

## Finding Ways to Deliver Complex Horizontal Infill Wells in Crestal Part of a Brown Field Reservoir

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### Keywords

Horizontal Well, Brown Field Development, Infill Drilling, Well Planning & Optimization.

### Summary

One of the modern proverbs "If you fail to plan, you are planning to fail" is appropriate in the case of planning and optimization of horizontal wells. Horizontal well placement remains an inordinate challenge in brown oil field reservoirs especially due to critical factors i.e. anti-collision issues with existing wells, intra-field faults, strati-structural uncertainty in crestal parts and oil water contact movement etc.

However, it is of paramount importance for development teams to plan and deliver horizontal wells with largest possible lateral sections. Also, draining attic oil from the uppermost reservoir layers is key in improving overall recovery factor of the field. In this paper we present a case study from Mangala field which has been on production since August 2009 and currently produces ~100,000 bopd with 75% water-cut (figure 1).

Field is a tilted fault-block structure with a three-way closure. The crestal part of the field is intersected by low angle gravity collapse faults, and there are also some N-S and E-W trending intra-field faults (figure 2). Owing to its high NTG and good reservoir quality (lower Fatehgarh reservoir, FM3), overall sweep is mostly gravity dominated. Bottom sands are swept with water/polymer while there is significant amount of oil remaining towards top part. Strati-structural elements (intra-field faults & stratigraphic thinning) along-with dynamic behavior (gravity dominated sweeps) poses biggest challenge in planning and optimization of horizontal wells.

Delivering a successful horizontal well requires an integrated and detailed multi-disciplinary analysis of all available subsurface datasets. This paper explains how these factors corroborating to uncertainties have been minimized and a horizontal well has been successfully delivered with required objectives.

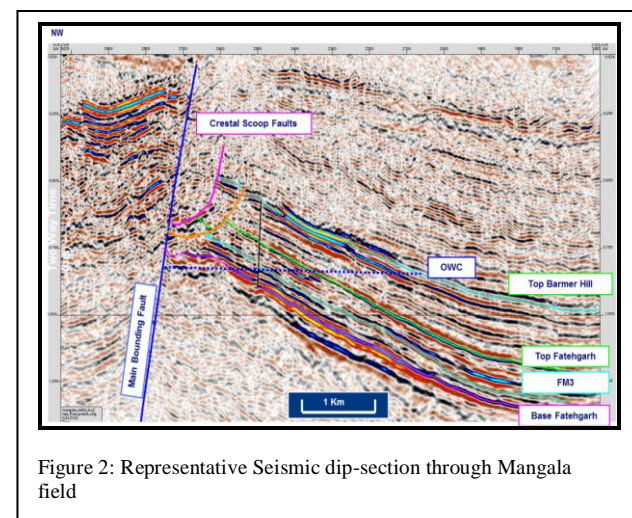
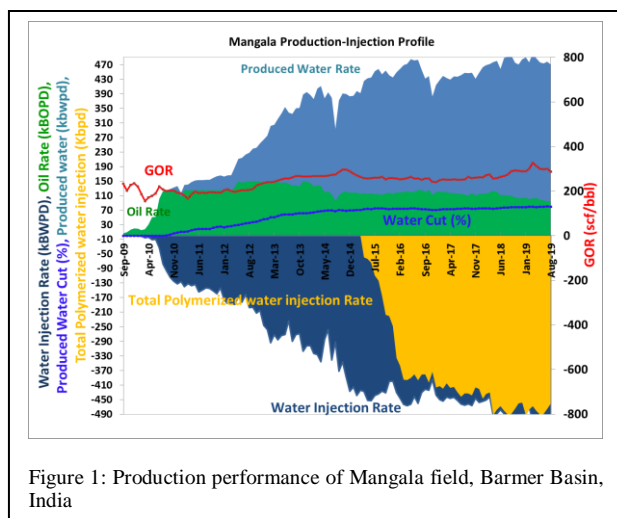


Figure 2: Representative Seismic dip-section through Mangala field

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### Field Overview and Associated Challenges

Mangala oil field, discovered in January 2004, is situated in the northern part of Barmer Basin, Rajasthan, India and was brought into production in August 2009 (figure 3). Main producing reservoirs are mainly fluvial sandstones of Fatehgarh formation deposited during the late Cretaceous to early Paleocene period overlying fractured volcanic basement.

