BARIUM SULFATE SCALE INHIBITION – A SUCCESS STORY

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Chevron operates a waterflood in Oklahoma with 60 wells of which 11 are injectors. An initial waterflood pilot was performed in 2006 in the Tussy formation by converting two producing wells to injectors to determine if a full-scale waterflood would be viable. The source of the injection water was the commingled production from about a dozen different leases. The response from these two pilot injectors was very positive, so the decision was made to proceed with an expansion of the Tussy waterflood.

Unfortunately there was an insufficient volume of salt water available for injection. The volume of produced water from the field was adequate to supply only the two pilot wells for injection, and if additional wells were to be put on injection an alternate source of water would be required. Several idle salt water supply wells were available for reactivation; however the available water is incompatible with the produced water. The water from the water supply wells is very high sulfate and the produced water is very high barium. Mixing these waters untreated could possibly result in BaSO4 scale since a waterflood using these same waters in the 70's and 80's resulted in BaSO4 scale.

Water analyses comparing current produced water and potential salt water supply water from idle supply wells were conducted. In the analyses, modeling was performed to determine the potential for scaling with mixing of the two waters using the Rice University Brine Chemistry Consortium Modeling Software ScaleSoftPitzer™. Scale predictions were modeled for surface and bottomhole conditions. Barite scale was of most interest since it is relatively insoluble and is difficult to remove upon precipitation. Anions and cations of interest are listed in Table 1 for both produced and supply water.

The high level of barium in VTU/Hoxbar produced water (360 Mg/L), with Stevens #30 WSW water containing 1,245 Mg/L Sulfates, if mixed, will result in significant barite deposition. Water chemistry criteria and operating parameters were run through ScaleSoftPitzer™ to determine the worst case scenarios for barite precipitation.

ScaleSoftPitzer™ scale modeling indicated worst case scenarios for barite formation with mixing water from the VTU/Hoxbar and the Stevens #30 at 75%/25% and 50%/50% (3 to 1 and 1 to 1 ratios) at both the wellhead and bottomhole. See Table 2 for saturation indices and predicted barite scale amounts. Saturation index demonstrates how far past equilibrium and the relative drive for scale to form, and scale amounts are predicted maximum weights of barite per volume in Mg/L that could form under the given conditions and water chemistries.

Synthetic brine was used for testing and was based on water chemistry mixes calculated with ScaleSoftPitzer™ software. Dynamic scale tube blocking testing was performed at ~90°F, using a pressure of 30 psi to simulate the given field conditions. See Table 3 for the chemistry of the synthetic brines.

Scale inhibition performance was assessed by screening Baker Hughes Petrolite™ Scale Inhibitor SCW260 scale inhibitor in the brine at different rates in the dynamic scale tube blocking test to determine the MEC (minimum effective concentration) for the product. To ensure scaling would occur in a reasonable amount of time, it was necessary to run the tests at ~90°F. The results of the tests seen in Figures 1 and 2 shows that the worst case scenario of 50% produced water and 50% make up water required a minimum treatment of 35 ppm of SCW 260.

No other compatible salt water source was available, so the two options were to proceed and treat the water for scale or not do the project at all. Many in-house and industry experts believed the chances of this project being successful were slim. Most experts believed that if the treatments were consistently applied, the scale could be controlled, but history has shown there are always reasons why chemical programs don't work. The decision was made to go forward using incompatible water with treatment because the potential reward was too great to not proceed. The team knew the risks and decided to create a plan to address the scale potential.
Given the heavy workload of Chevron's Field Operators, the team wanted to implement as much automation as possible so as not to unnecessarily increase the workload on the field operators. The plan was to divide the program into three segments; the supply water, the produced water and the producing wells.

