Enhanced Inhibitor Retention through Surface Precipitation and Molecular Interaction

Ping Chen, Thomas Hagen, Torstein Haaland and Tom Berge; Champion Technologies
Rex Wat, Olav Martin Selle, Hans Kristian Kotlar, Jens Olav Sæten and Pål Skillingstad; Statoil

Abstract

One of the major targets in designing an inhibitor squeeze treatment is to maximum the treatment life. This will lower the need for well interventions and hence will provide a more cost effective solution. Through a joint research program, a polymer additive had been developed and used as a rock surface charge modifier. This additive increased the number of favourable adsorption sites for the scale inhibitor, hence yielding an extended squeeze life.

Recently, as a continued effort through the joint research program, a new approach using the same polymer additive to further enhance squeeze life has been identified. This utilises a surface precipitation/interaction mechanism in addition to the enhanced adsorption attributed by the surface charge modification. As a result the overall inhibitor retention has been increased thereby further extension of squeeze life was achieved. This surface precipitation/interaction approach is different from a conventional precipitation squeeze where calcium is used. Also, unlike the conventional precipitation squeeze, the additive can be pre-injected and rapidly adsorbed on a rock surface. The subsequently injected inhibitor will react with the additive on the rock surfaces. This avoids the bulk precipitations where a permeability reduction was often caused by a conventional precipitation squeeze.

In this paper, the detailed experimental data and field data are presented. The mechanism of the surface precipitation and interaction between the additive and scale inhibitor are discussed.

1. Introduction and Background

Norne oil field is located at about 80 km north of Heidrun field and roughly 200 km from the north Norwegian coast. The field has been developed with a production and storage ship tied to sub-sea templates. Production started from the field in November 1997. Seawater breakthrough was recorded in some of the wells since 2004. Following deterioration in well performance, scale dissolver and inhibitor squeezes were performed from 2004.

Since Norne field has horizontal wells, the inhibitor placement was a challenge in order to achieve a good inhibitor squeeze life and prevent the wells from the scale damages. Although the strategy of combining squeezes with dissolver treatments was considered acceptable, a more effective long-term solution to the treatment of scaling in these horizontal wells is needed. As part of the evaluation program in the development of inhibitor placement methods in a horizontal well for Norne field, it was agreed that an investigation of techniques to extend scale inhibitor squeeze life would be undertaken.

In order to achieve a good inhibitor squeeze life, it is essential to maximum inhibitor retention without damaging the formation for an inhibitor squeeze treatment. Scale inhibitors can be retained in the reservoir by a number of mechanisms including adsorption and precipitation. The retention mechanism will be dictated by the inhibitor type and concentration, brine chemistry including pH, reservoir temperature and rock mineralogy. At lower pH, the weakly acidic scale inhibitor will tend to be more protonated/associated and thus can be retained on the rock surface through hydrogen bonding and Van der Waals forces. At higher pH, the scale inhibitor will tend to be more dissociated and thus can be retained on the rock surface by a number of mechanisms including weak Van der Waals forces and static electric forces due to metal ion bridging. Literature search shows that tremendous efforts have been made in the research into the new methods in the design of the longer inhibitor squeeze lifetime. In 1992, it was reported that an enhanced inhibitor adsorption could be achieved from a surface binding process due to the presence of calcium ions (i). The calcium ions may modify either the electro-chemical properties of the solid surface or they may complex with the inhibitor to aid adsorption. This calcium-enhanced adsorption process has been referred as the surface precipitation. Apart from the surface charge modification using Ca^{2+} to increase an inhibitor adsorption, Ca^{2+} is often used in an inhibitor precipitation squeeze treatment to extend the treatment life. In the precipitation squeeze, the Ca^{2+} is thought to react to a scale inhibitor, forming a complex of Ca^{2+}/inhibitor. At an appropriate temperature, pH and concentrations, Ca^{2+}/inhibitor complexes will turn into precipitates, resulting an increased inhibitor retention hence extending an inhibitor treatment life. A paper published in 1997 showed that the solubility and dissolution rate of Ca^{2+}/inhibitor complex precipitates had a significant influence on the inhibitor return concentration during back production stage of the inhibitor core floods (ii).

Instead of involving calcium, a method was introduced in 2000 in order to achieve a good inhibitor retention. In this method, inhibitor retention could be enhanced by the ester cross-linking of polycarboxylic scale inhibitors, leading to an improved inhibitor return curve (iii).

Since 2000, under a joint Statoil – Champion Technologies research program, several chemical additives have been identified that could be used to provide an effective method to improve an inhibitor squeeze life. The experimental test method and field results in the applications of these additive have been outlined in the recent publications (iv), (v) & (vi).

