

De Wijk Phase 2

Risk Analysis of wells older than 1976, considering reservoir pressures in De Wijk Phase 2.

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1. Dutch Management Summary

Dit rapport bevat een gedetailleerde technische risicoanalyse van de putten in De Wijk die voor 1976 geboord en/of verlaten zijn. In het De Wijk meet- & regelprotocol is een samenvatting opgenomen (EP201802203892).

In De Wijk zijn tot op heden 54 putten geboord, waarvan er 18 putten geboord en/of verlaten zijn vóór 1976. Deze 18 putten vallen daarmee binnen deze risicoanalyse. De stikstofinjectie zal alleen fysieke invloed hebben op putten die de ondiepe reservoirs van het De Wijk veld doorboren. Van de 18 putten die verlaten zijn vóór 1976 doorboren 15 putten deze ondiepe reservoirs.

De invloed van de stikstofinjectie op de drukontwikkeling in het gasveld is middels een dynamisch reservoirmodel onderzocht. Uit deze analyse is naar voren gekomen dat alleen bij de verlaten putten WYK-2, WYK-2A en WYK-3 de injectie kan leiden tot drukken die hoger zijn dan de huidige druk. Deze putten zijn allemaal geboord vanaf de vroegere WYK-2 locatie en volgens de wettelijke voorschriften (volledig en duurzaam) afgesloten van het reservoir. Vervolgens zijn deze putten onder het maaiveld verwijderd en is de WYK-2 locatie door NAM opgeruimd.

De isolatiedieptes en de gebruikte abandonnerings-methodieken voor deze putten zijn voor deze risicoanalyse opnieuw onderzocht. NAM concludeert dat deze putten bestand zijn tegen de verwachte effecten van de stikstofinjectie. Bij het verlaten van een put wordt het reservoir met cement geïsoleerd van het maaiveld. Van de putten WYK-2, WYK-2A en WYK-3 is het WYK-3 waar de isolatie het dichtst bij het maaiveld is uitgevoerd, deze put is daarmee de beperkende factor. Uit de huidige risicoanalyse volgt dat WYK-3 naar verwachting een reservoirdruk van 67,6 barg kan weerstaan. De WYK-2 en 2A putten zijn dieper geïsoleerd en zijn daardoor bestand tegen hogere reservoirdruk.

De operationele injectiedruk wordt met technische besturings- en meetsystemen op een veilige manier geregeld, zoals beschreven in het meet- en regelprotocol in hoofdstuk 3 (EP201802203892). Onder normale operationele omstandigheden wordt de druk boven aan de injectieputten automatisch gehouden op 66 barg. Uitwijkingen naar hogere injectiedruk zullen door de manier van opereren altijd van korte duur zijn. Berekeningen laten zien dat door drukverlies in de injectiepijp, tussen de injectiepijp en het reservoir en vervolgens drukdaling in het reservoirgesteente de reservoirdruk bij de WYK-3 put niet boven 67,6 barg kan uitkomen.

2. Introduction

The Minister of Economic Affairs has approved the *aanvraag Instemming Winningsplan De Wijk Fase 2 – (EP201609210335)* as submitted by NAM on the 30th of Sept 2016, including addendums, under a set of conditions outlined in the *Ontwerp instemmingsbesluit winningsplan voor De Wijk Fase 2*. All relevant documents can be found on: <http://www.nlog.nl/ter-inzage-legging-de-wijk-fase-ii>

One of these conditions outlined in Article 3, sub (e), is that NAM undertakes a risk analysis of wells drilled and/or abandoned before 1976, in relation to the maximum injection pressure. This document reports the findings of the requested risk analysis, and concludes that integrity of all wells drilled prior to 1976 will be maintained during the lifetime of the project. The analysis shows that the pressure at the location of the WYK-3 well will not exceed the allowed 67.6 barg for prolonged periods of time. Chapter 3 of the *Meet & Regel Protocol* (EP201802203892) details the operational procedures and automatic technical safety systems NAM has implemented to safeguard the limits of the injection pressure.

