Delta Facies Control on Production and Development Strategy for Recovery Factor Increase in Tivacuno Oil Field.

Introduction

Initial and secondary development through directional wells and later pilot and horizontal wells unveiled Cretaceous siliciclastic fluvio-estuarine tide dominated delta reservoirs in the Tivacuno heavy oil Field located in the Oriente Basin of Ecuador. The historical fluid production from M1 and T sandstone reservoirs are analysed for dynamic simulation representation. The shale layers occurrence embedded into reservoirs are reviewed as depositional feature that controlled the oil trapping, production behaviour and lead the secondary field development for recovery factor incremental. This document is mostly focused on the structural and stratigraphic geological control in production of M1 reservoir case.

Method

Exploration, appraisal and development wells, log and production data are integrated into static and dynamic modeling to visualize lithofacies and rock properties distribution. After initial field development, simulation outcomes were used to propose new well drilling campaign to increase recovery factor. Mud logging and electrical log data were incorporated for trajectory well plan design and well placement to the remaining oil zones identified by simulation runs. Once secondary field development through pilot and horizontal wells were achieved, their production behavior is compared with production outcomes from initial development wells to understand the reservoir performance and recovery factor increase.

Geological Settings

Tivacuno field is a structural dome four-way closure that trapped oil in Cretaceous sandstone reservoirs of Napo Formation, located in the Block 67 of the Oriente Basin’s Ecuador. The National Oil Company “CEPE” drilled the Tivacuno-1 exploratory well, which discovered heavy oil in T and M1 sandstones in 1970, based on sparse 2D seismic lines in Amazon jungle. Afterwards, further appraisal wells Tivacuno-2, Tivacuno-4 were drilled in 1971 and 1977 respectively. However, the field development was delayed because of nonexistent infrastructure in that remote area at that time. Later in the eighties, the Ecuadorian government open a leasing round where a private consortium led by Conoco Company awarded the operation in Block 67 and committed the development of Tivacuno Discovery.

Sedimentological studies realized in well cores obtained from Block 16 and Block 67 wells, have allowed the identification of sedimentary structures that suggest tide dominated sedimentation process through the deposition of channels, sand bars, muddy/sandy tidal flat and delta plain complex (Harms J. 1990, Bellosi et al. 2004). The variations of sea level through time played an important role in the sequential cycle’s deposition and distribution of delta facies which can easily develop remarkable lateral facies changes (Valdez et al 2008, Barragan et al 2004) enabling stratigraphic control in addition to the main structural hydrocarbon trapping framework in the petroleum system of the Oriente Basin.

Strong aquifers give the bottom and lateral water drive production mechanism for both T and M1 reservoirs. Due to the nature of the reservoirs and their good rock properties, the production of the wells started with lower water cut that easily ramp up to higher values in a few years. After getting stabilized water cut, the wells can keep producing at higher BSW >90% for a long period of time, more than a decade.

Initial Development Phase

Tivacuno Field Development Plan considered four wells drilled from Pad A and two wells from Pad B. In addition, the pads of Tivacuno-1 discovery well and Tivacuno-4 appraisal well were conditioned to put in production both wells. The well information acquired during drilling campaign let the geoscientist to visualize the reservoir architecture integrating the mudlogs, electrical logs and
sedimentological descriptions. Based on stratigraphic features, the conceptual geological model was established (figure 1), fluvial channels facies (unit E), shoreface and foreshore sandstone facies (unit B) and tidal channels facies (unit A) were unveiled from M1 sandstone reservoir. Currently, unit E and B are correlated laterally with the M1C unit mostly widespread deposited in bigger Southern Fields of Block 16, Amo, Daimi, Ginta and Iro heavy oil fields.

The DST acquisition in discovery well and subsequently Tivacuno-B-2 completion in M1 reservoir, showed that the lower perforations got an early water breakthrough. For that reason, the next well completions strategy in M1 reservoir were focused to produce from unit B. Four wells produced from M1 sandstone and three wells produced from T sandstone, one of them was the first horizontal well drilled in the operation of Block 67. The wells started their production around 3000 bopd average with 2% BSW reaching a pick production at 14000 bopd. Subsequently, a strong production decline and progressive BSW ramp up to 90% (6000 bwpd avg.) occurred in M1 and T reservoirs due to the fluid mobility ratios between heavy oil 18º API and formation water, combined with the good petrophysical rock properties (Φ: 13 – 24%, K: 150 – 3500 mD, Sw: 15 – 35%) and the nature of active aquifer. A decade after initial development, a static and dynamic modelling were worked to diagnose the production reservoir behaviour, to unveil unflushed areas and to locate possible targets of new producer wells. The simulation outcomes highlighted the structural top reservoir uncertainty towards the eastern flank of Tivacuno field, and the lack of impermeable shale layers required for history matching improvement. It was necessary to incorporate horizontal transmissibility barriers to control vertical water movement. The geological representation of this horizontal barriers could be given by laterally continuous thin shale-layers that can be observed on well logs. These horizontal barriers might be the most important feature governing reservoir fluid-flow behavior and well performance. (Royo J. et al 2005). Once the reservoir modelling issues and history match were handled, remaining unproduced hydrocarbon areas were highlighted in both M1 and T reservoirs. The forecasting scenarios for dynamic model were studied to evaluate an infill well drilling campaign and the improvement of recovery factor while doing investments for a second development phase in Tivacuno Field. The Base Case scenario considered only the existing producer wells keeping the natural depletion and the Case 1 scenario considered new wells producing from both M1 and T reservoirs, and recompletions in former well producers. Figure 2.

