Interference in NLW-GT-01 of Test NLW-GT-02

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Summary

- During the production test of well NLW-GT-02, the interference with the first well NLW-GT-01 was measured by instalment of several Fugro meters in the top of the static water column in this well.
- The deepest gauge registered the pressure in the top of the water column from 28/5 to 8/6 2018, showing a clear interference signal.
- Using a low Ct of 3.6E-6 psi-1, the permeability was 1550 mD and the channel width 1220 m, model-B. Also with extra inflow behind NLW-GT-01 or leakage through a side.
- The high anisotropy derived from this test and the individual well tests is most likely caused by the presence of several small faults parallel with the main bordering fault running south-east to north-west, Fig-01. The permeability at a right angle to these faults is 410 mD (model-B), explaining the radial (average) permeability of 800 mD and the distances to the flow-barriers observed during the individual well tests. A similar anisotropy was observed in a nearby geothermal doublet in the same Delft reservoir.
- The reservoir pressure response during interference testing shows a clear North Sea tidal influence, which did not influence the analysis. The air pressure during the test was rather stable and was thus not subtracted.

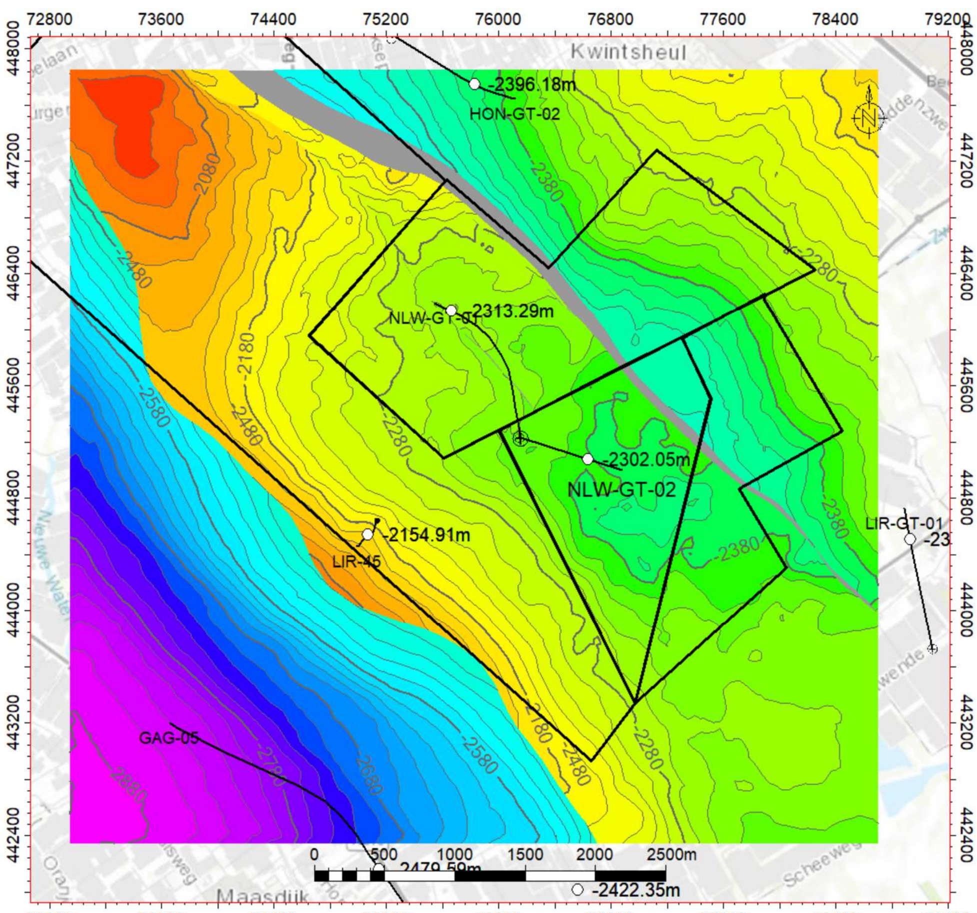

Figure 1 - Top Structure Map Delft sandstone (by PanTerra); Both Well NLW-GT-01 and well NLW-GT-02 are shown. Major faults that define this block are represented by the grey polygon in the NE and the abrupt colour change in the SW. Towards the NW the major faults connect, forming a boundary of this fault block, the Delft Reservoir becomes thinner towards the SE, which might be interpreted as a barrier/baffle in the interference test.

