Selective Completion Strategies for Optimizing Wormhole Development and Minimizing Near Wellbore Damage in Heavy Oil Using RECON HDD™ Well Logs

Historically, nearly 30% of Heavy Oil wells fail. Poor cement bond, flushed zones caused by mud surge, and improper clean outs are all operational factors that contribute to failure and/or abandonment. From a completions perspective, wells can fail due to: immobility of the sand/oil; near wellbore damage as a result of shale collapse; less permeable rock occluding the perforations; watering out due to typical logs’ inability to identify thin water zones. RECON HDD™ (High Definition Data) logging technology can identify problem areas within a Heavy Oil zone that contribute to these issues that may prevent optimal development of wormholes.

RECON’s HDD™ samples at 132 samples per meter, which is nearly four times greater than industry’s standard (28-40 samples per meter) for high resolution logs, and sixteen times more than industry standard (8 samples per meter) for main pass logs. RECON’s standard non-HDD™ main pass logging resolution is 33 samples per meter, equivalent to the industry standard for high resolution logs.

Typical logging speed for industry standard main pass resolution logs is 9 meters per minute. RECON standard main pass logs, which are the equivalent of industry standard high resolution logs, are run at 9 meters per minute (industry high resolution logs are run at 4 to 5 meters per minute). In comparison, RECON HDD™ logs are run at ~7 meters per minute. These advantages mean more data for the same amount of rig time, equating to better reservoir understanding at no additional cost.

This data allows oil and gas Operators to better employ alternative completion strategies that can enhance wormhole development and decrease occurrence of near wellbore damage which may inhibit production or cause casing failure.

RECON Petrotechnologies Ltd. developed the ability to sample at higher rates than previously seen in industry to allow for increased confidence in log derived porosity when compared to core and for clearer definition of bed boundaries, inter-bedded shale and impermeable layers.

Porosity Compared to Core

To validate HDD™ log porosity values against core plug values, RECON plotted core porosity versus RECON main pass log data and HDD™ log data. Core plug porosity values compared well to the average neutron and density porosities (Table 1 and Figures 1 and 2). The data showed a clear correlation between RECON HDD™ log data and core porosities. The core data compared to a RECON main pass log showed porosity differences up to 2.3%; HDD™ logs showed a maximum porosity variance to be less than 1.0% compared to core. This shows that greater confidence can be placed in log-derived porosity from HDD™ logs for
volumetric calculations, which may result in more accurate reserve estimates. Log data was acquired safely and efficiently with minimal impact to rig time. The result is less dependency on cutting core and, in turn, a decrease in drilling costs.

<table>
<thead>
<tr>
<th>Depth Interval MD (m)</th>
<th>Porosity (%)</th>
<th>Permeability (Horizontal)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Helium</td>
<td>RECON Main Pass Log</td>
</tr>
<tr>
<td>489.01-489.25</td>
<td>34.3</td>
<td>35.0</td>
</tr>
<tr>
<td>489.49-489.72</td>
<td>36.8</td>
<td>34.5</td>
</tr>
<tr>
<td>489.94-490.11</td>
<td>35.2</td>
<td>35.0</td>
</tr>
<tr>
<td>490.28-490.34</td>
<td>34.1</td>
<td>36.0</td>
</tr>
<tr>
<td>490.40-490.83</td>
<td>35.2</td>
<td>36.0</td>
</tr>
<tr>
<td>491.25-491.37</td>
<td>34.2</td>
<td>34.0</td>
</tr>
<tr>
<td>491.48-491.59</td>
<td>35.9</td>
<td>35.0</td>
</tr>
<tr>
<td>491.70-491.87</td>
<td>31.7</td>
<td>33.5</td>
</tr>
</tbody>
</table>

Porosity Difference +/- 2.3% +/- 1.0%

Table 1. Correlation between core porosity and log derived porosity as well as cored interval permeability.

