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Improved Method for Use of Chelation to Free Stuck Pipe and Enhance Treatment of Lost Returns

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Abstract

This paper describes how intentionally increasing the permeability of a non-aqueous fluid (NAF) filter cake can enhance treatments to free differentially stuck pipe and recover from lost returns. NAFs are well known for their ability to deposit thin, low-permeability filter cakes that reduce the risk of differential sticking. Yet, differential sticking still occurs and techniques to free the pipe have largely been ineffective. In addition, lost returns in NAF continue to be one of the industry's most difficult and expensive problems to solve.

The operator has developed an improved technique to increase the permeability of a NAF filter cake. The technique involves locally soaking the cake using a combination treatment that first conditions the cake and then removes a significant amount of the weighting material. Laboratory experiments have shown the technique can increase cake permeability by more than 850 fold.

There are at least two applications for this treatment. In the first, a pill is spotted across pipe segments (e.g., drill collars) believed to be differentially stuck. By increasing the cake permeability, pressure is allowed to penetrate the cake underneath the pipe, allowing it to more easily become free. Dissolving barite also reduces the shear strength of the filter cake, which may also facilitate freeing stuck pipe.

A second application is to enhance the performance of high fluid loss lost circulation material (LCM) treatments after NAF has damaged the fracture face permeability. Increased permeability enhances loss of the LCM carrier fluid and development of the immobile mass required to stop the growth of the fracture induced during lost returns. Formation integrity can then be rebuilt using rock mechanics-based techniques.

Introduction/Background

Barite Dissolvers

Barite dissolvers have long been used in the industry to combat scale in downhole tubulars.[1-2] Additionally, barite dissolvers have gained use as a means to treat formation damage from mud invasion since the primary weighting agent for drilling fluids is barite. Barite is extremely insoluble in most acids and typically requires specialized chelation agents to remove. EDTA and DTPA are the most common chelation agents. Similar compounds, variations, mixtures, and new dissolving compounds are also being developed.[3-4]

This paper explores the use of chelation agents for a different application. Rather than remove scale or barite within the formation, the objective is to remove barite that composes the filter cake. Because barite typically comprises a significant volume component of a typical filter cake, anything that removes the barite weighting agent has a tremendous impact on the filter cake properties.

Differentially Stuck Pipe

Differential pressure sticking (DPS) is a common worldwide drilling problem that results in significant increases in non-productive time and overall well cost.[5-6] Additionally, a DPS event may result in abandonment of the current hole and force a sidetrack. To mitigate DPS events, operators often minimize the overbalance (by decreasing mud weight), minimize stationary time, minimize drilled length through low pressure formations, increase drill collar and drill string stabilization, and optimize fluid properties in attempts to minimize the risk of sticking. However, despite the best efforts of operators a DPS event may still occur.

A common practice to free differentially stuck pipe is to pump a chemical "spotting" fluid.[7] The purpose of the fluid is to dissolve or break down the filter cake so the pipe can be freed. Most service companies provide multiple spotting fluid options. Water-based drilling fluids have engendered numerous spotting fluids that have been used successfully in the field. These spotting fluids are typically composed of NAF. These fluids function by reducing the area of contact and may penetrate the cake and relieve pressure differential.

Often, operators may choose to use a NAF while drilling if the risk of a DPS event is high. This minimizes the filter cake permeability and causes the pressure differential to develop more slowly upon embedment. Additionally, the filter cake is much slicker, thinner, and easier to shear – all factors that minimize the risk of a DPS event. While the use of a NAF is often sufficient to avoid DPS events, it is still known to occur. This is especially the case when the fluid incorporates bit-generated coarse solids that result in "leaky" and thick filter cakes exposed to unsupported drill collars. However, the industry currently has minimal available options to free differentially stuck pipe when drilling with a NAF.

