GEOSTEERING TECHNOLOGY SHOWS THE NEW DIRECTION FOR MAJOR PRODUCTION ENHANCEMENT IN WESTERN ONSHORE, INDIA: AN EXCEPTIONAL SUCCESS-STORY FROM ONGC AHMEDABAD ASSET


ABSTRACT

Increasing the reservoir contact through horizontal well drilling helps in enhancing the production profile. To fulfill the anticipated objective of the horizontal well; it is extremely essential for deviated section to land accurately on top of pay horizon followed by optimum placement of lateral section. Placing horizontal well in accurate manner within the thin silty-sand heterogeneous reservoir is almost impossible through geometric drilling. Absence of good quality seismic data also adds structural dip uncertainty to the complexity of these targets. Geosteering technology; which involves Real-time trajectory designing and modification based on the Geological uncertainty during drilling, is the cost-effective and scientific way to drill this horizontal well.

In the studied field, several attempts were taken previously to drill horizontal well geometrically but the production result was never encouraging. The recent ambitious plan of horizontal well drilling campaign, which follows successful completion of two well in past few months, was a turn-key project for the said Asset. Accurate well placement using Geo-steering technology has enabled to achieve manifold production enhancement in this field. Geo-steering workflow involves real time well trajectory designing while drilling based on layer earth model updation using LWD Image and Log data.

The high resolution LWD images in real time have been instantaneously utilized to compute the orientation of the geological features across the borehole with high degree of accuracy. These computed orientations along with real time log data is used to update the near wellbore structural and stratigraphic model. Accurate configuration of subsurface layer earth architecture helped in effective forward designing of the well trajectory. This interactive 24X7 real time process finally enabled the two consecutive successful horizontal well drilling within 1.5-2 m thick sweetest part of the reservoir with almost 95% NTG. The first well is situated in Wasna field resulting around 5 times increment in initial production compared to the other existing horizontal well. Another well drilled in Ahmedabad field which is expected to give production equivalent to 25 vertical wells in this field.

This paper illustrates an extraordinary successful case study which opens new and exciting possibilities for horizontal well drilling campaign in the Western Onshore India. After this successful execution, several future horizontal well drilling has already been planned using Geosteering technology in different field of Western onshore which will impact Oil and Gas production profile of India in a big way.

INTRODUCTION

Oilfields neighboring Ahmedabad city, Gujrat, India, are among the oldest oilfields in India, which have been producing oil for almost the last 50 years. Over the recent years, these fields have shown a gradual decline in production with time. The necessity to enhance production in these brown fields using innovative and cost effective new technologies was the key stimulus towards generating a field development plan using LWD Geo-steering technology. Previous attempts were taken to drill horizontal wells “geometrically” in these fields, but the results were not encouraging enough. To maximize recovery
of the reserves, the horizontal drainhole trajectory not only has to cut as much good reservoir facies as possible but since these fields are characterized by thin sand bodies of approximately 1 to 2 meter thickness in average with alternating coal seams, it is also very essential to maintain distance from the reservoir boundaries, and specially from the coal seams as entry into coal could cause severe borehole problems resulting a sidetrack. It was intricate to attain this objective by drilling geometrically as the trajectory would exit the reservoir with any slight variation in the structural dip or if encountered a sub seismic fault etc. All this challenges demanded for a holistic approach in horizontal well drilling, whereby a large amount of data from different platforms could be integrated in real time to create a reservoir model that could be updated in real time, to see the changes in reservoir facies and structure with respect to the drilled trajectory as drilling progresses. New generation multifaceted LWD tools, the data from which can be fed into high-end fast reservoir modeling software to give a clear picture of the subsurface, facilitate in defining the reservoir in real time while drilling. This valuable combination can be intelligently used to increase hydrocarbon recovery by optimizing our trajectory placement in the most prolific part of the reservoir.

