HIGH PERMEABILITY CONDUITS IDENTIFICATION FOR WELL PERFORMANCE IMPROVEMENT IN MUMBAI HIGH FIELD

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ABSTRACT

Mumbai High North field has production history of more than 35 years from multilayer carbonate reservoirs. During the initial years, the production was clean oil, but after water injection, water cut started. Presently, the average water cut of different layers ranges from 10 to 80%.

In some of the wells, it is observed that even with good oil saturation predictions (through logs and reservoir model), the production has been high with high water cut. In extreme cases, water cut even reaches 100%. Production Logging survey indicates that in some of these wells, production is mainly through thin streaks having thickness less than 1m. Also, salinity of produced water indicates that this is mainly injection water. This injection water should ideally provide sweep and pressure support, but its circulation harms the performance of the field in two ways - one, precious injection water is wasted and two, it does not allow oil to be produced from the rest of the layer leaving the bypassed oil in the reservoir.

This high productivity index of layer is due to high permeability of thin conduit. This is indicated by sharp build up of bottom hole pressure during well shut in. These high permeability (K) conduits have also found to have specific signatures on the Neutron Density logs. This trait is found both in producers and water injectors.

In first case study, high permeability conduits were identified from production log survey in a well which produced 2275 BLPD with 97% water cut after side track to new location. Closing of the conduit was attempted by squeezing cement and selectively perforating avoiding suspected conduits. After work over, well flowed 563 BLPD with 73% water cut giving oil gain of 90 BOPD. The plugging the circulating conduit at producer end resulted retaining of 1500 BWPD injected water in the reservoir, which gave gradual improvement in well performance.

In second case study, the producer well was closed due to 100% water with 2200 BLPD. Circulating conduit (from logs) was tracked to nearby water injector. The water injector was temporarily closed. The result was immediate gain of 100 BOPD which gradually increased to 200 BOPD in 10 months.

The two case studies indicate that closing water circulating conduits may have good potential in the improvement of field performance.

INTRODUCTION

Mumbai High field located about 165 km WNW of Mumbai city, is the largest and most prolific oil field in India. The field has been divided into two blocks - North and South based on a relatively low permeability zone.

The North field was put on production in May 1976. It achieved a peak production of about 1,52,000 BOPD in May 1986 and maintained a plateau period for about six years. The field has been developed with water injection which started in March 1984. Till now, 335 MMm3 water has been injected. Water cut in the field started in June 1984 and has gradually increased to 69%. The field has cumulatively produced around 150 MMt of oil with 150 MMm3 of water till 01.04.2011. Oil recovery of about 23% has been obtained.

Mumbai High North field is an anticline with eastern boundary fault. Structure is gently dipping towards west with 1.5 to 2°. The pays are of Miocene age, at 900-1400m depth and overlain by Pleistocene to recent clay/claystone sediments. The pays are classified from shallowest to deeper depth as LI, LII, S1 and LIII. The LII and LIII pays are the major oil reservoirs.
Lithology of LII & LIII is white to dirty white, micritic, fossiliferrous limestone with shale partings. LII has two sub units, namely, LII A and LII B. Unit LII B is further divided into B-a, B-b, B-c, B-d, B-e, B-f sub-layers. These sub-layers are separated by thin shale bands. Similarly LIII is divided into LIII A1, A2-I, A2-II, A2-III, A2-IV, A2-V, A2-VI, A2-VII, N, B, C, D, E sub layers separated by 1-3 m shale bands. Both reservoirs have gas-caps and limited aquifer support.

The field is currently producing oil at the rate of 75,000 BOPD through 280 strings with average water cut of 70% and GOR 213 v/v. Fifty percent of the strings are horizontal drain holes in one/two sub-layers. Currently, around 15 strings are producing with more than 90% water cut. Some of these are recently side tracked wells, where higher oil production was expected. One of such wells MHNX#A, after side track to new location produced only 61 BOPD with 97% water cut against expected oil rate of 250 BOPD from A2-VII & B. Another well MHNX#B completed in horizontal drain holes in LII B-c and LII B-d flowed 2200 BLPD with 100% water cut. Reasons for high water for these two wells have been diagnosed and following appropriate action, the performance of these wells has drastically improved. Case history of these two wells is the subject of this paper.