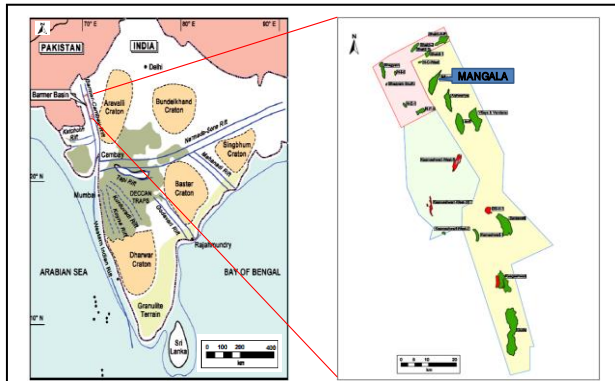


Figure 3: Location Map of Mangala Field, Barmer Basin, India

The Fatehgarh formation is further divided into five litho-stratigraphic units FM1-FM5 (figure 4). The reservoirs in the upper two units (FM1 and FM2) are

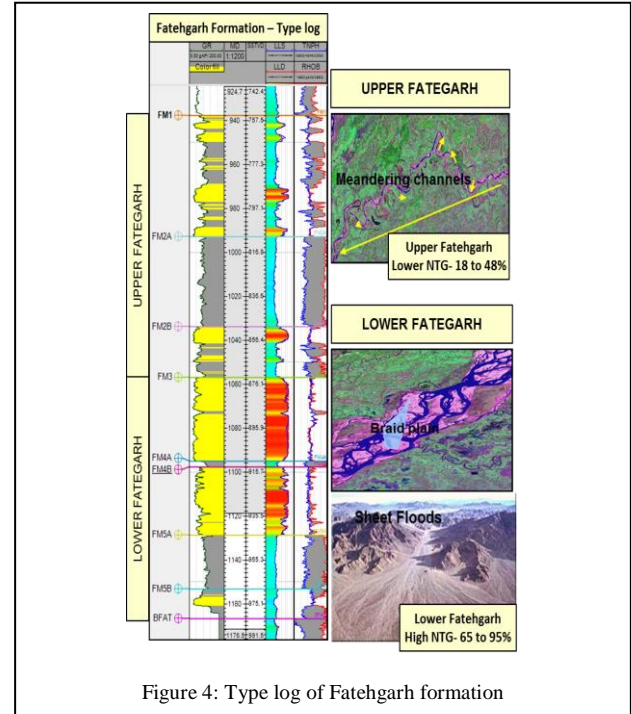


Figure 4: Type log of Fatehgarh formation

low sinuosity, single to multi-storey stacked meandering fluvial channel sands with NTG of 20 to 50%. In the lower three units (FM3, FM4 and FM5),

