Development strategy for thin oil column in reservoirs with strong water drive

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In a typical Gulf of Thailand oil reservoir, primary recovery efficiency tends to be in the 5-10% range. In the presence of strong water drive, the expected recovery factor can be 18% up to 40%. However, in reservoirs that have thin oil column on water, presence of strong water drive leads to early coning of water compromising the recovery efficiency. These thin oil sands on water are encountered in the western trend of Benchamas field. The conventional strategy to maximize recovery in reservoirs with thin oil column on water is to limit the production rate to impose small drawn down and control water coning. This approach trades-off initial rate and economic value for improved recovery.

The use of horizontal wells with inflow control device (ICD) completions to develop these thin oil sands allows production at higher rates and equalizes flow rate along the horizontal section to prevent pre-mature water breakthrough, thereby offering a solution that maximizes recovery without compromising on production rate or economic value. However, developing these thin oil columns with horizontal well requires the ability to accurately place the well at the top of the sand or at the gas-oil contact if gas cap is present. The thinner the oil column and the stronger the water drive, the more accuracy is required.

Recently, Chevron has successfully developed two marginal oil reservoirs with OOIP around 1 MMSTB and oil column thickness between 16 and 18 feet. These are the thinnest oil columns produced by horizontal wells in the Gulf of Thailand. These 2 wells are producing around 1500 bopd average for over 6 months with very little water and low GOR, and to-date have cumulative production of 220 MMBOE. Well placement and ICD completions were the keys to the success of these horizontal wells, which have opened up new opportunities to further develop thinner oil accumulations.

Geological overview

The majority of the oil reserves in the western trend of Benchamas field are found in Miocene coastal plain alluvial sediments. These sands were mainly deposited in point bars in meandering channels. Several channel sands are stacked together to form heterogeneous reservoir networks with thickness ranging from 10 to 150 feet. Well logs indicate high porosity between 20 and 30 percent and high permeability between 500 and 4000 mD. Oil column thickness ranges from 3 to 70 feet, some of which are sandwiched between a large gas cap and aquifer. Recent RFT data show that these reservoirs remain at initial pressure (or very small depletions) regardless of several years of extensive production. Well logs in several infill wells drilled in early 2012 showed sands with bottom water encroachment that had uniform sweep leaving minor amounts of residual oil. These recent well data, along with production data, confirm strong water drive in most reservoirs.

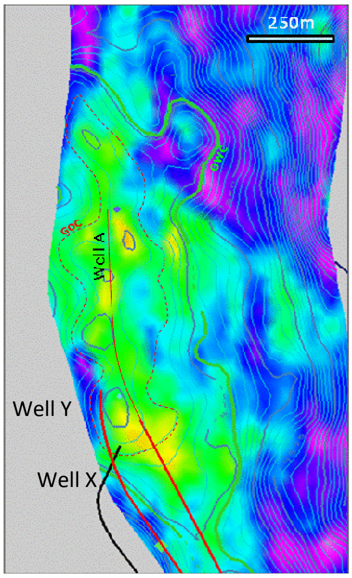

Figure 1: Structure map of well A target

In this project, horizontal well A (Figure 1) targeted a shallow reservoir which forms a 3-way dip closure with a rollover against a fault. The sand thickness is approximately 65’ in the crestal area and 5’ in the southern flank. This reservoir has a large gas cap, 18’ oil column with strong water drive.

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Drilling challenges and best practices

Thin oil columns similar to the above target reservoir, when completed with a deviated well, usually starts producing at high water cut after a few weeks of production and maintain liquid production. A poorly placed horizontal well without ICDs may also prematurely produce water because of the following reasons:

- Horizontal section too close to OWC.
- The better reservoir quality sections produce at higher rates and cone water sooner.

Therefore, well placement at the top of the reservoir or GOC is critical to maximize the vertical distance from the aquifer.

In this project, good reservoir characterization was the key to the development of an accurate pre-drill well plan, which minimized the need for real time adjustments. Real time LWD data (Gamma Ray, Neutron, Azimuthal Density, and Azimuthal Resistivity) was used by the geo-steering team to interpret the reservoir real time to ensure optimum well placement. Azimuthal resistivity was important as it allowed for the detection of reservoir boundaries, i.e. sand top, sand bottom, and OWC. Azimuthal density was used to control the well trajectory along the bed dip. Above factors along with good communication between the geo-steering team and the offshore execution team allowed the well to be placed within a 4 foot TVD window using a positive displacement motor with a bent sub (Figure 2).

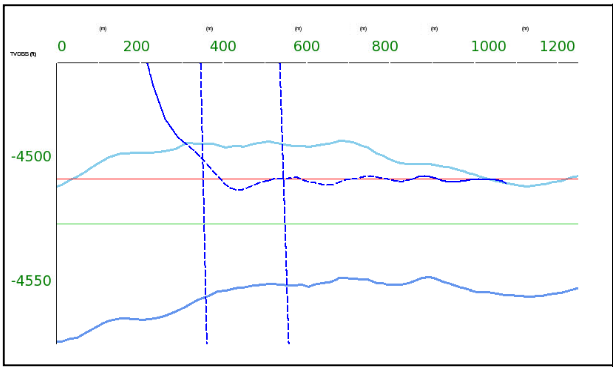

Figure 2: Well A was placed at the GOC +/- 1'.

