1.3 Weatherford Scaling Tests

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Weatherford International are a large company providing products and services to the oilfield industry. Laboratory tests were performed in order to determine if Hydroflow could be used to prevent scaling in oil wells. Weatherford have since purchased a license to manufacture the technology and have exclusive rights to treating limescale in "up-stream" oil and gas field applications.

Method of Testing
Water was passed through narrow tubes and simultaneously heated. The pressure due to blockages was measured and the tubes examined by eye. The water contained ions that cause both barium sulphate scale and calcium carbonate scale (limescale). Tube of different diameter were used and the flow rate was altered.

Figure 1.3: The scaling of an untreated pipe (left) compared to a pipe treated with Hydropath (right) (page 10).

Results
Without treatment, the pipe became blocked in just seven minutes (test 1A, page 4). The blockage was solid and it took a high pressure to clear it (page 4). The Hydropath unit used was shown to cause the scale to form in suspension rather than on the surfaces of the tubes. In tests 1 and 2, the

tubes used for testing were very narrow and the water had a very low flow rate, so a small pressure increase can be seen in the treated system until the water washes away the precipitate (page 5). Test 3 used a $\frac{1}{4}$ inch tube with a higher flow rate.

The difference in the amount of scale formed on the pipes with and without Hydropath was observed visually. Not only was there significantly more scale on the untreated system, but it could easily be seen that the scale was hard and required manual scraping, unlike tin the treated system, where the deposits were soft, powder-like and easily brushed away.

WEATHERFORD INTERNATIONAL INC.

CLEARWELL SCALE INHIBITION RESEARCH STUDY

Prepared for

Weatherford

Prepared by

Hycal Energy Research Laboratories Ltd.

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Tony Ma
General Manager
Weatherford – Hycal Laboratories
Calgary, Canada

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SUMMARY

Study Objective

At the request of Mr. Stuart Ferguson of Weatherford International Inc. (Weatherford), Hycal Energy Research Laboratories Ltd. (Hycal) conducted a laboratory study to investigate the viability of a technology known as *Clearwell Hydropath* scale inhibition. The objective of this study was to evaluate the Clearwell Hydropath scale inhibition unit to determine if the unit prevented scale on pipe walls for field applications. Weatherford is considering licensing or acquiring the technology to provide as a service to its clients. The unit is designed to create an electrical field around tubing. This electrical field in turn creates seed crystals held in suspension in the aqueous phase. These seed crystals act as sights for other crystals to attach and grow rather than attaching to the tubing walls to create scale. As the crystals grow, they are carried in suspension in the aqueous phase (see Appendix B for Clearwell technical data).

Conclusions

The following conclusions are provided to enhance understanding of the laboratory data and offer additional insight relative to Hycal's experience with laboratory and field processes. They represent our interpretation as to possible mechanisms and physical phenomena that may be occurring within the laboratory models that have been studied.

These laboratory experiments are micro-scale representations of the field scenario; however, macro-scale phenomena may override behaviour exhibited in the laboratory. A more thorough development of these conclusions is presented in the "Discussion" section.

1. A tube block experiment was designed to create an environment for the potential of barium sulfate scale using incompatible brines with a salinity of 90,000 ppm.

2. The system was heated to 50°C and run atmospheric pressure.

3. The results indicate that use of the Clearwell Hydropath technology reduces the tendency of scale formation on tubing walls by the formation of seed crystals creating adhesion sights while in suspension in an aqueous phase.

4. See "Discussion" section for a detailed description of the experimental sequence.

5. The manufacturers also claim that the unit can inhibit corrosion and bacteria. It is recommended that a separate study be commissioned to investigate these claims.

