P 075

**Petrophysical Studies of Hazad Formation from Jambusar Field**

Sanjiv Satyarthi * J P Lakhera, Dipika Solanki, A K Jain

**Summary**

The current work, presents petrophysical studies on twelve selected core segments, identified and provided by CEWELL. The project has undertaken by CEWELL on Re-Evaluation of logs of Hazad formation of Jambusar field. The objective of the study is for better understanding of depositional environment and the hydrodynamic behavior of the sands. Petrophysical studies have been carried out and data on Effective Porosity ($\Phi_e$), Air Permeability ($K_a$), Irreducible water saturation ($S_{irw}$), pore size distribution (PSD) pattern and Electrical resistivity parameters “$a$, $m$ & $n$” have been generated.

**Keywords:** Porosity, permeability, Irreducible water saturation, Archie's Constant, “$a$”, Cementation Factor, “$m$” & Saturation Exponent, “$n$”

**Introduction**

The current work is carried out Petrophysical studies of Hazad formation of Jambusar field to generate factual petro-physical data on twelve selected core segments from JAMBUSAR# A (cc-1) JAMBUSAR#B(CC-2 & cc-4) JAMBUSAR #C (CC-3) & JAMBUSAR# D (cc-1 & cc-3)

**Method**

Core samples were extracted to completely remove original reservoir fluid and salt by using toluene & mixture of acetone-methanol respectively, dressed & dried at 60°C for about 5-6 hours as per API, RP-40, 3.12 & 3.13. Laboratory experiments were carried out to generate following parameter:

1) Effective Porosity ($\Phi_e$), Grain and Bulk Density as per API RE-40, 3.30, 3.31, 3.32 & 4.3
2) Air Permeability ($K_a$) by Ultra-Perm™ 400F (Core Lab. USA). $K_a$ values are corrected for Klinkenberg’s slippage effect as per API RP-40, 3.4, 3.5.15 & 4.4
3) Capillary Pressure parameters by Mercury Injection Capillary Pressure (MICP) technique and following parameters were generated:-
   - Displacement ($P_d$)
   - Pore Size Distribution (PSD) pattern
   - Irreducible Water Saturation ($S_{irw}$)
4) Electrical resistivity measurements by AERS-702, Ambient Electrical Resistivity System,Coretest systems, USA at 200gpl brine for computation of :-
   - Archie’s Constant, “$a$”, Cementation Factor, “$m$” & Saturation Exponent, “$n$”

![Figure 1](image1.png)

**Results & Discussions**

**Basic Petrophysical & Mercury Injection Capillary pressure (MICP) studies:-**

The data on basic petrophysical parameters of sixteen from samples from JAMBUSAR# A, CC-1, JAMBUSAR # B,
CC-2, & CC-4, JAMBUSAR # C, CC-3, JAMBUSAR # D, CC-1, & CC-3, are given in Table-1. The capillary pressure parameters like $P_d$, PSD pattern & $S_{irw}$ are given in Table-2. The curve of $C_v$ vs. $S_w$ as % of pore space for all the eight studied samples are given in Fig.-1. The analysis of data suggests that:
- Effective porosity ($\Phi_e$) ranges from 1.89 – 21.93 %.
- Air permeability varies from 0.01 - 99 md.
- Grain density ranges from 2.55 – 3.20 gm/cc whereas bulk density values are in between 1.88-1.98 gm/cc.
- MICP studies on eight samples for illustrating the interconnection/distribution of the pore throats/pore aperture radii & to assess $P_d$ & to estimate PSD pattern and $S_{irw}$.
- MICP studies exhibit better interconnection & better distribution of the pore throats & pore aperture radii along with favorable (0.5 - 20 Kg/cm$^2$) $P_d$. $S_{irw}$ varies from 11 – 66%.

Electrical Resistivity Measurements (“a, m & n” Parameters)–“a, m & n”, Hazad Formation of Jambusar Area

Electrical resistivity measurements at 100% brine saturation was performed on twelve samples for the computation of “a” & “m” whereas de-saturation studies at partial saturation was performed on four samples for “RI vs Sw” data at limiting salinity of 200gpl brine for the estimation of “n”. The computed “a, m & n” values from Hazad formation of Jambusar field are 1.0092, 1.758 & 2.404 respectively, Table-3 & Fig.-2(A+B).

