Optimising the transition from waterflood to GOGD in a fractured carbonate reservoir in Sultanate of Oman

Introduction

Field X is in Northwest of Oman, at very shallow depth (crest of the field at around 100 m ss). The field consists of 17 km long and 2.5 km wide monocline structure with several stacked carbonate reservoir units. The main reservoir is the Natih formation with Shuaiba as the secondary reservoir [1]. Natih reservoir is highly fractured and have been intensely deformed through different structural events. Natih reservoir is sub-divided into seven units ranging from A to G. Natih E reservoir is one of the prolific reservoirs and is further divided into five sub-units: E1, E2, E3, E4a and E4b. The reservoir accounts for almost 25% of the total field Stock Tank Originally In Place (STOIIP).

The structure aligned along North West (NW) – South East (SE) direction, dipping at around 16 degrees to the North East (NE). The field is bounded by a major fault in the South West (SW) and an erosion surface at the top, further sealed by thick Fiqa shale. The crest of the field is faulted & fractured and most likely enables communication across all Natih reservoirs.

Waterflood to GOGD Transition

Natih E reservoir was developed initially under natural depletion with vertical wells. Following the unsuccessful water injection trials, a full-scale Gas Oil Gravity Drainage (GOGD) development [2] [3] using horizontal wells was implemented for the highly fractured E1/E2 reservoirs with gas injection in the Natih A reservoir.

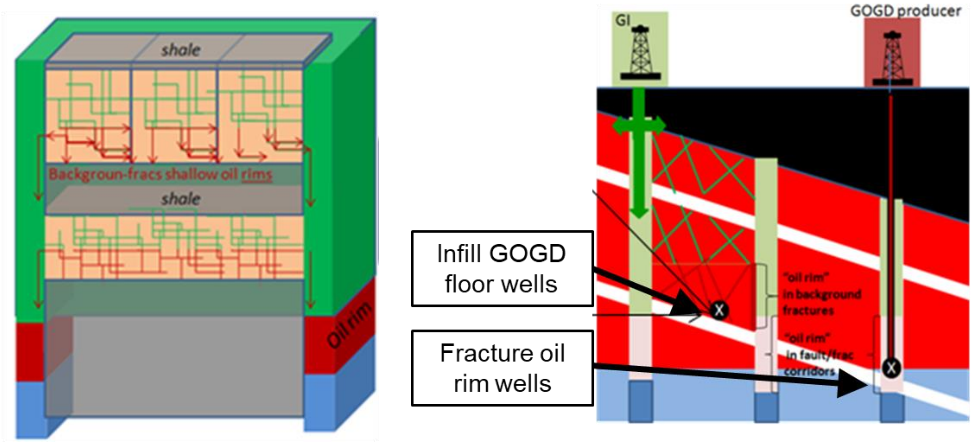

***Figure 1**: Gas oil gravity drainage (GOGD) process [4]*

The deeper E3/E4 reservoirs were not considered for initial GOGD deployment for their low fracture density. Waterflood development was implemented for the E3/E4 reservoirs starting 1997 using horizontal wells [4] [5] [6]. Water injection assisted in recovering back the production for the followed by rapid increase in water cut reaching up to 80% in 2007.

Following an extensive review, a new Field Development Plan (FDP) was implemented for E reservoir in 2010, which proposed for conversion of hybrid GOGD/water injection development to a full-scale GOGD development across all sub-units. The FDP proposed dedicated gas injection in the reservoir for faster transition to GOGD followed by progressive reduction of water injection for E3/E4 reservoirs to protect against oil re-imbibition.

New crestal gas injectors were drilled, and dedicated gas injection was initiated from 2009 onwards from the crest at a depth of ~ 300 m TVDss. Water injection in the reservoir completely stopped in 2016. New oil producers were drilled at final rim location at a depth of 480 to 500 m TVDss to recover oil through the GOGD process. Further transitional wells (floor wells) were also added in many areas at depths ranging from 430 to 450 m TVDss to supplement the GOGD recovery. Many of the existing oil producers were also repurposed as transitional wells and final rim wells. The GOGD recovery mechanism has helped in recovering back production from the reservoir. Water cut in the reservoir has reduced validating the successful transition from water flood to GOGD.