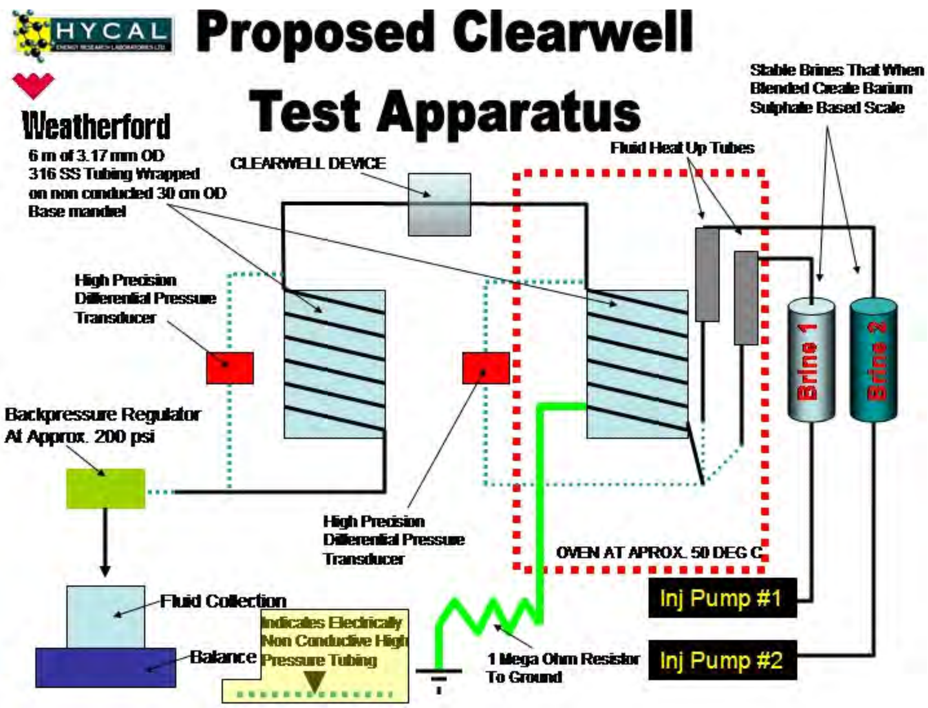
6. We recommend that the Clearwell Hydropath unit be field tested to verify the laboratory results.

DISCUSSION

Test 1: Dynamic Tube Block Test Using ⅛" Tubing Coils/Barium Sulfate Scaling Brines

Test 1A: Untreated

Test 1 was performed at 50°C using the following apparatus:



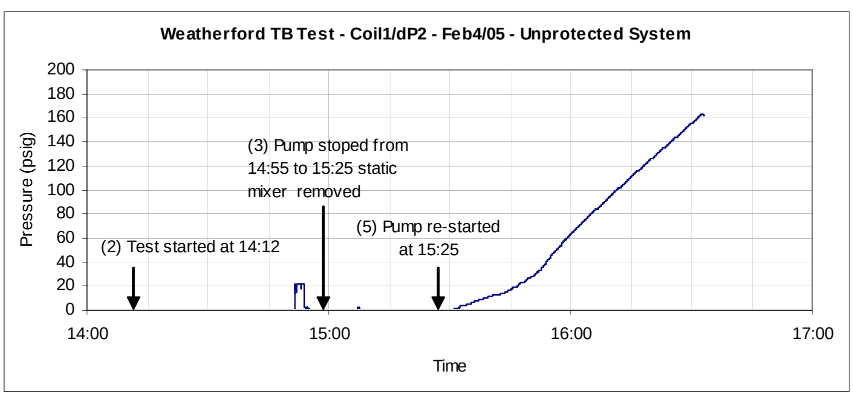
Set-up Outside Oven

Set-up in Oven

Test 1A was performed using a heated injection coil of each incompatible brine (see Appendix A for compositions) into a mixing zone followed by a ⅛ " diameter heated tube block coil. Pressure differential was measured across the tube block coil to monitor the effect as scale formed to block the tube. Another coil was set up outside the oven, downstream of the first coil. Pressure differential was also monitored on the second coil. The entire system was calibrated with de-ionized water to obtain a baseline pressure differential. The baseline pressure differential across the entire system was 0.2 psig.

Each brine was housed in a large capacity transfer vessel and injected using a positive displacement pump. The brines were injected simultaneously into individual heated injection coils and mixed at a junction just upstream of the heated tube block coil. The flow rates used were 50 mL/hour for each brine, for a combined rate of 100 mL/hour. This rate is approximately equivalent to 2 bbl/day of flow through a 2" diameter pipe. This is considered a very low flow rate.