On the supply water side it was decided that automated chemical pump skids would be installed with automation to continuously monitor the performance of the skid. Each skid was to have solar-powered redundant chemical pumps and a logic controller to adjust the rate of chemical as the rate of the supply water changed. All of the salt water supply wells have ESPs with VFDs to adjust the frequency based on injection water demand. If the tank level is low, then the ESP will speed up to supply more water for injection, and conversely if the tank level is high, then the ESP will slow down or turn off since additional water is not required. The chemical pumps are able to adjust their rate by monitoring the supply water rate from the ESP using a preset ppm input by Chevron. There is also additional logic in the ESP controller which will not allow the ESP to run if there is no chemical pumping. In addition, the performance of the chemical pumps is monitored remotely by Baker Hughes Petrolite™, and if the chemical rate is lower than a certain ppm, then an alarm is sent to Baker Hughes Petrolite™ and Chevron via text and email.

On the produced fluid side, solar-powered automated chemical pump skids similar to the skids installed on the salt water supply wells were installed at production headers where multiple producing wells were combined into one trunkline. The produced fluid side presented different challenges. There are multiple producing wells coming into one header, and all of these wells run using pump off controllers (POCs) so they all start up and shut down at different times, meaning the rate into each header is always changing. In addition the cut of every well is different, and it is only necessary to treat with scale inhibitor based on the water rate so it is not feasible to utilize the ppm control. Neither do we have a rate meter at the headers since we don't have separation and there will be quite a bit of gas skewing the perceived rate. Water cuts usually don't change dramatically overnight, and since each well is only a small percentage of the total header rate, the chemical rate was controlled by setting the pump at a specified rate and then re-evaluated monthly based on the well tests of all the wells going into that header. The rates of the chemical pumps will continue to be monitored and alarms will be sent if the rate goes below the preset minimum alarm. Additionally, manual chemical pumps were set at each producing well. These pumps were all set to pump at some minimum rate to act as insurance in case of a malfunction of the automation and monitoring. In addition to the manual chemical pumps located at all producing wells, every producer was squeezed with the scale inhibitor and all wells were tested monthly for residuals and re-squeezed when the produced water residuals fell below the Minimum Effective Concentration (MEC) of 45 ppm.

As a precaution all new injection wells were squeezed with Baker Hughes Petrolite™ SCW-260 prior to being placed on injection. This was done to prevent the formation of scale as the wells were initially placed on injection. Since incompatible water was being injected, that water would be mixing downhole and have a possibility of forming scale near the wellbore and inhibiting injection. The squeeze jobs were done to hopefully prevent that from happening.

The most important aspect of any chemical program is its effectiveness. The way the effectiveness of this program is measure is through a very comprehensive monitoring program. There is monthly sampling and testing of all supply, produced and injection water. The analysis includes all of the typical ion concentrations, pH and scaling indices. In addition a millipore filter analysis is collected at the injection plant and the filtrate is analyzed to determine what suspended solids are in the water. There are also a few scale coupons installed in the system to monitor for scaling. All of this data is collected and reviewed monthly. In addition a quarterly chemical review is held with a comprehensive cross-functional team. This is a very important and critical part of the program and one of the reasons for our success.

The monitoring program is also seen as not only monitoring success or failure of the program, but also an opportunity to recognize deficiencies and make corrections. One example of this is when one of the millipore filters showed $BaSO_4$ particulate. There was no scale on any of the coupons or any seen on any downhole or surface equipment, but there was some suspended barium solids that showed up in our filter. Further investigation revealed that a few new wells were put on-line and the water was not being treated. This was remedied by adding chemical pumps to the new wells. Subsequent to treating the new wells, the particulate was no longer present.

Overall the chemical program has been very successful in that since implementing use of the incompatible water, there has been no $BaSO_4$ scale seen deposited on any pumps, tanks or tubing. Probably the best indicator of our treating program effectiveness was when we pulled the tubing from an injector that had been on an injection since 2006. The injection tubing is 2-3/8" J-55 8RD EUE with Tuboscope TK Fiberline. When the tubing was pulled, the liner was completely intact and in good condition, but had ~1/4" of heavy oil and solids on the liner. It came off the tubing fairly easily and an analysis indicated the presence of some barium sulfate particulate similar to what was seen in our millipore filter. This was not surprising since we had seen the same thing on the millipore filter from the injection tank which was the source of injection water for this well. What was encouraging was that there was no solid barite plated out on any of the tubing, packer or surface connections after over seven years of continuous service. Since injection began in 2006, a total of eight million barrels of water has been injected and there have been no significant barium sulfate scale issues.

