LABORATORY EVALUATION OF FILTERCAKE CLEANUP TECHNIQUES AND METALLIC SCREENS PLUGGING MECHANISM IN HORIZONTAL WELLS

Gloria S. Garcia-Orrego
Kinder Morgan CO_2 Company LP

ABSTRACT

Tests were conducted to evaluate the plugging mechanisms of metallic screens after cleaning up the filtercake developed on an unconsolidated core by two exiting drill-in fluids (DIF's). Two simulated drill solids, clay or 75-μm reservoir sand were added as drill solids to these DIF's. Metallic screens were used to simulate the sand control device. The DIF's tested included a sized-calcium carbonate (SCC) and a sized-salt (SS).

The presence of the drill solids was found to affect the particle size distribution as well as the mean size (D_{50}) of the particles of the bridging and weighting material (BWM) and loss control material(LCM) of the DIF's.

On the basis of the observations, it can be concluded that SCC filtercakes tended to result in minimum dislodging pressure (MDP), leading to higher regained-flow capacity and lower plugging of the screen. In contrast, SS filtercakes required high MDP, decreasing the regained-flow capacity highly and causing severe plugging of the screens.

INTRODUCTION AND STATEMENT OF THE PROBLEM

The present research studied the impairment of the screen permeability caused during backflow of the filtercake developed by two existing drill-in fluids (SCC and SS). The mechanism of the plugging of the metallic screen was evaluated by displacement of these DIF's with and without drill solids. The degree of plugging was attributed to the concentration, particle size distribution, and chemical composition of the solid material that constituted the filtercake. Finally, the study examined the effectiveness of HCl to degrade the filtercake and restore the flow capacity of the system (unconsolidated sandstone-screen) before the well is put on production.

This residual filtercake can plug the screens during backflowing once the residual filtercake is dislodged from the formation.

The objectives of this research can be described as follows.

1. Investigate the correlation between particle-size distribution of the solid material component of the filtercake and the plugging of the screen.
2. Carry out qualitative microscopic observations of the filtercakes to characterize the pore throat connection among particles as well as to visualize the cohesion among particles with and without simulated drill solids.
3. Conduct a qualitative correlation based on the internal structure of the filtercake and chemical clean up behavior of the filtercakes.
4. Evaluate the cleanup of the filtercakes developed by SCC and SS DIF's altered by drill solids.
5. Investigate the screen plugging mechanisms caused by backpressure on whole or residual filtercakes after chemical removal of the filtercake.

LITERATURE REVIEW

The emphasis in this research is on recent completion failures in which screen plugging caused by filtercakes deposited on the face of the formation has been found to be the primary cause. The screen plugging, which occurs during the initial production of the well, has been successfully duplicated in the laboratory through small- and large-scale tests, and the mechanisms involved in the plugging of the screens have been identified. Total or partial plugging of the screens in the presence of filtercakes developed by these DIF's laden with drill solids leads to high backpressures, which promotes the incrustation of solid particles through the screen openings.

The problem of reduction of productivity caused by screen plugging has been evaluated through two stages. The first one is related to the mechanism of the plugging caused by the filtercake developed by the DIF's, and the second one is related to the cleanup of the filtercake. Both topics have received some attention in the literature.

Browne *et al.*[1] performed several tests to evaluate the physical removal of filtercakes or to assess the effectiveness of chemical removal. The authors concluded that the differential pressure to lift off and initiate flow through the filtercake is a function of both mud type and formulation.

Browne *et al.*[2] stated that the quality control of the mud systems during drilling is necessary for maximum productivity of horizontal wells completed with sand-control prepacked screens.

Ryan *et al.*[3] described a major industry study into the effectiveness of mud cleanup techniques for horizontal wells. Their experimental work was carried out to quantify mud damage and to evaluate overall cleanup techniques to remove the damage caused by the filtercake in the presence of screens.

Fraser *et al.*[4] investigated the mechanism by which filtercakes are developed against sandstone faces, as well as their nature and implications for their removal during the cleanup period

Hodge *et al.*[5] carried out an evaluation of the best DIF for the unconsolidated formations completed in horizontal wells. The evaluation of the fluid candidates focused on both DIF properties and formation-completion damage.

Burnett *et al.*[6,7] examined the role of drill solids in causing formation and completion damage in horizontal openhole completions. The laboratory work performed used a variety of core flow techniques to simulate DIF filtercake deposition and well production in horizontal, openhole completions. They stated that the drill solids are a significant source of insoluble material of the filtercake that can be deposited on screens, resulting in a drastic productive reduction. These drill solids suspended in the DIF become integral parts of the filtercake, affecting its removal.

