HeaveLock™ - an autonomous downhole tool for automated drilling

The last step on the path towards full drilling automation are tools that act autonomously, without the need of the driller to interfere (Thorogood et al., 2010). Such tools rely on their sensory data and make decisions using advanced control algorithms, keeping control variables in check and correcting any unwanted events before they have a chance to occur. HeaveLock™ is one such tool, currently being developed by a small start-up company in Trondheim with roots at NTNU with support from Equinor, Innovation Norway and the Research Council of Norway. HeaveLock™ addresses the important issue of avoiding downhole pressure oscillations due to surge & swab effects, caused by vertical movement of floating drilling rigs due to swell. Solving this problem is an important step towards accelerated introduction of Managed Pressure Drilling (MPD) techniques on floating rigs and drill ships in harsh weather environments. MPD has large potential when it comes to significantly improving IOR on mature fields, since it enables drilling of previously "un-drillable" wells with narrow pressure windows.

MPD is a drilling technique that allows improved control of downhole pressure compared to conventional drilling. MPD has been offered by all major drilling service companies for almost 20 years and has gained wide use in such applications as onshore drilling and drilling from fixed offshore installations in shallow water. MPD has also been introduced in offshore drilling from floaters, but mainly in regions with relatively mild weather and limited swell such as South China Sea and Brazil.

Utvinningsutvalget suggested in 2011 that utilization of MPD on floaters is one of the twelve measures to reduce costs and improve oil & gas recovery on the NCS. According to the Norwegian Petroleum Directorate, MPD is an important technology to achieve a boost in IOR and its utilization on the NCS was considered a priority (NPD, 2009). Rystad Energy report from 2012 estimated potential pre-tax value from utilizing MPD from floaters on six chosen NCS case fields to be more than 11 billion NOK between 2013 and 2030 (Rystad, 2012). Associated gross value (including costs collected as revenues by service companies) would then be almost 35 billion NOK. This value was claimed to originate from cost reductions (20%) and increased revenues (80%). The main assumption in the report was that MPD would be available on floaters from the start of 2013 and more than 1000 wells were pointed out as potential candidates, see Figure 1.

“North Sea would see the most rough seas, but HeaveLock™ would really apply anywhere MPD is used on a floater. GOM might see more benign seas than the North Sea but heave is still going to be an issue on floaters”
Subject Matter Expert, major oil company

Projection in the report was that 45% of the production on NCS would be within the potential scope of MPD from floaters by 2020. In an earlier study made by the Society of Petroleum Engineers (SPE) and published in the Journal of Petroleum Technology (JPT), more than 600 SPE members predicted that the share of offshore wells to utilize MPD would be around 40% in 2015 (Jacobs & Donnelly, 2011).

Higher utilization of MPD on NCS floaters has four main advantages:

1. Accelerated production and boost in IOR
Drilling in depleted mature reservoirs with tight pressure margins

►Predicted value from accelerated production and drilling the un-drillable wells on 6 NCS fields 2013-2030 was over 13 billion NOK (Rystad, 2012).

2. Ability to drill previously un-drillable exploration wells
Deepwater exploration

►Mandarin East HPHT well (BG) was only possible to drill due to utilization of MPD. MPD-related savings offset the costs of MPD by 185% (Syltøy et al., 2008).

3. Reduced costs due to less Non-Productive Time during drilling, related to pressure control

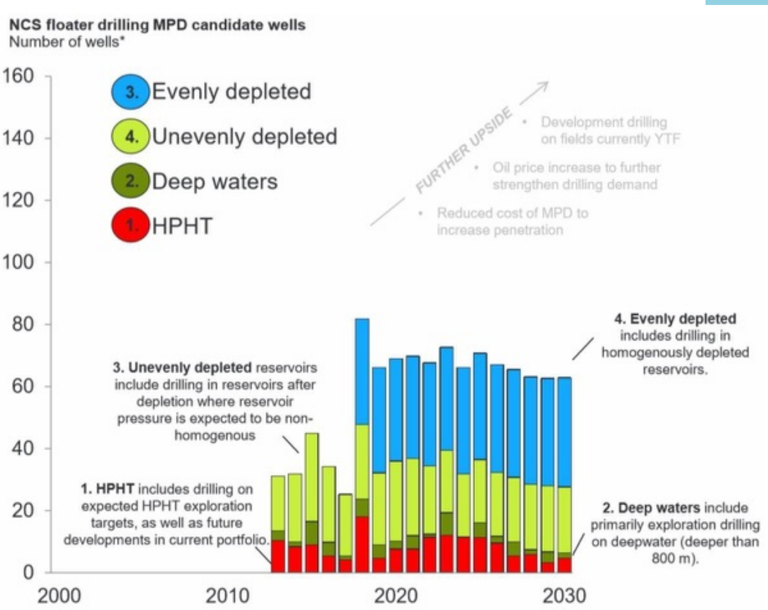


Figure 1 Over 1000 wells, mainly on mature fields, were considered as candidates for MPD from floaters (Rystad, 2012).