Figure 1: M1 reservoir structural cross section showing the facies distribution interpretation, conceptual geological model, source former Maxus-YPF G&G team 1996
Secondary Development Phase
The Operator decided to follow up a contract extension of Block 67 with the Ecuadorian government, based on the exciting forecast outcomes of Tivacuno’s dynamic model worked in 2005. Figure 2. Additional investment was required for committing a secondary development phase that considered new well drilling campaign applying lessons learnt from development of Block 16, where high angle pilot and horizontal boreholes were drilled to optimize oil production while monitoring upcoming waterfront surface. Two high angle pilot boreholes and their further horizontal borehole sections were drilled into M1 sandstone reservoir, TIV-A-6 and TIV-B-3. Likewise, one high angle pilot borehole and its horizontal borehole TIV-A-7 were drilled to deeper T sandstone reservoir, which helped as additional pilot borehole for well placement of next two horizontal wells in M1 reservoir TIV-B-4 and TIV-B-9 and two horizontal wells in T reservoir, TIV-B-5 and TIV-B-8. Figure 3 
Log information of pilot boreholes showed activation of gamma ray, as well as resistivity slump in the same depth of in the M1 sandstone unit B, suggesting the influence of production from former producer wells and the presence of water legs replacing the flushed oil zone. However, the sandstone unit E was found surprisingly preserving the initial oil water contact depth, which was supposed to be moved upwards because of hydraulic connection between unit E and unit B. The tidal process played an important role for controlling the deposition of shale layer locally at the top of sandstone unit E. In that sense, the shale layer distribution generated a small dome embedded in the main anticline hydrocarbon trap, which allowed the OWC fluid contact preservation. Likewise, the presence of this shale layer controlled the water breakthrough from the bottom water drive to lateral water drive process into the sandstone unit B that overlay the unit E, such reservoir behaviour was evidenced by gamma ray activation and resistivity decrease in the pilot boreholes. The hydrocarbon preserved in sandstone unit B, exposed challenging targets for landing and geosteering horizontal wells in a small oil column no more than 30 feet vertical. The horizontal wells started average producing 1200 bopd, high 85% water cut average (7200 bwpd) per well. They achieved great cumulative oil 1300 Kbls average by well. The recovery factor increased after secondary development from 13% to 37% in M1 reservoir and 21% to 32% in T reservoir. Figure 2 shows the simulation forecast production scenarios (2005) and their comparison against real production of two development phases. The artificial lift system ESP radial pumps have improved their run life cycle three times in second development phase, from 350 - 1070 days to 872 - 3383 days. The number of well interventions to change failed ESP’s was reduced 60%, keeping more stable production along the years.
Figure 3: M1 reservoir static model, structural cross section showing the facies distribution post second development phase. Pilot (P) and horizontal (H) borehole logs showed shale baffle layer distribution, flushed oil zone and the preserved hydrocarbon column underneath.

Conclusions
The tidal sedimentation process played an important role for controlling locally the sandstone and shale layer deposition of M1 and T reservoirs, which created such a particular geological condition to have a smaller dome structure embedded in the main Tivacun dome structural hydrocarbon trap.
Initial and second drilling phase development in Tivacuno Field have demonstrated that M1 and T Cretaceous sandstone reservoirs in Block 67 of Ecuadorian Oriente Basin are capable to achieve 31% heavy oil recovery factor with primary recovery methods.
Simulation run outcomes supported additional investment in drilling campaign for Block 67 contract extension with the Ecuadorian authority. Afterwards, the pilot and horizontal boreholes drilled in second development phase have been getting the real oil production and they are representing the estimated 2005’s forecast, which correspond to 24 % recovery factor incremental of M1 reservoir production and 11% incremental of T reservoir production, even larger than former simulation.

Acknowledgments
The authors would thank to: Repsol Ecuador for supporting the continuous investment and publications, the former workers from Madrid and Ecuador. Also, the permission of Ministerio de Energía y Recursos Naturales No Renovables del Ecuador “MERNNR” to publish the current paper.

References