Regardless of the believed mechanism of DPS, it can be agreed that by removing barite (a significant portion of the filter cake), the sticking force will be reduced. This occurs either by decreasing the shear strength of the cake (by decreasing the pressure differential and by creating voids within the filter cake) or simply by relieving some or all of the pressure differential. This paper presents a method to free differentially stuck pipe in a NAF by removing barite from the filter cake, thereby increasing filter cake permeability. Additionally, the method would be applicable to water-based drilling fluids.

Lost Returns

Lost returns is a common worldwide drilling problem that has significant costs due to lost drilling fluids, lost time, potential wellbore influx, and induced wellbore instability. Losses through propagated fractures constitute the overwhelming majority of lost returns in the industry (as opposed to vugular losses or seepage losses). The operator has developed Fracture Closure Stress (FCS) practices to combat losses by utilizing a rock mechanics approach.[8-9] In brief, integrity can be built in a formation by increasing the width of a fracture. This can be done with multiple approaches as varied as traditional LCM, cement, polymers, or adhesive solids. The process of building integrity requires (1) the fracture tip be isolated from the wellbore so pressure can be applied to widen the fracture to increase its closing stress, and (2) that the width be built to a level that achieves a stress exceeding the wellbore pressure required to drill ahead. Isolation of the tip from wellbore pressure occurs when the LCM and barite lose sufficient carrier fluid to become immobile.

One potential issue with these stress building operations, especially in NAF, is that very high fluid loss is needed to form the immobile mass in the fracture faces. If fluid loss is inadequate, the solids remain mobile, pressure continues to be transmitted to grow the tip and it is not possible to build pressure within the fracture to increase closing stress. Lost returns are often difficult to treat in NAF due to the very low fluid losses achieved with most NAF filter cakes and the inability to dehydrate the solids. While the native permeability of the formation might allow rapid leakoff of the FCS fluid, a tight NAF filter cake on the fracture face prevents this from occurring. This paper presents a method to increase the permeability of the filter cake prior to the FCS treatment. By increasing the permeability of the filter cake on the fracture faces, greater leakoff would occur and an immobile mass would be deposited.

Experimental Procedure

Fluids

A generic non-aqueous drilling fluid was used for all filtration and rolling tests. The mud was 13 lbm/gal (barite weighted) with PV=18 cp, YP=15 lbf/100 ft^2, HTHP fluid loss (250°F, 30 minutes)=5 cc, and OWR=75/25.

Three chelation agents were obtained through vendors. These agents are primarily marketed as barite scale removers. They will be labeled Agent A, B, and C throughout the rest of the paper.

Two pre-flush fluids were used for some of the testing and obtained from vendors. They will be labeled Fluid X and Fluid Y throughout the rest of the paper. Fluid X is a common solvent used in drilling and Fluid Y is a mutual solvent.

Viscosity of the fluids was measured at a series of temperatures. The effect of pressure on viscosity was not included due to minimal expected differences between atmospheric conditions and maximum test pressure of 300 psi. The viscosity results were extrapolated to 250°F to estimate the viscosity at the elevated temperature due to the fact the agents would boil at atmospheric pressure at that temperature. The viscosity results are used in the permeability calculations.

HTHP Filtration

A double-ended HTHP fluid loss apparatus was used to conduct the filtration experiments. The results of the filtration experiments were used to calculate filter cake permeability at various stages of treatment. Initially, several HTHP fluid loss tests were run on ceramic disks to establish a baseline for the drilling fluid. The procedure was modified from typical to ensure a thick filter cake was produced. The filtration occurred at 180°F for two hours at 300-psi pressure differential. The filtrate volume versus time was recorded throughout the filter cake build-up phase. Upon completion of filtration, the cell was allowed to come to room temperature and then disassembled. The thickness of the filter cake was measured at multiple points using a caliper.