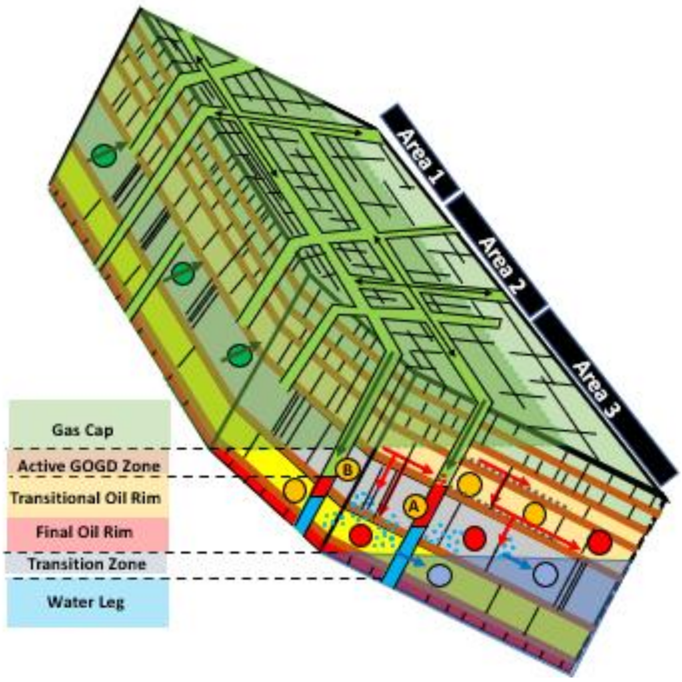

Figure 2*: Plumbing diagram in GOGD process*

Optimisation of GOGD Development

The transition process was conceptually challenging as studies indicated oil loss due to re-imbibition into matrix blocks. A gradual reduction in water injection was implemented to prevent oil to re-imbibe into waterflood matrix block.

Long horizontal final rim producers and transitional wells to draw the gas towards the final rim producers. New seismic data and logs suggested many wells inadvertently crossed large fracture corridors. Many of these wells eventually saw gas breakthrough. An optimisation program called for identification of fracture zones and eventually redrilling these wells as split wells to continue GOGD.

New data also indicated aerial variability in fracture density. Few sectors suffered from poor GOGD performance. Additional transitional wells were drilled to enhance the gas flows toward the rim wells. This helped in accelerating GOGD transition.

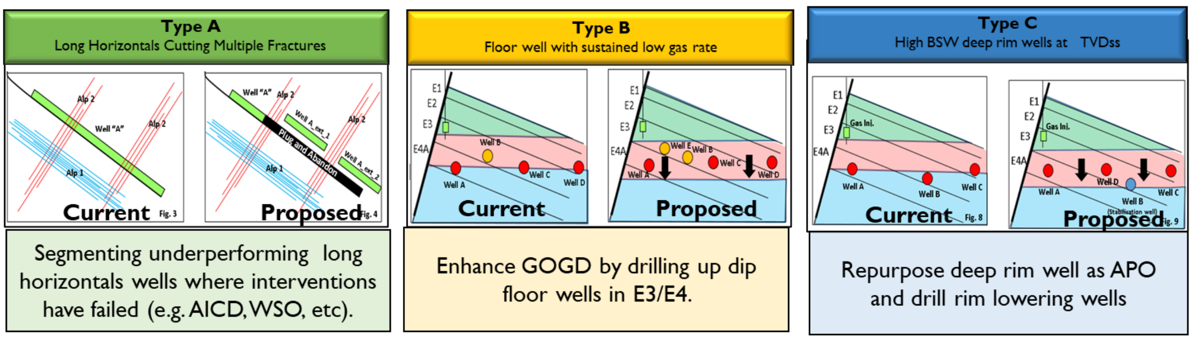

Figure 3*: GOGD optimisation strategies*

The transition from waterflood to GOGD also left-over large volume of injected water in the reservoir inhibiting gas movement towards rim wells. The optimisation plans included reopening of the old injectors as producers and drilling new set of rim lowering wells [8] to draw out injected water as well as produce incrementally from oil-water transition zone.