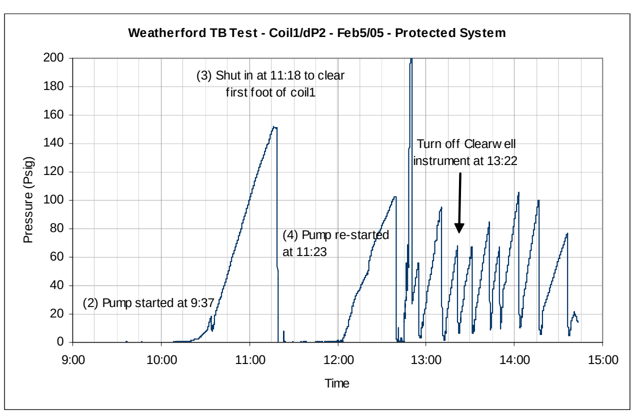
The first test was not treated with the Hydropath unit and pressure build-up was observed in seven minutes, resulting in plugging of the system with barium sulfate scale (see pressure profile of the upstream heated coil below). It should be noted that the test was attempted twice. There was a packed static mixer in-line initially which plugged. The static mixer was removed and the test was restarted. It took a total of 1100 psig pressure using distilled water to flow through the plug once it was established.



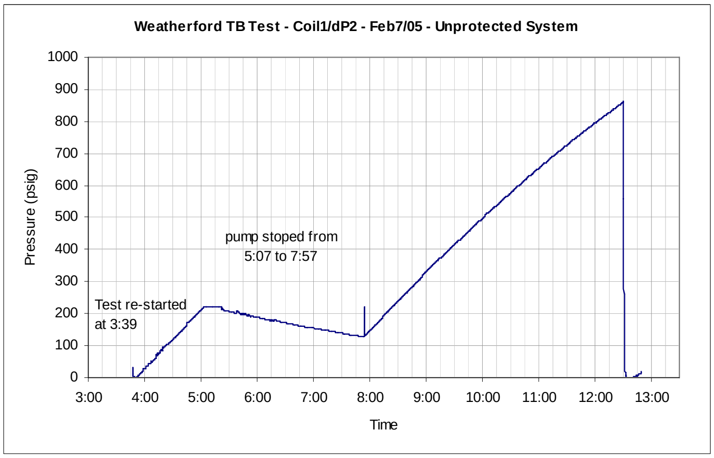
Test 1B: Hydropath Treated System

This test was run identically to the untreated test with the exception that the Clearwell Hydropath unit was placed in line between the tube block coil inside the oven and the tube block coil outside the oven (see photo below).

The results of this experiment showed that pressure began building after 45 minutes of flow. This pressure build-up continued for another 90 minutes. The system was opened at the mixing junction to remove build-up of precipitate. The flow continued for a period of time until plugging was observed. The plug broke free at approximately 100 psig and pressure began building until the plug broke free again. This cycle continued for an hour. The Hydropath unit was turned off and flow continued to see if the scale would form and plug the system off completely. This did not occur after 90 minutes (see pressure profile below).



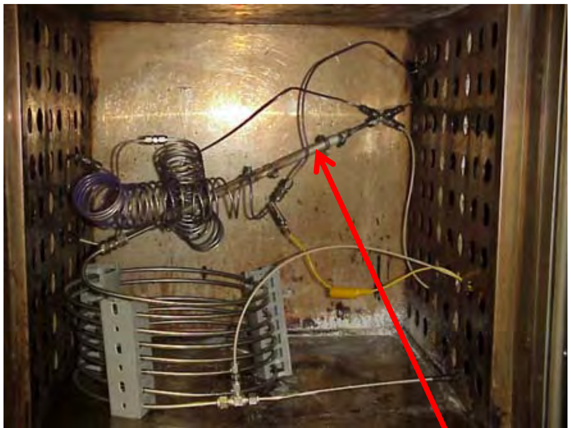
The system was shut-in with the Hydropath unit turned off for 36 hours and then restarted. This time the system plugged off completely. The conclusions that can be drawn from this effect are that the entire flow loop, including the injection brines, were treated and resulted in the seed crystal being formed. When the unit was first shut off, scale did not form due to a lingering effect from the treatment. Only when the system was shut off for 36 hours was the scale able to form as the seed crystals were no longer available in the system.



