DEEPA™ Stimulation of Natural Fracture Networks in Austin Chalk

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Summary
DEEPA™ in-situ acidizing of natural fracture networks in the Austin Chalk enhances production from hydrocarbon producing wells in this formation. Laboratory tests confirmed that DEEPA™ acidizing of fractured Austin Chalk core material increases fracture conductivity. A field trial in a depleted Austin Chalk well with low reservoir pressure increased total fluid and gas production rates by 50 - 100%. Full stoichiometric acid generation was attained with 100% dissolution of the predicted quantity of carbonate as determined from soluble calcium measurements on back produced spent DEEPA™ fluid.

DEEPA™ stimulation of newly drilled horizontal sections in an adjacent Austin Chalk well, where production was steadily declining successfully increased the oil production rate. Production has stabilized at 60% above the pre-stimulation rate and there was an estimated 65% increase in estimated ultimate recovery (EUR).

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1. Background

DEEPA™ is a catalyst based technology for the in-situ production of acid within oil/gas well-bores and reservoirs. The technology has been proven in the field for deep matrix acidizing of oil producer and water injector wells and Cleansorb is developing the use of DEEPA™ for a range of other acidizing applications with U.S. and European based operators.

The Austin Chalk formation in Texas is characterised by very low matrix permeability, typically <1mD, combined with natural fracturing. Oil within the rock matrix has to migrate into the natural fracture system in order to be produced by wells intersecting the fracture network(s). To date, attempts to stimulate production via acidizing have been ineffective. The high rate of reaction between conventional acids and carbonate rock prevents such acids penetrating deep into the fracture network before it spends. DEEPA™ offers a means of acidizing deep within the micro-fracture network to increase fracture conductivity and increase production rates in formations such as Austin Chalk.

Conventional stimulation treatments in the Austin Chalk rely on large volume water fracs requiring 10 - 20 pump trucks and ancillary equipment for each treatment. Even relatively large DEEPA™ treatments can be pumped using standard oilfield equipment e.g. 1-2 pump trucks, a blender unit and a couple of frac tanks for holding/mixing DEEPA™ fluid.

DEEPA™ fluid is low hazard and non-reactive when pumped. Typically no corrosion inhibitors are required and DEEPA™ constituents and reaction products are low toxicity and readily biodegradable.

2. Laboratory Tests

Prior to field work, laboratory tests were carried out at an independent laboratory to assess the effect of DEEPA™ acidizing on the conductivity of fractures in Austin Chalk cores. Due to the difficulty in obtaining representative naturally fractured cores, non-fractured Austin Chalk core material was selected and a fracture was induced in the laboratory along the length of the core.

In order to ensure fluid flows through the fractures and not around outside of the core during tests, the cores were held in a sealing sleeve with a confining pressure of 1,000 p.s.i. The effect of in-situ acidizing of the induced fractures
using DEEPA™ was assessed by comparing the conductivity of fractures before and after DEEPA™ treatment. Three DEEPA™ formulations were tested. The respective changes in fracture conductivity after treatment with formulations 1, 2 and 3 were: +23%, -18% and -59% (formulation 2 produces twice as much acid as formulation 1; formulation 3 produces twice as much acid as formulation 1 but twice as fast).

The interpretation of these results by the test house and the operator was that DEEPA™ had produced acid and dissolved material at the fracture face. Low levels of dissolution of material from the fracture face (observed with formulation 1) produced an increase in fracture conductivity. As the extent of dissolution of material from the fracture faces increased (formulations 2 and 3), surface irregularities which held the fracture open were dissolved and the fracture closed under the high confining pressure leading to an apparent reduced fracture conductivity.

The reduction in conductivity observed with formulations 2 and 3 was considered to be an experimental artefact which actually indicated successful acidizing.

Down-hole, where natural fractures remain open due to the distribution of stresses in the formation natural fractures are unlikely to be subject to compressive forces. The operator and Cleansorb agreed that down-hole, DEEPA™ treatments should dissolve material from within fractures that remained open thereby in all likelihood increasing fracture conductivity. As the next stage in the evaluation process, a DEEPA™ acidizing treatment was carried out in a depleted vertical well with low reservoir pressure to demonstrate in-situ acid production and carbonate dissolution under reservoir conditions.