The technology is based on the modification of the rock surface charge to create a more positively charged and less repulsive surface to the negative charged scale. The additive contained the desired functionality to adsorb onto the more negatively charged rock surface. It is believed that the adsorbed additives present a less negatively charged surface than the rock itself, altering the double layer and thereby the interaction forces between chemicals and the mineral surface with which the scale inhibitor compounds can interact. The inhibitor was expected to be adsorbed on the additive coated rock surfaces through static electric forces, hydrogen bonding and Van der Waals force. The pre-treatment of the reservoir zone with the additive or a combination of the squeeze chemical and the additive is therefore expected to enhance the scale inhibitor adsorption through a bridging-type mechanism.

When one of the additives (bridging agents) was tested for the inhibitor applications in Statfjord and Norne oil fields, it was found that under a given pH, temperature and concentration, the additive reacted with a selected scale inhibitor, forming white gel like precipitates. The precipitates could dissolve when the solution pH, chemical concentration and temperature are changed. The further investigations showed that the dissolving process of formed precipitates could be a hydrolysis process in which the inhibitor dissociated from the additive. Like the process of calcium/scale inhibitor precipitation in improving an inhibitor squeeze life, the precipitation interaction between the additive (bridging agent) and scale inhibitor may significantly increase the inhibitor retention and hence extend an inhibitor treatment life. In other words, under a controlled manner with given pH, temperature and chemical concentrations, the pre-flushed additive will react with the subsequently injected scale inhibitor, leading to a precipitation and increasing the inhibitor retention. Unlike the conventional calcium/inhibitor precipitation squeeze, the additive (bridging agent) can be pre-injected and rapidly adsorbed on a rock surface (vii). The subsequently injected inhibitor will react with the additive on the rock surfaces. This avoids the bulk precipitations where a permeability reduction was often caused by a calcium/inhibitor precipitation squeeze.

Based on the above observations, a research program was set up to carry out comparative tests to study the inhibitor precipitation/additive interaction method as outlined below:

- Beaker tests to compare inhibitor retention levels with and with inhibitor precipitation/additive interactions.

- Core floods to compare inhibitor return profiles with and with inhibitor precipitation/additive interactions.

In this paper, the laboratory details and results for the above comparison study are firstly presented. As a part of the study program, the inhibitor dynamic loop tests were also performed and results are presented. Finally, a field result is discussed.

2. Experimental Details

The laboratory test work reported in this paper was performed using the following materials:

Brine: 6% of NaCl brine, synthetic seawater and Norne formation brine. The brine chemistry of the formation brine and seawater is presented in Table 1.

Chemicals:
Inhibitor A = Phosphorus end-capped co-polymer.
Inhibitor B = Phosphorus end-capped co-polymer.
Additive C = Multi-functional additive (bridging agent)

In the test program, candidate scale inhibitors considered for use in the field were tested using OSPARCOM guidelines through independent GLP approved laboratories. The independent GLP tests confirmed that both Inhibitor B and Additive C provided satisfactory environmental properties. Both Inhibitor B and Additive C are classified as 'yellow' and Inhibitor A is classified as "red" under SFT guidelines. Inhibitor B and Additive C were thus environmentally acceptable for applications in the Norne field.

Rock Substrate: All core materials used in this study were representative of the main production interval under investigation.

Basic Tests: Industry standard test procedures were performed to confirm that the inhibitors were compatible with Norne produced brines and seawater and were thermally stable under Norne test conditions. In addition, the compatibility of the additive with Norne produced brines and seawater was evaluated, its thermal stability was confirmed.

Dynamic Loop Tests: Dynamic scale loop tests were undertaken to evaluate the performance of Inhibitor B under Norne conditions. The tests were performed under worst-case barium sulphate scaling conditions (50/50 synthetic Norne formation water and synthetic seawater).

The conditions for the dynamic loop tests were:

- Temperature: 98°C
- pH: 5.5
- Flow rate: 10ml/min.
- System Pressure: 100 psi
- Inhibitors: Inhibitor B with and without Additive C.

The test coil was pre-scaled in the absence of scale inhibitor to create a standard test surface. The minimum inhibitor concentration (MIC) was identified as the lowest concentration of scale inhibitor required to prevent an increase in differential pressure of more than 1 psi over a three-hour test period.

Experimental Procedure of Adsorption (Bridging)/Precipitation Beaker Tests

A representative reservoir core material was used throughout this study. The core materials were crushed and sieved to less than a 2 mm size fraction. The disaggregated rock material was then allowed to dry before the adsorption tests. The adsorption test procedure can be summarised as follows:

- Prepare Inhibitor A at 10,000 ppm and Additive C at 10% 6% NaCl (w/w) brine respectively.