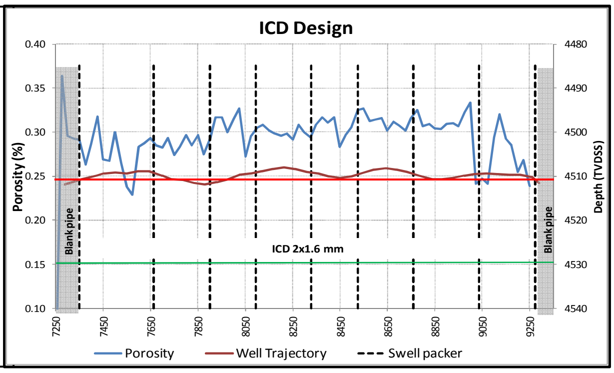

Figure 3: Chart on the right shows ICD size of 2x1.6 installed to equalize flow along horizontal well.

As the oil column was only 18', ICD completion was used to avoid premature water coning through high permeability streaks. The ICD completion compartmentalizes the lateral section with swell packers and uses nozzles of varying size to equalize flow along the horizontal section. The nozzles effectively apply a greater choke on higher permeability sections and lower choke on lower quality sections resulting in equal contribution from all parts of the reservoir. The same method is used to choke down sections of the wellbore that are closer to the water contact to delay water coning. Placement and sizing of the ICD's were done based on the initial reservoir modeling and then was adjusted as LWD data were obtained (Figure 3).

Well performance

Since the well was placed at the GOC, initial production showed high gas rates but with increasing cumulative production, gas rate decreased indicating that the GOC started moving up due to the strong bottom water drive. The well has been steadily producing at around 1000 bopd with cumulative production of 140 Mbbls and 160

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MMscf with no water production. At design conditions, horizontal well had a PI of 60 bbl/d/psi while average PI of a deviated well is less than 10 bbl/d/psi, confirming the ability to achieve low drawdown and high rate in this well design.

Simulation study was also performed on this reservoir to understand the differences between recovery factors in horizontal wells vs. deviated wells (Figure 4). The results show horizontal wells will recover ~26% of the in-place hydrocarbons while the 2 deviated wells together will only recover 14%. Recovery factor in deviated wells is compromised as it induces water coning very fast, couple of weeks after initial production. In addition to delaying water coning, horizontal wells can also produce oil at very high water cuts later in well life resulting in higher recovery factor. Production performance of well “A” (Figure 5) along with results from simulation study proves that horizontal well with ICDs is an attractive development concept to maximize initial rate and value without compromising recovery factor in reservoirs with gas cap and strong water drive.

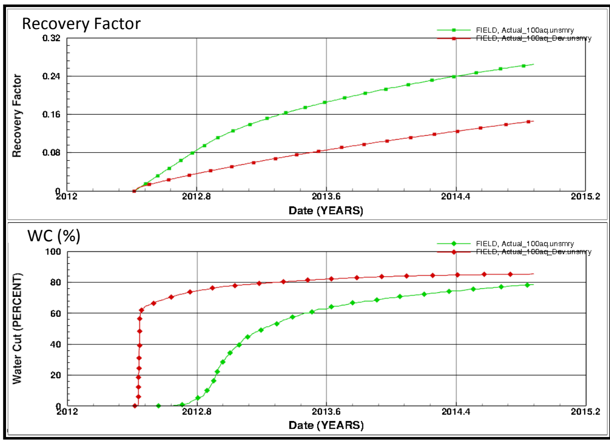

Figure 4: Simulation result compare between horizontal well (green line) and deviated well (red line) performance, (top) recovery factor, (bottom) Water cut.

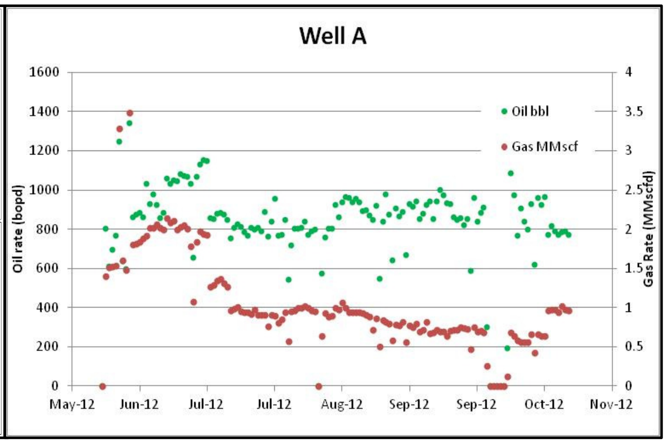

Figure 5: Well A production profile, gas production keeps decreasing with stable oil rate

Future application

In the past, it was nearly impossible to place a horizontal well into an 18’ oil column reservoir with a 2’ vertical target window. Technology has been continuously improving the accuracy of horizontal well placement and has enabled success in this project. This technology is applicable to further develop thin remaining attic oil in strong water support reservoirs and also can be applied in waterflood reservoir to maximize oil recovery, and has the potential to add significant volumes of recoverable reserves from Gulf of Thailand. Integrated efforts of various disciplines and the application of fit for purpose technology have led this project to a great success.

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