**Figure 1.**

**Figure 2.**

Figures 1 and 2. Core porosity plotted against RECON main pass (33 samples/meter) and HDD\(^\text{TM}\) (132 samples/meter) logs. HDD\(^\text{TM}\) clearly shows better correlation as well as inter-bedded laminations.
Bed Boundary Definition

The following example shows how HDD™ logs can define the zone of interest top and base compared to lower resolution logs more accurately. The main pass log shows the zone top at ~488.5m to ~488.8m, and the base at ~491.7m to ~492.2m. HDD™ logs show the porous zone (greater than 30% porosity) top at 488.8m and base at 491.8m (Figures 3 and 4). Perforations should be offset from overlying shales to reduce the risk of shale collapse and/or spalling as the completely failed region around the wellbore develops. The thickness of this buffer is dependent on the thickness of the zone. Using standard main pass logs, Operators run the risk of not properly offsetting completions/perforations from overlying shales or other more friable rocks. These rocks are more susceptible to near wellbore collapse, resulting in occlusion of perforations and, in some cases, casing damage and/or collapse. This can result in costly workovers and potential loss of the well.

**Figure 3.** RECON Standard 33 samples/meter Log

**Figure 4.** RECON HDD™ 132 samples/meter Log

**Figure 3 and 4.** RECON main pass log (33 samples/meter) and HDD™ log (132 samples/meter) showing top and base of zone of interest. An ideal ~0.5m offset from overlying friable rock is better defined using HDD™.

Impermeable/Less Permeable Layer Definition

A key factor affecting wormhole development is rock permeability. In the case of Heavy Oil, this means the ability to move the oil and sand. RECON plotted horizontal permeability vs. resistivity in order to illustrate the correlation between the LL3 curve and permeability. Figure 5 and 6 show the LL3 curve from RECON standard main pass and RECON HDD™ logs plotted with horizontal permeability (from Table 1). The LL3 curve on the main pass has poor correlation with the core samples; the HDD™ LL3 curve shows a better degree of correlation, allowing Operators to make inferences as to which layers within the zone could be targeted to optimize wormhole development.Adjacent lower permeability layers can act as pillars when higher permeability layers are developed, which can be beneficial in terms of wormhole
growth. These lower permeability layers are relatively more friable and subject to fragmentation due to perforating. This can lead to near wellbore failure resulting in workovers, casing failure or loss of the well.

**Figure 5 and 6.** RECON main pass log (33 samples/meter) and HDD™ log (132 samples/meter) show a high degree of correlation between the horizontal permeability (mD) against the LL3 curve in the HDD™ case.

**Figure 7.** Examples of the types of produced debris that can result from poorly designed completions programs. This has the ability to occlude perforations and incapacitate pumps.

www.reconpetro.com
Conclusions

In the past, the belief was that more holes of a larger size were needed in order to stimulate production. This essentially served to “shake things up” down-hole causing near wellbore instability. This may still be the preferred method of completion, depending on the thickness of the zone of interest. As Operators move away from core areas, they see a need to focus their completions to maximize recovery from thinner, more laminated formations than previously exploited. RECON HDD™ well logs can accurately identify the high permeability layers of a reservoir, allowing an Operator to optimize wormhole development and avoid plugging and/or failure hazards. RECON logs can efficiently and effectively define zone boundaries and inter-bedded friable and/or lower permeability layers.

Increasing reservoir complexity means Operators must look to increase understanding of their zones of interest. A new completion approach for these Heavy Oil reservoirs, using higher resolution log data, has been proposed by various industry professionals. Operators no longer seek to complete a pay zone with the maximum number of large perforation holes as possible. They now believe that focusing perforations on more permeable layers, offsetting perforations from more friable layers and avoiding lower permeability layers will result in better success rates for Heavy Oil wells. RECON has established its HDD™ logging technology as a leader in the ability to differentiate and identify these problem areas and contribute to the success of Heavy Oil wells.

