SPE Brazil Flow Assurance Technology Congress
Rio de Janeiro, Brazil, November 06 – 08 2024

WaterLock – A new method for hydrate plugging risk assessment

Frode Nygård[1*], Torstein Austvik[2], Xiaoyun Li [2], Kjell Magne Askvik [3], Anna Nina Knutsen[2]
[1]Equinor ASA, N-4035 Stavanger, Norway, * fron@equinor.com
[2]Equinor ASA, N-7053 Trondheim, Norway
[3]Equinor ASA, N-5254 Bergen, Norway

Abstract
Hydrate control philosophy is an important part of flow assurance studies. The topic of interest here, is a shut-in operation of a flowline system without any hydrate mitigating actions, allowing operation inside the hydrate domain. Typical flowline systems applicable are gas-condensate and oil systems with low water content. The calculated water hold-up values from a multiphase simulator, SWH (Simulator Water Hold-up), have been the main parameter in evaluating hydrate risk in Equinor so far. In our guidelines, the maximum SWH value during a shut-in, needs to be below 10 - 20 vol% to qualify for a "do-nothing" strategy. However, the SWH value is a weak parameter when assessing hydrate risk during shut-ins and following start-ups. A new methodology called the WaterLock method is developed to improve the hydrate risk evaluations of these systems. The WaterLock method evaluates the actual water distribution in the low points along the flowline. Field data has been analysed with the new tool to set new requirements for hydrate management. The ambition is to analyse multiple systems and map relevant risk indicators. From these mappings, optimized guidelines with new limits and rules should be drawn and will then be used in evaluation of new systems where field data are not available.

Keywords
Flow assurance; Hydrate management, Plugging risk; WaterLock.

Introduction
Equinor (former Statoil) has since the 1990s developed the hydrate management concept [1]. Sloan's title [2], *A changing hydrate paradigm – from apprehension to avoidance to risk management,* explains the history beautifully simple. As illustrated in Fig. (1), the hydrate management concept allows operation inside the hydrate domain and has been a step change from former philosophy of hydrate avoidance, where it was not allowed at all to enter the hydrate domain.

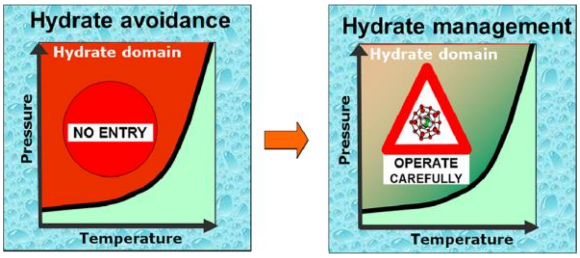

Figure 1. Hydrate avoidance versus hydrate management [1].

The industry has several standard design options for hydrate management of shut-in flowlines such as fluid displacement, depressurization, and inhibition; [3], [4]. Another possibility, not often mentioned, is to evaluate if flowline systems can be shutdown with no hydrate control measures, the so called "do-nothing" strategy [5]. Hydrate control of flowlines with low water content are typical candidates. Gas condensate systems with low water content or oil production systems with low water cut and high production rate might be candidates for a "do-nothing" strategy. The water hold-up from a multiphase simulator, SWH (Simulator Water Hold-up), has been a key parameter in risk analysis when evaluating the feasibility of a "do-nothing" strategy. Fig. (2) shows the SWH along a flowline during steady state flow (upper graph) and shut-in (lower graph), [1]. Initially the requirement was that the predicted maximum SWH along the flowline should be less than 10 vol% during shut-in to qualify for the "do-nothing" strategy in Equinor [1], [5].