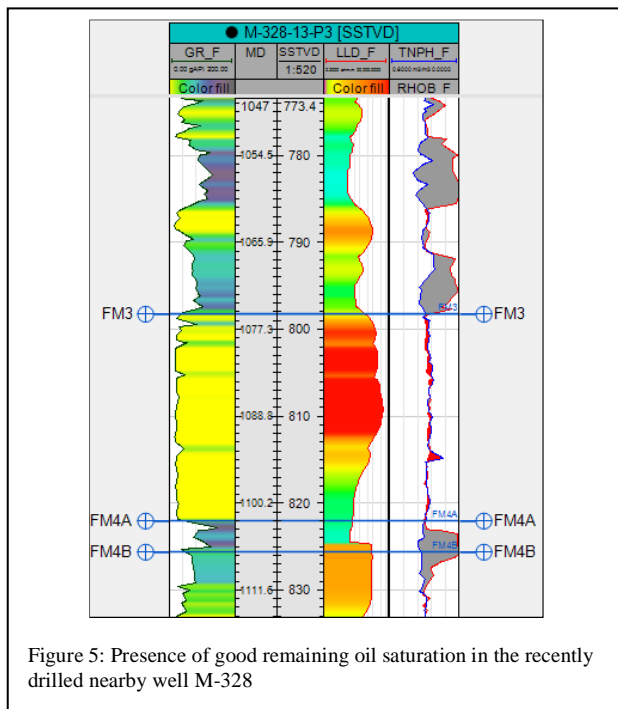


Figure 5: Presence of good remaining oil saturation in the recently drilled nearby well M-328

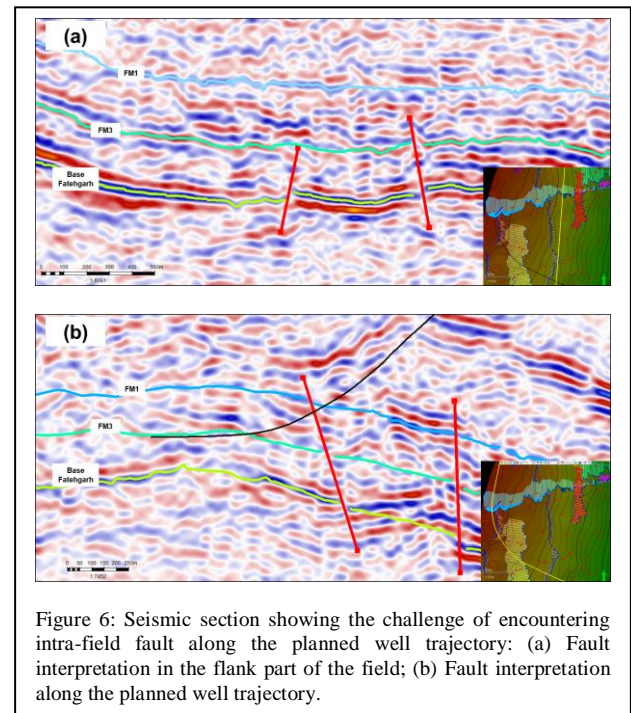


Figure 6: Seismic section showing the challenge of encountering intra-field fault along the planned well trajectory: (a) Fault interpretation in the flank part of the field; (b) Fault interpretation along the planned well trajectory.

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the reservoirs are multi-storey braided channel and sheet flood sands with NTG of 70 to 95%. The reservoir characteristics of the Fatehgarh sands are excellent, with porosities in the range of 21-26% and average permeability is approximately 5 darcies.

The main uncertainties related to delivering horizontal wells in crestal part of the Mangala field includes geological and dynamic behavior elements. The geological uncertainties mainly include reservoir thickness variation and presence of intra-field faults. FM3 reservoir has an average gross thickness of 20-25m in the crestal part of the reservoir. However, few wells drilled in the up-dip location encountered thickness of as low as 6-8m.

Poor seismic imaging masks any significant deterministic impedance contrast in the area affected by low angle gravity collapse faults. Hence, seismic data doesn't help to predict reservoir thickness and presence of intra-field faults. Drilling results of well M-323 shows a sudden dip change and missing reservoir section at FM3 level which indicates possibility of an intra-field fault. With poor seismic imaging providing only partial answers, local stratigraphic variation becomes one of critical

uncertainties during planning and optimization of a horizontal well in the area. Time lapse saturation (RST) and recently drilled well data shows very high remaining oil saturation in the uppermost part of FM3 reservoir (figure 5). Owing to its high NTG and good reservoir quality, overall sweep in FM3 is mostly gravity dominated. Bottom sands are swept with water/ polymer while there is significant amount of oil remaining towards top part of FM3. Steep rise of water-cut in all the deviated crestal producers during the early field life, is one of the key challenges. Keeping all these factors in mind it was ideal to drill horizontal wells in these uppermost parts of FM3 reservoir to accelerate production from Mangala field in addition to adding reserves.