The next phase of the testing included testing various combinations of temperature, solvent, and agent. Upon building the initial filter cake as described above, the drilling fluid was carefully removed from the filtration cell and the solvent was added. This was run through the cell for at least one hour at 300 psi differential until a constant filtration rate was achieved. Due to flammability issues, the solvents were not run at elevated temperatures. The solvent was then carefully removed from the cell. The agents were then added and the filtration data recorded as a function of time for both 70°F and 250°F at 300 psi differential. The testing variables are shown in **Table 1**.

Upon completion of the filtration tests the cell was completely disassembled and visual inspection of the filter cake on the disk was conducted. Additionally, control tests without solvent and using base oil instead of an agent were conducted for the sake of comparison.

Rolling Tests

Several rolling tests were also conducted. Ten grams of barite were added to a 250 mL bottle with 80 mL of agent. The bottles were rolled at 70°F or 150°F for 24 hours. The slurry was then centrifuged and decanted. The centrifuged liquid was then run through a standard API fluid loss cell at 100 psi through filter paper to remove any fine barite that was not centrifuged. The remaining powder (after the centrifuge and after the filtration) was washed with water and allowed to dry. The mass of the dried powder was then measured.

Additionally, chemical analysis on the decanted and filtered fluid was conducted to determine the amount of elemental barium in solution. Elemental analysis control tests were also conducted on the chelation agents to determine the initial amount of elemental barium in the agents, if any.

Differential Pressure Sticking Tests

Small scale differential pressure sticking tests were conducted in a unique differential pressure sticking apparatus ("stickometer"). The test apparatus consists of a chamber that accommodates a cylindrical core (4-inch diameter with 2-inch hole made of sandstone or ceramic) of known permeability. **Fig. 1** schematically illustrates the apparatus. Drilling fluid is circulated throughout the system and a pressure differential of 500 psi is allowed to occur on the core between the "wellbore" and the "formation." A dynamic filter cake is then deposited on the walls of the core. Situated within the core is an aluminum rod that creates an annulus through which the fluid can flow **Fig. 2** is a photo of the rod situated in the core in a disassembled state for illustrative purposes. Once filter cake deposition is completed, the rod can be embedded into the filter cake. The rod also has pressure transducers in it to measure the pressure inside the filter cake. After remaining stationary for a set amount of time, load to free the pipe in an axial direction is applied and the freeing force recorded.

In the tests conducted for these experiments, a generic water-based drilling fluid (WBM) was used rather than the NAF from previous tests. The WBM was used to ensure a thick filter cake would be formed which is needed to get the most meaningful pressure data from the transducers. The use of a WBM should have no effect on the viability of the test. In fact, it may be possible to skip the solvent (pre-flush) phase when using a WBM. This option was not explored in these tests in order to be consistent with the filtration tests.

After filter cake build up, the pipe was embedded and the pressure recorded as a function of time. The solvent (Fluid X) was then spotted into the chamber and allowed to filter in the chamber for approximately 10 minutes. Finally, the agent (Agent A) was spotted into the chamber. The transducer records pressure at all times. All tests were conducted at approximately 75°F. A control test using only Fluid X was also conducted to determine if the solvent had a significant contribution on the pressure response and sticking force.

Results & Discussion

HTHP Filtration

Multiple tests were run to establish a baseline filter cake permeability and thickness. **Fig. 3** shows a typical filtrate volume versus time for the baseline tests. A line was fit to the final data points (once steady state filtration rate was achieved) and the slope was determined. Using the filtration data and the filter cake thickness, the permeability of the filter cake was calculated used the darcy equation. Due to consistency of the filter cake thickness and filtration data (slope varied very little during initial tests), the calculated average permeability was used as the initial point for all future comparisons.

The baseline cake thickness under the HTHP conditions was found to be 2.5/32-in. (0.078-in.). The initial cake permeability was found to be 9.78E-5 md. This is the same order of magnitude for filter cake permeability reported in previous studies.[10-11]

As described in the Experimental Procedure, the next phase was to remove the drilling fluid and replace it with a pre-flush solvent. An example of filtration of the solvent through the deposited filter cake is show in **Fig. 4** in which Fluid X is utilized. It can be seen that a steady state filtration rate rapidly forms. Recalculation of the filter cake permeability after this stage indicates no change in permeability during the solvent phase. This is expected as the solvents simply change the wettability of the filter cake rather than remove any particles.