**Conclusions**

The following conclusions are drawn, based on the study of cores from JAMBUSAR# A, CC-1, JAMBUSAR # B, CC-2, JAMBUSAR # B, CC-4, JAMBUSAR # C, CC-3, JAMBUSAR # D, CC-1 & JAMBUSAR # D, CC-3.
- Effective porosity ($\Phi_e$) ranges from 1.89 – 21.93 % & geometric mean $\Phi_e$=14.85%.
- Air permeability varies from 0.01 - 99 md & geometric mean $K_a$=0.38 md.
- Grain density ranges from 2.55 – 3.20 gm/cc whereas bulk density values are in between 1.88-1.98 gm/cc (Table-2).
- Mercury Injection capillary pressure studies exhibit the presence of macro & mesopore.
- The pore geometry is mainly fabricated by 10 to 55% macro (10-25 µm) & 8 to 50% meso (1-10 µm).
- Displacement ($p_d$) and Threshold pressures ($P_{th}$) pressure are favorable (0.5-20 Kg/cm$^2$) for the initiation of smooth displacement of wetting phase and entrapment / accumulation of non-wetting up to larger available pore space.
- Port pressure ($P_{35}$) i.e the minimum buoyancy pressure required to accumulate 35% NWP is also favorably low (1.0-15 Kg/cm$^2$) against the studied section.
- Non-wetting phase (NWP) saturation ranges from 34-90% whereas irreducible water saturation (Sirw) is around 10-66%.
The computed “a, m, n” values from Hazad formation of Jambusar Field are 1.0092, 1.758 & 2.404 respectively.

Acknowledgements

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Table-1: Basic Petrophysical Data, Hazad Formation of Jambusar Field

<table>
<thead>
<tr>
<th>S. N.</th>
<th>Well No./CC No./Int.</th>
<th>Segment</th>
<th>Lab. S.N. Position in piece</th>
<th>$\Phi_e$ %</th>
<th>$K_x$ md</th>
<th>G.D. gm/cc</th>
<th>B.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>JAMBUSAR/A, CC-1</td>
<td>T-4, 11cm</td>
<td>274.8cm</td>
<td>16.87</td>
<td>*</td>
<td>2.64</td>
<td>2.33</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>T-10, 16cm</td>
<td>275.12cm</td>
<td>21.93</td>
<td>21.70</td>
<td>2.63</td>
<td>2.22</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>T-22, 14cm</td>
<td>276.4cm</td>
<td>14.33</td>
<td>0.14</td>
<td>2.62</td>
<td>2.36</td>
</tr>
<tr>
<td>4</td>
<td>JAMBUSAR # B, CC-2</td>
<td>T-1,12cm</td>
<td>277.8cm</td>
<td>21.92</td>
<td>99.00</td>
<td>2.62</td>
<td>2.22</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>T-2,14cm</td>
<td>278.2cm</td>
<td>17.82</td>
<td>*</td>
<td>2.58</td>
<td>2.26</td>
</tr>
<tr>
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<td>T-27, 10cm</td>
<td>279.10cm</td>
<td>15.60</td>
<td>68.03</td>
<td>2.60</td>
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</tr>
<tr>
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<td>T-8,18cm</td>
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<td>0.01</td>
<td>2.57</td>
<td>2.32</td>
</tr>
<tr>
<td>9</td>
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<td>T-27, 15cm</td>
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<td>0.01</td>
<td>2.55</td>
<td>2.28</td>
</tr>
<tr>
<td>10</td>
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<td>T-13,16cm</td>
<td>283.2cm</td>
<td>18.08</td>
<td>0.01</td>
<td>2.64</td>
<td>2.33</td>
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<td>11</td>
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<td>T-13,14cm</td>
<td>284.14cm</td>
<td>14.45</td>
<td>0.012</td>
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<td>2.32</td>
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<tr>
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<td>T-15,12cm</td>
<td>285.10cm</td>
<td>12.15</td>
<td>*</td>
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<tr>
<td>13</td>
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<td>T-27, 16cm</td>
<td>286.14cm</td>
<td>12.95</td>
<td>*</td>
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<td>2.89</td>
</tr>
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<td>14</td>
<td>JAMBUSAR # D, CC-1</td>
<td>T-9,19cm</td>
<td>287.5cm</td>
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<td>4.08</td>
<td>2.55</td>
<td>2.17</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>T-28, 14cm</td>
<td>288.14cm</td>
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<td>7.76</td>
<td>2.58</td>
<td>2.22</td>
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<td>16</td>
<td>JAMBUSAR # D, CC-3</td>
<td>T-17,15cm</td>
<td>289.2cm</td>
<td>19.20</td>
<td>0.11</td>
<td>2.64</td>
<td>2.28</td>
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* irregular Core pieces