- Adjust the pH of these stock solutions to the required values. The pH of the 10% solution of Additive C in 6% NaCl was adjusted to 3 whilst the 10,000 ppm of Inhibitor B solutions were adjusted to pH 3 and 5 respectively.

- Weigh out 16 gram of disaggregated rock material and transfer into a 100 ml jars.

- Add 32 ml of the pH adjusted Additive C solutions and mix with the crushed core. The bottles were then placed in an oven pre-heated to 85 °C.

- After 5 hours, replace 25 ml of the supernatant with an equal volume of the pH adjusted scale inhibitor solution. After 24 hours, the inhibitor concentrations in the supernatants were then analysed and scale inhibitor adsorption was calculated.

- This test was repeated in the absence of Additive C using just 6% NaCl brine at the required test pH to condition the crushed core prior to introduction of the scale inhibitor under evaluation.

All tests were performed at 85°C and not at reservoir temperature due to safety precautions in the lab. Blank samples without scale inhibitor and control samples without crushed core were included in the tests.

Inhibitor B was analysed by direct measurement of the phosphorus content via Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP).

Experimental Procedure of Core Flood Tests

Core floods were designed to evaluate the effect of the Additive C on the return profiles of Inhibitor B. However, the interaction/precipitation between Inhibitor B and Additive C was controlled by adjusting the pH of 10% inhibitor B solutions. For Core flood 1, the pH of 10% inhibitor solution was adjusted above neutral where there was no precipitation interactions when 10% additive C was mixed with 10% Inhibitor B solution. For Core flood 2, 10% inhibitor B solution was made at a pH of ~3 to ensure a precipitation interaction between Inhibitor B and Additive C.

The synthetic Norne formation water used in the core flood study was adopted to prevent the formation of scale during the long term flooding of the core plug. Sulphate ions were omitted and the brines were filtered through a 0.45 mm membrane filter prior to use. The brine was adjusted to pH 5.5 prior to injection.

Outline Procedure for the comparative Core floods 1 and 2:

- Initial synthetic formation brine injection.
- Overnight crude saturation and heat up to 98°C.
- Pre-treatment permeabilities to crude oil in forward flow (FF) and reverse flow (RF) directions, T = 98°C.

- Pre treatment brine saturation to Sor at 98°C.
- Pre treatment brine permeabilities at Sor in FF and RF directions, T = 98°C.
- Formation water injection in RF direction (Norne FW) at 98°C.
- Preflush injection (5 pore volumes of 10% Additive in 6% NaCl brine) in RF direction at 98°C.
- Shut in (5 hours) at 98°C.
- Main chemical injection (10 pore volumes, 10% Inhibitor B in 6% NaCl brine at pH above neutral (Flood 1) or at pH ~3 (Flood 2)) in RF direction at 98°C.
- Shut in (overnight) at 98°C.
- Oil injections and peameabilities to crude oil in forward flow (FF) and reverse flow (RF) directions, T = 98°C.
- Inhibitor return profile – FF Direction – 5 days at 98°C (100% Norne FW).
- Post treatment brine Permeabilities in FF and RF directions, T = 98°C.
- Post treatment crude saturation at 98°C.
- Post-treatment crude permeabilities in FF and RF directions, T = 98°C.
- Cool to room temperature and dismantle core holder.

3. Experimental Results and Discussions

3.1 Basic Tests

Initial testing was undertaken to confirm compatibility with Norne formation water and seawater and thermal stability under simulated application conditions. Inhibitor B and Additive C were all shown to be compatible and thermally stable.

3.2 Dynamic Scale Loop Tests:

Dynamic scale loop tests were undertaken to evaluate the performance of Inhibitor B under Norne conditions. The tests were performed under worst-case barium sulphate scaling conditions (50/50 synthetic Norne formation water and synthetic seawater). Figure 1 details the test results of Inhibitor B. As seen in Figure 1, the MIC of Inhibitor B was determined at 10ppm.

3.3 Beaker Test Results:

Precipitation Interaction between Inhibitor A and Additive C: the results of chemical precipitation interactions between Inhibitor A and Additive C are illustrated in Image A. Image A displays the digital photo taken on two samples at 85°C. The sample at the left appeared clouded as both 10,000 pm of Inhibitor A and 10% Additive C in 6% NaCl brine were mixed at pH 3. The sample at the right side was clear as both 10,000 ppm of Inhibitor A and 10% Additive C in 6% NaCl brine were mixed at pH 5. These experimental results show that the precipitation interactions between Inhibitor A and Additive C could be controlled by adjusting solution pH. A low pH environment created a favourable condition for a precipitation process.