Several mechanistic models made for hydrate risk evaluation can be found in the literature [6], [7], [8]; but have met challenges to integrate with the industry [9] and become part of day-to-day flow assurance work. Normally, hydrate risk assessments are based on results from standard multiphase simulations in combination with PVT and fluid property evaluations. In commercial multiphase simulation software, the pipeline geometry is modelled with multiple straight pipe sections. The pipeline profile is based on an approximated pipeline profile and the results should be checked against the as-laid pipeline profile (when available). However, it is normally not feasible to model the exact as-laid profile (often given with one point every 1 m) due to computation time. Therefore, pipe section lengths are optimized against computation time and accuracy of hold-up estimations. From these evaluations, a maximum pipe section length of about 15 m has been found to be acceptable in Equinor. Combined with field data evaluations, this has led to the present SWH requirement in Equinor for "do-nothing" strategy of less than 20 vol% in any section during shut-in (increased from former requirement of 10% when the requirements to pipe section lengths were not specified).

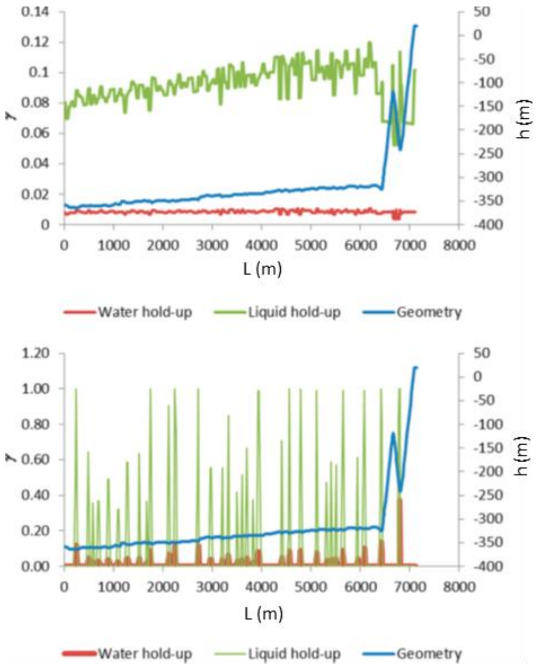

Figure 2. Water hold-up (SWH) during steady state (upper graph) and shut-in (lower graph) conditions in a production flowline, [1]. L is the flowline length and h the vertical distance.

In the present article, the hydrate management concept is taken a step further. The rationale behind is the statement that the water hold-up value from a multiphase simulator is a weak parameter when assessing hydrate risk during shut-ins and following start-ups. This is because it is highly dependent on the pipe geometry used in the simulator and the calculated water hold-up is an averaged value over a pipe section, not giving clear information of the severity of the actual low point.

The new WaterLock methodology

The suggested step change in hydrate management of flowlines is called the *WaterLock* method. This methodology bases itself on the use of accurate pipeline profiles (for example top-of-pipe or as-laid profiles) when assessing the hydrate risk. It is not necessary to simulate with the as-laid profile in a multiphase simulator, if this will result in un-manageable simulation time, but the as-laid profile should be used when assessing the low-points of interest with the WaterLock tool (described in next section). As illustrated in Fig. (3), the WaterLock method (upper figure) evaluates the actual water distribution in the low point in contrast to results from standard simulation software giving an averaged water hold-up over the entire section connected to the low point (lower figure in Fig. (3)).

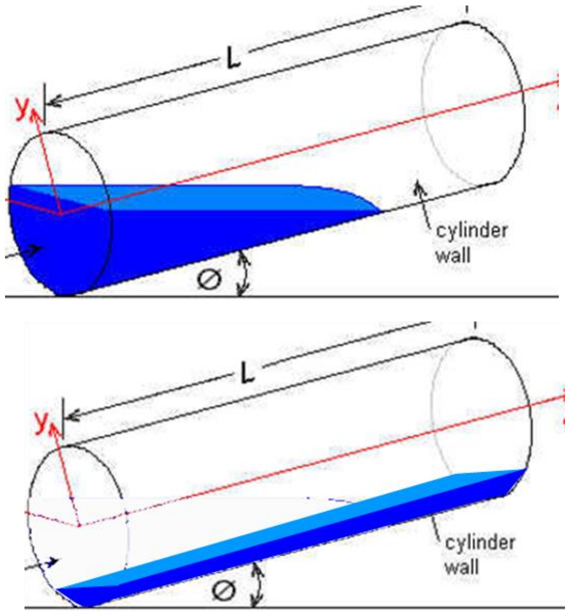

Figure 3: Actual water distribution in a low point as assessed with the WaterLock method in upper figure. Water hold-up during shut-in as reported in simulation software (SWH) in lower figure.

