Use of DST for Effective Dynamic Appraisal: Case Studies

In the west Africa deep offshore region, most turbiditic-series reservoirs are structural traps with a stratigraphic component and severe faulting. Evaluation of connectivity and characterization of the reservoir heterogeneities before development decisions are the main challenges. Two extended drillstem tests (DSTs) acquired at a relatively early stage of the appraisal had a significant effect on the development projects.

Case Study 1

Well A was the third appraisal well of a Nigerian deepwater field. The well was the first in the southern fault block. Hydrocarbon presence had been proved in the central and northern compartments, but the southern compartment was separated from the central compartment by an east/west fault having significant throw.

Formation-testing-log (FTL) measurements confirmed the presence of oil in the reservoir sands. Preliminary pressure/volume/temperature (PVT) analyses carried out on the FTL samples indicated a fluid very close to saturation pressure, while permeability estimates from FTL mobility and magnetic-resonance (MR) -log data indicated permeability ranging from 1 to 3 darcies. Therefore, it was decided to run a DST on the reservoir interval with perforations across the entire sand portion of the reservoir.

Test Design. Well-test-design software was used to define an optimal test sequence. The major problem encountered in these deep offshore tests was programming a buildup test longer than 30 hours. Both gauge resolution and tidal effect strongly influence the late-time derivative, and even after deconvolution of tidal effect, it may not be possible to obtain a denoised signal because of high permeability of the unconsolidated sands in turbiditic channels. The other constraint was that bubblepoint pressure was very close to initial pressure. Thus, to avoid liberating gas in the reservoir, high flow rates could not be achieved.

The design required two buildup tests to account for transient depletion between the two buildup tests. Different models do not generate the same transient depletion: a channel model generates more transient depletion than a single-fault model. Therefore, the well-test analyst can diagnose events that are beyond the buildup derivative. The cumulative oil produced during the drawdown between the two buildup tests was computed to generate a 50-kPa depletion for a connected reservoir with 8.7×10^6 m^3 of stock-tank oil originally in place (STOOIP). A main objective was to characterize the seismic attenuation on the east side of the well.

Data Overview. Because of problems during cleanup and a high skin value during the first buildup, BU1, another flow period and a second buildup, BU2, were performed. During the second flow period, with a large pressure drawdown, the derivative signature was perturbed by tidal effects after 10 hours' shut-in. The tidal effect was removed, and the buildup derivatives of BU2 and the final buildup, BU3, were compared after tide deconvolution. They were practically superposed. Therefore, BU2 and BU3 are selected for analysis because of their greater durations.

Pressure-Transient Analysis. The derivative of the most obvious model indicated a single no-flow-boundary model. This boundary was in line with the seismic attenuation seen on attribute maps. In this case, the seismic attenuation reflects the eastern limit of the fairway. The rate history match was quite good but slightly overestimated the transient depletion between BU2 and BU3.

The derivative also can be matched easily with a model of two parallel no-flow boundaries. In this case, the late-time-derivative signature was analyzed as linear flow. The derivative match was very good, but the rate-history graph significantly overestimated transient depletion between BU2 and BU3. Without a two-buildup acquisition, this model would have been used.

Starting from the single no-flow boundary, a good match was obtained by including a reduction of transmissivity, which could model transmissivity reduction between multilayered channels inside the fairway. Both derivative and transient depletion between the two buildup tests were matched. The no-flow boundary at 220 m corresponds to the east limit of the fairway as mapped from seismic data. This investigation yielded a 9.9-km^2 area with 23.8×10^6 m^3 of STOOIP connected to the well.

Possible Aquifer Presence. A model with an aquifer on the eastern flank was run, but it implied the presence of a no-flow boundary, either westward or northward, that did not agree with seismic data. Also, the aquifer modeled by mobility and storativity change must be 1200 m from the well, which was far beyond the seismic-amplitude attenuation seen at 200 to 300 m from the well. This model yielded 15.6×10^6 m^3 of STOOIP connected to the well.

A mobility reduction was introduced in the model to improve the match on the rate-history plot with an aquifer closer to the well. The pressure data were matched, but the aquifer remained too far away to agree with seismic data (amplitude attenuation). This case yielded 10.5×10^6 m^3 of STOOIP. Although models with an aquifer on the eastern flank matched pressure-transient data, they were not used because of disagreement with seismic data.

Test Interpretation and Coherency With Geological Model. The tests results were

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analyzed in term of dynamic characteristics and geometries compared with the predefined hypotheses in the test design. The permeability deduced from the permeability-thickness product, *kh* (i.e., approximately 2 darcies), was in line with the core permeability measurements (1 to 3 darcies). The single no-flow limit seen by the test was to be correlated with the eastward fairway limit as interpreted before the test. No other limit was recognized by the test, not even the major fault 2 km north of Well A.

If the geological model was taken into account and the east fairway limit was retained, the main challenge was to evaluate from which reservoir level the oil was produced. With the current depositional model, which considers turbiditic-depositional channels with no strong erosion, increasing Formation A net thickness to 21 m over a surface of 7.2 km^2 overlapping the west (updip) visibility limit of the fairway provided the most probable model, which was consistent with the reprocessed seismic data.