Precipitation Interaction between Inhibitor B and Additive C: Image B displays the digital photo of the test samples where 10% Inhibitor B was mixed with 10% Additive C at ratios of 10:90, 50:50 and 90:10.. The pH of 10% Inhibitor solution was adjusted 3. Similar to Inhibitor A mixing with Additive C, all three samples appeared clouded where the precipitation interaction between Inhibitor B and Additive C took place. Image C shows the SEM picture of precipitated Inhibitor B with Additive C.

Inhibitor Adsorption/Precipitation Tests: The static beaker tests were designed to demonstrate that the enhanced inhibitor retention could be achieved through the interaction/precipitation between the selected scale inhibitor and additive. The experimental results are presented in Table 2 and Figure 2 respectively. The crushed rock materials were preconditioned with 6% NaCl brine or 10% additive at pH 3 respectively. The inhibitor adsorption/precipitation were performed with the addition of 10,000 ppm of Inhibitor A at pH 3 and 5 respectively. The samples using 6% NaCl brine preconditioning were the control samples. Four experimental data were obtained for comparison as follows:

Case 1 Inhibitor adsorption at pH 3 where the sample was preconditioned with 6% NaCl at pH 3;

Case 2 Inhibitor adsorption at pH 5 where the sample was preconditioned with 6% NaCl at pH 3;

Case 3 Inhibitor adsorption/precipitation at pH 3 where the sample was preconditioned with 10% Additive C at pH 3;

Case 4 Inhibitor adsorption at pH 5 where the sample was preconditioned with 10% Additive C at pH 3;

The precipitation interaction occurred for Case 3 when 10,000ppm of inhibitor solution at pH 3 was added into the sample which was preconditioned with 10% Additive C at pH 3. Due to the precipitation interaction, the highest retention level was obtained at 7.61 mg/g for Case 3. Two control samples present a similar adsorption level, which stands at 3.93 and 3.85 mg/g respectively for Cases 1 and 2. Case 4 gives the inhibitor adsorption level at 5.04 mg/g, where the sample was preconditioned with 10% Additive C at pH 3 where no precipitation took place.

The data suggests that under the conditions adopted:

- Inhibitor A retention on the rock surface significantly increased in the presence of Additive C through the combined precipitation/bridging mechanism. At pH 3, the presence of Additive C almost effectively doubled the amount of Inhibitor A adsorbed in comparison with the adsorption level of controlled sample.

- Inhibitor A adsorption on the rock surface also increased in the presence of Additive C through the bridging mechanism. At pH 5, the presence of Additive C effectively increased amount of Inhibitor A adsorbed by 31% in comparison with the adsorption level of controlled sample.

- Inhibitor/Additive precipitation interaction can be achieved through pH adjustment of inhibitor solution. The precipitation occurs at a low pH. However, it is believed that while the precipitation process occurs, it is not working along. The combined precipitation and bridging process causes the overall enhanced inhibitor retention.

3.4 Core Flood Results

Although a good inhibitor retention level was achieved through the combined precipitation/bridging mechanism, it is important to understand the inhibitor desorption/release properties and also to understand if the combined precipitation/bridging will not reduce the formation permeability. For this purpose, core flood work was carried out. In this program, two core floods were carried out using Additive C and Inhibitor B using a same core plug. However, the pH of inhibitor solutions was controlled to make Flood 1 as a "pure bridging" flood and Flood 2 as a combined precipitation and bridging flood. Since the same core plug was used for the comparison purpose, the core plug was washed with a significant amount of synthetic formation water to ensure the inhibitor concentration to reach zero before second core flood starts.

Permeability evaluations: Oil permeability evaluations were often carried out before and after the chemical applications. Any oil permeability reductions after the chemical injection would imply a certain degree of pore pathway blockage for the tested cores. The damage mechanisms often involve a water block, solid precipitation, emulsion formation and fines mobilization etc. In some cases, due to the immiscible nature between oil and introduced fluid, the relative permeability effect plays an important part in the oil permeability reduction if the residual fluid saturation was changed.

Table 3 shows the determined crude oil permeability recorded in both forward and reverse flow directions at the stages of before and after chemical applications. From Table 3, it can be seen that in Flood 1, 88% of oil permeability was recovered after the injections of Additive C and Inhibitor B at pH above neutral. The initial oil permeability at 98°C was recorded at 169 md in the forward direction and 178 md in the reverse directions. After the inhibitor Additive C/Inhibitor B injection, the flow back permeability was determined at 157 md in the forward direction and 149 md in the reverse directions. In Flood 2, the average oil permeability was recovered at 117% after the injections of Additive C and Inhibitor B. The Initial oil permeability at 98°C was recorded at 155 md in the forward direction and 161 md in the reverse directions. After the inhibitor Additive C/Inhibitor B injection, the flow back permeability was determined at 185 md in the forward direction and 184 md in the reverse directions. It is likely that the enhanced oil permeability in Flood 2 was cause by a possible wettability change as a result of surface precipitation due to the reaction between Additive C and Inhibitor B.