The SWH is defined as a volume ratio of the water volume in the pipe section, W_{vol}, to the total volume of the actual pipe section, V_{sec}, as shown in Eq. (1). In comparison, the WaterLock (WL) is defined in Eq. (2) as the cross-sectional area occupied by water in the actual low point, W_{area}, divided by the cross-sectional area of the pipe section, $A_{cross\text{-}section}$.

$$SWH = W_{vol}/V_{sec} \quad (1)$$
$$WL = W_{area}/A_{cross\text{-}sec} \quad (2)$$

The implications of this new way of thinking are illustrated in Fig. (4). Here, section A and section B make up the low point of interest. The two sections are of different length/volume to illustrate how section length affects the SWH numbers. Moreover, the water volume is lower in the upper figure compared to the lower figure in Fig. (4). As a result, the SWH is different in section A and section B and between upper and lower figure but gives no clear picture of the hydrate risk. Therefore, the assertion is that SWH provides little information about the hydrate risk. On the other hand, by using the WaterLock method it can be seen from Fig. (4) that for the case in the upper figure, space is available for gas to pass on top of the water phase. In contrast, any gas passing through the low point in the lower figure, will bubble through the water phase and therefore has an elevated risk of forming large amount of hydrates [10], [11].

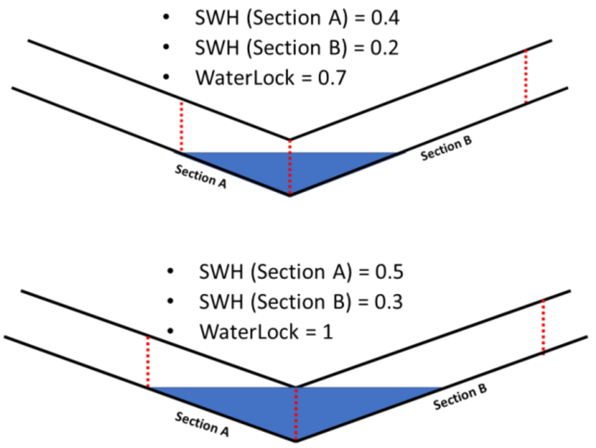

Figure 4: Actual water distribution in a low point as assessed in the WaterLock method. Red dashed lines define the sections. Upper figure WaterLock = 0.7. Lower figure WaterLock = 1.

The WaterLock tool

An in-house WaterLock tool (Python code) is developed for accommodating the WaterLock method. Code inputs are the flowline geometry (preferably the as-laid profile) of the actual system and the water and liquid content along the flowline (after a shut-down or at steady-state) from a commercial multiphase simulator. The code identifies all the low points and redistributes liquid in the chosen flowline profile. In addition to water lock, other risk indicators (RIs) are calculated and made available as output from the WaterLock tool. For example, *equivalent water slug length,* assuming full diameter water slug, says something about the risk during a start-up if the water accumulated in the low point travels like a slug through the system. *Local water cut in low points* is another important RI. As shown in Fig. (5), a water lock equal to one is not telling anything about the length of the water lock. Accordingly, a RI is also made covering this, defining the *water wetted length of upper wall*. To establish new RIs and optimize existing ones are still work in progress in addition to evaluate if combinations of different RIs can provide increased insight to hydrate risk.

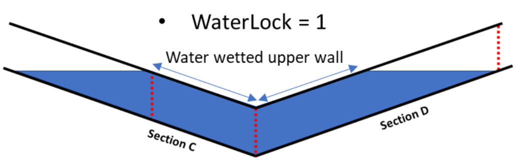

Figure 5: Water lock length parameter, water wetted upper wall.