Written By:
Jarett Gough, P.Geol. – Senior Technical Advisor, RECON Petrotechnologies Ltd.

Major Contributions By: Kirby Hayes – Kirby Hayes Incorporated.

Kirby Hayes has an extensive cased-hole wireline background. Currently his company, KHI, established twelve years ago, represents several corporations offering services and products primarily involved in heavy oil production in the Lloydminster area. Kirby has conducted various seminars, short courses and workshops; co-authored technical papers, articles and patent applications, and prepared many presentations on wide-ranging topics of interest to heavy oil producers. Kirby is a member of the Oilfield Technical Society and the Petroleum Society of CIM. He has been an executive for both Societies. Kirby was an integral part of the establishment and the fund raising for the OTS Heavy Oil Science Center. In 2003 he received an Outstanding Service Award from the Petroleum Society for “industrious participation in the affairs of the Petroleum Society and the CIM for guidance and inspiration of the membership, and contribution to the body of knowledge of the Petroleum Industry”.

Acknowledgements:
James Ablett –Senior Account Manager, Enterprise Sales, RECON Petrotechnologies Ltd.
Ron Krawchuk – Reservoir and Production Services, RECON Petrotechnologies Ltd.

For further information please contact RECON Petrotechnologies Ltd. and visit:
Case Study Example

A less aggressive approach is looked at as being the future of heavy oil. The use of shot phasing’s of 120°, 180° or 0° in order to maintain stable pillars within the thinner, inter-layered, more permeable zones, all the while decreasing impact on more friable layers. This can decrease the risk of near wellbore failure and/or fragmenting, which can result in costly workovers and the potential loss of the well. More gradual increases in pressure drawdown are recommended to decrease the risk of destabilizing the near wellbore region as well.

These considerations were taken into account as a potential completion program was developed for the example well shown in this paper.

Figure 8. Suggested completion strategy based on perforation offset from overlying shale and perforation offset from inter-zone less permeable layer. Can also be employed as a strategy to avoid underlying water.
Completions can therefore be carried out either as two separate perforations at the same time, or as individual staged perforations, starting with the uppermost layer until production levels are marginal and then returning to the wellbore to complete the lowermost zone. As a result of this approach the overburden pressure is relieved due to the production of the uppermost portion. This particular approach will lessen the risk of shale collapse and spalling as well as near wellbore damage and perforation plugging due to damage to the less permeable inter-layer.

Based on industry recommendations for development and the use of RECON HDD™ well logs to identify issues that may arise, one can see the potential to significantly reduce the unacceptable 30% failure rate that is commonplace in today’s industry.
Further Examples:

Example 1: Potential Thin Bottom Water

This example shows a Sparky Heavy Oil zone on a typical 1:480 miniplot scale (Using RECON 33 samples/meter data). The zone of interest is defined from 615.5m to 619.8m. This is an ideal example of a thin bottom water zone which is one of the primary reasons for heavy oil well failure and/or abandonment. Without properly offsetting the perforations in order to minimize the impact on the underlying impermeable shale barrier, Operators run the risk of creating pathways for water migration and ultimately having the well water-out prematurely. Typically, Operators would complete this well from 615.5m to 618.0m.

Figure 9. Sparky Heavy Oil Target with thin bottom water. Typical completion would be to perforate from 615.5m to 618.0m. Great care must be taken to avoid fracturing the underlying shale and opening up pathways for water migration from the thin water layer beneath.
Using RECON HDD™ logs, the completion strategy can be revised to optimize wormhole development while decreasing the risks of fracturing the underlying shale and having the well water out. With the increased resolution, Operators can see the bed boundary definition of the underlying shale clearly. Perforations can then be placed from 616.0m to 617.4m allowing for the proper offset from the shale and, in turn, resulting in better wormhole development in the more permeable layer of the zone. The underlying shale can then act as a barrier preventing water inflow. This limits the risk of causing near wellbore damage to the underlying shale. By maintaining this buffer zone between the base of the perforation and the shale, you decrease the risk of water inflow and subsequent loss of the well due to premature watering out.