25% of drilling-phase NPT on NCS floaters is likely addressable with MPD technology

►4-7% of the total drilling NPT is addressable by MPD, corresponding to savings of 3-5 mNOK per month for one drilling rig (assumed day rate 2.4 mNOK). Overall projected value for 6 NCS field cases 2013-2030 was >3 billion NOK (Rystad, 2012).

4. Safer operations

►Utilization of MPD provides superior well control and early detection of kicks.

meters, the drill string is fastened to the drill floor to perform an extension with another pipe stand. During such extensions, the drill string cannot be heave-compensated, and it thus starts to move up and down in the well like a piston, creating downhole pressure oscillations. Much of the point with MPD is to keep the downhole pressure steady and within a tight window, defined by reservoir characteristics. Understandingly, large downhole pressure oscillations due to swell cannot be tolerated. These oscillations are referred to as “surge and swab effects”, see Figure 2. Surge (pressure increase) can damage a well, fracking it and reducing its future productivity.

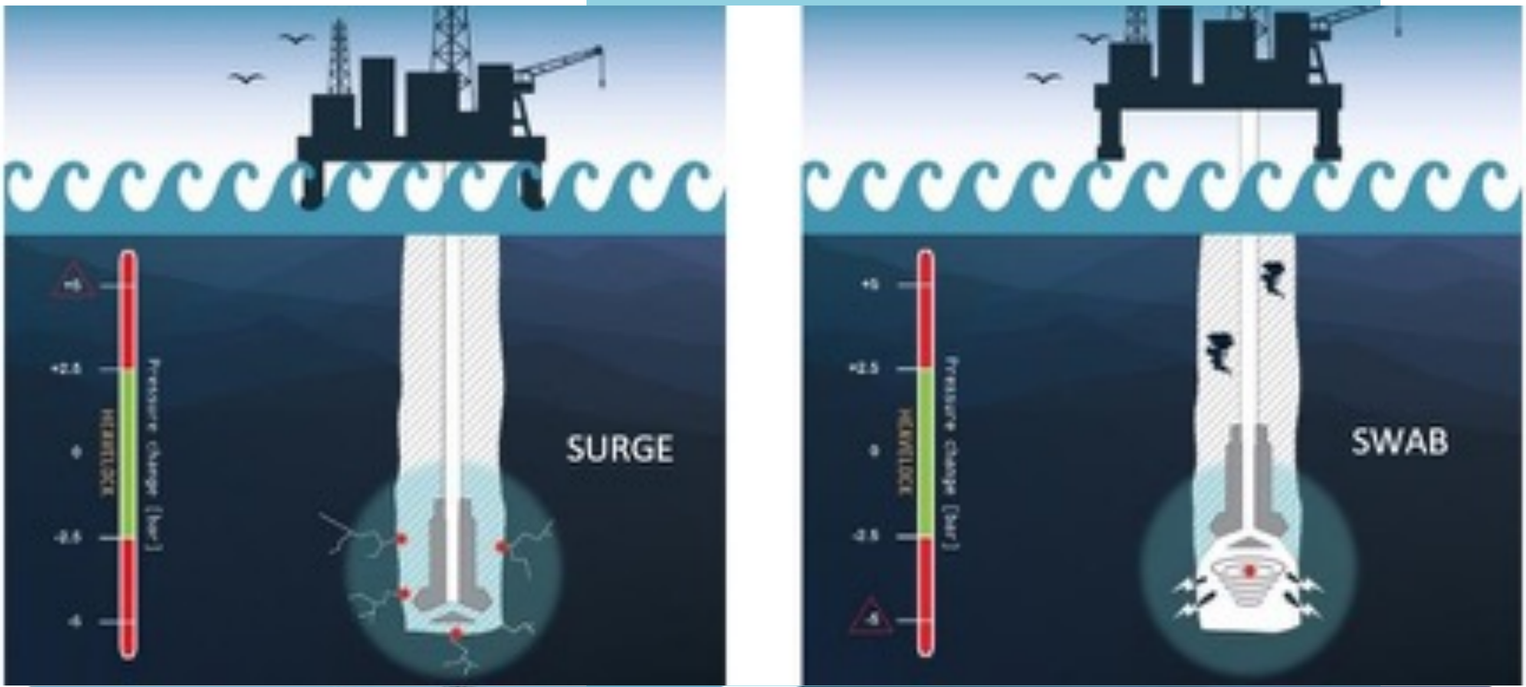
“You would need HeaveLock™ everywhere” Subject Matter Expert, another major oil company

Despite the significant upside and the positive forecasts, very few MPD wells on NCS have been drilled from floaters per today. A version of MPD called Controlled Mud Level (CML) has been utilized by Equinor on the Troll field and by Lundin on the Alta/Gotha field, although not more than 20 wells in total have been drilled utilizing CML (Rystad forecasted 180 wells between 2013 and 2018). There are many factors contributing to this fact. The oil price crisis of 2014-2017 certainly did not help. But there is also a technology gap; efficiency of MPD from floaters is seriously hampered by swell.