In the last decade, MWD and LWD have made rapid stride to outpace the industries demands for technologies that can be used to manage and exploit real time data, integrating it to drilling programs for a faster, more efficient and more accurate drilling and placement. Faster data transmission rates from downhole helps in more data per unit time, so more inputs for modeling and simulation hence better results. The increased bandwidth means along with conventional basic formation data, now azimuthal borehole images could also be transmitted up in real time. The use of LWD images in real time proved to be a breakthrough in the well placement domain, making the transition from conventional correlation based well placement to more advanced Image based well placement. In addition the introduction of rotary steerable systems made drilling more efficient with an increase in overall ROP, maintaining good hole conditions and accurate bit placement. Massive volume of high quality data can be acquired now in real time using modern MWD and LWD tools. This data is then transferred from the rig to real time interpretation centers via web based system called InterAct, where the data is interpreted, fed into modeling and simulation software to gauge the reservoir geometry with respect to the trajectory in real time and thus optimize trajectory placement in the sweet zone.

Two such wells were drilled in the last 6 months under the horizontal well drilling campaign, in Wasna and Ahmedabad field, situated very close to the Ahmedabad city, and the resulting success has essentially proved that image based well placement can be very effective in increasing production from these depleting reserves by accurate drainhole placement in the reservoir sweet zone.

GEOLOGY OF THE AREA

The Cambay basin in Gujarat State (Western Region) is between lat. 21° and 24"N and long. 71°30' - 73°30'E. The basin is bounded on the west by the Saurashtra Peninsula, which is covered almost completely by Deccan trap basalts except in the northeast, where Mesozoic rocks crop out. The basin extends toward the north and may be connected with the shallower Banner and Kutch basins (Mathur et al, 1968). On the northeast, the basin is bounded by the Precambrian Aravalli-Delhi outcrops, just west of which is a thin fringe of Mesozoic outcrops. The Aravalli Series (Precambrian) with Deccan trap outliers delimits the basin on the east. On the southeast, the basin is limited by the Deccan trap basalts. It extends southward in the Gulf of Cambay to an unknown distance under the shelf. On land, the basin has a total area of more than 50,000 sq km (courtesy: L. L. Bhandari and L. R. Chowdary) (ref: fig1)

The main targeted formation in this basin is the Kalol Pay sand. The Kalol Formation comprises of thick wedges of lower to middle Eocene terrigenous strata which form a significant part of the sedimentary fill of the Cambay Tertiary basin, western India. The main producing sedimentary unit corresponding to
Kalol IX and X (Sertha Member) consists of two parasequences representing two independent episodes that are separated from each other by persistent transgressive shale. Parasequence I corresponds to K-X sand. Parasequence II corresponds to K-IX Sand. The facies here can be lithologically characterized by interlayered carboniferous shale, siltstone, claystone etc. The formation natural Gamma Ray is on the higher side in the reservoir zone and neutron-density curves show small separation. Resistivity is in the range of 10 to 40 ohm m and average porosity ranges between 20 to 30% in the reservoir zone (Sharma et. Al 1996).

OBJECTIVES & CHALLENGES:

The target formation for both the wells is K-IX Sand. The K-IX sand is one of the most exploited pay present all over Cambay basin and is the target pay sand for most of the oilfields here. The foremost objectives were:

1. Land the well just after entering K-IX sand and confirming the formation top.
2. Drill the drainhole trajectory in the most resistive part of K-IX layer avoiding exits.
3. Maintain distance from K-IX coal seam at top and shale below.
4. Correlate log signatures in real time with offset well logs to update the 3D structural model in Petrel while drilling.
5. Pick structural dips in LWD azimuthal density image to calculate structural dipping trend with high degree of accuracy in real time and use this to update the 2D layer earth model.
6. Correlate log signatures with drill cuttings at site while drilling to create a greater degree of certainty regarding trajectory placement in the expected sweet zone.

The major challenges were

1. To maintain horizontal drainhole trajectory constantly in the high resistivity reservoir sweet zone because of immense lateral heterogeneity in terms of both structure and lithology and the pay thickness being less than 3 meters.
2. Sensor offsets in case of using a LWD BHA, causing measurements to lie at a distance behind the bit combined with shallow depth of investigation of the azimuthal measurements makes this a reactive technology for well placement, whereby a formation boundary needs to be crossed till the point the sensors starts reading the change in formation, before taking a reactive action to drill back into the reservoir (ref: fig2).
3. The presence of coal seam at the reservoir top posing a threat to borehole collapse in case of accidental entry into it.