Contents

1 Introduction

Well NLW-GT-01 was tested from 28/02/18 with a multi-rate test for 9.5 hours with rates varying between 215 and 428 m3/hr, followed by a build-up period of 21 hours. The test analysis showed a permeability of 700 mD of the 83 m net sand of the Delft and Alblasserdam sandstones. Two flow barriers were observed, not necessarily sealing, at distances of 250 and 700 m. The position of the second flow barrier with respect to the nearest one is uncertain.

The test of the second well, NLW-GT-02, was conducted from 31/05/18 14:55 with a multi-rate test for 9.5 hours with rates varying between 223 and 450 m3/hr, shut-in 01/06/18 00:23:20. The test results showed a permeability of 800 mD for the 57 m net sand of the Delft sandstone. A single flow barrier was observed at 370 m, possibly not fully sealing.

The Fugro meters, installed in NLW-GT-01, show a clear interference signal some 2 hours after the start of the test of NLW-GT-02, with a maximum pressure drop of 0.53 bar.
In spite of the falling liquid level by the expanding gascap, exposing all 3 gauges subsequently to gas, the deepest gauge remained long enough in the water column for a successful analysis.

2 Well Positions

The well distance at mid reservoir (2380 mtv) is presented in the table below. But in view of the deviation of NLW-GT-01 and -02, these distances may be varied about 50 m depending at which depth the reservoir communication is maximal.

East m	North m	Well	Distance to NLW-GT-01 in m	Dist in ft
75639	446150	NLW-GT -01	-	-
76729	445055	NLW-GT -02	1545	5070

3 Reservoir and Pressure / Rate Data

The net sand thickness was set to the average between NLW-GT-01 and NLW-GT-02 at 72 m (236’). The porosity in both wells has been assumed to be 18.7%, which has been used during the analysis.
The same total compressibility of 6.E-6 psi-1, as used in the analysis of both individual well tests, has initially been applied. The hot water viscosity from both NLW wells of 0.433 cP was used.
In view of the unexpected high observed permeability, a lower Ct of 3.6E-6 psi-1, as used in a nearby Delft reservoir doublet, has been tried as well, resulting in a reduction of the permeability from 2770 mD to 1550 mD.

Fig-1 presents the data from all 3 gauges, g-1 at 146.85, g-2 at 136.85 and g-3 at 126.85 m-NAP. The reported pressures in m-water were multiplied with 0.098064 to obtain the pressure in bar.
In order to correct for the difference between the SG of the hot water, entering or leaving the well at reservoir depth and the SG of the cold water above the meter, these pressures were multiplied with the SG ratio of 0.958 between hot and cold water, using the pressure difference between g-1 and g-2 with a gradient of 0.10751 bar/m versus the hot water gradient of 0.1030 bar/m established during the NLW-GT -01 test.
Note that the pressures of the shallower gauges have been increased by 1 and 2 bar for plotting purposes.

It is evident that during day 34 the shallower gauge g-2 entered a lighter fluid floating on top of the brine, as the increasing gas pressure pushed the water level downwards. On day 36 this gauge was clearly hanging in the expanding gas cap. This increasing wellhead pressure is probably caused by gas coming out of solution, after the installation of the gauges. Just before installation the wellhead pressure was about 20 bar, build-up after the test of NLW-GT -01. The sudden pressure release caused more gas to come out of solution.
The deepest gauge shows a normal pressure trend up to day 38. The top gauge entered the lighter fluid already during day 32.

Fig-2 also presents the flowrate data in m^3/hr in purple. For the analysis these rate data have been blocked-off in 4 flow periods. Using only one average rate during the same production time did hardly change the analysis ensuring that the reduction to 4 individual rate periods did not influence the analysis.