3. Scope of analysis.

To date, 54 wellbores have been drilled in the De Wijk field. 18 wellbores (including side-tracks) were drilled and/or abandoned prior to 1976. An overview can be found in Table 1.

Table 1: Overview of wellbores drilled prior to 1976 in the De Wijk Field

Well	Spud Date	Abandoned	Well Status	Penetrates the De Wijk Phase 2 Reservoir?
WYK-1	1949	1949	Abandoned	Yes
WYK-4	1951	1978	Abandoned	No
WYK-4A	1951		Producing	No
WYK-2	1951	1975	Abandoned	Yes
WYK-2A	1951	2004	Abandoned	Yes
WYK-3	1951	1994	Abandoned	Yes
WYK-5	1951	1973	Abandoned	Yes
WYK-5A	1951	1987	Abandoned	Yes
WYK-5B	1951	2006	Abandoned	Yes
WYK-6	1952		Producing	Yes
WYK-7	1953	1954	Abandoned	No
WYK-8	1960	1975	Abandoned	Yes
WYK-12	1960	1975	Abandoned	Yes
WYK-10	1960	1975	Abandoned	Yes
WYK-11	1960		Producing	Yes
WYK-9	1960	1975	Abandoned	Yes
WYK-13	1973		Suspended	Yes
WYK-14	1974	1994	Abandoned	Yes

Figure 1 shows the De Wijk Phase 2 Top Reservoir (*Basal Dongen Tuffite*) map. Underlying Triassic reservoirs (~1500m TVDSS) were the main target for most wells in the field prior to 2016. These wells were drilled near vertically through the shallow reservoirs that will be developed during Phase 2. Purple squares indicate their location on the map.

Figure 1 and Table 1 show that:

- Of the 18 wellbores drilled prior to 1976, 3 are drilled outside of the De Wijk Phase 2 field area. The remaining 15 penetrate the Phase 2 reservoir.
- Of these 15 wellbores 12 are located at the flanks of the field, while 3 are located at the crest (WYK-2, 2A and 3).

Note also their location in relation to Phase 2 injection wells (yellow), production wells (red) and observation wells (black).

