Production Enhancement through Efficient Segmented Completion Technique in Neelam Field

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Summary
Horizontal wells have been drilled extensively in Neelam Field in western offshore basin in recent years where several challenges have been faced such as increased cost, short well life, limited accessibility, uneven stimulation, less productivity and high water production (>90%). In order to optimize horizontal wells to overcome such challenges, an innovative segmented completion technique was proposed and successfully implemented.

Initially some wells were completed based on only LWD logs in a horizontal drain hole across carbonate reservoir but that was not enough successful in reducing water cuts for heterogeneous and texturally challenging carbonate reservoirs. This innovative segmented completion technique provided a method to choose the most appropriate horizontal drain hole section with lateral heterogeneity and demonstrated the value of having segmented completions in terms of oil gain and water management as well as improved accessibility. Sonic Scanner-CMR tools were lowered in single run as a combination in 6” horizontal drain-hole after basic log data acquired through logging-while-drilling (LWD). Significant lateral variations of heterogeneities were determined with above log data, which were used as input for efficient segmentation. Zones with possible fractures were determined and isolated with blind tubing. Zones for effective swell-packer placement were determined based on acoustic radial profiling by avoiding zones with alteration/damage. Porosity partitioning analysis and facies variation was efficiently quantified for better understanding of rock-quality (RQ) indicators in combination with permeability variation.

Segmentation completion technique was introduced in three wells of Neelam field. Production data have supported the success of this technique providing future opportunity to optimize the production and reducing higher water cuts of horizontal wells delaying early water cuts in sustainable manner. Implementation of this technique increased production accessing deeper horizontal areas, with an optimized cost and time savings.

Introduction
Neelam Field in western offshore basin was discovered in Jan-1987. Early production was taken from Platform-1 from March 1990 and full development plan was implemented from Jun 1994. 11 producer platforms and 2 injector platforms were installed (Figure 1). Bassein (carbonate) formation is the main producer in Neelam field. Present day production challenge is high water production (>90%).

There are various production challenges due to textural variations in carbonate reservoirs. Carbonates exhibit a wide range of heterogeneity in porosity-permeability relationships. Three basic components making the precipitated carbonate rock are carbonate grains, micrite particles and micrite crystals. The porosity types associated are as given: (i) Macro pores: interparticle porosity between carbonate grains, (ii) Meso pores: interparticle porosity between the micrite particles; and (iii) Micro pores: pore space between the micrite crystals. Fossiliferous & mud supported carbonates introduce more heterogeneity with organic porosity (Figure -2, 3).

Since carbonates are inherently brittle, additional complexities arise due to stresses and fracturing. Pore water chemistry & diagenesis create secondary porosity or kill primary porosity. Figure-3 describes fracture enhanced pore connectivity, solution enhanced pore connectivity and diagenesis. Dolomitization & cementation related tortuosity
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Figure 1: Location of Neelam field under study with platform details and structure map at Bassein formation.

changes also increase the complexity of carbonate reservoirs (Figure - 3).

Hence complete characterization of mineralogy—limestone vs. clay vs. dolomite; differentiating porosity & pore connectivity – rock texture; analyzing the role of fractures/karst networks (Figure-2,3); and determining wettability & relative permeability help in proper oil & water volumes estimation and maximize oil gain during production. Therefore, NMR log was recorded in 6” drain hole for carbonate characterization.

Earlier 6” drain holes were being segmented for completion with only LWD basic logs in this field. Figure 4 shows typical LWD basic log based segmentation of drain holes. LWD neutron porosity and density logs (NPHI-RHOB) show more or less homogenous limestone. Drop in resistivity is taken as an indication of increase in water saturation. Low resistivity intervals were isolated with blind tubing. Water cut was reduced from 90% to 70% in a few cases with no significant improvement in oil rates because carbonate properties variation along the length of the drain hole was not captured well by the LWD Triple Combo log alone.