Even though this program has been very successful it has not been without challenges. The first challenge was trying to get the automation lined out. In the early stages of implementing the automation, we received literally thousands of texts and emails saying our chemical rates were too low. The problem was that we were trying to set our tolerances too tight on the alarms, and trying to find a reasonable level of tolerance for the chemical rates was a challenge. We wanted to make sure we had enough chemical pumping for protection but we were also trying not to over-treat unnecessarily. This problem was compounded by the fact that early in the life of the waterflood, our produced water rates were very low which made the chemical requirements low. Since we expected fairly high water rates as the flood responded, we sized the chemical pumps accordingly, but this meant at the early stages the pumps were moving extremely slow and the automation had difficulty distinguishing between low and no chemical rates. What we did to mitigate this challenge was to install smaller plungers early and then change them out as chemical requirements increased. Another challenge was the use of the solar pumps on our salt water supply wells. The chemical rates at the salt water supply wells were fairly high, and during extended periods of cloud cover, there were times when the chemical pumps would run out of power. This was remedied by electrifying all of the pump skids at the salt water supply wells since electricity was available nearby.

The single most important factor in the success of this program is the dedication of the team to its success. This team was committed to making this program successful from the beginning. Everyone understood the risk of failure and wanted to do everything possible to ensure the success of the project. This type of program was not something that had ever been done in our area, so there was some apprehension by the field operators especially concerning the automation. This was amplified in the early stages of implementation when we were receiving hundreds of alarms each day, but as the operators received training, became familiar with the equipment and the alarm parameters were fine tuned, everyone became much more comfortable. The salt water supply wells had been idle for years so their water composition was somewhat uncertain. This made water sampling and analysis turnaround a critical part of the program. Prior to this project, the typical turnaround from requesting a sample to actually seeing the analysis was

~30 days, but everyone agreed that initially it was important to get sample results much more quickly. The operators and chemical vendor agreed to coordinate and expedite the sampling and analysis so that results could be reviewed in approximately one week in the early phases of the waterflood until we were confident in the results of the treating program. The success of this program was a total team effort and the results could not have been achieved without the cooperation and dedication of every member of the team. As a result of this chemical program, an old field has new life.

Lessons learned for successful barium sulfate scale inhibition program:

- A full team effort is required – everyone must be 100% committed
- Don't treat at minimum required treatment levels – things happen
- Solar not desired unless necessary, due to cloud cover
- Millipore analysis helps identify problem areas
- Alarm parameters need to be set with reasonable variance in mind
- Uncertainty requires FREQUENT water analysis
- Multiple coupons should be installed to verify efficacy of program
- Program should be a team effort - not chemical vendor or customer driven

Table 1 Water Analysis for Produced Water and Make up Water

Ion of Interest	VTU/Hoxbar Produced Water Mg/L	Stevens #30 Salt Water Supply Well Water Mg/L
Calcium	2,479	2,760
Total Alkalinity	360	42.7
Barium	343	0.57
Magnesium	936	171
Sulfates	7.43	1,245

Table 2 Saturation indices and predicted barite scale amounts for VTU-Hoxbar/Stevens #30 75/25 & 50/50 mixes.

Mix Ratios	**Barite - Wellhead**		**Barite-Bottom Hole**	
VTU/Stevens #30	**Saturation Index**	**Predicted mg/L**	**Saturation Index**	**Predicted mg/L**
75/25	2.64	160	2.27	160
50/50	2.72	318	2.35	317

Table 3 Brine chemistry from the VTU-Hoxbar/Stevens #30 mixes used in dynamic scale tube blocking testing.