Fig. 5 shows a typical result of several treating agents after being placed in the HTHP cell after the solvent treatment (Fluid X in this case). It can be seen from the plot that initially the filtration rate through the filter cake can be quite low. However, eventually the filtration rate begins to rapidly increase and then reaches a steady state. The intercept of the steady state portion of the filtration curve with the x-axis is defined as the "activation time." These results are all at constant pressure differential, cake thickness, and flow area. The slope of the steady state portion defines the filtration rate used in the permeability calculations.

Also in Fig. 5, the effect of using a base oil rather than an agent can be seen. After 800 minutes, the filtration rate remains low and at a fairly constant rate. The permeability remains unchanged from the initial deposition. This is the expected result and provides confidence the agents are having a real effect and the testing method is valid.

The effect of using a pre-flush solvent is shown in **Fig. 6**. By skipping the solvent, the filtration rate remains constant for over 700 minutes when using an agent that typically has an effect after 200 minutes. It can be concluded the agents are unable to penetrate the filter cake if the filter cake is not initially conditioned by some solvent. The agents and the base oil that composes the NAF are immiscible.

A summary of the filtration test results is provided in **Table 2**. It should be noted the activation time and permeability increases are only under the laboratory conditions tested. It is expected at greater downhole temperatures and greater downhole pressures, the activation time would substantially decrease and the permeability may further increase. From the table, it can be noted the combination of Fluid Y and Agent A at 250°F resulted in an increase of filter cake permeability of over 850 times. The end filter cake permeability was 8.56E-2 md compared to the initial value of 9.78E-5 md. The activation time is quite variable throughout and is not easily repeatable from one test to the next. The focus is the permeability increase rather than the activation time.

Visual examination of the filter cakes following treatment was conducted to check for gaps or holes that could give the fluid an easy exit path. Nothing was found to suggest the tests should be invalid. It can be concluded that during the tests, uniform dissolution of barite occurred rather than a quick route out.

Rolling Tests

Results of the rolling tests are show in **Fig. 7**. This chart shows that temperature has a large effect on the amount of barite removed, consistent with the HTHP filtration results. In addition, Agent A was able to reduce the barite by 39% after 24 hours at 150°F. Agent B was able to reduce the barite by 27%. It should be noted that dynamic rolling tests are much more conducive to barite removal than might occur in a static wellbore. Therefore, static HTHP filtration tests are much more indicative of actual downhole behavior. Rolling tests were chosen to further illustrate the barite dissolving effect using a common industry procedure.

The results of the chemical analysis for elemental barium in the filtered solution are shown in **Fig. 8**. It can be seen from the plot that Agent A has a large concentration of barium in solution, as expected from the HTHP tests. Also, the concentration increases with temperature. Agent B has a fairly large concentration of barium while Agent C did not have a large concentration (using the secondary y-axis in the figure). Agent C had a higher viscosity than the other agent which may have a deleterious effect on the rolling results. A control test found the agents have an immeasurable amount of barium prior to exposure to barite.

Differential Pressure Sticking Tests

Results of the differential pressure sticking tests are shown in **Fig. 9.** It can be seen from the plot the sticking force in the apparatus is greatly reduced when using the spotting treatment of Fluid X and Agent A. For a 2-hour embedment, the sticking force was reduced approximately 80% by using the spotting treatment compared to no treatment. The pressure transducer data for one of the tests conducted is shown in **Fig. 10** (all tests had similar pressure responses). The plot shows that upon embedment the pressure beneath the embedded pipe begins to decrease and thus a pressure differential is formed. However, upon addition of Agent A into the chamber (after Fluid X), the pressure begins to increase and eventually reaches the same level as the pressure in the chamber. Therefore, the pressure differential is entirely relieved due to increased permeability of the filter cake.