**CASE HISTORY OF PRODUCER WELL MHNX#A**

Well MHNX#A was drilled in year 1986 in SE direction with approximately 1500 m horizontal drift at LIII top. Vertical well MHNX#V on the platform, drilled at the same time. Logs (Figure-1 & Figure-2) indicate that LIII in both wells have similar nature and sub-layers have similar reservoir characters with good chances of continuity in the area.

In well MHNX#A, sub-layers A2-V, A2-VI and A2-VII (1876-1888m) were on production from 1986 to 2006 and cumulative oil production was 0.43MMt. The oil rate had declined to 168 BOPD with 70% water-cut. In January 2006, during work over for making short radius drain hole, all the open intervals were squeezed and cased hole...
formation resistivity was recorded. The Figure-1 also shows the cased resistivity of year 2006 as black dots superimposed on open hole resistivity logs of year 1886. Fairly un-depleted oil saturation was observed in the interval 1992-1995m of LIII B. Accordingly, SRDH was made in this sub-layer in the month of January 2007. Drain hole initially produced 286 BOPD with 30% water cut. However, by April 2010, water cut increased to 57% and oil rate declined to 133 BOPD. At this stage, the well was side tracked to new location towards platform, midway between vertical well MHNX#V and MHNX#A.

Open hole logs of the side tracked well MHNX#Az are given in Figure-3. Log indicated partial depletion with resistivity of 6-8 ohm.m compared to original resistivity of 10-15 ohm.m in A2-VII and B of well MHNX#V and MHNX#A (Figure-1 & Figure-2). Even with oil saturation observed in year 2010, A2-VII and B in well MHNX#A are expected to produce oil with 75% water cut. The well was completed single with 3 ½” tubing and gas lift in A2-VII (1551-1560m) and B (1563.5-1572m).

Test data of stabilized flow as on 28-July-2010 was: FTHP: 234 PSI, GIP: 910 PSI, oil rate of 61 BOPD, liquid rate of 2273 BLPD, gas rate of 4598 SCMD, water cut of 97% and produced water salinity of 28,665ppm. Formation water salinity is ~22,000ppm of NaCl and salinity of injection water is 33,000 ppm of NaCl.

Field model had predicted 250 BOPD with 70% water cut. The high water cut was neither in conformity with field model prediction nor with recorded log characteristics. The first suspect was bottom water, which was present at 1580m, 8m (5.5m in tvd) below the bottom most perforation (Figure-3). However, salinity of produced water (28,665ppm) was close to injection water salinity (33,000ppm) indicating injection water breakthrough. To confirm water source, production logging was carried out.

During stabilization of flow, it was observed that flowing bottom hole pressure (FBHP) was high (more than 1710 PSI), flow was un-stabilized and flow meter spinner was varying 0-5 rotation per second. After gas injection was augmented, though the flow stabilized, FBHP remained still high. The production log indicated that almost all the production is from 1551-1553m of A2-VII. Other open intervals1553-1560m of A2-VII and 1563.5-1572m of B layer were not contributing any appreciable amount (Figure-4). Flowing bottom hole pressure at 1551m was recorded as 1705 PSI. With one hour of shut in, bottom hole pressure was 1715 PSI and in next 11 hours, it increased only by 5 PSI to reach 1720PSI.

The high liquid flow rate of the order of 3000 BPD at small draw down of less than 30 PSI from thin layer was inferred to indicate presence of high permeability conduit in the well. It was interpreted that the conduit was creating
high FBHP, which in turn was not allowing other layers to produce. The high permeability conduit was characterized by drop in shallow resistivity and density value of open hole logs of MHNX#Az (Figure 4).