Results and Discussion

The WaterLock method provides the user with an overview of the water distribution, the degree/severity of water locks, and the other risk indicators predefined in the most accurate geometry of your system at hand. Furthermore, by using the tool to analyse field data of systems where the “do-nothing” strategy has been used, experience can be gained and accommodates the user to set limits on different risk indicators. These risk indicator limits can then be used when analysing new systems in a project phase. One example of such field data analysis performed with the WaterLock tool is shown in fig. (6). Here, two flowline systems are evaluated: Flowline 1 with a diameter of 9’’ and Flowline 2 with a diameter of 10.6’’. Both flowline systems are gas condensate systems with produced water. The flow rates given are the gas flow rate before the systems were shut-in. The WaterLock values reported are averaged over the three low points with the highest WaterLock values. All the Flowline 1 and Flowline 2 cases were started up successfully, except the Flowline 2 case with WaterLock > 0.9, which resulted in a hydrate plug. Based on the WaterLock values for plugging and non-plugging cases, a WaterLock value below 0.7-0.8 is suggested for safe hydrate management.

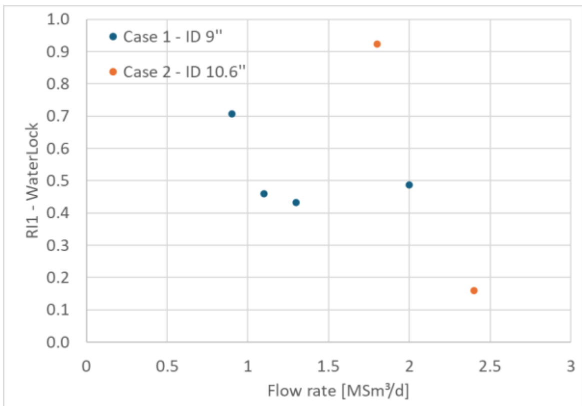

Figure 6: WaterLock estimations of field data from two different gas condensate flowlines.

Using the WaterLock value below 0.7 as a criterion, we have applied the method on to another flowline system with oil production to define the region of “do-nothing”. The sensitivity analysis in Fig. (7) shows how both the water lock (upper figure) and the water cut (lower figure) scale nicely with the total water content in the flowline. The WaterLock value at approximately 0.7 corresponds to about 20 m³ in total water content and a water cut slightly above 10% as illustrated by the red dashed lines in Fig. (7). Cold start-ups have been successful using these criteria.

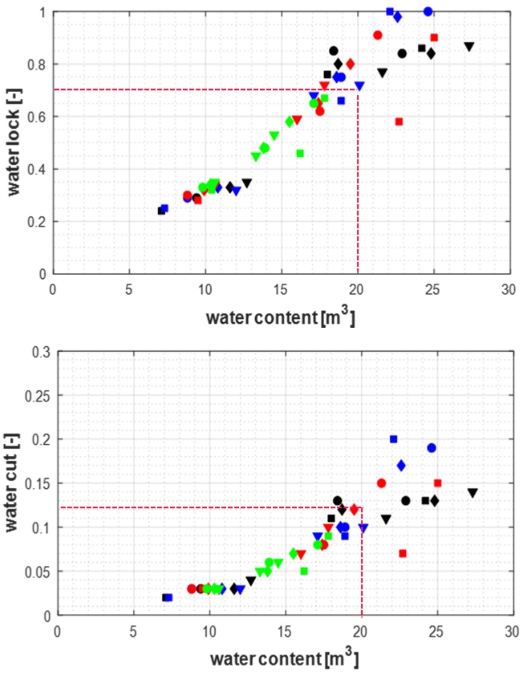

Figure 7: A sensitivity analyses of an oil system is performed with the WaterLock tool. Upper figure: WaterLock. Lower figure: water cut.

