Evaluation of Well Interference and Injection Performance from Analysis of Time-lapse Pressure Transients

Introduction

Understanding of hydraulic communication between wells within a reservoir is crucial for reservoir characterization and management as well as decision making on future production strategy and drilling of new wells. The main technologies for revealing well communication today are inter-well tracers and different forms of interference testing and analysis of well data such as pressure, rate and temperature (Bourdet, 2002), (Houze, Viturat, & Fjaere, 2015) accompanied by different complexity and scale reservoir simulations for the data interpretation and further prediction of reservoir behavior. Wide deployment of Permanent Downhole Gauges (PDG) has provided perfect basis for application of well testing methods (Bourdet, 2002), (Houze, Viturat, & Fjaere, 2015) to pressure monitoring data, where time-lapse Pressure Transient Analysis (PTA) becomes one of the main tools in gaining knowledge about well and reservoir behavior and performance in dynamics (Shchipanov, Berenblyum, & Kollbotn, 2014). In this paper, applications of time-lapse PTA, integrating well interference analysis and different complexity simulations are discussed, based on data interpretation for a fault-block reservoir developed with long horizontal wells.

Field case

The reservoir in focus is a fault-block without internal faults (Figure 1) limited by sealing faults from all sides making well interference crucial for drainage strategy and sweep efficiency. Three horizontal producers in the South part of the field have been analyzed using pressure transient data from PDG and flow rates. 2D analytical and 3D numerical models were employed to interpret the pressure transients with following verification via history matching. The field shape was approximated by a rectangular box in the analytical simulations, while numerical model captured the field geometry (Figure 1).

Figure 1 Top view of the field with 3 horizontal producers (wells A, B, C) and slanted injector (well D) (left), ‘box’ approximation in 2D analytical model (center) and 3D numerical model (right).

Figure 2 Reservoir non-linear cross-section with the producers (wells A-C) and the injector (well D), top view shown in Figure 1 (left).
Reservoir cross section (Figure 2) illustrates three horizontal wells in the first (upper, main) layer being produced, where the well A partially penetrates also the second layer. It is assumed no connectivity with the underlaying flow units (third layer and below) due to sealing layer between second and third layers. The production wells are supported by one slanted injector (well D), which started to inject into the upper layer almost a year after the start of the production. It should be noted that the main upper layer divided into two sub-layers for our study purpose (dash-line in Figure 2), where the upper sub-layer has much higher permeability than the lower one. Well B penetrates only the upper sub-layer, while wells A, C and D - both sub-layers.

The well A started production at the same time as well C and four months before the well B (Figure 3). The baseline 2-week well shut-in survey with measuring Pressure Build-ups (PBU) was planned and carried out for all the producers after five months of production (survey 1). All wells were shut-in during this baseline survey. Subsequent extensive interference testing was then conducted for each pair of the wells (e.g. to see response in observation well to production in active well, survey 2) to assess lateral connectivity of the field and then impact of the water injection.

![Figure 3 Production history of wells A-C: wells A and C started production form start-up and well B - four months later.](image)

**Time-lapse Pressure Transient Analysis**

Time-lapse PTA of the shut-in responses including analysis of the interference surveys allowed to evaluate lateral reservoir connectivity and to address the changes in the well productivity over time and effect of injection on the individual producers.

Summarizing results of the diagnostics (Figure 4), the following observations and findings may be highlighted:

- It is difficult to detect an early radial flow regime in any of the pressure transients, likely due to complicated well trajectory (Figure 2).
- No visible effect on transient responses from going 10% below bubble point pressure is observed (e.g. well B, comparing surveys 1, 2 and 3, 4).
- Pressure derivatives and overall historical pressure decline both argue that the external reservoir boundaries are sealing (a ‘closed chamber’ fault-block).
- No late pseudo-radial flow regime is developed in the transient responses due to interference with nearby wells and field boundaries preventing possible developing of the regime.
- Strong communication between all the wells was revealed from the interference testing (e.g. survey 2 for wells B and C) and no flow barriers were found in between of the wells.
- Injection improves performance of the producers (downward shift of the derivatives for wells C and A), which may be related to increased reservoir flow capacity (Figure 2).
Figure 4 Time-lapse PTA of the production well responses (pressure build-ups) with diagnostics based on comparison of the pressure transients and the pressure derivatives.

The observations and findings from the time-lapse PTA diagnostics have been verified employing both analytical and numerical simulations (Figure 1). The analytical simulations for well A have shown (Figure 5) that effective well length has moderate effect on well performance and pressure decline. Simulations for well B (Figure 5) have shown that the late-time derivative behavior may be reproduced only with integration of the nearby wells into the analysis dictated by strong interference response observed (the late-time derivative decrease). The interference proved that there is hydraulic communication between the producers, which was reproduced in the analytical simulations.

Figure 5 PTA (PBU1) and matching of history of the wells A (left) and B (right) with 2D analytical model.

The analysis also showed that flow capacity area around well B seems to be lower than for the wells A and C, as illustrated with the mismatch for well B in Figure 5 obtained with the flow capacity estimated for wells A, C. Introducing of water injection into the analytical model has affected matching of the overall pressure depletion reflecting pressure support (Figure 5, Well B). This has minor effect on the derivative match and did not help to match the observed downward shift of the derivative (Figure 4, wells C, A). The hypothesis of increasing reservoir flow capacity due to injection as the reason for the derivative shift was further tested with 3D numerical model.

An increase of the effective thickness contributing to the flow capacity (Figure 2) of the reservoir after the injection start was studied with multi-layer numerical model. Introducing two sub-layers in the main upper layer in the model (Figure 2) based on permeability contrast inside the layer helped to match the observed derivative shift (Figure 4). The best match was achieved with the transmissibility value of 0.1 between the sub-layers (Figure 6). These results argued that the injection in both sub-layers in well D may activate flow in the low-permeability lower sub-layer and its inclusion into production via the wells A and C connected to this sub-layer.
Conclusions

The study has highlighted the importance and value of designing and conducting of well interference surveys, which may be aligned with regular field shut-ins, but should specify well shut-in schedules:

- It helps to understand reservoir / well connectivity and performance over time in cost efficient way.
- Base-line survey is important for time-lapse PTA for a green field with long horizontal wells.

The following conclusions may be drawn based on the time-lapse PTA integrating interference analysis accompanied by history matching for the field in focus:

- The faults limiting the block are sealing and no flow barriers between the wells were found.
- Strong communication between the producers was revealed with the well drainage areas evaluated.
- Significant pressure depletion may have an impact on analysis of communication with newly drilled wells: depleted pressure area may have similar to active production well signature in transient responses of observation well, as it was shown by the analysis of well B.
- Introducing injection after the initial production phase caused improvement of production performance, which seems to be associated with added connected volumes within the same production zone and activation of low permeability layers.

Combining different complexity models improves efficiency of interpretation:

- 2D analytical simulation was a good starting point for the analysis of the fault-block reservoir with long horizontal wells, answering many questions and accelerating the interpretation procedure.
- Assembling and matching of 3D numerical models enabling accurate description of reservoir and wells was facilitated significantly by the results from the analytical interpretations.

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References