### Methodology

The quality of the 3-D seismic data covering Mangala field is "fair to good" over the flank part of the field, but "poor" at the crest adjacent to the main bounding fault (MBF), which poses a significant challenge to seismic interpretation. To safeguard planned horizontal well (pre-drill name Crest-H2) from any structural surprises a detailed review of existing seismic interpretation and well correlation has been done.

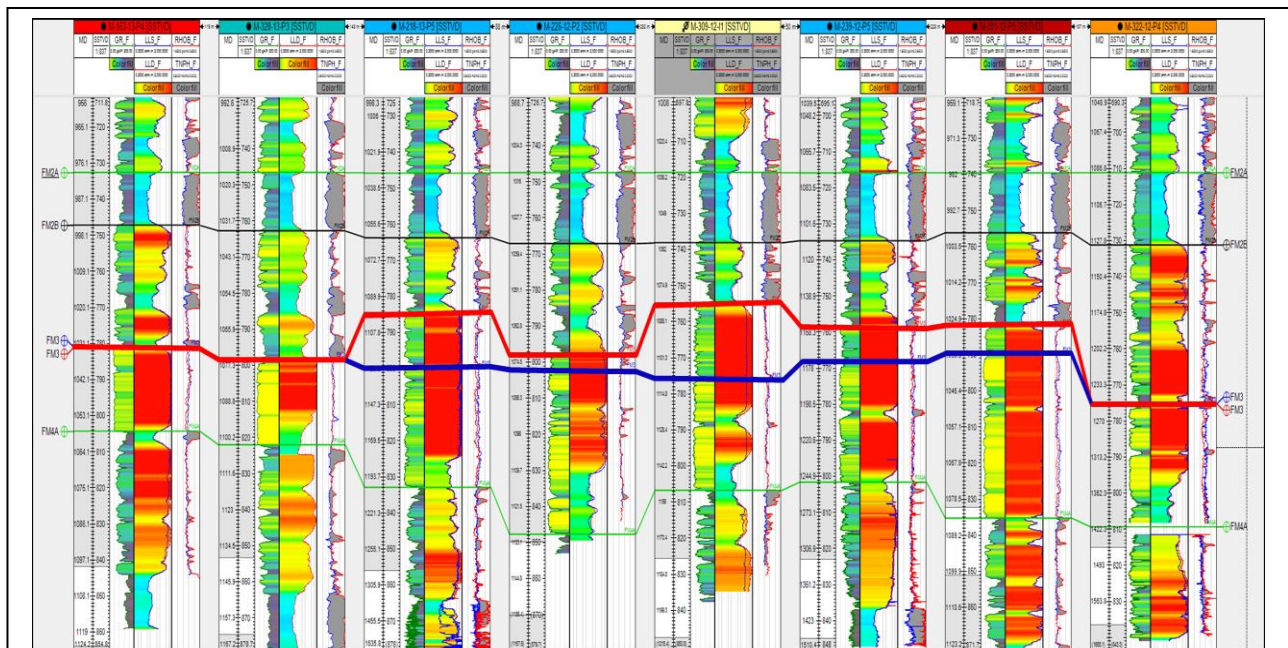


Figure 7: Detailed well correlation of nearby wells; Old FM3 markers highlighted in red color & Revised FM3 marker in blue color.