Vertical movement of floating drilling rigs and ships due to swell is called “rig heave”. Rig heave is normally compensated by control of the draw works during drilling, but every 30

Swab (pressure decrease) can cause hydrocarbons to enter the well bore during drilling, a potentially dangerous well control situation called “kick”. This problem has been identified as one of the main factors preventing widespread utilization of MPD when drilling from floating rigs and ships. During an Equinor-hosted workshop in May 2018, devoted to MPD from floaters, a panel of industry experts from service and operator companies agreed that issues related to surge and swab during connections are the one of the main technical reasons MPD has not seen wide implementation on floaters in harsh weather environments.

Several methods of dealing with surge and swab effects have been proposed earlier.



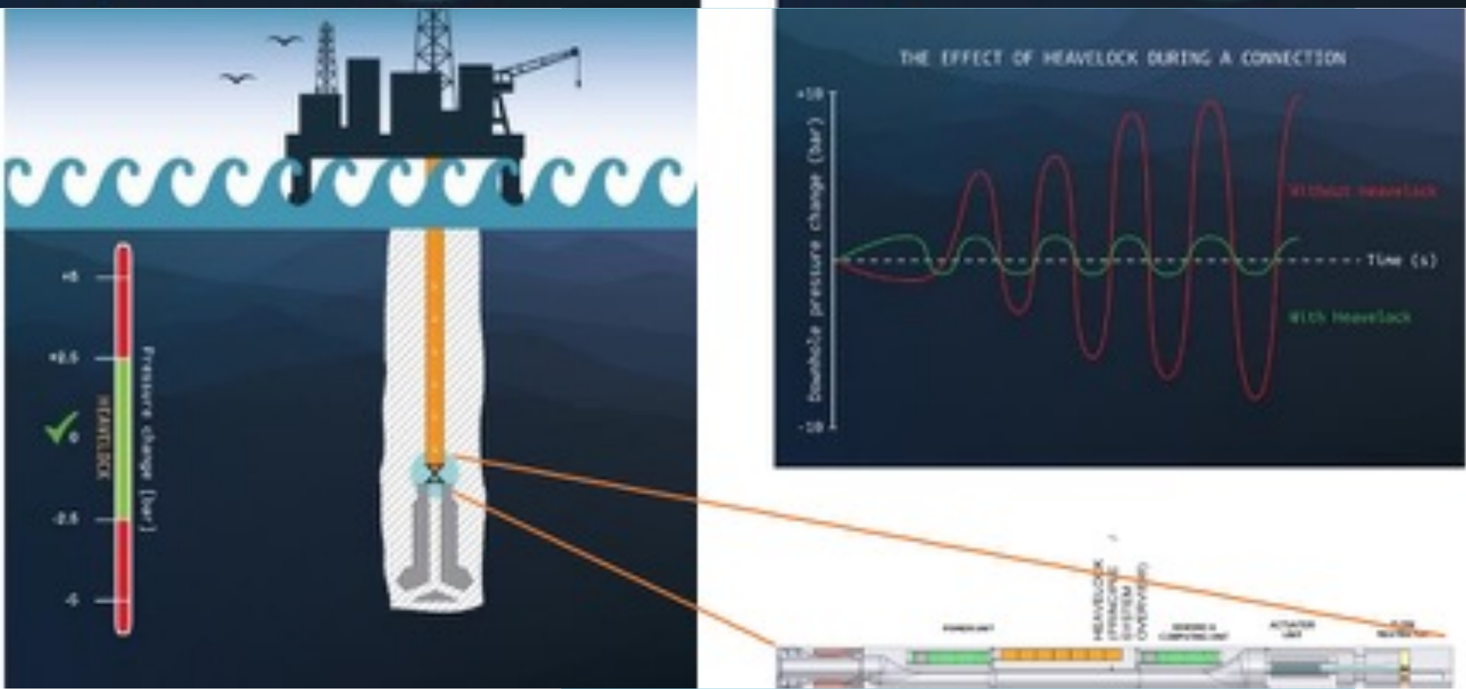


Figure 2 (top) Surge and swab phenomena cause downhole pressure oscillations that can damage a well or lead to a kick.