WELL PLACEMENT WORKFLOW

The well placement workflow essentially involves extensive “pre-job” study first which basically aims at understanding the target reservoir, the field geology, the log signatures for target zone, surprises while drilling in the past, structural trend in the already drilled zone, presence of fluid contacts in the reservoir etc. This requires collection of all the available data concerning the area of interest, primarily offset well logs, offset well surveys, structural contour maps, formation tops, 3D surfaces and 3D reservoir model if possible. Prolonged discussions were held with client extending several sessions to know and understand the target zone in detail.

The next stage is the prejob modeling part, which involves creating a 3D structural model in Petrel interface, using the offset well point data set. The offset well logs are then squared to extract properties of interest like GR, resistivity, density, porosity etc in the geo-steering software. A 2D section is then extracted from the Petrel 3D structural model that extends along the planned trajectory called the Curtain section. Now the log properties extracted by squaring the offset well logs are propagated into the 2D
curtain section. The product is a 2D section along the planned trajectory with properties populated from the offset wells (ref: fig3).

This is followed by a series of forward modeling along the planned trajectory in the extracted curtain section in RTGS. Forward modeling involves running complex algorithms to create synthetic log responses for properties like GR, resistivity, density and neutron, to mimic the LWD tool response for the same set of properties that would be produced in case of a LWD Bottom Hole Assembly (BHA) run in similar formation conditions as in the model. Numerous scenarios are created in this stage to study the LWD tool responses in situations like when trajectory cuts the reservoir from top or bottom, or trajectory maintains its stay in the reservoir, or sudden appearance of a sub-seismic fault causing trajectory to move into a non reservoir zone in an abrupt manner. The response of the azimuthal density image is very critical in determining whether the trajectory has cut the structure stratigraphically up or down or when maintaining parallel with the reservoir. The advanced algorithms available now also takes into the account the relative dip between geological beds and borehole trajectory in addition to the point data models, thus enabling us to do propagation resistivity measurements modeling for complex scenarios’ like bed boundary effect, shoulder bed effect, polarization horns where the resistivity curves shows separation due to varying depth of investigation, varying vertical resolution and also tool measurement physics (ref: fig 3).

After the Prejob phase, comes the very important phase of “RT Monitoring” or the while job phase. This phase essentially involves analyzing and correlating real time formation evaluation log data transmitted from the rig via web based system called InterAct. The transmitted data is directly fed into the geo-modelling software for various modeling and simulation activities. The modeled synthetic logs are then compared with the measured logs transmitted from the wellsite. A good match between them indicate that the layer earth model is good and representing the subsurface structure. As a result, no adjustments are required to the drilled trajectory. If there is a mismatch between the synthetic and measured logs then the model is adjusted to match the synthetic logs and the measured logs and accordingly the trajectory is modified in the best interest of the well (ref: fig 4). The image data transmitted from rig is also fed into the software, where dips are picked. The dips calculated from image, arguably the most accurate representation of formation dip are then used to validate the structural trend. Also signatures on the image tell us whether the trajectory has cut the formation and gone stratigraphically down (sad face) or stratigraphically up (happy face) (ref: fig 5a). Various other signatures help to recognize whether the trajectory has entered and bounced back from a bed (hour glass or bulls eye) or maintaining parallelism to the formation (rail tracks) (ref: fig 5b). Based on the relation between the drilled trajectory and the corrected formation model, it is decided whether to make changes in the trajectory or to maintain the same course to steer within the best facies of the reservoir.

INITIAL PROGNOSIS

Based on seismic data and offset well correlation, the initial prognosis about the expected subsurface structure was made. For Well-B in Ahmedabad Field it was seen that the structure was dipping up at an angle of about 1.5° - 2°. For Well-A in Wasna field, the structure was estimated to be dipping at an angle of 1° - 2° deg down dip.

THE STRATEGY

To acquire ‘up to date’ information about the target layer properties and to have the accurate depth estimate of the target layers, it was decided to go for a pilot hole for both the cases. The Pilot hole was planned to drill till K-IX formation. So the initial landing and drainhole plans were modified based on the surface tops picked from the pilot hole log data. Also forward modeling was carried out by propagating
pilot hole log properties in the 2D curtain section, and multiple scenarios’ were analyzed, to get a more accurate representation of the log signatures expected while drilling.