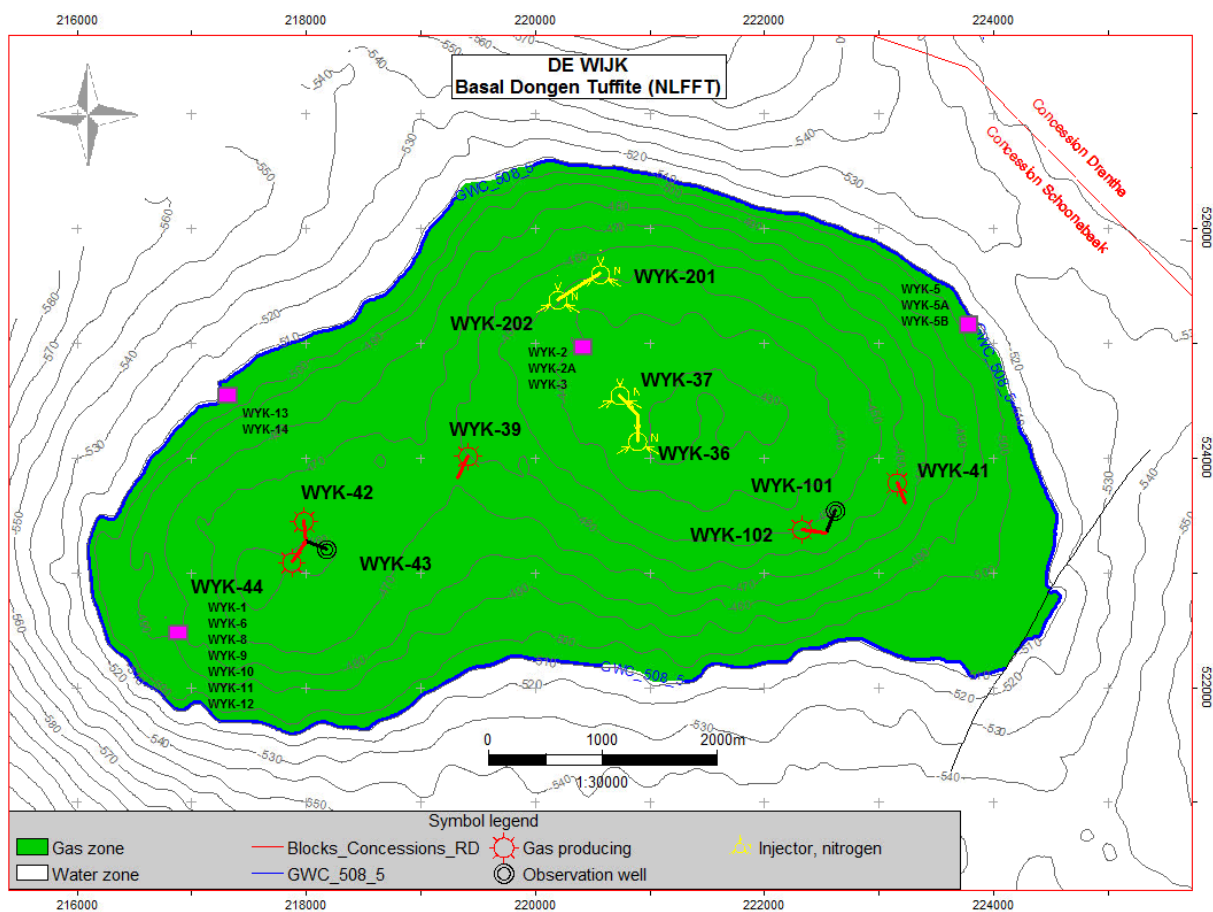


Figure 1: Map of Top Reservoir for Phase 2 (Dongen Tuffite). Purple squares indicate the location of wells drilled before 1976.

4. Change in reservoir pressure due to N₂ injection

Reservoir pressures in De Wijk Phase 2 will not be equal everywhere in the field. N₂ injection will increase reservoir pressure nearby the injection wells (crestal area of the field) and gas production will cause reduced pressure near the production wells. As a result, most wells within the scope of this

analysis will experience decreasing, rather than increasing pressures – due to their position on the very flanks and near producers (see Figure 1).

Wells on locations De Wijk-5, De Wijk-6 and De Wijk-13 will experience a minor pressure decrease, while wells on the De Wijk-2 location (WYK-2, WYK-2A and WYK-3) will experience an increase in reservoir pressures. The reservoir pressure in the reservoirs for De Wijk Phase 2 was 61 bara prior to an initial phase of production in the 1960's (*Winningsplan EP201609210335*).

By the end of field life, the pressure will equilibrate back to current reservoir pressure as the production philosophy is to keep the Voidage Replacement Ratio (VRR) close to 1.0 (*Meet & Regel protocol EP201802203892*).

For the wellbores where pressure is expected to further decrease there are no additional risks from the De Wijk Phase 2 development.