Figure 3 (bottom) HeaveLock™ downhole choke is able to stabilize the pressure under the drill bit during surge and swab through precise control of the mud flow.

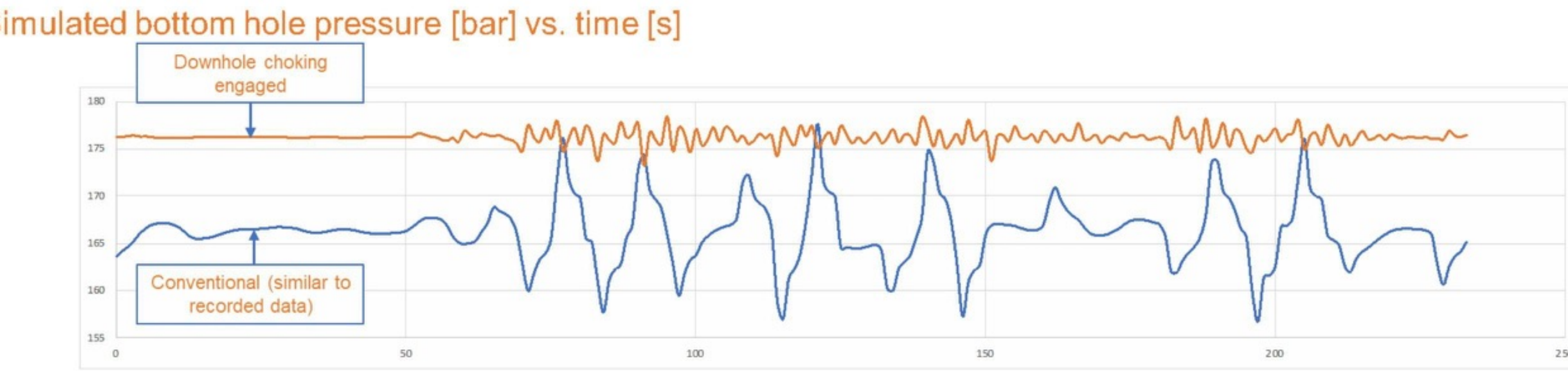


Figure 4 Simulated North Sea well - downhole pressure oscillations with (orange graph) and without (blue graph) HeaveLock™ engaged. Significant wave height is only 2 meters in this example.

Attenuation of downhole pressure oscillations using the topside choke has been proposed as a way of dealing with the heave-related issues (Pavlov et al., 2010). This idea has been investigated extensively with the conclusion that such a solution is theoretically possible (Landet et al., 2012, Albert et al. 2015, Mahdianfar et al. 2016). However, simulations of a realistic drilling operation reveal severe shortcomings of this approach, mainly linked to the combination of time delays being in the same order as wave periods, complicated multiphase flow in the annulus and highly stochastic character of ocean waves (Strecker et al., 2017; Strecker and Aamo, 2018). Other approaches have mainly been centered around compensation of the motion of the drill string during connections, rather than compensation of the downhole pressure. Drill string motion compensation is an approach associated with high mechanical complexity and high costs.

HeaveLock™ is a downhole choke valve, to be installed in the drill string as a part of the bottom hole assembly (Kvernland et al., 2018), see Figure 3. It senses movements of the drill string using an accelerometer and controls the flow of drill mud accordingly, thereby compensating for pressure variations under the drill bit. During swab, more mud is allowed to pass. During surge, the mud flow is restricted. Precise control of the mud

Figure 5 Pilot-scale HeaveLock™ prototype, ready to be tested at IRIS Ullrigg in Stavanger

flow keeps the downhole pressure steady. A Continuous Circulation System (CCS) is required to use HeaveLock™ and is available from several drilling equipment suppliers today.

The idea of downhole choking originates from NTNU and the company Heavelock AS was started in Trondheim in 2015. Using an in-house well simulator, it was shown that pressure oscillations could be reduced from ~20 barg down to less than 5 barg when HeaveLock™ was engaged, see Figure 4. A commonly utilized limit for downhole pressure oscillations in MPD is approximately +/- 2.5 barg. These numbers were later confirmed in laboratory scale experiments. First full scale prototype of the HeaveLock™ choke valve was tested in realistic flow and pressure conditions in mud loop of IRIS Ullrigg in Stavanger during the summer of 2018, see Figure 5".

Next phase in the HeaveLock™ development process is to design and construct a prototype for the first full-scale downhole test, which is planned to be carried out using an onshore test drill rig some time in 2020. Heavelock AS is pursuing partnerships with additional E&P companies as well as a drilling service company in order to succeed with the development. The ambitious goal of Heavelock AS is to contribute to higher utilization of automated and digitized drilling solutions and become an enabler for MPD operations from floating rigs and drillships, thus unlocking additional IOR potential on the Norwegian Continental Shelf and beyond.

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