Inhibitor Return Profile Comparison: The inhibitor effluent profiles during inhibitor post-flush stages for Floods 1 and 2 are shown in Figure 3. The blue square line shows the inhibitor return profile for the precipitation flood using Additive C and Inhibitor B. The pink dot line represents the inhibitor return profile for the flood using Additive C and Inhibitor B without precipitation. By comparison between inhibitor return curves, it can be found that Flood 2 offers a significant higher inhibitor concentration return than that of Flood 1.

The effect of pH and surface precipitation mechanism seemed to have contributed to the higher inhibitor concentration return for Flood 2. In the previous beaker tests, it was found that Additive C reacted with Inhibitor A or B, forming the white precipitation materials and resulting in a high inhibitor retention. The pH plays an important part in the precipitation process. The precipitation occurs when lower pH 10% Inhibitor B mixes with 10% Additive C. The precipitation process further enhances the bridging effect hence the increased inhibitor squeeze life.

Material Balance Calculations: For a further comparison purpose, the percentages of inhibitor recovered and pore volumes reached at 300 and 500 ppm for Floods 1 and 2 are presented in Table 4. At both concentrations, the precipitation flood presents a longer pore volume and a lower percentage of inhibitor recovery. For example, as seen from Table 4, at 300 ppm the postflush volumes of the precipitation flood (Flood 2) reached 156 pv. The flood without precipitation only gives a pore volume of 48.3. Also, at 300 ppm, while

~81.4% inhibitor was recovered for the precipitation flood, the flood without precipitation had a 92% inhibitor recovery rate. The material balance calculation data demonstrated that the precipitation flood presents a longer inhibitor return than the flood without the precipitation.

Injection Pressure Profiles: For both Floods, a stable differential pressure was recorded throughout the pre-flush of synthetic formation brine and main chemical injection stages. Injection pressure profiles recorded during the preflush and chemical injections for Core Floods 1 and 2 are presented in Figures 4 and 5. Very low differential pressures (< 0.5 psi) were recorded for all injection stages indicating that neither the pre-flush nor the main chemical injection stages in both core floods caused progressive formation damage.

4. Field Treatments

Based on the laboratory studies, the method to deploy the scale inhibitor using the combined precipitation/bridging mechanism has been developed. So far, a number of precipitation/bridging squeeze treatments using Additive C and Inhibitor B have been successfully conducted. Taking one of the treatments as an example, the squeeze treatment was carried out using the following design for Well A:

Preflush:	10 M3
Preflush-2:	60 M3 10% Additive C in 6% NaCl.
Main pill:	220 M3 10% Inhibitor B in seawater.
Overflush:	100 M3
Tubing Volumes:	48 M3
Shut in:	12 hours

After the treatment, the well bean up was carried out without any problem. Also, no process problems were reported during the back production.

In this treatment, Additive C was deployed as part of the pre-treatment to enhance scale inhibitor retention through the combined precipitation/bridging mechanism. After the pre-treatment stage Inhibitor B was squeezed. The treatment for Well A has so far protected the production of approximately 200,000 m3 of brine and was still ongoing at the time of writing the paper. The latest inhibitor concentration measurement is significantly above the laboratory determined MIC (~38ppm), suggesting that this treatment has the potential to further extend treatment life. The ability to protect significant volumes of brine may offer significant economic benefits to the field in terms of increased well availability, lower total chemical costs, improved operational logistics as well as simplifying the job execution.

5. Summary and Conclusions

As a part of the ongoing program to study inhibitor placement methods for Norne field, chemical additive C has been identified to act as an inhibitor squeeze enhancer. The additive can work as a bridging agent to modify a surface charge in favour of inhibitor adsorption. The additive can also react with the selected scale inhibitor, forming the precipitates under a given condition. This precipitation interaction can significantly increase inhibitor retention for an inhibitor squeeze treatment. The slow release of inhibitor to the produced brine through the hydrolysis/dissolution process can enhance an inhibitor treatment life. By using Additive C, a combined mechanism, through precipitation/interaction and bridging adsorption attributed by the surface charge modification can be realised. As a result, the overall inhibitor retention has been increased thereby further extension of squeeze life was achieved. In this work, the static beaker test and core flood work were carried out. Based on these experimental results, conclusions can be drawn as follows:

- Inhibitor retention on the rock surface significantly increased in the presence of Additive C through the combined precipitation/bridging mechanism. At pH 3, the presence of Additive C almost effectively doubled the amount of Inhibitor A adsorbed in comparison with the adsorption level of controlled sample.