Wells that are expected to see an increase in pressure due to N₂ injection (WYK-2, WYK-2A and WYK-3) have been studied in more detail. These wellbores have all been abandoned. All wells have been correctly abandoned: they successfully passed the observation period, before being cut below the surface to return the location to original condition (*Winningsplan EP201609210335*).

The side-tracked wellbore WYK-2A kicks off through a milled window at a depth of 1061-1081m TVNAP, which is well below the Phase 2 reservoir depth. The well has been correctly abandoned and therefore, no further risks have been identified for this side track.

Considering the wellbores that will experience increase in reservoir pressure due to N₂ injection NAM has further investigated the abandoned wells WYK-2 and WYK-3.

5. WYK-2 and WYK-3 well status

The WYK-2 well penetrates the Phase 2 reservoir at a depth of 442m TVDNAP. Prior to abandonment, annular pressures had been observed in the 9 5/8" x 7" annulus, likely originating from the Dongen Tuffite reservoir. During abandonment, the seal to this reservoir was reinstated by milling and cementing a window in the 7" production casing over the Ieper Clay, from a depth of 417m to 396m TVDNAP (Cement plug #3 in figure 2). The success of cement plug #3 was confirmed during the post-abandonment observation period. For the purpose of this risk analysis, to be on the safe side, the top of the cement plug was taken as the effective depth of the seal (396m TVDNAP). It is expected that the actual depth of the seal is deeper. The attempt to seal-off the B-annulus by perforating and squeezing cement (plug #2) cannot be indisputably tested. The depth of this plug has not been taken as the depth of the effective seal.