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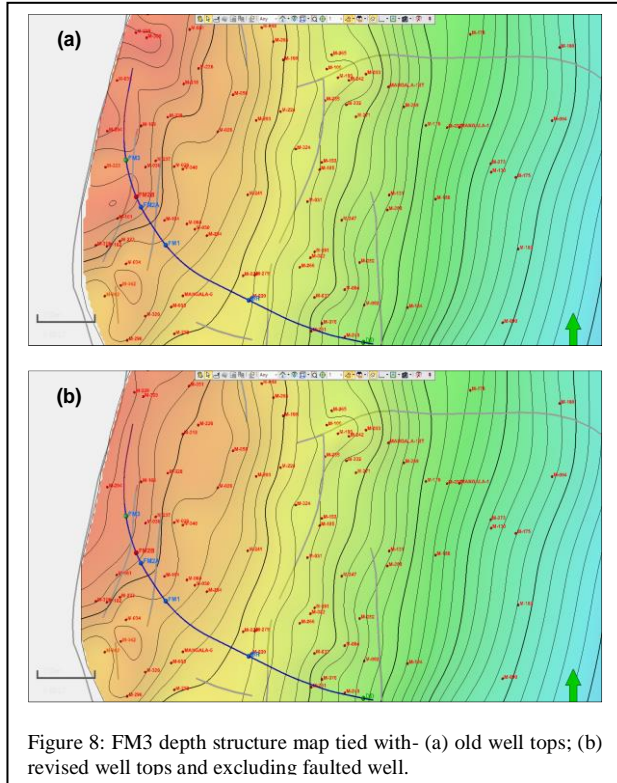


Figure 8: FM3 depth structure map tied with- (a) old well tops; (b) revised well tops and excluding faulted well.

An intra-field basement fault has been interpreted in seismic dataset towards downdip direction from the planned horizontal well. However, there is no clear evidence of extension of the same fault to FM1/FM3 level (figure 6a). Also, it was not evidently seen along the planned well trajectory (figure 6b). Nearby existing well M-323 encountered relatively thinner FM3 sand unit which indicates the possibility of an intra field fault in the area. Though, none of the other wells crossing through the possible fault shows any significant missing/repetition sections.

Wells M-323 situated very close to MBF and up-dip from the landing point of planned horizontal well. TST thickness map of the FM3 interval suggests that there is stratigraphic thinning towards up-dip direction near the planned well. However, there is no clear evidence of faults in the area as seen in seismic. Also, review of existing well correlation suggests that FM3 top marker can be slightly modified based on gamma ray and neutron-porosity logs signature (figure 7). In few of the wells, as shown in well correlation section, resistivity log indicates very high oil saturation consistently from bottom FM2b sands to FM3 sands which profoundly interferer the

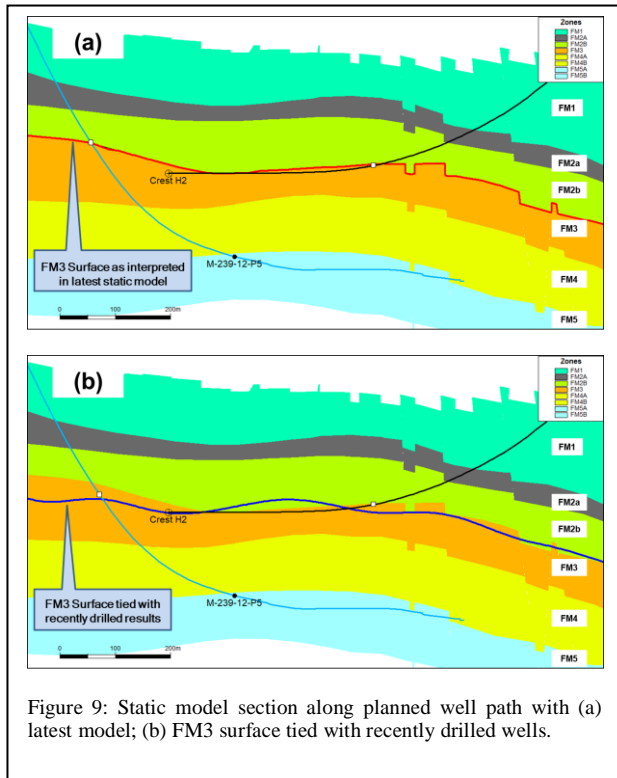


Figure 9: Static model section along planned well path with (a) latest model; (b) FM3 surface tied with recently drilled wells.