The control test using only Fluid X without Agent A exhibited no increase in pressure beneath the pipe after four hours of treatment. Additionally, no reduction in sticking force was measured. It can be concluded that the pressure response and sticking force reduction are due solely to the barite chelation behavior of Agent A and that Fluid X only ensures compatibility between the agent and the filter cake.

Conclusion & Summary

The operator has developed an improved technique to increase the permeability of a NAF filter cake. The technique involves locally soaking the cake using a combination treatment that first conditions the cake and then removes a significant amount of the weighting material. Laboratory experiments have shown the technique can increase the cake's permeability by more than 850 fold.

Increasing filter cake permeability will allow a mechanism for differentially stuck pipe to become free. The pressure differential will be relieved, the shear strength of the filter cake will be decreased, and the filter cake may generally just fall apart. All mechanisms would be effective to free stuck pipe. Additionally, increased filter cake permeability will enhance leakoff from LCM pills and development of the immobile mass essential to the success of FCS treatments to build integrity.

Acknowledgements

The authors wish to express their appreciation for valuable suggestions and recommendations from Bob Williamson and Fred Dupriest, ExxonMobil.

Nomenclature

NAF	= non-aqueous fluid
EDTA	= ethylene diamine tetraacetic acid
DTPA	= diethylenetriaminepenta-acetic acid
DPS	= differential pressure sticking
FCS	= fracture closure stress
LCM	= lost circulation material
PV	= plastic viscosity
cp	= centipoises
YP	= yield point
HTHP	= high temperature-high pressure
md	= millidarcy

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Table 1: Variables used in the HTHP filtration tests.

Solvent	Temperature	Agent
Fluid X	70° F	Agent A
Fluid Y	250° F	Agent B
None		Agent C
		Base Oil

Table 2: Results of HTHP filtration tests.

Agent	Temperature	Solvent	k (md)	Permeability Change (treated/initial)	Activation Time (min)
Agent A	250° F	Fluid Y	8.33E-02	852	60
Agent A	250° F	Fluid X	5.55E-02	567	60
Agent C	250° F	Fluid Y	2.43E-02	248	10
Agent C	250° F	Fluid X	2.13E-02	218	54
Agent C	70° F	Fluid X	1.97E-02	201	358
Agent B	250° F	Fluid X	9.45E-03	97	238
Agent A	70° F	Fluid X	7.56E-03	77	256
Agent B	70° F	Fluid X	5.00E-03	51	495
None	70° F	None	9.78E-05	N/A	N/A

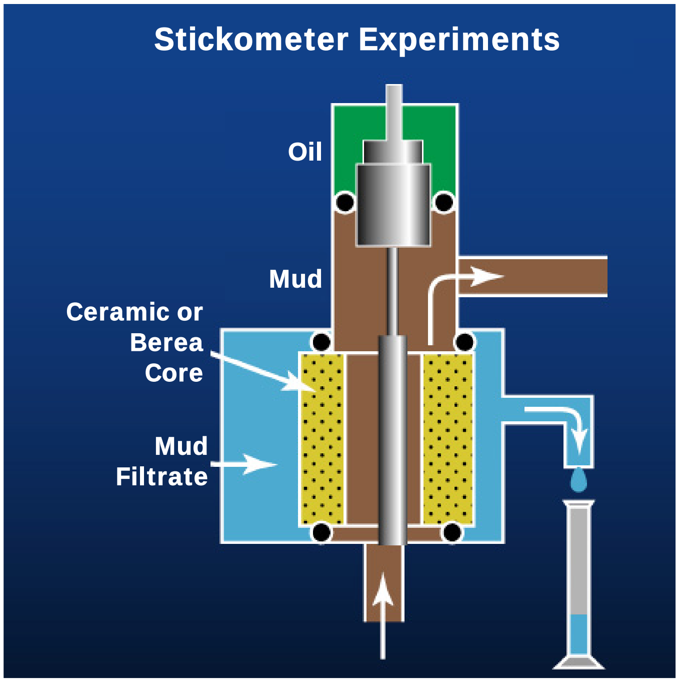

Figure 1: Schematic laboratory apparatus to simulate differential pressure sticking.