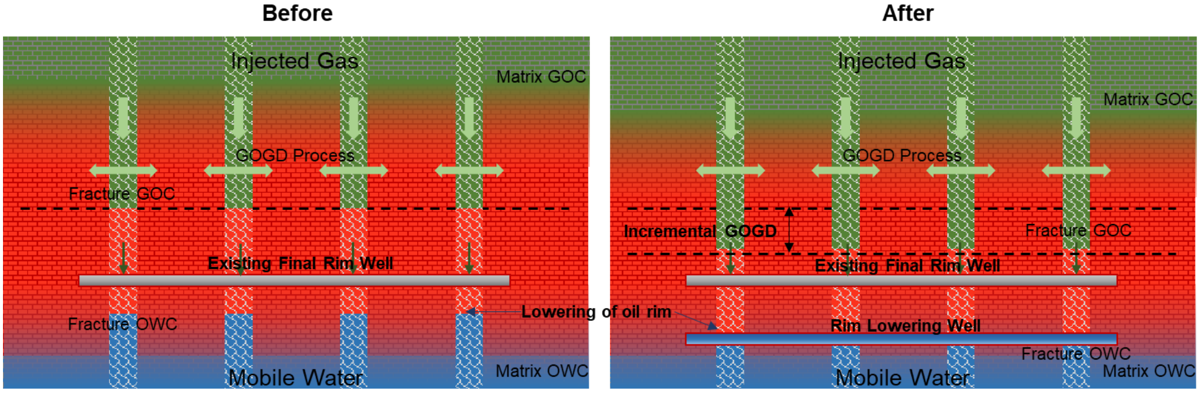

***Figure 4**: Rim lowering well conceptual model*

Fracture density is higher the central area of the field resulting in smaller size matrix blocks (SMBs). Matrix blocks in this area are small with average dimensions of 200 m x 100 m. Previously drilled horizontal wells in this area are producing at high Gas Oil Ratio (GOR). In many cases, it is challenging to plan replacement horizontal wells avoiding Alpine II fractures. As such, a vertical/slanted well development is proposed to enhance recovery and reduce the gap to Top Quartile (TQ) recovery

It is difficult to conclude if historical production from horizonal wells effectively depleted the SMBs. Hence, large uncertainty exists in remaining oil saturation in SMBs. An appraisal plan was developed to test the vertical /slanted development concept in the GOGD system and thus further enhance recovery from the field.

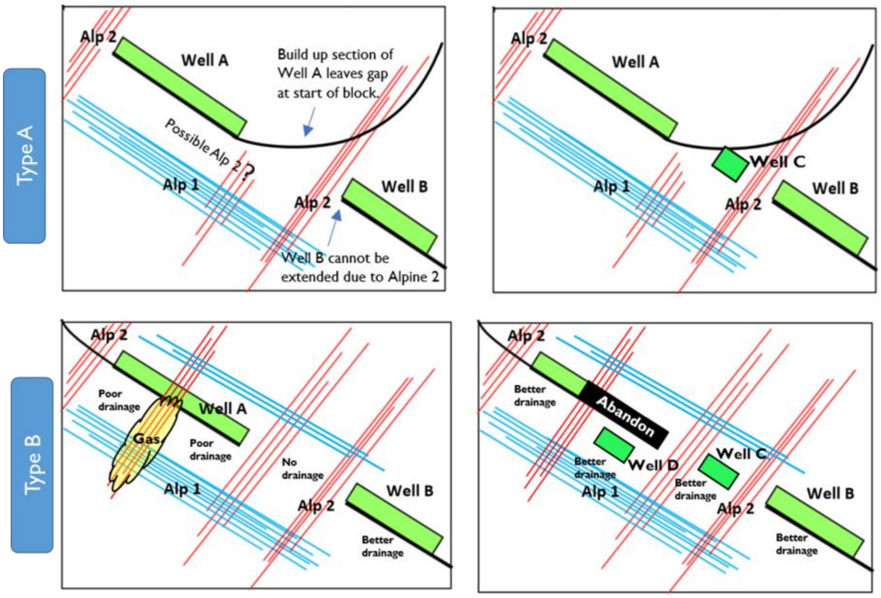

***Figure 5**: Small matrix block opportunities*

Further, WRFM interventions were implemented in field with operations like surface gas breakthrough controllers, gas shut-off, downhole autonomous gas control valves to manage transitional wells as GOR rose.

Results, Observations, Conclusions

The transition from waterflood to GOGD over 5 years has been smooth and a successful reversal of water cut in wells in most areas have been observed. The gradual reductio of water injection and onset of gas injection has helped in minimizing oil re-imbibition as well as maintaining the reservoir ratio to expectation level

The optimisation adjustments with active WRFM intervention, additional transitional wells, re-drilling wells and rim lowering has helped in greatly enhancing the efficiency of GOGD process and reduce greenhouse gas (GHG) emissions for the field. This has accelerated oil production and reduce gap to top quartile (TQ) recovery.

Novel/Additive Information

The case study describes a successful transition of drive mechanism in a mature field. A co-ordinated WRFM strategy, data collection and action initiation has helped to optimise the transition and achieve higher recovery. The FDP implementation serves as a template for similar transition in other fields worldwide.

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