Table-2: Mercury Injection Capillary Pressure (MICP) Data, Hazad Formation of Jambusar wells.

<table>
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<tr>
<th>S. N.</th>
<th>Well No./CC No./Int.</th>
<th>Segment provided</th>
<th>Lab. S.N. Position in piece</th>
<th>$\Phi_e$</th>
<th>$K_r$</th>
<th>$S_t$rw</th>
<th>$P_{d}$</th>
<th>$P_{th}$</th>
<th>$P_{35}$</th>
<th>PSD Pattern % $&gt;10\mu$</th>
<th>$&gt;1\mu$</th>
<th>$&lt;1\mu$</th>
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<tbody>
<tr>
<td>1</td>
<td>JAMBUSAR/A, CC-1</td>
<td>T-10, 16cm</td>
<td>275.12cm</td>
<td>21.93</td>
<td>21.7</td>
<td>13</td>
<td>1.8</td>
<td>2.0</td>
<td>3.0</td>
<td>Nil</td>
<td>62</td>
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<tr>
<td>2</td>
<td>JAMBUSAR # B, CC-2</td>
<td>T-1,12cm</td>
<td>277.8cm</td>
<td>21.92</td>
<td>99.0</td>
<td>0.7</td>
<td>0.75</td>
<td>1.2</td>
<td>4.5</td>
<td>35</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>T-2,14cm</td>
<td>278.2cm</td>
<td>17.82</td>
<td>*</td>
<td>12</td>
<td>0.7</td>
<td>0.8</td>
<td>2.5</td>
<td>15</td>
<td>50</td>
<td>35</td>
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<tr>
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<td>T-27, 10cm</td>
<td>279.10cm</td>
<td>15.60</td>
<td>68.03</td>
<td>10</td>
<td>0.5</td>
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<td>30</td>
<td>15</td>
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<td>JAMBUSAR # B, CC-4</td>
<td>T-8,18cm</td>
<td>282.15cm</td>
<td>15.34</td>
<td>0.01</td>
<td>66</td>
<td>20</td>
<td>25</td>
<td>-</td>
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<td>Nil</td>
<td>100</td>
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<td>6</td>
<td>JAMBUSAR # C, CC-3</td>
<td>T-13,16cm</td>
<td>284.14cm</td>
<td>14.45</td>
<td>0.012</td>
<td>59</td>
<td>10</td>
<td>15</td>
<td>-</td>
<td>Nil</td>
<td>8</td>
<td>92</td>
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<tr>
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<td>T-27, 16cm</td>
<td>287.5cm</td>
<td>21.68</td>
<td>4.08</td>
<td>45</td>
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<td>0.85</td>
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<td>25</td>
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<td>JAMBUSAR # D, CC-1</td>
<td>T-9,19cm</td>
<td>288.14cm</td>
<td>20.48</td>
<td>7.76</td>
<td>25</td>
<td>0.5</td>
<td>0.55</td>
<td>1.6</td>
<td>10</td>
<td>52</td>
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<tr>
<td>S. N.</td>
<td>Lab. S.N.</td>
<td>Position (m)</td>
<td>Ka (md)</td>
<td>Area</td>
<td>Length (cm)</td>
<td>RESIS. (ohm-m)</td>
<td>Ro (ohm-m)</td>
<td>Formation Factor FR</td>
<td>Fractional Porosity</td>
<td>RI</td>
<td>Sw, %</td>
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<tr>
<td></td>
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<td>T-10.16cm</td>
<td>21.93</td>
<td>5.07</td>
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<td>57.506</td>
<td>0.733074</td>
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<td>T-22.14cm</td>
<td>0.14</td>
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<td>80.736</td>
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<td>T-1.12cm</td>
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<td>T-2.14cm,10cm(T)</td>
<td>68.03</td>
<td>5.06708</td>
<td>3.759</td>
<td>58.681</td>
<td>0.791012</td>
<td>12.71907</td>
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<td>T-1.13cm,11cm(T)</td>
<td>0.01</td>
<td>5.07506</td>
<td>5.211</td>
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<td>80.40016</td>
<td>0.0189</td>
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</table>