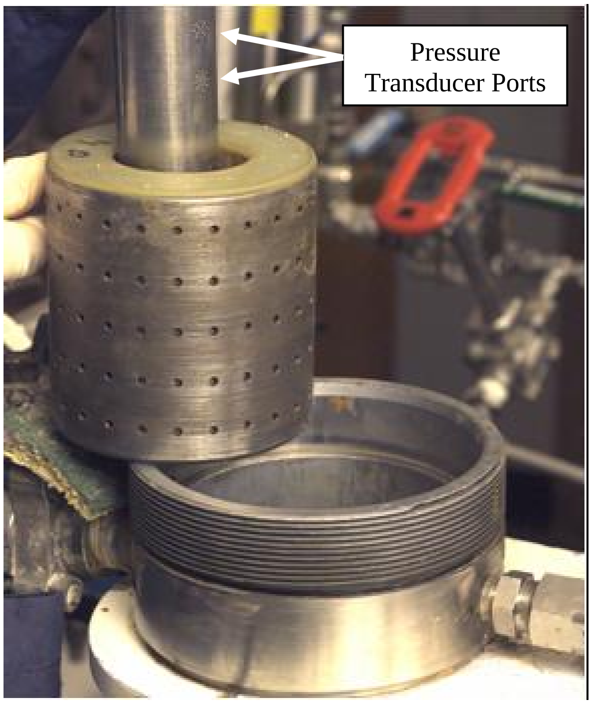

Figure 2: Photo of typical core, embedded pipe (note pressure transducers), and top of test chamber in partial photo of differential pressure sticking apparatus.

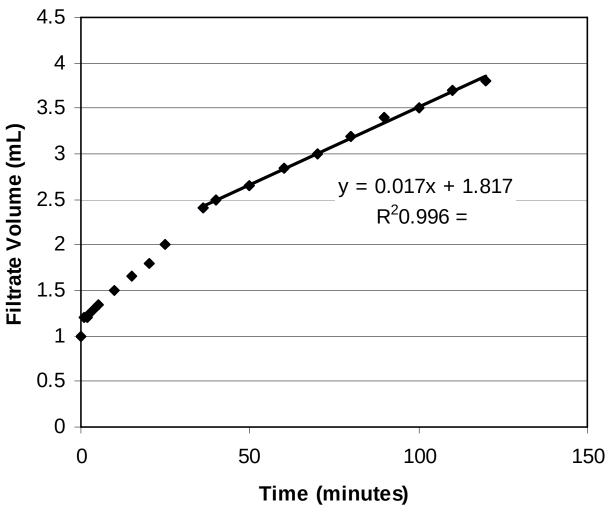

Figure 3: Plot of filtration volume versus time for NAF through HTHP apparatus. Notice steady state filtration rate after 50 minutes.