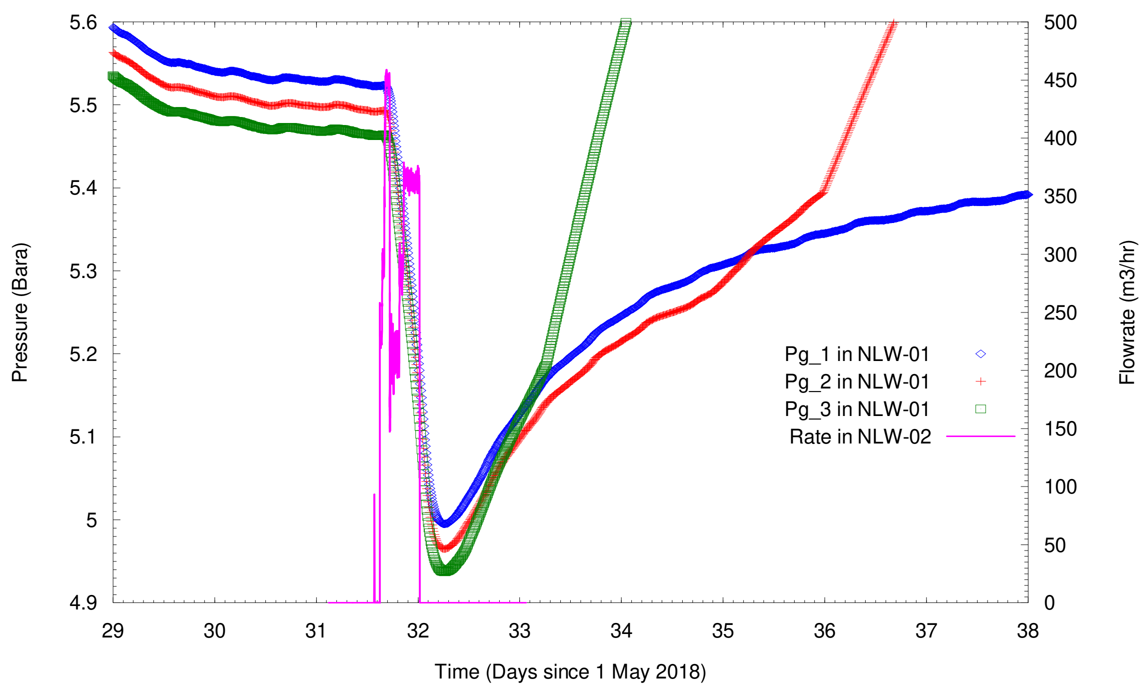

Figure-02: Pressures of three gauges in NLW-01 plus production rates in NLW-02

4 Model Matching

The used reservoir model is a rectangular box with sealing boundaries, see Figure-3. In this box, the two wells were set at a distance of 1545 m. The closed end of this finite channel was initially estimated to be at least 20 km north-west of NLW-GT-01. The total length and width of this channel was obtained from the model match.

Using the high Ct of 6E-6 psi-1, a perfect match (Model-A red line) was obtained for a finite channel of 730 m width and 8930 m long with a permeability, in the direction of the channel, of 2770 mD, Figure-3.
The producing well, NLW-GT -02, is 4570 m from a sealing end of this channel.

The channel end behind NLW-GT-01 however, is best matched using a Constant-Pressure (CP) boundary, at a distance of 2810 m from NLW-GT-01, to allow extra inflow of aquifer water into this narrow channel. This may be caused by a widening of the channel and/or leakage through one or both of the channel sides.

Using the lower Ct of 3.6E-6 psi-1 as used in a nearby doublet, a similar good match was obtained (green line, model-B) for a permeability of only 1550 mD. Also in this model, the total length of the channel has been minimised by reducing the distance of the sealing end from NLW-GT-02 to 3050 m. The resulting channel width for this case is 1220 m with a total length of 6700 m, but again with a CP boundary behind NLW-GT -01.

In Figure-5, the model response is subtracted from the observed pressures. This pressure difference (green points) is then compared with the air pressure variation around 1.014 bar (red points). The large sinus-shape in the gauge pressures is clearly the tidal influence from the North Sea tide as demonstrated by the tide in Maassluis (divided by 30, blue points).
The reported air pressure in Rotterdam is apparently also weakly influenced by the tide (movement of instrument?). As the air pressure variation has to be divided by 3 before subtraction, it will hardly influence the model match and has therefore not been taken into account.