RI vsSw, n = 2.772 at 200gpl
Position: T-10,16cm, φe=21.93%, Ka=21.70md, Jambusar # A, CC - 1

RI vsSw, n = 2.269 at 200gpl
Position: T-1,12cm, φe=21.92, Ka= 99.00md, Jambusar # B, CC - 2

RI vsSw, n = 2.35 at 200gpl
Position: T-2,14cm,10cm(T), φe=15.60%, Ka=69.03md, Jambusar # B, CC - 2

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Table 3: “a, m & n” HAZAD FORMATION OF JAMBUSAR FIELD

JAMBUSAR # A, CC-1

JAMBUSAR # B, CC-2

JAMBUSAR # B, CC-4
<table>
<thead>
<tr>
<th></th>
<th>Sample</th>
<th>Depth</th>
<th>Vol %</th>
<th>Porosity</th>
<th>Water Saturation</th>
<th>Oil Saturation</th>
<th>Gas Saturation</th>
<th>R1 (ppm)</th>
<th>R2 (ppm)</th>
<th>R3 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>281</td>
<td>T-8,18cm,2cm(T)</td>
<td>0.01</td>
<td>5.09104</td>
<td>4.035</td>
<td>97.714</td>
<td>1.232877</td>
<td>19.82404</td>
<td>0.1430</td>
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<tr>
<td>7</td>
<td>282</td>
<td>T-8,18cm,15cm(T)</td>
<td>0.01</td>
<td>5.03919</td>
<td>3.726</td>
<td>87.607</td>
<td>1.184832</td>
<td>19.0515</td>
<td>0.1534</td>
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<tr>
<td>8</td>
<td>283</td>
<td>T-13,16cm,2cm(T)</td>
<td>0.01</td>
<td>5.02716</td>
<td>3.092</td>
<td>67.054</td>
<td>1.090204</td>
<td>17.52994</td>
<td>0.1808</td>
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<tr>
<td>9</td>
<td>284</td>
<td>T-13,16cm,14cm(T)</td>
<td>0.012</td>
<td>5.04715</td>
<td>2.689</td>
<td>97.245</td>
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<td>T-9,19cm,5cm(T)</td>
<td>4.08</td>
<td>4.89697</td>
<td>4.706</td>
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<td>8.906279</td>
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<tr>
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<td>T-9,19cm,14cm(T)</td>
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<td>0.659836</td>
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</table>

RI vs Sw, n = 3.688 at 200gpl

Position: T-9,19cm,14cm(T), *Φe=20.48%, Ka=7.76md, Jambusar # 47, CC - 1*

<table>
<thead>
<tr>
<th></th>
<th>Sample</th>
<th>Depth</th>
<th>Vol %</th>
<th>Porosity</th>
<th>Water Saturation</th>
<th>Oil Saturation</th>
<th>Gas Saturation</th>
<th>R1 (ppm)</th>
<th>R2 (ppm)</th>
<th>R3 (ppm)</th>
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<tbody>
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<td>12</td>
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