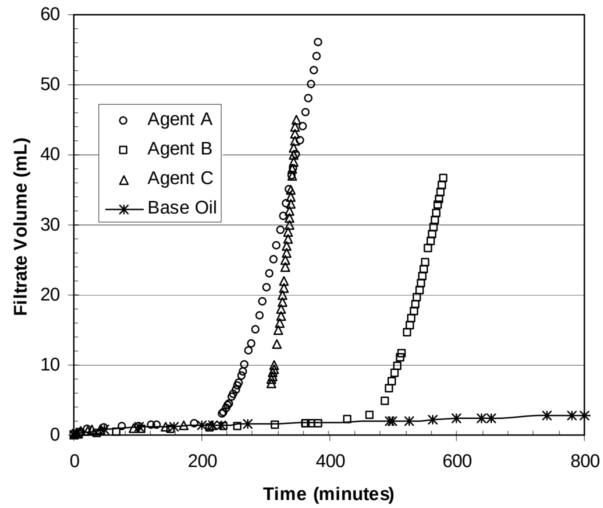

Figure 5: Plot of filtration volume versus time for various agents (and base oil) through deposited filter cake after solvent treatment (Fluid X and 70°F). Notice rapid increase in filtration rate for the agents after an initial activation time. Notice the base oil exhibits no change in filtration rate throughout the test, as expected.

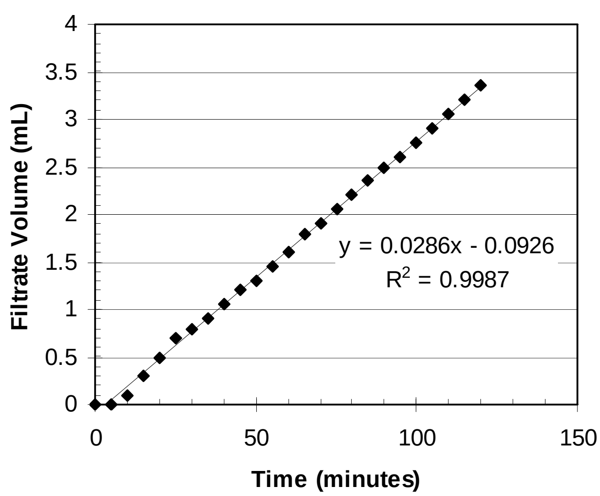

Figure 4: Plot of filtration volume versus time for solvent (Fluid X) through deposited filter cake. Notice steady state filtration rate forms after just a few minutes.

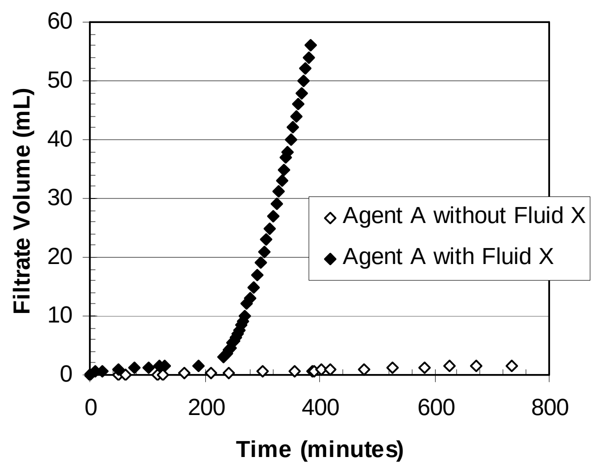

Figure 6: Plot of filtration volume versus time for Agent A at 70°F with and without use of Fluid X in the solvent phase. Notice that without the solvent phase, the filtration rate does not change throughout the test.

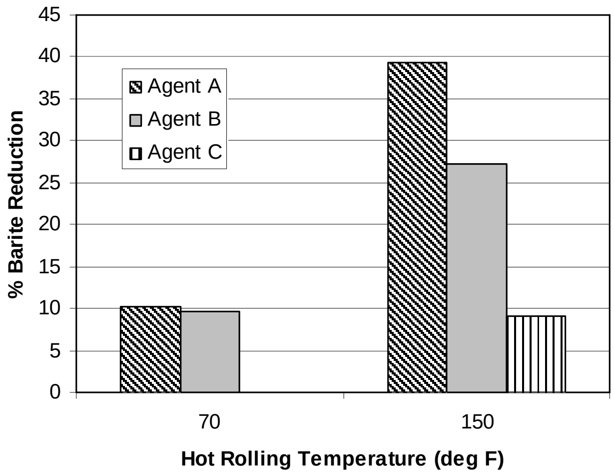

Figure 7: Chart of barite reduction for agents after 24 hours of hot rolling at 70°F and 150°F. Notice large temperature effect and that Agent A have the greatest impact.