- Inhibitor adsorption on the rock surface also increased in the presence of Additive C through the bridging mechanism only. At pH 5, the presence of Additive C effectively increased amount of Inhibitor A adsorbed by 31% in comparison with the adsorption level of controlled sample.

- Core flood tests confirmed that the precipitation interaction using Additive C significantly improved the retention and release characteristics of Inhibitor B. The combination of

Additive C and Inhibitor B with the precipitation presents a better inhibitor return than that without the precipitation. The precipitation mechanism made the contribution in the enhanced inhibitor return and could extend inhibitor squeeze life.

- Both floods show no significant permeability damage. Flood 2 with the precipitation/interaction between Additive C and Inhibitor B even displays an enhanced permeability recovery. It is likely that a surface precipitation of Additive C and Inhibitor B resulted in a core wettability change towards a favourable condition hence enhanced oil permeability.

- The field results have demonstrated that the good scale inhibitor treatment life was achieved.

6. Nomenclature

GLP = Good laboratory practice.
MIC = Minimum inhibitor concentration.
OSPARCOM = Oslo Paris Commission.
SFT = Norwegian Pollution Control Authority.
SEM = Scanning electron microscopy.

7. Acknowledgement

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Table 1 Brine Chemistry

	Norne Formation Water	Seawater
Ion	ppm	ppm
Na	16460	10890
Ca	1331	428
Mg	229	1368
K	559	460
Ba	94	0
Sr	105	0
Cl	28500	19766
SO_4	0	2960

Table 2 Inhibitor Adsorption/Precipitation Level Comparison

Pre-Conditioning	**Retention mg/g at pH 3**	**Retention mg/g at pH 5**
6% NaCl brine	3.93	3.85
10% Additive C at pH 3	7.61	5.04

Table 3 Oil Permeability Comparison

Flood No.	**Injection Direction**	**Before chemical Injection (md)***	**After Chemical Injection (md*)**	**Recovery %**	**Average Recovery %**
1	Forward	169	157	93	88
1	Reverse	178	149	83	
2	Forward	155	185	120	117
2	Reverse	161	184	114	

Table 4 Material Balance Calculations For Core Floods 1 and 2

Flood Type	PV at 500 ppm	Recovery % At 500 ppm	PV at 300 ppm	Recovery % At 300 ppm
Flood 1 No precipitation	37.6	92.0	48.3	93.0
Flood 2 precipitation	63.2	81.4	156	84.5

Image A: 10,000 Inhibitor A mixed with 10% Additive C at 85°C at pH 3 (left) and pH 5 (right).

Image B: 10% Inhibitor B mixed with 10% Additive C.

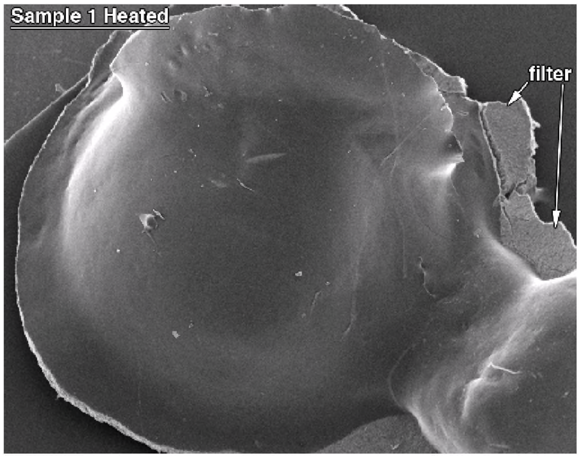

Image C: SEM of precipitated Inhibitor B with Additive C.