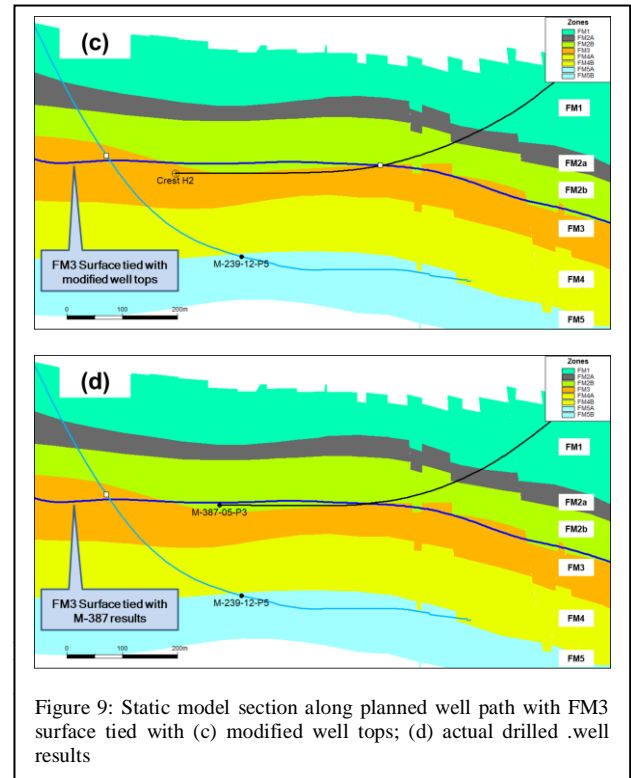


Figure 9: Static model section along planned well path with FM3 surface tied with (c) modified well tops; (d) actual drilled well results

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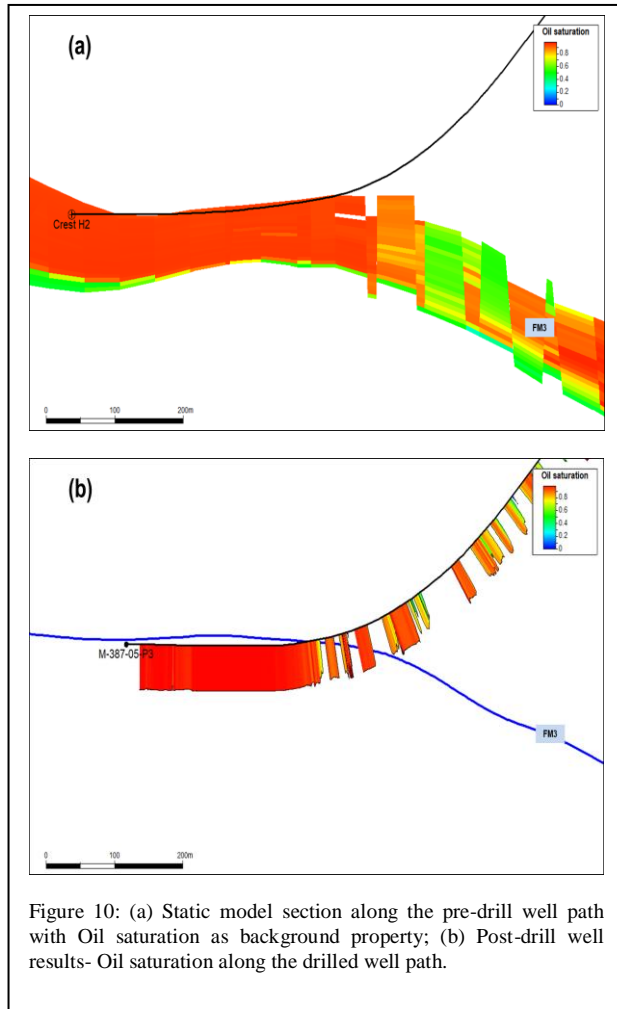