Figure 2: Determination of porosity types from NMR logs

Figure 3: Porosity distribution and heterogeneity in limestone

Theory and Method:

Sonic Scanner provides 3D measurements with large volume of investigation. It includes 3D velocity radial profiling & thomsen gamma based pore connectivity and open fracture characterization (Collett et al., 2011). It provides permeability enhanced due to fractures which will help to identify intervals to isolate. Anisotropic rock mechanical properties provide rock competence for correct placement of swell packers (Figure- 8,9,10).

Figure 4: This figure shows typical LWD basic log based segmentation of drain holes.
NMR provides primary porosity partitioning & rock typing in which macro-meso-micro porosity can be identified being independent of lithology (Figure-2). We can also calibrate primary permeability and characterize rock heterogeneity (Tang and Cheng, 2004). Drain-hole segments can be decided and fine-tuned swell-packer placement can also be carried out with the data provided by NMR and Sonic scanner.

**Fracture characterization from acoustic data:**

Understanding natural and drilling induced fractures is essential to safely drilling a well and maximizing production. While seismic interpretation methods can give us a high level view of areas of fractures, it is at the borehole level we can really understand how fractures intersecting or near the wellbore may interact (Market et al., 2017). By measuring the discrete location of fractures intersecting the wellbore, induced fractures, and altered near-wellbore stress fields, we can understand the effect of the wellbore on the surrounding environment. One scenario is that of a lateral production well through a reservoir, as illustrated in Figure 5.

Not only is near-wellbore fracture analysis important, but understanding how far the fractures extend away from the wellbore can be vital, particularly in situations like those of Figure 5, where a fracture extends to connect the wellbore with a nearby water zone, a highly undesirable effect, but one which, if understood, can be planned for by placing appropriate fracture barriers or not stimulated a zone at all. Hence, acoustic data has been used in the case studies of this article.

While micro-image and ultrasonic image logs may provide higher resolution fracture characterization than sonic data can provide, the ability of acoustics waves to penetrate deep into the formation adds valuable information about the extent of fractures. This information can be particularly valuable in situations like those of Figure 5, where it is critical to understand if open fractures that intersect the wellbore extend far from the wellbore and connect to nearby hazards, such as the water zone in case studies of this article. This technique works best on large aperture, fluid filled fractures and is applicable to vertical, deviated, and horizontal wells.

**Stoneley waveforms analysis:**

Stoneley fracture detection and amplitude/attenuation methods are best suited to detect fractures transecting the wellbore (Hornby et al., 1989). Sonic waves travelling along the wellbore will be reflected when they encounter any boundary of impedance contrast. This could be a formation change, a change in the wellbore diameter, or an open fracture, as illustrated in Figure 6. Closed fractures are difficult to see with this technique, unless the material filling the closed fracture is of strong impedance contrast with the surrounding formation. Hence accurate interpretation of stoneley reflection logs is necessary (Escandón and Montes, 2010).

The chevron patterns might be identified by events (fractures, hole effects, bed boundary). The first step in fracture characterization is to determine the minimum energy requirements for an event to be classified as a legitimate reflection (not noise). After which, the borehole caliper curve(s) are used. Areas of borehole rugosity or similar sudden changes to the borehole shape will cause stoneley reflections. Any reflections found in areas corresponding with these washouts should not be considered as fractures (Tang...
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and Cheng, 2004). Auxiliary data such as the gamma ray, neutron porosity, bulk density, compressional and shear slownesses should be used to identify chevron patterns due to bed boundaries. Thus, we can categorize the characteristic chevron pattern due to fracture that indicates that the tool has logged across an impedance contrast.

**Case studies of Segmented Completion Technique in Neelam field:**

The benefits of this quick integrated analysis assisted in modifying segmentation strategy efficiently with 5 swell-packers compared to initial plan of 3 swell-packers in isolation of possible zones for water break-through in three wells (Figure-8, 9, 10) and integrated analysis result was available for decision making within couple of hours from logging, thus reducing decision time (Kisku et al., 2019).

![Completion Design](image)

**Figure 7:** Modification in segmentation strategy efficiently with 5 swell-packers compared to initial plan of 3 swell-packers for isolation of possible zones for water break-through.