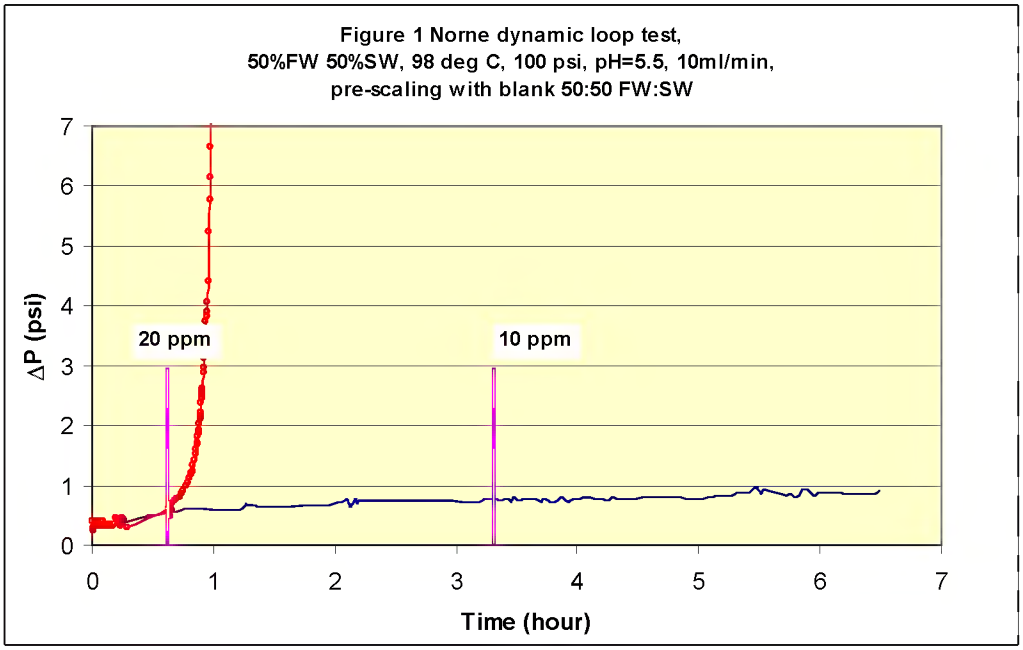

Figure 1 Norne dynamic loop test,
50%FW 50%SW, 98 deg C, 100 psi, pH=5.5, 10ml/min,
pre-scaling with blank 50:50 FW:SW