Based on the production logging results, work over program was designed to squeeze cement in all the layers and open selectively avoiding suspected high permeability layers. The opened layers were 1557-1560 m of A2-VII and

- Squeezed all perforations
  - A2-VII : 1551-1560m
  - B : 1563.5-1572m
- Selectively perforated
  - A2-VII : 1557-1560m
  - B : 1565-1570m

Figure- 4 Flow meter response in well MHNX-Az and open hole logs with pre & post work over perforation
1565-1570 of B layer. The intervention was successful in reducing water circulation as indicated by lower salinity of produced water and resulted in oil gain (Table-1).

<table>
<thead>
<tr>
<th>Test date</th>
<th>FTHP</th>
<th>Liquid Rate BLPD</th>
<th>Water Content</th>
<th>Oil BOPD</th>
<th>Water BWPD</th>
<th>Total Gas M3 day</th>
<th>Remarks</th>
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<tr>
<td>04-07-10</td>
<td>234</td>
<td>1,904</td>
<td>94</td>
<td>121</td>
<td>1,783</td>
<td>38,077</td>
<td>Well diverted to main, on 04.07.10</td>
</tr>
<tr>
<td>16-07-10</td>
<td>241</td>
<td>2,257</td>
<td>97</td>
<td>65</td>
<td>2,192</td>
<td>25,883</td>
<td></td>
</tr>
<tr>
<td>28-07-10</td>
<td>234</td>
<td>2,273</td>
<td>97</td>
<td>61</td>
<td>2,212</td>
<td>25,819</td>
<td>Salinity=28665ppm,</td>
</tr>
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</table>

Work over

<table>
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<tr>
<th>Test date</th>
<th>FTHP</th>
<th>Liquid Rate BLPD</th>
<th>Water Content</th>
<th>Oil BOPD</th>
<th>Water BWPD</th>
<th>Total Gas M3 day</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>06-10-10</td>
<td>241</td>
<td>562</td>
<td>73</td>
<td>149</td>
<td>413</td>
<td>31,967</td>
<td>Salinity=26910ppm,</td>
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<td>19-03-11</td>
<td>241</td>
<td>516</td>
<td>72</td>
<td>147</td>
<td>369</td>
<td>33,210</td>
<td></td>
</tr>
<tr>
<td>26-05-11</td>
<td>256</td>
<td>513</td>
<td>59</td>
<td>212</td>
<td>301</td>
<td>40,207</td>
<td>Salinity=23400ppm,</td>
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<tr>
<td>11-09-11</td>
<td>256</td>
<td>466</td>
<td>52</td>
<td>225</td>
<td>241</td>
<td>42,063</td>
<td>Salinity=23985ppm,</td>
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</table>

Table 1: Production performance before and after work over for closing high permeability conduit.

Case history of producer well MHN#D

The well MHN#D was side tracked in Oct-2006 and two short radius drain holes (SRDH) were made in LII B-c and one in LII B-d. During drilling drain hole in B-d, mud loss was observed during drilling due to which one hole was terminated short of target depth. The well was completed single with gas lift. Well initially flowed 332 BOPD with 82% water cut. The oil rate gradually decreased and the well was closed in May-10 due to 100% water cut. 

Analysis for this anomalous water-cut was carried out. It was seen that well MHN#CWI, a conventional water injector in LII B-c, d, e, f located approximately 500m away from multilaterals of wells MHN#DOP (Figure-5) may be responsible for water cut. The reservoir pressure of water injector well MHN#C WI from bottom hole pressure fall off (PFO) studies and reservoir pressure of oil producer well MHN#DOP from influx studies were compared. Avery good correspondence between pressures of the two wells was observed (Figure-6).
Open hole log correlation of well MHN#C and MHN#D (Figure-7) shows characters of LII B-c and LII B-d are same in the two wells and there is likelihood of good reservoir continuity. Approximate drain holes’ placement is plotted on the logs (Figure-7) wherein the arrows indicate zones having suspected high permeability conduits. To identify the maximum water in-taking zone, production logging in MHN#C was attempted but data could not be recorded due to obstruction at 1463m which is with in perforation. The production logging was planned with the objective of finding injection profile.