The tidal noise did also not hinder the analysis. As this is mainly a symmetrical "noise" it has also been ignored.

Resulting matched model properties

Model	K, mD	X, m	Y, m	Xp, m	Yp, m	Xw, m	Yw, m	WIP, MMm3 *)
A	2770	8930	730	4570	300	6120	420	66
B	1550	6730	1220	3050	300	4590	700	83

*) Minimum water in place (WIP), as boundary at X is a source (CP).

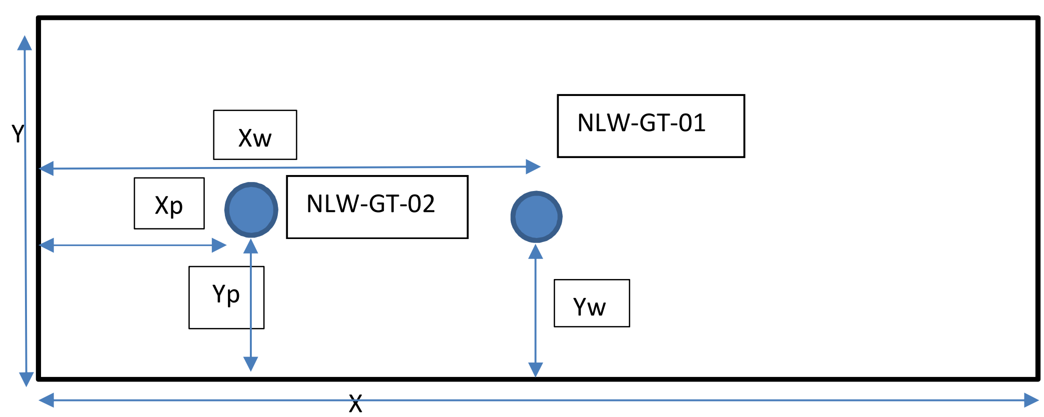

Figure 3 Reservoir Model Schematic used in the calculations

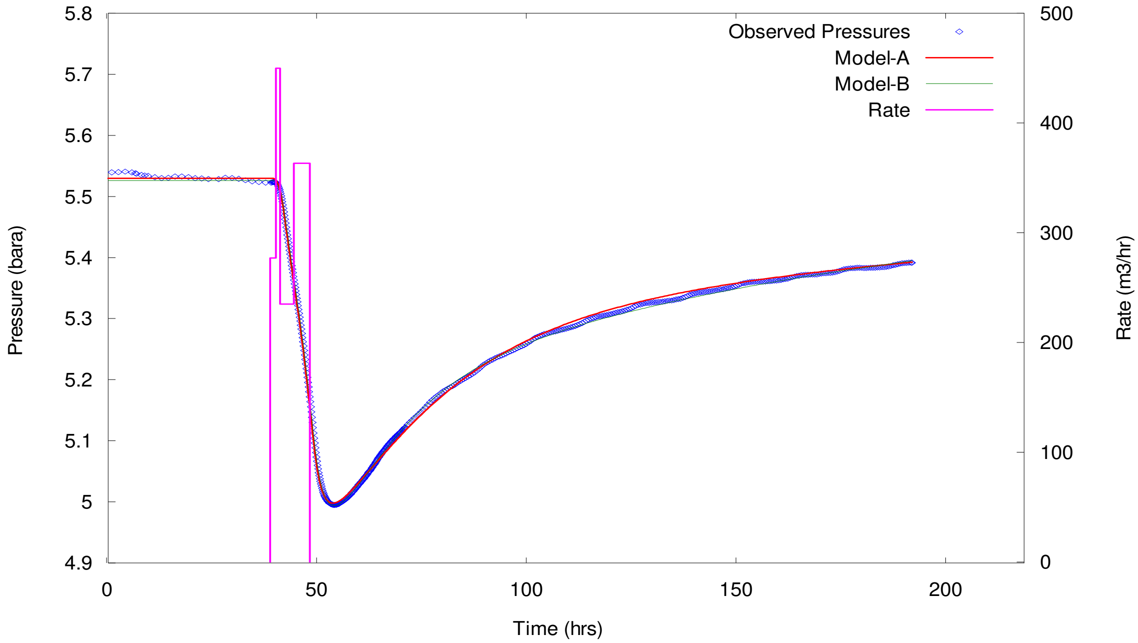

Figure-04: Model match of observed interference signal of g-1.