Test 2: ¼" Tube Block Test Using Barium Sulfate Scaling Brines

Test 2A: Untreated with ¼" Tubing

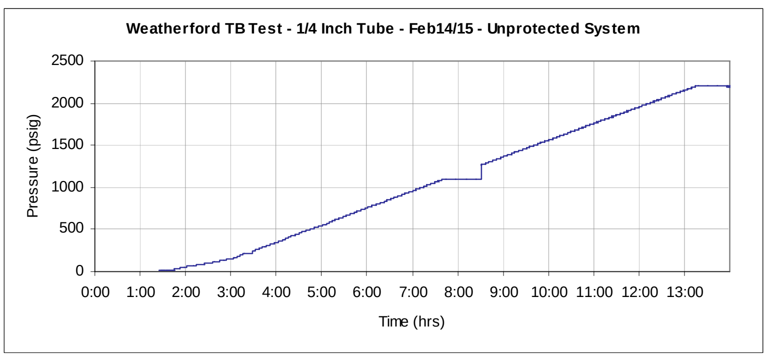
This test was devised to the flow through a larger bore tubing so that the large seed crystals could remain in suspension and flow through the system rather than plug off due to settling in restrictions. The apparatus was exactly the same as the previous experiment with the exception of the tube block coils and downstream lines which were all ¼" tubing rather than ⅛". Also, an observation coupon was placed in line just below the mixing junction so we could observe the formation of scale during flow. The thought was that we could observe scale in the untreated test and see no scale in the subsequent treated test. Below is a photograph of the observation tubing in line. The tubing was machined by cutting a window using EDM techniques.

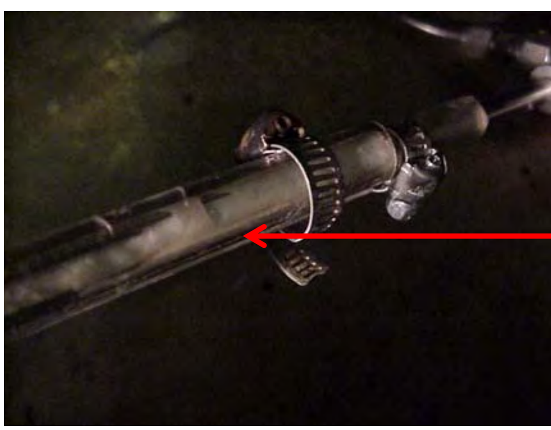


Observation Window In Line

Close-up of Observation Window

This experiment showed pressure build-up after only 45 minutes of flow. This resulted in the observation window plugging up with scale and precipitate in approximately three hours. Flow was continued for 10 hours (see pressure profile below).



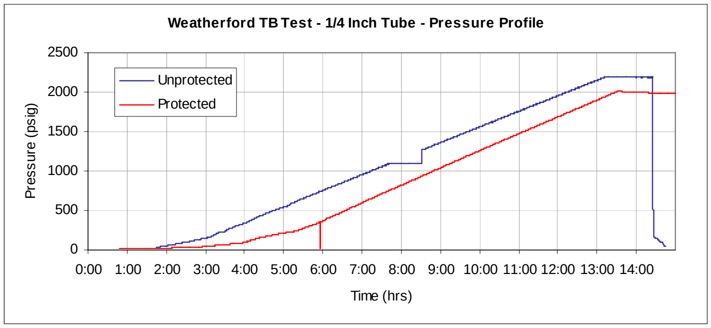


Precipitate in Window

Photo of Plugged Tubing

Test 2B: Treated with ¼" Tubing

The test was repeated with the Clearwell Hydropath unit in-line as in Test 1B with ⅛" tubing, with the exception that ¼" diameter tubing was used. This time we observed similar behaviour to the untreated test with a delay of about two hours. The system still plugged but it was determined that the plugging was due more to the precipitation of solids because of low flow rates and not the scaling of the tube walls (see comparison pressure profile below).