VTU-Hoxbar – Stevens #30 75/25 Mix

Na^+	(mg/l)	30,247
Mg^{2+}	(mg/l)	647
Ca^{2+}	(mg/l)	3,571
Ba^{2+}	(mg/l)	280
Cl^-	(mg/l)	54,585
SO_4^{2-}	(mg/l)	312
Alkalinity	(mg/l)	308
pH	pH	6.89

VTU-Hoxbar – Stevens #30 50/50 Mix

Na^+	(mg/l)	28,011
Mg^{2+}	(mg/l)	488
Ca^{2+}	(mg/l)	3,301
Ba^{2+}	(mg/l)	187
Cl^-	(mg/l)	49,969
SO_4^{2-}	(mg/l)	623
Alkalinity	(mg/l)	220
pH	pH	6.73

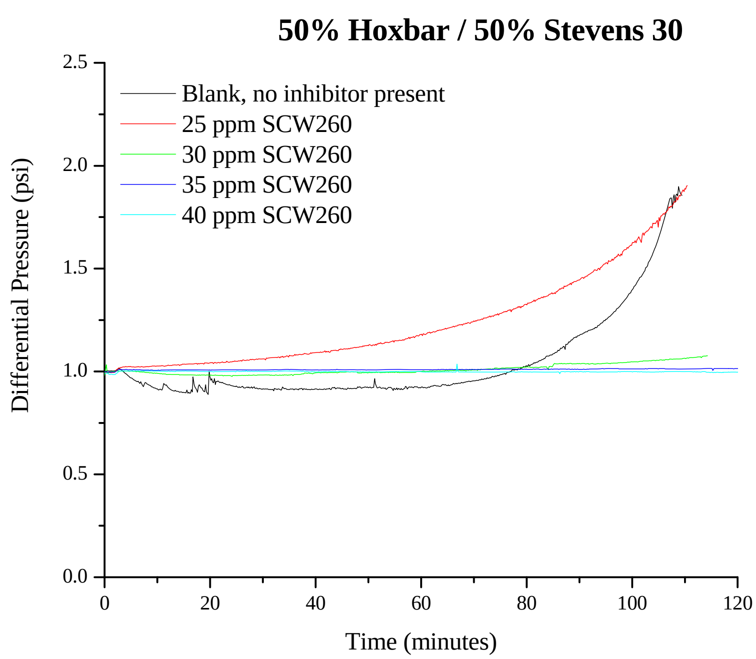

Figure 1 - MEC (Minimum Effective Concentration) for the 50/50 mixture of the waters was 35 ppm.

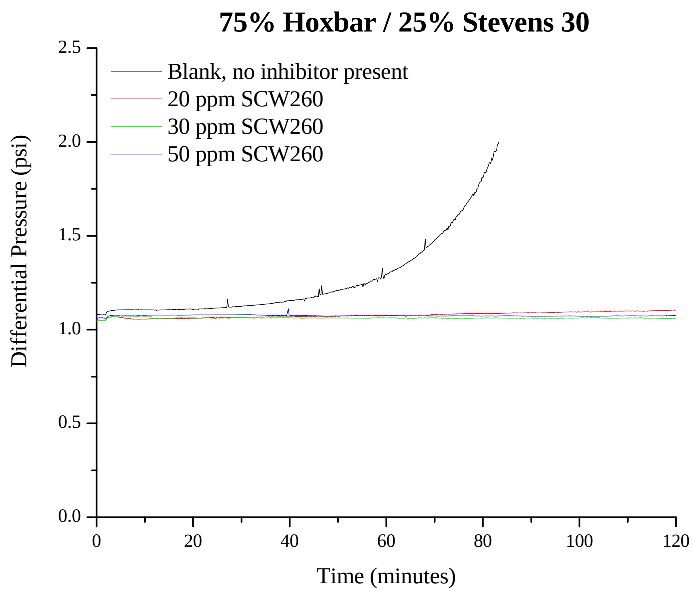

Figure 2 - MEC (Minimum Effective Concentration) for the 75/25 mixture of the waters was 30 ppm.