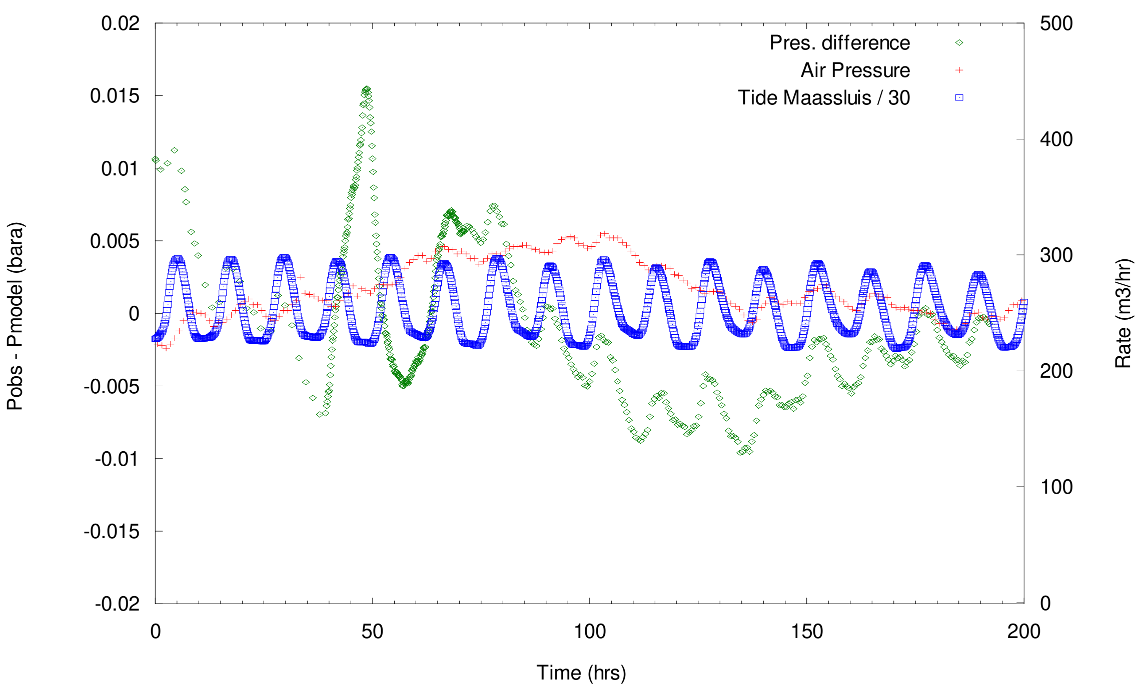

Figure-05: Deviations from model response compared with Air and Tide Pressure.

5 Conclusions and Recommendation

The good model matches show an exellent communication between both wells.
The model with a relatively high Ct of 6E-6 psi-1 results in an unexpectedly high permeability and a rather narrow channel width.
Use of a lower Ct value of 3.6 E-6 psi-1, derived earlier for a neighbouring doublet in the Delft reservoir, resulted is a much less extreme permeability anisotropy and a more likely channel width. Model-B is therefore considered to represent the most likely reservoir situation. The anisotropy in this model is kx of 1550 md and ky of 410 mD, resulting in a radial permeability of 800 mD.
This permeability anisotropy also explains the rather low distances to flow barriers, calculated with the radial permeability of 700 – 800 mD during the individual well tests for both wells.

The significant anisotropy, probably caused by the presence of several parallel sub-seismic faults, has been observed in nearly all warm-water doublets, that have been tested so far.

During the interference test no communication with nearby active warm-water wells has been detected.

In view of the failure of two of the three gauges after a short correct measurement, it is recommended to blow-off the gas from the annulus/tubing in the first well at regular intervals during the drilling of the second well, ensuring a stable water column during the interference testing.