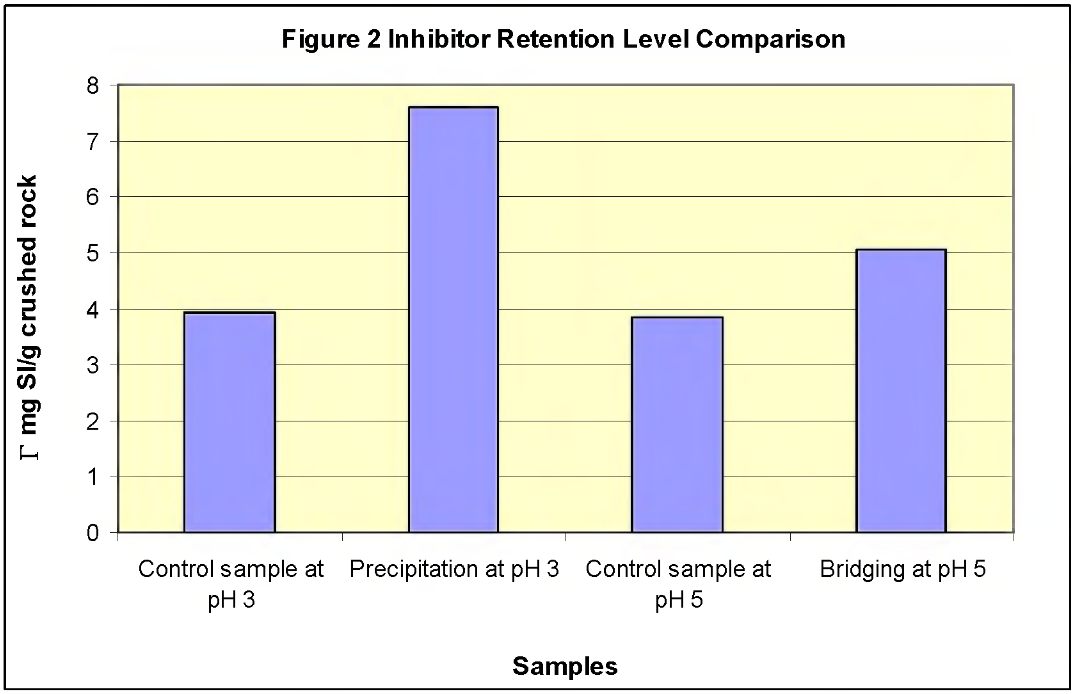

Figure 2 Inhibitor Retention Level Comparison

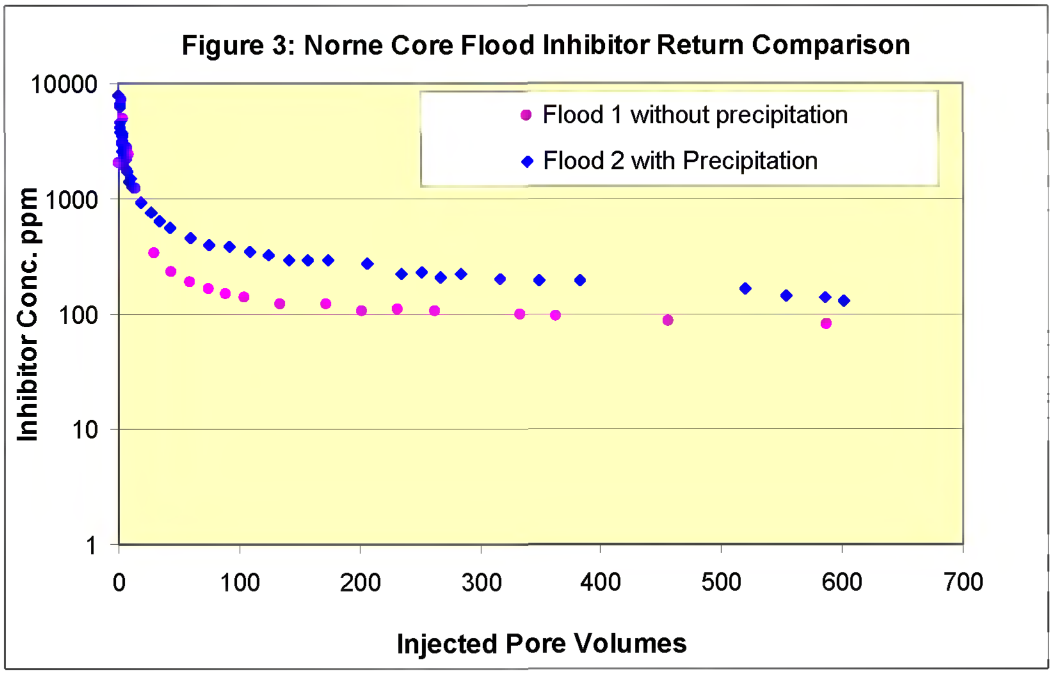
Figure 3: Norne Core Flood Inhibitor Return Comparison

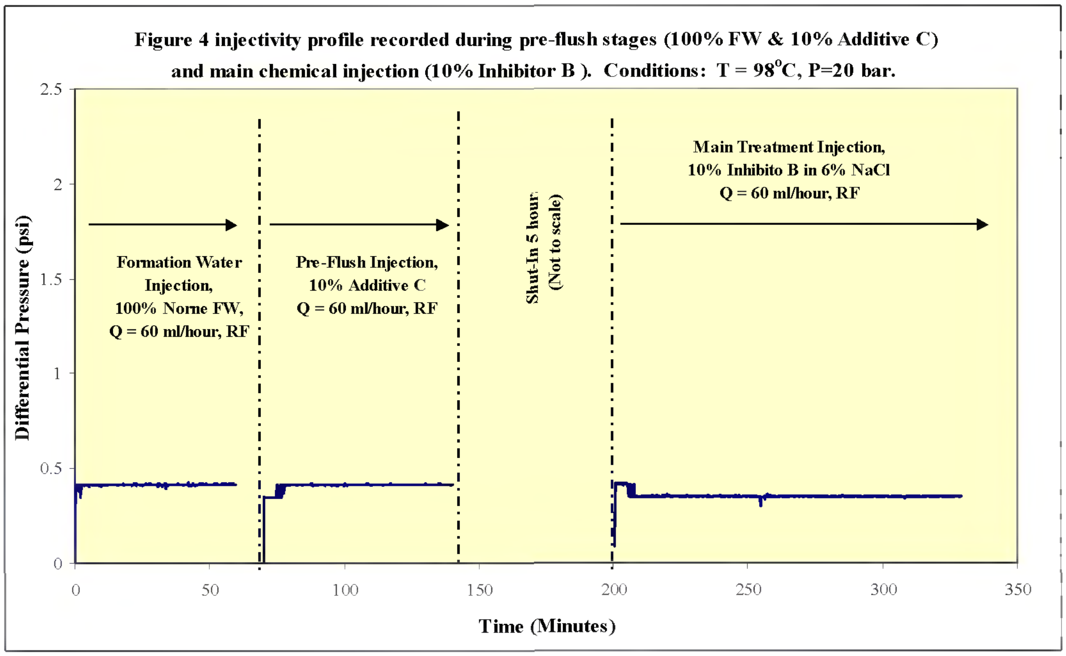
Figure 4 injectivity profile recorded during pre-flush stages (100% FW & 10% Additive C) and main chemical injection (10% Inhibitor B). Conditions: T = 98°C, P=20 bar.

Figure 5: Injectivity profile recorded during pre-flush stages (100% FW & 10% Additive C) and main chemical injection (10% Inhibitor B). Conditions: T = 98°C, P=20 bar.