Based on the log analysis and surface tops picked in the pilot hole log, it was decided to land the 8½” section just below the K-IX sand-top (<1m in TVD below K-IX coal) after confirming the log signatures at an inclination of about 87° to 88° for both the wells. Thereafter a 250m drainhole section was to be drilled tracking the best facies in the target formation.

TOOL SELECTION

A right BHA is very essential to get the right results. The combination of LWD, MWD and Directional Drilling tools should be such that we get an optimum performance on drilling efficiency, steering control, data transmission rate from downhole, amount and type of data transferred etc.

The BHA used for drainhole section in Well-A consisted of LWD tools capable of providing basic triple-combo logs (resistivity-density-thermal neutron porosity) and images. Positive Displacement Mud Motor was used for steering and directional control. The combination is good for steering as well as data transfer was optimum. However during the slide sections, azimuthal image could not be acquired, as to generate image the BHA needs to be rotating to scan the borehole 360° constantly. So every slide section was reamed again to get the image data. This affected the average ROP.

To improve the drilling performance in terms of ROP and hole stability, Rotary Steerable System (Power Drive-RSS) was introduced for the drainhole section in the next well (Well-B). Power Drive helped in increasing the average ROP significantly and at the same time maintained a smooth borehole for effortless completion afterwards. In addition, the continuous rotation of the BHA (RSS can build, drop or turn while rotating) ensured that azimuthal image was acquired at all time.

REAL TIME JOB SCENARIO

Case 1: Well-A

A geometrically drilled horizontal well was already drilled in this field but the production result was not very encouraging compared to the cost of a horizontal well. And a common trend was set to drill inclined drainhole and then fracture the reservoir to increase permeability or production path-ways. As a result a myth was created for this silty-sand reservoir with low permeability. It was believed that drilling horizontal well itself will not increase production but one have to fracture the formation anyway. Thus it was crucial at this stage as the failure would kill the aspiration of drilling horizontal well in this part of the country for ever and a success could change the entire development scenario.

A pre-drill plan was created based on the initial prognosis. The 8½” landing was done precisely (<1m) below K-IX sand top as planned and it was seen that the target layer came 1m shallower in TVD than expected. Log correlation and 2D layer earth model updation performed in real-time showed that structure was 1.5 to 2 deg up dip at the landing point. Dips picked on density image were projected along the drilled trajectory in the geo-modeling software validated the structural dipping trend. A revised plan for drainhole was thus formulated keeping in mind that this can be also a local undulation as pre-drill model showed a dipping down trend.

An integrated approach where data from different sources were analyzed, interpreted and modeled simultaneously helped in successfully geo-steering the drainhole in the 1.5 to 2 m thick sweet zone (relatively high resistivity) with an NTG of ~100%. It was seen in the initial part of the trajectory that formation dip was slightly higher than the pre drill prognosis of 1.5°. Dips picked on azimuthal density
image confirmed the increase in structural dip. The adjustment caused the actual trajectory to fall below the plan trajectory till 1800m MD (ref: fig 6, zone A). After 1800m MD, the structural dip trend started changing and formation dip reduced to about 1° down dip as confirmed from dips picked on density image. The final part of the trajectory was drilled above the plan trajectory (ref: fig 6, zone B). Real time decision making and active trajectory control while drilling helped in achieving an extra meterage of 57 m more than the planned length within reservoir (ref: fig 6).

**Case 2: Well-B**

The second horizontal well to be drilled in this campaign was B in Ahmedabad field very near to Ahmedabad city. The pre drill model created based on seismic data and structural contour maps showed an up dip trend of the formation at about 1.5° to 2°. Based on this an initial plan was made to land the well just below K-IX sand top and then drill the drainhole at an inclination of around 91° to follow the formation dipping trend.

Landing for 8½” section was done as planned just (<1m) below K-IX sand top. Target layer came 1.5m deeper in TVD compared to the prognosed depth. Log correlation and RTGS layer earth modeling along with dips picked on density image confirmed that structure is up dip at the landing point at about 1.5°. The drainhole plan was thus revised for change in depth of the landing point and it was decided to pursue the pre-drill plan inclination wise to follow the structural trend.