Case Study 2

The second case study concerns Well X, an exploratory well drilled to test a deep offshore prospect. The main purpose was to prove the presence of a commercial oil accumulation and to acquire sufficient information for an early appraisal program. Well X encountered the reservoir series of interest, with two of the target sands having significant oil column but no proved gas cap connected to the reservoir.

The Level R1 reservoir, the shallower of the two major oil-bearing reservoirs, was encountered with a net oil thickness of approximately 40 m, a significant part of which was in thin laminated facies, which were tentatively interpreted as the overbank facies of nearby lateral channel sands. FTL pretests taken in the shallow gas zone above the oil-bearing interval inferred the presence of a possible gas cap. The presence and position of a water contact at the base of the reservoir was not proved. However, well-log, FTL, and core data established the presence of an oil/water contact (OWC).

Geophysical interpretation indicated high fault density around the well location in both reservoirs of interest, with the density on the shallower R1 reservoir being more significant. Preliminary PVT analyses carried out on the FTL samples indicated a fluid very close to saturation pressure, while permeability estimates from regional analogy indicated permeability of at least 1 darcy. Average permeability indicated from MR log across the interval was 800 md. Therefore, it was decided to run a DST on the shallower reservoir to determine the oil accumulation connected to the well.

Test Design. Because the bubblepoint pressure was very close to initial pressure, as indicated from preliminary fluid PVT estimates, high flow rates could not be used (to avoid two-phase flow in the reservoir). Several northeast/southwest-trending faults of varying throw have been interpreted across the reservoir. Seismic studies indicated two significant faults with similar characteristics. Toward the north and south of the well, an amplitude dimming was observed, which could correspond to the facies limit or, to the south, could be linked to a possible OWC. Therefore, the test was designed with a sequence and duration to allow discriminating between possible responses, given the reservoir configuration. The cumulative oil produced during the drawdown between the two buildup tests was computed to generate at least a 50-kPa depletion for a 1.3×10^6-m^3-STOOIP volume limited by the two faults and the amplitude pinchout to the north and south of the well.

Pressure-Transient Analysis. Buildup stabilization led to an estimated *kh* of 51,400 md·m, yielding a permeability value of 2,100 md for a 24.5-m net reservoir thickness. The skin value was approximately 138. There was a clear improvement of skin from BU1 to BU2.

The high estimated skin may have been the result of damage around the wellbore during drilling operations (extensive logging and several wiper trips could have left a thick mudcake on the very permeable formation). Also, the average permeability estimated from the FTL mobility was significantly lower (280 md) than the test permeability, indicating drilling damage around the wellbore. At the late times, the derivative showed a decrease of the mobility, which is characteristic of a model having two parallel no-flow boundaries (i.e., slope=0.5).

Transient Depletion. Log interpretation indicated 24.5 m net reservoir thickness. The perforations are at the top of the reservoir. To distinguish between perforation skin and total skin, the partial-penetration model was used, and the sensitivity to the vertical-/horizontal-permeability ratio was studied.

The most obvious match for the late time from the derivative signature would be a model with two no-flow boundaries parallel to the well, the so-called channel model. This model gives an excellent match on the derivative, with no-flow boundaries at 130 m and 220 m from the well. One of the matching no-flow boundaries (130 m) corresponds to the distance of a mapped fault close to the well. However, this model cannot be used because of the poor match of the transient depletion.

To match the transient depletion while maintaining a good match of the derivative, a linear composite model was used. This solution uses at least one zone of reduced mobility, which was parallel to the sealing boundary. The first attempt was to introduce this zone of poor mobility 200 m from the well and the parallel no-flow boundary 120 m from the well. The derivative match was acceptable, and the transient-depletion match was excellent. The no-flow boundary corresponds to the approximate distance of the western fault as mapped from seismic data.

To improve the derivative match, the lateral extent of the degraded zone was limited (i.e., introducing similar reservoir characteristics as in the near wellbore, but at a short distance), thereby creating a three-zone linear composite model. Matching of the late time of the derivative was improved, and the transient-depletion match remained excellent. If the no-flow boundary corresponds to the western fault as mapped from seismic, then good facies beyond the east levee or leaky fault was necessary to match the transient depletion between the two buildups.

Test Investigation. Only the no-flow boundary 120 to 130 m from the well and the explicit need to introduce a low-mobility zone in the other direction approximately 200 m from the well were required to respect the transient depletion within the investigated radius. To obtain the minimum connected volume, additional limits to the north, south, and east were introduced.

With this first hypothesis, the distance investigated by the test was approximately 1800 m to the north and south containing an area of 2.95 km^2 and at least 1.43×10^5 m^3 of STOOIP. The well-test analysis showed that only one of the many faults was sealing; thus, only this one fault affects the dynamic performance.

Conclusions

These two DSTs highlight the interest of test sequences, including two buildup tests and a drawdown. This drawdown should be long enough to generate transient depletion between the two buildup tests. The drawdown allows, by matching the pressure and rate-history graphs, to discriminate between models that match the pressure derivative. The two-buildup-test sequence was key when the major objective of the test was to prove connectivity and a minimum STOOIP connected to the well. JPT