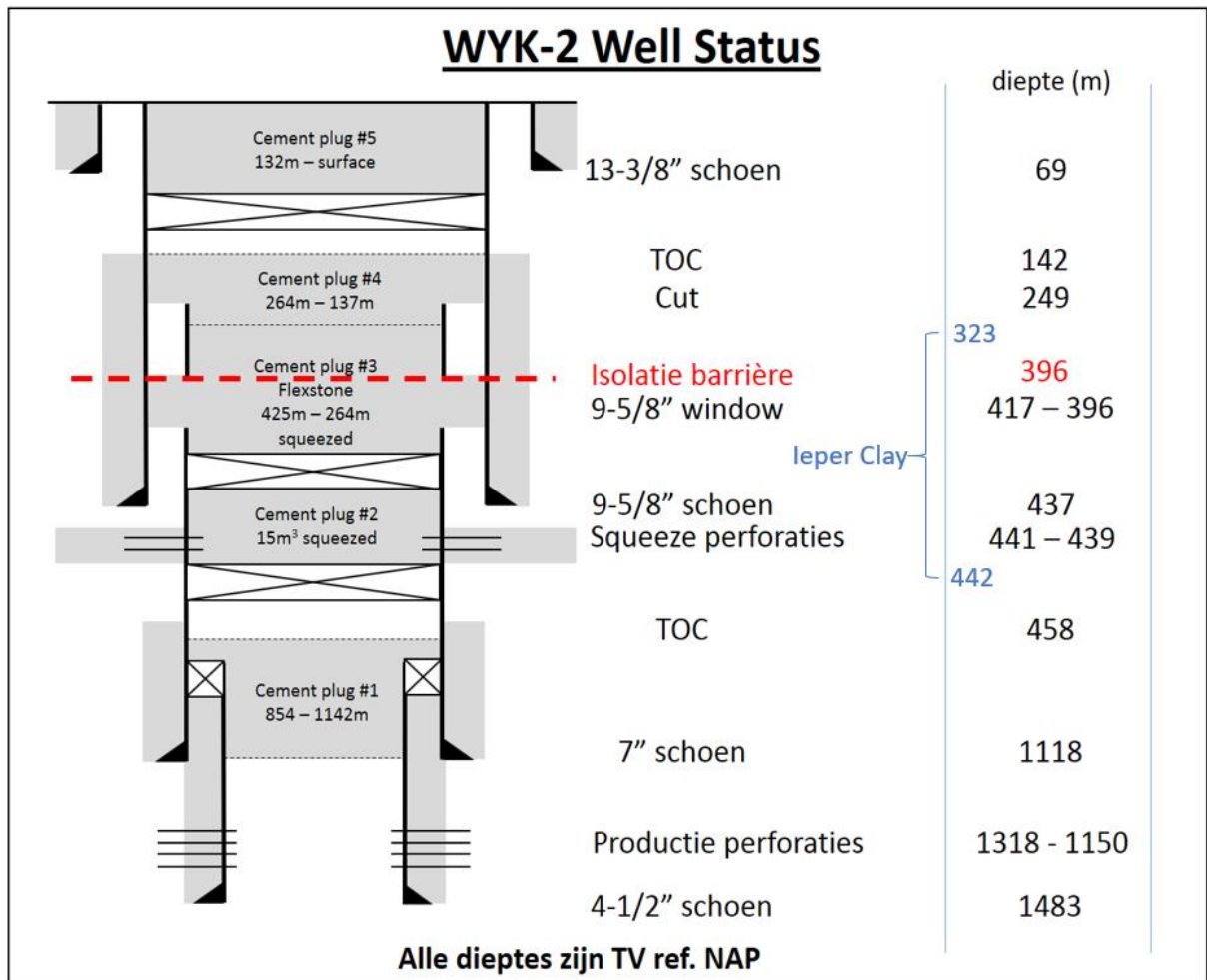


Figure 2: WYK-2 well status diagram including proven barrier.