Test 3: ¼" Tube Block Test at High Flow Rates Using Incompatible Barium Sulfate and Calcium Carbonate Brines

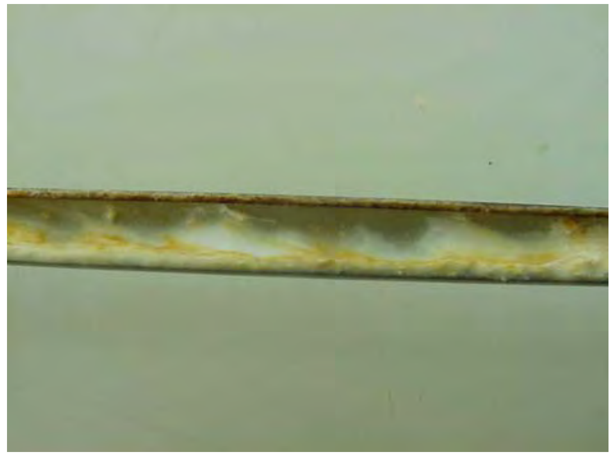
Test 3A: Untreated System

This test was designed to incorporate the large diameter tubing coupled with a higher flow rate to determine if settling in the system is a result of scaling or low flow rate. Also, the brine was changed to include a calcium carbonate component in addition to the barium sulfate scale used previously. The visual window was in place in this test.

The flow rate was increased to 300 mL per hour on each of the two brines plus a 3000 mL/hour flow of distilled water for a total flow rate of 3600 mL/hour. This is equivalent to approximately 70 bbl/day of flow through a 2" diameter pipe.

There was no pressure across the system to speak of (less than 1 psig). This indicated that there was no plugging due to settling. The flow continued for a three-hour period when it became obvious from visual observation in our windowed coupon that scale precipitation had occurred. The system was dismantled and severe scale build-up on the walls of the tubing and in the injection end was observed (see photographs below). Once the scale had dried, it required mechanical scraping to remove.

Injection End of Tubing



Scale Build-up in Tubing

Test 3B: ¼" High Flow Rate Treated with Hydropath Unit

The test was repeated with the Clearwell Hydropath unit in line. The flow was initiated over a three-hour period to replicate the untreated test. Once again, there was very little pressure differential even at the high flow rates. The test was discontinued after three hours and the windowed test coupon was removed and dismantled. The difference in the injection end of the tube and the pipe itself was dramatic. When the tubing was still wet, there did not appear to be any residue or scale formation. Once the tubing dried, there was a thin film of precipitate but it was easily brushed off, indicating that crystals were settling out of the brine film rather than scaling.

Comparison of Untreated Tube (right) to Treated Tube (left)

Untreated Tube (left) Treated Tube (right)

It is obvious from these photographs that tubing treated with the Clearwell Hydropath unit is cleaner than the untreated tubing.

DESCRIPTION OF EQUIPMENT

Pressure Measurement

Pressure differential is monitored using Yokogawa pressure transducers. The transducers are mounted directly across the core and measure the pressure differential between the injection and production ends. The pressure transducers have sensitivities ranging from 0 to 2 psig and 0 to 4000 psig and are rated as accurate to 0.01% of the full-scale value. The appropriate transducer size is selected based upon the expected permeability and associated range of accompanying differential pressures for a given core sample. The signal from the pressure transducer appears on a multi-channel digital terminal from which the test operator records pressure readings during the displacement processes. The signal can also be downloaded to a computerized continuing data acquisition system for long-term runs.

Temperature Control

The core holder and associated injection fluids are contained in a temperature controlled air bath to simulate reservoir temperature. The oven contains a circulating air system to eliminate internal temperature gradients and can control at temperatures from 20 to 200°C with a rated accuracy of ±1°C.

APPENDIX A

Brine Compositions

APPENDIX B

Clearwell Technical Data