, the agglomerate settles down forming a bed. Since steel is hydrophilic, this bed can consolidate and form a deposit, if the time in contact in enough [2]. Once the aggregates deposit (region 3), the signals remains stable over time, indicating the mixture is more homogeneous, without the passage of big particles by the sensors.

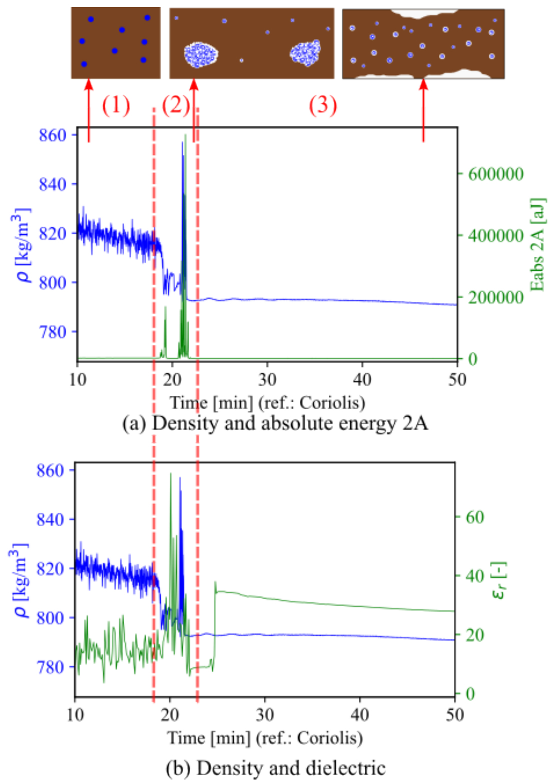

Figure 2. Density synchronized, in relation to the Coriolis, with (a) the absolute energy from probe 2A and (b) with the dielectric

In general, this behavior was present for both flow rates and with or without wax. At higher flow rate the main difference would be that hydrates, in general, present a lower induction time and present a higher initial growth rate, probably due to a better mixing of the system.
Moreover, the presence of wax in the system mainly changed the hydrate fraction of the system

at both flow rates, as can be seen in Fig. 3 and Fig. 4.

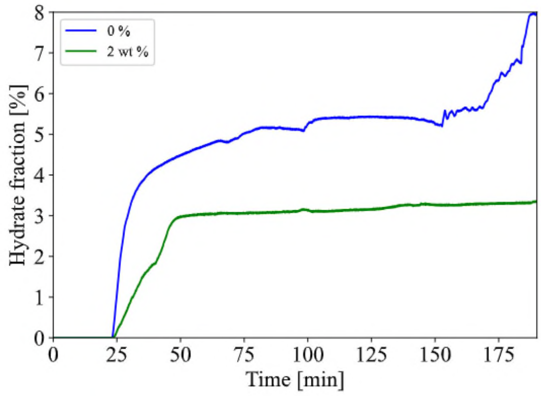

Figure 3. Hydrate fraction as function of the time and wax fraction (0 and 2%) at 200 L/h

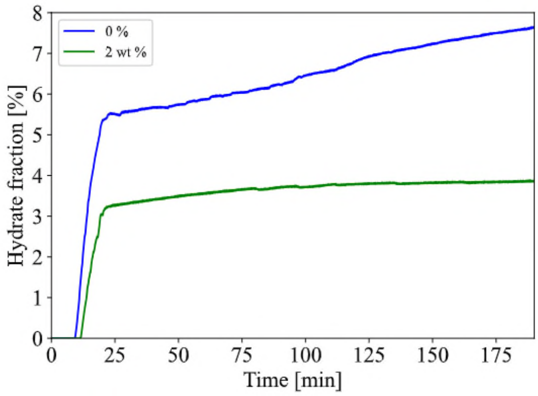

Figure 4. Hydrate fraction as function of the time and wax fraction (0 and 2%) at 400 L/h

In this work, it is hypothesized that the reduction in the hydrate fraction in the presence of wax is related to the increased viscosity of the waxy oil. Figure 4 shows the viscosity curve of pure Kerdane and Kerdane with 2 wt % of wax content, measured in ambient pressure and 4°C conditions. As can be observed, the wax not only changes the behavior of the oil from Newtonian to shear thinning, but it also increases the viscosity by a factor of almost 2.

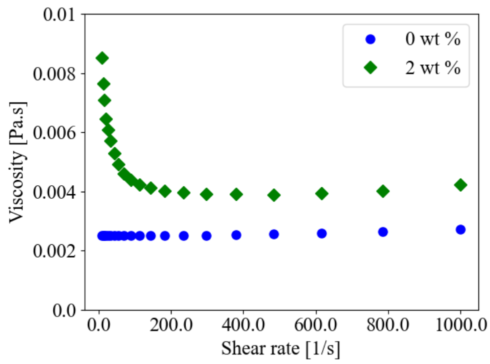

Figure 4. Impact of the shear rate on the viscosity

The increase viscosity results in a lower Reynolds number and, therefore, a less turbulent system. Less turbulent system means that the dynamic pressure forces that contribute to control the size of the agglomerates are inferior, allowing more agglomeration in the system. More agglomeration, by its turn, will result in less active surface for crystallization and, consequently, lower hydrate fraction.

Conclusions

In this work, it was experimentally studied the hydrate formation in an under-shear emulsion in the presence and absence of wax.

The results of the wax-containing and the wax-free system were compared in order to provide insights of the possible effects of wax on hydrate crystallization.

Based on the results, it is hypothesized in this work that the main effect of wax is the increased viscosity, which impacts on the hydrodynamic forces acting on the particles and affects agglomeration as a consequence. Since the system is limited by the active surface for crystallization and hydrates are porous structures [3], agglomeration will play an important role in water conversion of the system.

Responsibility Notice

The authors are the only responsible for the paper content.

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