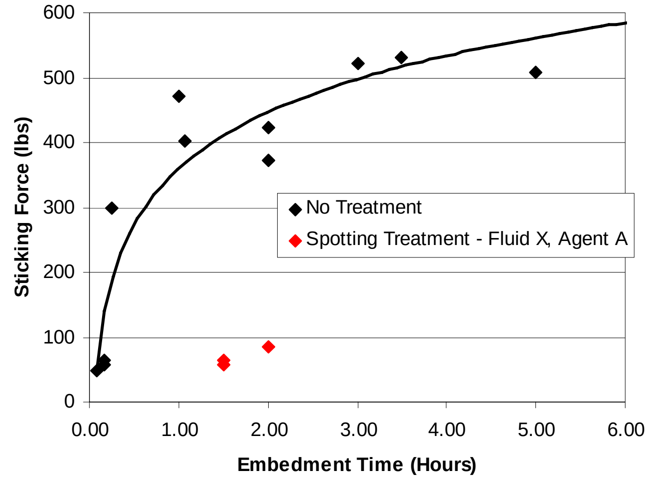

Figure 9: Plot of differential sticking force in test apparatus for multiple tests without spotting treatment and tests with spotting treatment. Note dramatic decrease in sticking force with treatment.

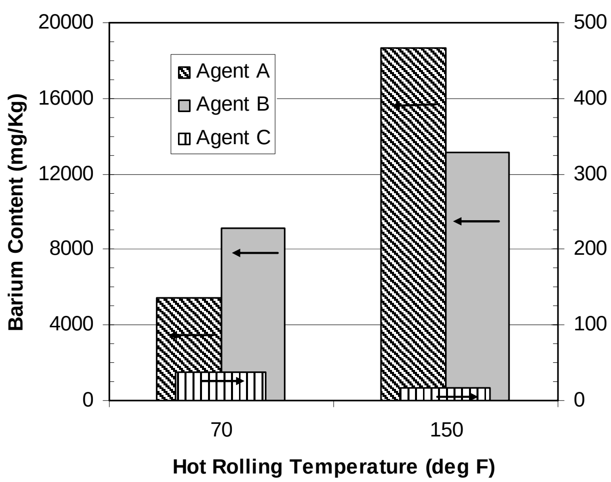

Figure 8: Chart of barium concentration in fluid after rolling tests. Notice large temperature effect and that Agents A & B have large concentrations of barium in solution.

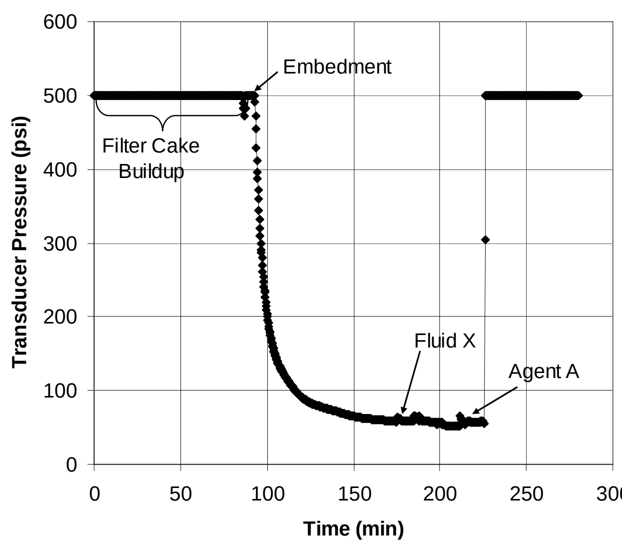

Figure 10: Plot of pipe transducer pressure data. Note decrease in pressure upon embedment into the filter cake and increase in pressure following treatment with Agent A.