EXPERIMENTAL MATERIALS

Drill-In Fluids Used

Two new types of DIF's were tested: sized salt (SS) and sized calcium carbonate (SCC) drill- in fluids.

The SS IF systems are based on a blend of a xanthan gum biopolymer, a crosslinked hydropropylated starch derivative, and sized sodium chloride (NaCl) as primary BWM. The polymer blend mixed in a saturated brine (NaCl – 1.106 gm/cc) make-up fluid keeps the graded salt from dissolving. A blend of modified starch and sized sodium chlorides form the loss control material (LCM), which provides fluid-loss control and viscosity.

The SS systems[8] comprised undissolved salt particles in a size distribution specific to the pore throat diameter of the interval being completed or drilled. The resulting fluids are nondamaging, inhibitive, lubricating and shear thinning with good suspension characteristics. The cubic structure of sodium chloride allows tight, strong packing that forms thin, impermeable filtercakes.

The SS systems can significantly reduce well productivity because it impedes flow capacity in the near-wellbore region. The damage may be characterized by unbroken gel residue having limited mobility or by insoluble polymer fragments[9] produced by BWM.

Hydrochloric acid (HCl) is used to degrade the starches and xanthan gum in the filtercake formed by water-based SS. Proper displacement, soak, and wash procedures are essential to achieve optimal production.

Suspension and filtration polymers in the SS system overlay and fill in between the salt particles, developing an ultralow-permeability membrane that must be treated chemically with either acid or oxidizer. Although acid systems and other oxidizing agents will work to break the polymer chains and improve the flow efficiency of the completion, several advantages have been demonstrated with the use of the enzyme systems.[9]

Hale *et al.*[10] have suggested using 10% HCl to remove the SS filtercake (acid strength can be reduced at temperatures less than 200^0F). The acid is displaced into the open hole and allowed to soak for 6 hours. Then the well is circulated with under saturated brine to remove the remaining salt.

A SCC DIF uses calcium carbonate ($CaCO_3$) as BWM. The calcium carbonate has a broad particle size variation to bridge rock pore throats with a permeability ranging from a few millidarcies (md) to over 10 Darcy (D).[11] The calcium carbonate is mixed with 0.5% silica gel, which increases the viscosity of the system and produces a shear-thinning fluid with a high viscosity at low shear rates.

Addition of polymer filtration control agents provides a low leak-off rate that produces a thin, erosion-resistant, lubricating SCC filtercake. Biopolymers are used as viscosifier, and potassium chloride (KCl) as part of the brine is used for inhibition and filtercake dispersibility.

Hale *et al.*[10] have suggested that to remove the SCC filtercake, higher strength (10-15%) HCl may be used, depending on the temperature and DIF density. Typically, the acid is displaced into the open hole and allowed to soak for 6 hours. A second soak is usually employed to remove the residual filtercake. Then, the well is circulated with completion brine.

The composition and the description of their additives of both DIF's used in this study as provided by vendors are given in Table 1.

Filtercake

The filtercake is formed when differential pressure is applied on a DIF during the drilling operation. Solid particles suspended in the DIF are retained at the surface of the porous medium, leading to the formation of the filtercake. Filtercake thickness and compaction increases with time. The filtercake typically comprises solids, either starches or cellulose polymers and calcium carbonate or sodium chloride particles, with water as the liquid interstitial.[11]

In the filtercake formation, the sizes of the particles present in the DIF often cover a wide range. While the majority of the particles are retained to form a filtercake, a small amount of finer ones may be retained into filtercake. Therefore, the permeability of a filtercake depends upon the extent of the compression to which it is subjected, as well as the amount of fines retained within the filtercake.[12] It has been demonstrated mathematically that a high content of ultrafine material produces a remarkably impermeable filtercake,[12] which precludes the movement of fluid through its pore throats and avoids any fluid invasion.

Drill Solids

During drilling operations, clay and other fine particles can be released from the formation when the forces acting on them can no longer keep them on the pore spaces. These particles constitute the drill solids that become suspended into the DIF, form part of its filtercake.

Clay as Drill Solids

Calcium montmorillonite, which is used to represent clay drill solids, was simulated using Rev Dust™. The composition obtained by the use of energy dispersive spectroscopy (EDS) is shown in Fig. 1 depict the individual elements present in the clay. The clay is characterized by a cloudy appearance, Fig. 1, but the clay particle consists of an indefinite number of layers stacked on top of each other.