**1. Well A:**

The parent well was producing with 92% water cut before sidetracking. The objective was to exploit the un-drained area between various platforms. This sidetrack well was drilled as an oil producer in Bassein pay. 6” DH was drilled with RSS-LWD with HGS-NDDF mud. Applying this segmented completion technique (described in Figure 8), well flowed oil with initial 10% water cut in a sustainable manner and with a significant delay in early water cut increment during production.

**2. Well B:**

The parent well was producing sub-optimally oil with high water cut @ 98%. The performance of the well indicated that the well had de-saturated around its drainage area and therefore it was planned to sidetrack the well towards the area with good oil saturation and better reservoir facies. This well B was completed as an oil producer in 6”DH in Bassein pay. 6” drain hole was drilled with RSS-LWD with NDDF-HGS mud. Applying segmented completion technique (described in Figure 9), well flowed oil with initial 30% water cut in a sustainable manner and with a significant delay in water cut increment during production.

**3. Well C:**

The parent well was producing oil with 96.8% water cut. This well B was completed as an oil producer in 6”DH in Bassein pay. 6” DH was drilled with RSS + LWD + Stethoscope. Sonic-Scanner log was recorded in 6” drain hole section. CMR log was planned but it could not be recorded due to held up in this well. Applying segmented completion technique (described in Figure 10), well started flowing oil with initial 15% water cut with a much reduced water cut than earlier production data.

**Conclusion:**

The latest generation sonic tools use multiple receivers and multi frequency sources to get more information about compressional and shear velocities, formation damage, fractures characterization, rock anisotropy and lateral facies changes. Thus Sonic scanner, NMR and LWD basic log data were used for successful implementation of segmented completion of horizontal drain-holes in carbonate environments. All the above three case studies show that this segmented completion technique was successfully implemented to overcome challenges like high water production (>90%), increased cost, short well life, limited accessibility and less productivity. Thus, execution of this technique increased production accessing deeper horizontal areas, with an optimized cost and rig time savings.

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Figure 9: Segmented completion in well B showing various log outputs and interpretation of fractured reservoir and swell packer, blind and perforated tubing placement. Track description from top to bottom: 1: Rock quality; 2: Formation damaged zone; 3: Young’s Modulus, Shear Modulus and Bulk Modulus; 4: NMR permeability and Sonic scanner derived permeability; 5: Measured and modeled Stoneley Reflection coefficients (downgoing and upgoing wave) and Thomsen gamma parameter; 6: Deviation and TVD; 7: Capillary pressure profile; 8: NMR T2 distribution curves’ projection; 9: NMR T2 distribution curves, T2 cut off, T2im_di_cmr; 10: NMR derived permeability curve with facies distribution; 11: Bin porosity and total porosity curves; 12: Free fluid volume, capillary bound water, clay bound water and total porosity curves; density log; 13: Poisson’s ratio ; Vp/Vs ratio; 14: Slowness curves of compressional, shear and stoneley waves; 15: Density, Neutron porosity and PE log curves; 16: Resistivity curves; 17: Rate of penetration, GR log, Bit size and Caliper; 18: Energy anisotropy

Figure 10: Segmented completion in well C showing various log outputs and interpretation of fractured reservoir and swell packer, blind and perforated tubing placement. Track description from top to bottom: 1: CRVP (Compressional radial variation profile); 2: Formation damaged zone; 3: Young’s Modulus, Shear Modulus, Bulk Modulus; 4: Measured and modeled Stoneley Reflection coefficients (downgoing and upgoing) and Thomsen gamma parameter; 5: Stethoscope pressure; 6: Stethoscope mobility; Sonic scanner derived mobility; 7: Deviation and TVD; 8: Poison’s ratio and Vp/Vs ratio; 9: Slowness curves of compressional, shear and stoneley waves; 10: Density, Neutron porosity and PE log curves; 11: Resistivity curves; 12: Rate of penetration and GR log, Bit size, Caliper; 13: Energy anisotropy