Salinity of produced water was 32,700 ppm of NaCl (Table-2). This value is very close to the salinity of injection water, which is 33,000 ppm. The salinity of formation water in LII is about 20,000ppm. From consideration of i) salinity of produced water, ii) injector–producer reservoir pressure correspondence, iii) good porosity and iv) mud loss history during drilling indicate that one or more high permeability layer (s) are circulating water from MHN#C WI to MHN#D OP.

Since layer specific data was not available, water injector well MHN#C WI was closed on 14-June 2010. Had it been known that particular layer is responsible for water circulation; only that layer could have been closed. The test data of oil producer is given in table-2

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Liquid Rate (BLPD)</th>
<th>Oil Rate (BOPD)</th>
<th>Water Rate (BWPD)</th>
<th>W/C %</th>
<th>SAL (PPM)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-Dec-09</td>
<td>2263</td>
<td>206</td>
<td>2058</td>
<td>91</td>
<td>32760</td>
<td></td>
</tr>
<tr>
<td>26-Apr-10</td>
<td>1769</td>
<td>145</td>
<td>1624</td>
<td>92</td>
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<td></td>
</tr>
<tr>
<td>14-May-10</td>
<td>2201</td>
<td>19</td>
<td>2182</td>
<td>99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-May-10</td>
<td>2189</td>
<td>0</td>
<td>2189</td>
<td>100</td>
<td></td>
<td>Closed on 16.05.10</td>
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</tbody>
</table>

Table-2 Production test data of well MHN#D OP before intervention in well MHN#C WI
The effect of closing water injector was positive in oil producer. The well MHN#D OP started producing oil, which gradually increased to around 200 BOPD. Salinity of produced water also showed downward trend and reduced to

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Liquid Rate (BLPD)</th>
<th>Oil Rate (BOPD)</th>
<th>Water Rate (BWPD)</th>
<th>W/C %</th>
<th>SAL (PPM)</th>
<th>REMARKS</th>
</tr>
</thead>
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<td>30-Jul-10</td>
<td>2404</td>
<td>102</td>
<td>2302</td>
<td>96</td>
<td>32175</td>
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<td>11-Sep-10</td>
<td>2276</td>
<td>178</td>
<td>2098</td>
<td>92</td>
<td>27495</td>
<td></td>
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<tr>
<td>05-Oct-10</td>
<td>2439</td>
<td>199</td>
<td>2240</td>
<td>92</td>
<td>31590</td>
<td>Acid spotting 4th Oct'10</td>
</tr>
<tr>
<td>06-May-11</td>
<td>2472</td>
<td>192</td>
<td>2280</td>
<td>92</td>
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<td></td>
</tr>
</tbody>
</table>

Well MHN#C WI was closed on 14th June 2010

Table-3 Production test data of well MHN#D OP after intervention in well MHN#C WI

CONCLUSIONS

High permeability conduits are active in Mumbai High North field. These conduits are responsible for injection water circulation from injector to producer, suppressing production from other open layers. Identification of these conduits is possible by production logging. Mud loss during drilling, sharp static bottom hole pressure build up, low density (high porosity) of formation as seen in open hole logs and injector-producer pressure correspondence are found as indicators for presence of high permeability conduits. It is possible to reduce water circulation by intervention either in producer or in the injector to improve production performance of the well.

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REFERENCES


ABOUT AUTHORS

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Shailendra Kumar Verma: Born 23-11-1953, Petroleum Engineer from ISM Dhanbad, has 34 years of experience as Reservoir Engineer in the national E&P company. Has lead all spheres of field development from green field to brown field development. Presently, he is Sub-surface Manager of Mumbai High Asset.