The WYK-3 well is located close to WYK-2 and penetrates the Phase 2 reservoir at the same depth of 442m TVDNAP. During abandonment, the seal to this reservoir was reinstated by perforating and squeezing cement through the 7" production casing over the leper Clay, from a depth of 384m to 382m TVDNAP (Cement plug #2 in figure 3). Prior to this perforation and cement-squeeze operation, annular pressures had been observed in the 9 5/8"x 7" annulus, likely originating from the Dongen Tuffite reservoir. The success of cement plug #2 was confirmed by the disappearance of these annular pressures as confirmed during the post-abandonment observation period. As for WYK-3, for the purpose of this risk analysis, the top of the cement plug was conservatively taken as the effective depth of the seal (382m TVDNAP).

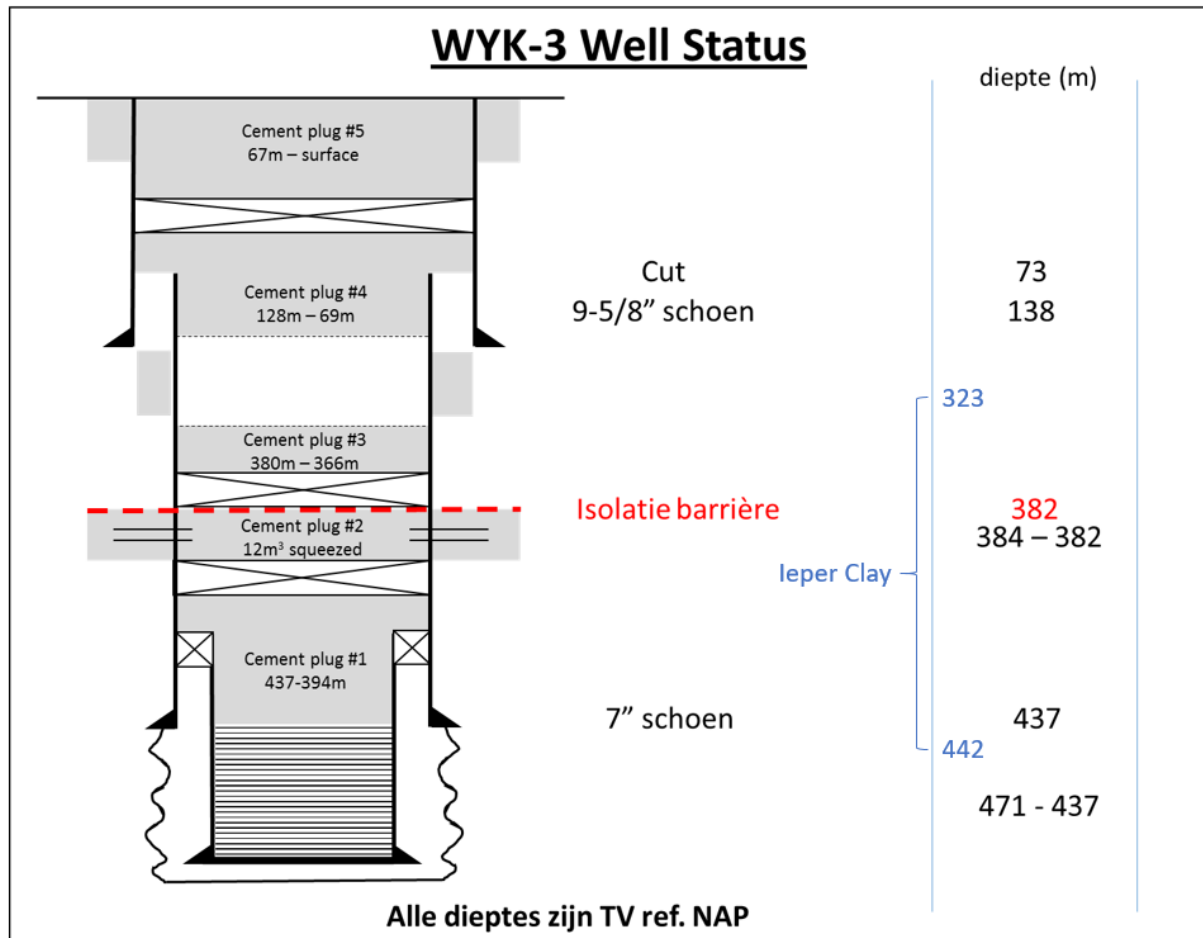


Figure 3: Well status diagram of WYK-3, including proven barrier

The maximum pressure that the seals can hold, will be determined by the formation strength of the leper claystone at the effective depth of the seal. This is conservatively taken as the top of the Cement plug #3 in WYK-2, and Cement plug #2 in WYK-3. The Cement plugs themselves are proven to be gas tight, and the cement type “Flexstone blend” used in WYK-2 & 3 has a minimum compressive strength of 2250psi (155bar) at the given conditions.

6. Assessment of Formation strength.

NAM conducted an Extended Leak-Off test in the WYK-202 well to further assess the strength of the leper Claystone seal (XLOT, 2016). The report of this test was submitted as an addendum to the winnings plan. The test confirmed a minimum horizontal stress of 1.77 bar/10m or 1.8 sg (reference: Ground Level). This minimum horizontal stress (Lower bound) is a conservative approach for fracture propagation, as it assumes no intrinsic rock strength, nor internal friction.

The composition and properties of the Phase 2 reservoir gas are well known based on historic production samples and confirm a gas gradient of 0.035bar/10m.

Figure 4 shows the Lower bound fracture pressure for the leper claystone, plotted against depth, using the XLOT result gradient. The Top and Base of the leper are the same for both WYK-2 and WYK-3 wellbores, and are indicated with black horizontal lines. Using the gas gradient from top reservoir to the effective depth of the seal (i.e. 382m TVDNAP, the top of the cement plug in WYK-3 as explained before), it follows that the leper claystone in WYK-3 is expected to be able to hold a reservoir pressure of at least 67.6 barg at a depth of 442m TVDNAP.