The drainhole section was successfully geosteered using the same holistic approach as we did for Well-A. As soon as drilling started, synthetic logs were matched with measured logs to update the layer earth model and it was observed that in contrary to our earlier expectation, the structure actually started behaving the opposite way. The beds were actually dipping down at about 1.5° in contrast to the pre-drill model which predicted the beds to be dipping up. The azimuthal density image showed no signatures in this well as trajectory was in a homogenous layer with almost uniform density. So dip picking could not be done here to authenticate the layer earth model. But owing to high data quality and reliable modeling results, it was decided to adjust the trajectory and drop inclination to 89° to remain in the reservoir. At ~1920m MD, it was informed from rig that bit was bouncing from bottom. Measures were taken instantaneously and it was decided to build inclination to 90 deg. The trajectory just grazed the reservoir bottom at 1920m MD and bounced back in to the sweet zone. The horizontal section was drilled at an average inclination of 89° thereafter and the final trajectory was placed almost 2m in TVD below the initial plan. The drainhole length was extended by 50m compared to the initial plan because of the good log responses and higher confidence in the subsurface structural trend (ref: fig 7).

**RESULTS**

With the integration of well placement technology into the systematic workflow for horizontal well drilling, the foremost expectation was that the current production scenario would improve by a leap. The two successfully completed well met this expectation and drastically enhanced the whole production scenario in this area. In the Wasna field, the current average production from vertical wells is ~1.5 ton/day and from the offset horizontal wells is ~ 3 Ton/day. In case of Well-A, the initial production was 11.7 Ton/day which has currently increased to 13 Ton/day with no water cut which is a drastic 4-5 fold increase in production (ref: fig 8).

In case of Well B, the initial production is 11 Ton/day which is limited by surface facilities at present. Client is expecting this figure to double with the installation of some new production facilities. The initial production is almost 6 times the average production from any offset well in this field (ref: fig9).
CONCLUSIONS

Several factors need to be considered for a field development plan especially when it aims at increasing recovery from an already depleting reserve. One such very important factor to think over is the accurate placement of drainhole to maximize reservoir exposure so that recovery could be maximized with very little or no water cut or to delay water encroachment to the drainhole.

In context to Ahmedabad and Wasna field which are characterized by very thin reservoir sand bodies sandwiched between coal seams, it is extremely essential to place the drainhole accurately in the reservoir sweet zone away from the shale and coal beds. Conventional image based well placement technique provided the exact solution by placing two drain holes entirely within the target zone in these fields within a span of 6 months. The high level of expertise, excellent coordination among the team members, fast and efficient decision making process helped in gaining the extra mileage by achieving an NTG of ~100% even with the use of a reactive well placement technique for both the wells.

The production scenario has enhanced dramatically with almost 4 fold increase in production compared to the offset vertical and horizontal wells in the Wasna field and an initial production almost 6 times the average production from offset wells in Ahmedabad field. The lesson learned in Well-A were implemented in Well-B and helped to reduce cost by Rs. 700,000,000 (7 crores).

The so called myth in these fields was to come to an end and a new era for field development was at its beginning in this part of the country. The new well planes are under review and high angle wells are now converted to horizontal drainholes to optimize production from these fields.

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REFERENCES


Fig1: Cambay Basin Western onshore India

Fig2: Reactive well placement- meterage lost in the non reservoir zone due to sensor offset and shallow depth of investigation on density measurement.
Fig 3: Well Placement work flow
Fig 4: Layer earth model update by matching synthetic logs with measured logs while drilling.

Fig 5a: Signatures on azimuthal image
Fig 5b: Signatures on azimuthal image

Fig 6: Well-A: Curtain section showing plan vs actual trajectory and decision point in real time. Image signatures were interpreted in real time to gauge drainhole position with respect to the formation.
Fig 7: Well-B: Curtain section showing plan vs actual trajectory and decision points in real time. Dips could not be picked here because density variation was very subtle as trajectory maintained its course in the reservoir.

Fig 8: Production results for Well-A, Wasna Field

Fig 9: Production results for Well-B, Ahmedabad field