3. Field Test 1. - DEEPA™ Acidizing in an Austin Chalk Vertical Well

3.1 Well Selection

The selected well was in the Austin Chalk and had several adjacent wells suitable for future DEEPA™ trials. Core material for these wells was not available so testing proceeded to field trials (the laboratory tests had been conducted on Austin Chalk cores from other wells).
3.2 Formation Characteristics

Austin Chalk; Permeability <1md; Porosity 10%; BH Temp. 190°F - 200°F.

3.3 Treatment Outline

A 100 ft vertical interval was treated as follows:

- 1300 bbls slick water pre-flush
- 300 bbls DEEPA™ formulation 2 (see section 2.)
- 175 bbls slick water post-flush

All stages were pumped at approximately 10 bbls/min which was below the fracture initiation pressure.

The well was shut in for 72 hours and back production of injected fluids initiated via swabbing until produced water was relatively free from particulates. The down-hole pump was re-installed on day 5 (post treatment) and oil production, water production, gas production and calcium levels in the produced water were monitored over the following 50 days.

3.4 Field Tests Results

Preparation and injection of DEEPATM fluid was carried out according to plan with no operational problems. A brief summary of well production data is given below:

<table>
<thead>
<tr>
<th></th>
<th>Pre-DEEPA Production</th>
<th>Peak Production</th>
<th>Production at day 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas mcfd</td>
<td>17</td>
<td>38</td>
<td>34</td>
</tr>
<tr>
<td>Oil bpd</td>
<td>10</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td>Water bpd</td>
<td>16</td>
<td>57</td>
<td>28</td>
</tr>
</tbody>
</table>

By day 50 all the 1880 bbls of injected treatment fluid had been recovered from the well. Following the trial the well was taken off production prior to abandonment as originally planned.

3.5 Extent of Acidizing Down-hole

The extent of acidizing achieved down-hole was evaluated by comparing the
cumulative amount of soluble calcium in the produced water with the amount which would be released by complete conversion of acid precursor into acid and reaction of the acid with carbonate (injected fluids are normally fully recovered from Austin Chalk). The calculated cumulative quantity of soluble calcium in the produced water up to day 50 is consistent with there being 100% conversion of acid precursor into acid and reaction of acid with the formation (see Figure 1. below).

Figure 1.

3.6 Conclusions and Actions

The initial trial met 3 key treatment objectives:

- Production was stimulated
Effective acidizing was achieved down-hole with high levels of conversion of acid precursor into acid and stoichiometric calcium dissolution

- DEEPA™ acidizing did not create formation damage or impair production

4. **Field Test 2 - DEEPA™ Acidizing in an Austin Chalk Horizontal Well**

4.1 Well Selection

Following the success of the initial field test where fluid production was stimulated in an old vertical well, a larger DEEPA™ acidizing treatment was carried out on an Austin Chalk dual horizontal lateral re-entry drilled from an existing vertical well located close to the first trial well.

4.2 Formation Characteristics

Austin Chalk: Permeability <1 md; Porosity 10%; BH Temp. 190°F - 200°F.

4.3 Treatment Outline

On completion of drilling the new dual horizontal laterals the well was put on production for approximately 3 months to establish the production decline curve before DEEPA™ stimulation. A DEEPA™ stimulation was then carried out with the objective of acidizing the fracture network feeding the 2 new horizontal laterals:

800 bbls of a high strength DEEPA™ formulation that produced approximately 10% acid equivalent *in-situ* was pumped to formation down the tubing annulus. As DEEPA™ fluid is low-corrosivity when pumped the down-hole pump and sucker rods were left in place.

50 bbls of water was then pumped so as to displace DEEPA™ fluid from the vertical section of the well-bore.

The well was shut-in for 72 hours to allow *in-situ* acid production to occur.
Production was started and oil and water production rates were monitored to assess the effect of stimulation in comparison with the predicted production decline curve pre-stimulation.

The combined volume of both open hole horizontal sections was 100 bbls so the volume of DEEPA™ fluid pumped allowed for 700 bbls to be displaced into the fracture network surrounding the new horizontal sections. By leaving the well bores filled with DEEPA™ fluid it was expected that residual drilling damage in the form of Austin Chalk drilling cuttings fines might also be removed.

4.4 Treatment Results

Pre and post stimulation oil production data are shown in Figure 2 below. From a situation where oil production was steadily declining, DEEPA™ acidizing stimulated production. The DEEPA™ treatment stabilized oil production at around 60% above the pre-stimulation rate.

4.5 Conclusions and Actions

The operator judged the treatment to be a success.

Figure 2.