De WIJK-3 & WIJK-2

Pressure Depth plot

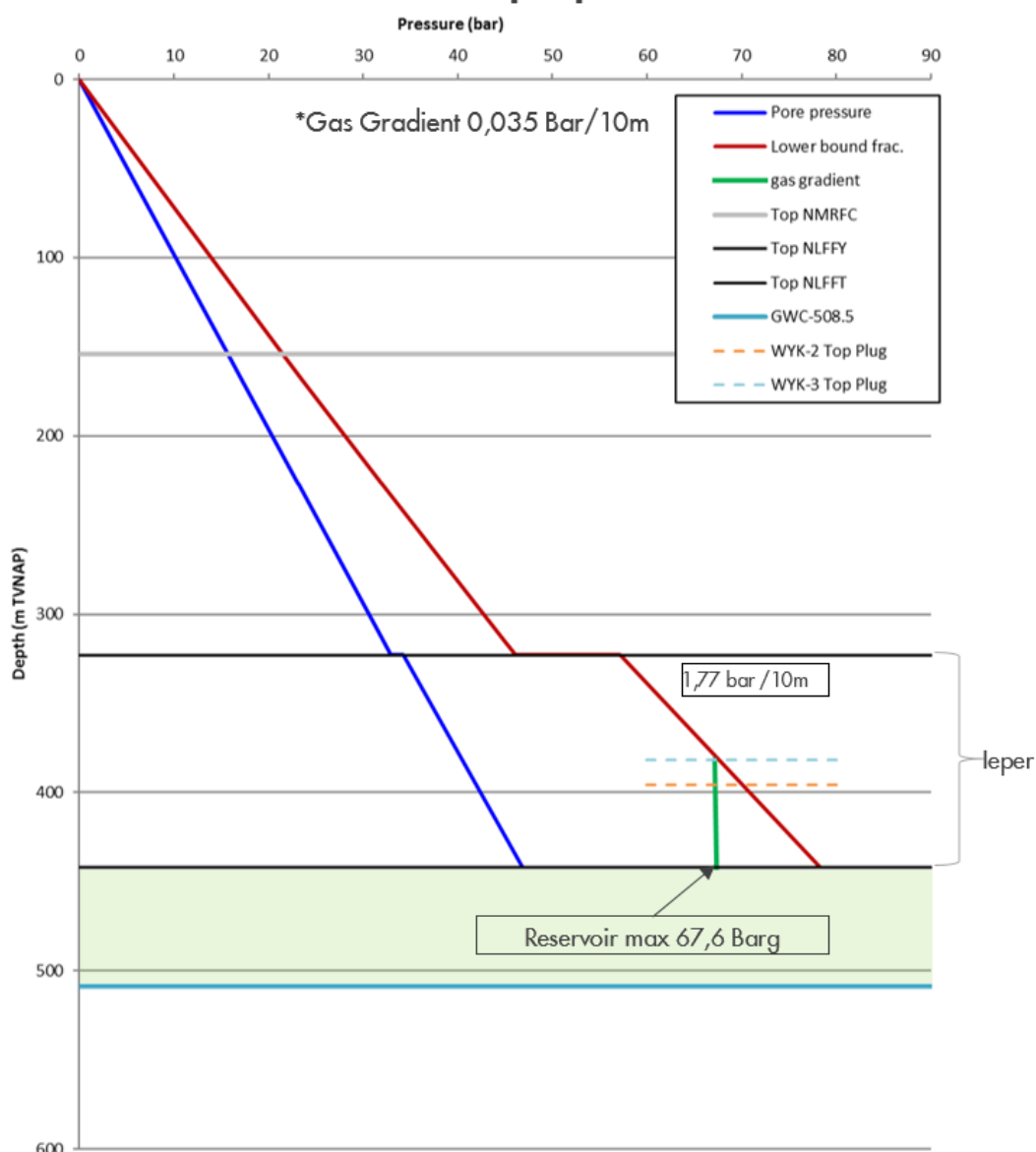


Figure 4: Pressure depth plot for WYK-2 & WYK-3

Note that the WYK-2 well - which has the same top and base leper, gas gradient and fracture gradient – will be able to hold a higher reservoir pressure, as the plug is set deeper (396m TVDNAP).

Chapter 3 in the Meet & Regel Protocol De Wijk Fase 2 (EP201802203892) details the operational procedures, the technical safeguards and the regulatory controls in place to prevent exceeding this pressure at the WYK-3 location.

7. Conclusions

The integrity of the 18 wellbores drilled and/or abandoned in the De Wijk field prior to 1976, has been analysed against the forecasted reservoir pressures as per *Winningsplan De Wijk Fase 2 – (EP201609210335)*. Of these 18 wells, 15 penetrate the Wijk Phase 2 reservoir.

Only the WYK-2 and WYK-3 wellbores will be exposed to increased reservoir pressures due to N₂ injection. A conservative approach has been used to determine the effective depth of the reservoir

seal as reinstated during abandonment. Using a gas gradient to the top of the cement plug and the leper fracture gradient derived from XLOT (2016), a maximum reservoir pressure was calculated. This results in a limit to the reservoir pressure at the WYK-3 location of 67.6 barg - at a reservoir depth of 442m TVDNAP. The WYK-2 and -2A wellbores have been abandoned with deeper plugs, and can therefore withstand higher pressures.

Chapter 3 in the *Meet & Regel Protocol De Wijk Fase 2 (EP201802203892)* details the operational procedures, the technical safeguards and controls in place that will ensure reservoir pressures are not exceeding 67.6 barg at the WYK-3 location.

8. Reference list

1. Aanvraag Instemming Winningsplan De Wijk Fase 2 – (EP201609210335)
2. Ontwerp instemmingsbesluit winningsplan voor De Wijk Fase 2
3. De Wijk leper Fracture Pressure Review 2016 – For External publication (EP201701215156)

Above reference documents can be retraced via NLOG: <http://www.nlog.nl/ter-inzage-legging-de-wijk-fase-ii>

- 4- Meet & Regel Protocol De Wijk Fase 2 (EP201802203892)