The results in Fig. (6) show how the WaterLock method is used in analyzing field data and used for setting limits for a “do-nothing” strategy in Fig. (7). The ambition is to extend these field data analyses to multiple systems and be able to map up all relevant RIs. From these mappings, optimized guidelines with new limits and rules should be drawn. These guidelines will then be used in evaluation of new systems where field data are not available. Finally, this method is foreseen to have an even greater potential if combined with online flow assurance models and machine learning techniques [12].

Conclusions

The WaterLock methodology is an improved solution for hydrate management evaluation of flow line systems. The WaterLock method pinpoints the degree of water lock in the low points of the pipeline geometry of choice, directly displaying if the gas has a possible passage besides bubbling through the water phase. Assessing the water lock itself is found superior to utilizing the SWH (Simulated Water Hold-up) as the latter is an averaged value over a pipe section and does not give a clear sense of hydrate risk severity. Furthermore, it is foreseen that the WaterLock method will become a valuable tool in both new-builds and for systems already in operation. By gaining more experiences from field operations and using the WaterLock method to analyse the field data, new optimized guidelines can be developed, and new industry standards can be created.

Responsibility

The authors are only responsible for the paper content.

References

[1] Kinnari, K.; Hundseid, J.; Li, X.; Askvik, K. M. *J.* Hydrate management in practice*, Chem. Eng. Data*, 60(2), 437-446, 2015

[2] Sloan, E.D. A changing hydrate paradigm - from apprehension to avoidance to risk management, *Fluid Phase Equilibria*, 228–229, 67–74, 2005.

[3] Cardoso, C.A.B.R.; Gonçalves, M.A.L.; Camargo, R.M.T. Design options for avoiding hydrates in deep offshore production, *J. Chem. Eng. Data,* 60, 330−335, 2015.

[4] Olajire, A.A. Flow assurance issues in deep-water gas well testing and mitigation strategies with respect to gas hydrates deposition in flowlines - a review, *Journal of Molecular Liquids,* 318, 114203, 2020.

[5] Sloan, E.D. Hydrocarbon hydrate flow assurance history as a guide to a conceptual model, *molecules*, 26, 4476, 2021.

[6] Chaudhari, P.; Zerpa, L.E.; Sum, A.K. A correlation to quantify hydrate plugging risk in oil and gas production pipelines based on hydrate transportability parameters, *Journal of Natural Gas Science and Engineering*, 58, 152-161, 2018.

[7] Kinnari, K.; Labes-Carrier, C.; Lunde, K.; Hemmingsen, P.V.; Davies, S.R.; Boxall, J.A.; Koh, C.A.; Sloan, E.D. Hydrate plug formation prediction tool – an increasing need for flow assurance in the oil industry, *open.library.ubc.ca,* 2008.

[8] Zerpa, L.E.; Sloan, E.D.; Sum, A.K.; Koh, C.A. A correlation to quantify hydrate plugging risk in oil and gas production pipelines based on hydrate transportability parameters, *Journal of Petroleum Science and Engineering*, 98-99,122–129, 2012.

[9] Aman, Z.M. Hydrate risk management in gas transmission lines, *Energy Fuels*, 35, 14265−14282, 2021.

[10] Pickarts, M.A.; Ravichandran, S.; Ismail, N.A.; Stoner, H.M.; Delgado-Linares, J.; Sloan, E.D.; Koh, C.A. Perspective on the oil-dominated gas hydrate plugging conceptual picture as applied to transient shut-In/restart, *Fuel*, 324, 124606, 2022.

[11] Sloan, E.D.; Creek, J.; Sum, A. Chapter two – Where and how are hydrate plugs formed, *Natural Gas Hydrates in Flow Assurance*, Elsevier inc, Web, 13-36, 2011.

[12] Qin, H.; Srivastava, V.; Wang, H.; Zerpa, L.E.; Koh, C.A. Machine learning models to predict gas hydrate plugging risks using flowloop and field data *Offshore Technology Conference*, OTC-29411-MS, 2019.