Figure 10: (a) Static model section along the pre-drill well path with Oil saturation as background property; (b) Post-drill well results- Oil saturation along the drilled well path.

interpretation of FM3 top during well correlation. While re-interpretation it has been observed that bottom FM2b shale unit is absence in few of the crestal wells which adds uncertainty in FM3 marker interpretation. However, detailed review highlights that the gamma ray response is slightly different for FM2b sand units and FM3 sand units. FM3 sand units are cleaner with lesser shale content than FM2b sand units. Therefore, this noticeable between FM2b sand and FM3 sand has been marked while re-interpretation of FM3 top by using gamma ray log response in combination with neutron-density logs.

New depth structure maps have been generated with revised well markers and keeping nearby faulted

wells out from the well-tie workflow. Revised structure maps look more geologically consistent and there are no anomalous dip changes due to faulting/missing sections in the wells (figure 8). Logs of 15 new wells drilled recently as well as various RSTs conducted across FM3 show a column of ~12-15 m of oil remaining in top part of FM3. Also, similar saturation distribution is observed in history matched dynamic simulation model. Hence, it was very critical to keep the lateral section of the well as close as possible to the top of reservoir (figure 9).

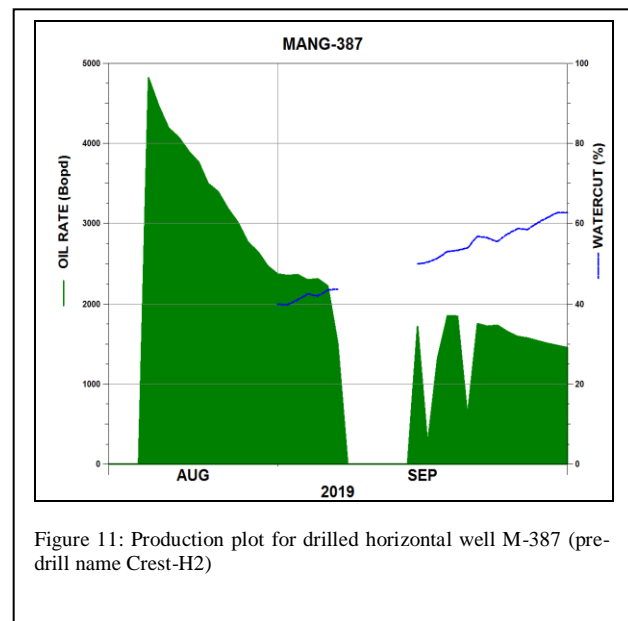


Figure 11: Production plot for drilled horizontal well M-387 (pre-drill name Crest-H2)

### Results

Well M-387 (pre-drill name Crest-H2) has been drilled successfully with reservoir drain-hole section of approximately 250m horizontally through the top of the reservoir sand in very high remaining oil saturation. Well M-387 has been drilled with real-time geo-steering to keep the lateral section as close as possible to the reservoir top (figure 10). M-387 has been drilled and completed with the same rig to accelerate the production from the Mangala oil field. It has been hooked-up and brought online and put in production with an electrical submersible pump (ESP) from the beginning itself. Initial oil rate from the well was ~5000 bopd with less than 10% water cut (figure 11).



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### Conclusion

To enhance ultimate recovery from the reservoir and maximize production from the attic oil it is important to optimally place the horizontal infill wells in uppermost part of the reservoir. However, there are many uncertainty factors related to geology, reservoir, production & drilling which need to be taken care of before drilling a horizontal well. Integrated analysis of available subsurface datasets allows adjustment of existing strati-structural model and helped in better understanding of dynamic behavior of the field. It is important for the success of any horizontal well drilling campaign to integrate all available dataset and perform a multi-disciplinary analysis to minimize the subsurface uncertainties.

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