**Figure 10.** HDD™ pass of Example 1 log showing a thin shale lamination overlying thin bottom water. With HDD™, perforations can be accurately offset from the underlying shale and thin water in order to prevent fracture of the shale causing pathways for water migration resulting in the well watering out prematurely.
Example 2: Less Permeable Zone Definition

This example shows a Sparky Heavy Oil zone on a typical 1:480 miniplot scale (Using RECON 33 samples/meter data). Traditionally, the top and base of the completed interval would be 604.5m to 611.2m respectively. The miniplot tends to over-estimate the porosity for the uppermost sand sequence, while under-estimating the porosity of the lowermost sand sequence. Typical completion strategies for this well would be to shoot all of the zone or the uppermost sand (604.5m to 606.0m) and the lowermost sand (608.8m to 611.2m). By doing this, Operators run the risk of fracturing the overlying shale and causing near wellbore shale collapse and spalling, as well as perforating into a less permeable zone within the lowermost sand which may inhibit wormhole development.

Figure 11. Typical Sparky Heavy Oil target. Traditional completion program would be to shoot the entire zone from 604.5m to 611.2m or two separate completions of 604.5 to 606.0m and 608.8m to 611.2m.
Using RECON HDD™, logs the completion strategy can be revised to optimize wormhole development while decreasing the risks of near wellbore collapse and subsequent casing failure. With the increased resolution, Operators can see that the uppermost sand is not as clean as shown on the miniplot and may offer some difficulty in terms of effective wormhole development as a result of the lower permeabilities demonstrated by the LL3 curve. The HDD™ logs also show the bed interfaces more clearly between shales and sands, as well as less permeable layers within the lowermost sand. With this information, Operators can offset the completions in order to optimize wormhole development, while decreasing near wellbore effects such as shale collapse and/or spalling, and perforation plugs as a result of the perforating process.

Figure 12. HDD™ pass of Example 2 log showing shale interbeds and permeability barriers. Suggested completion intervals and timing shown may help decrease the risk of near wellbore failure as well as increase effective wormhole development by targeting more permeable horizons.
**Example 3: Inter-bedded Shale Lamination**

This example shows a Sparky Heavy oil zone that has cut out the General Petroleum (G.P.) on a typical 1:480 miniplot scale (Using RECON 33 samples/meter data). Traditionally, the top and base of the completed interval would be picked at 590.0m and 595.0m respectively. The miniplot tends to under-exaggerate the internal structure of the zone and makes it difficult to resolve any inter-bedded shales and less permeable features. Historically, this zone would be completed with one perforation spanning from 590.0m to 595.0m. By doing this, the internal structure is not recognize, and you run the risk of shale collapse and near wellbore damage that may result in the plugging of the perforations or, in the worst case, near wellbore collapse and costly workovers or loss of the well.

**Figure 13.** Sparky Heavy Oil target. Traditional completion program would be to shoot the entire zone from 590.0m to 595.0m.
Using RECON HDD™ logs, the completion strategy can be revised to optimize wormhole development while decreasing the risks of near wellbore collapse and subsequent casing failure. With the increased resolution, multiple thin bed shale laminations within the zone can be identified that could result in fragmentation and perforation occlusion as a result of the perforating process. A completion program that offsets perforations from these layers can be designed that will allow for optimal wormhole development within the most permeable layers of the zone. By completing the zone less aggressively, using the recommended shot phasing and suggested timing, an Operator has the ability to increase the success rate of this well as well as similar reservoirs.

Figure 14. HDD™ pass of Example 3 log Zone Of Interest showing shale interbeds that cannot be identified with Standard logs. Suggested completion intervals and timing shown may help decrease the risk of near wellbore failure as well as increase effective wormhole development by targeting more permeable horizons.