The chemical composition of the calcium montmorillonite clay is an important factor to take into account, when tiny particles of this clay are suspended in a strong, saturated DIF composed of sodium chloride. In the presence of this kind of DIF's, clay particles can collapse. In such way, calcium montmorillonite clay particles can approach each other so closely that the attractive forces predominate and agglomeration occurs. This happens when the double layers, previously mentioned, between the particles are compressed by increasing sodium chloride concentration.[13]

Sand as Drill Solids

Sand as drill solids was obtained from a core recovered from a Conoco well. Part of the core was triturated and the sand was sieved using a 200-mesh screen to obtain a mono-sized particle of 75 μm.

Fig. 2 shows the chemical composition of the sand that is compounded mainly by silica (SiO_2), although some traces of other components such as calcium and aluminum were identified. Sands can be considered inert drill solids. This means that they are chemically inactive when they are suspended into the DIF, but they can affect the physical properties of the solids present in DIF's.

Poroplus Metallic Screen

A Poroplus™ metallic screen[14] was used in the laboratory tests. The metallic screen is a device with three layers, as shown in Fig. 3, with spacing between the layers of each wire, gauged such that formation particles entrained in the produced fluids are selectively sorted and bridges the various wire spaces according to the gauge or screen size. Thus. Thus, with selected gauge spacing designed to retain particular formation sands, the particles are selectively sorted and bridged within the layers of the screen according to the grain size exhibited by the formation particles.[15]

Mechanism of Screen Plugging

The severity of the plugging and the widths of the slots that can be plugged depend on the particle size distribution of the whole filtercake or residual filtercake mix with reservoir sand collapsed onto the screen. Plugging is more likely to occur when the flow is started at high pressure.[16]

There are at least two ways by which a production screen can be damaged in a horizontal well. The first way is when the filtercake formed at the sandface is backflowed at the beginning of production.[3] The second is when the unconsolidated sandstone collapses and deposits with a residual filtercake onto the screen.[7]

Plugging of the screens is initiated when reservoir fluid flows towards the screen and the finest fraction of solid particles that form the filtercake are separated from the bulk and transported towards the screen.[16] These particles form a filtercake along the screen slots with a much lower permeability than the bulk filtercake, restricting the flow through the screen slots. The filtercake that forms along the slots when they became plugged is generally thin and can be easily removed. However, some particles invade the slots and get trapped into the internal wraps of the screens, consequently reducing the overall flow efficiency of the screens.

The cause of the screen plugging has been attributed to the size and presence of ultrafine and fine material in either the filtercake or the collapsed formation. The action of fines as a flow restriction in an openhole completion is known, but often considered to exist only immediately after the completion.

The size, type, and quantity of fine particles smaller than 45 µm may play a starring role in the screen plugging.[17] These particles can enter the slots and bridge the inner layer of the screens. Additionally, fines greater than 5% or so would provide a sufficient quantity to plug the screens, causing significant impairment of the screen permeability and reducing well productivity.

LABORATORY WORK METHODS

The most important objectives of the laboratory work presented in this research[18] are aimed at investigating how to remove filtercakes by using potassium chloride (KCl) or hydrochloric acid (HCl) and how residual filtercakes left against the unconsolidated core plug metallic screens.

The project addressed various characteristics of the filtercake altered with simulated solids and the effect of these drill solids in filtercake removal prior to installing a metallic screen into the wellbore. The following aspects were taken into account to carried out the laboratory work:.

1. The initial laboratory work focused on determining of the particle size distribution (PSD) of the weighting and bridging materials used in two existing DIF's, SCC and SS. The most important components of the DIF's, the BWM, were altered by two types of simulated drill solids, clay and 75-µm sand, to observe their PSD performance.

2. Scanning electron microscopy (SEM) imaging was used to study the internal structure of the filtercake developed by original SS and SCC weighted at 10.5 ppg. Then the simulated drill solids were added to the DIF, and new filtercakes were built up. SEM was used extensively.

3. The final area of experimental investigation addressed the behavior of the backflow through the whole filtercake and residual filtercake. This laboratory work was divided into three sections. The first set of tests compared the backflow of the filtercake after 3% KCl cleanup. The second section examined how DIF filtercakes impaired the screen permeability.

   The last area of the investigation dealt with the cleanup or removal process of the filtercake using 5% HCl at two different temperatures. Afterwards the residual filtercakes were backflowed through a 125-µm screen to observe its plugging.

Dry Sieve Analysis

A sifter was used to obtain the particle size distribution (PSD). The particle-size analyzer contains an assortment of sieves arranged according to decreasing opening sizes. The mesh sizes used were 300, 212, 106, 90, 75 and 45 µm.

SEM Imaging

The microscopic structure of the DIF filtercakes built up under static conditions at a differential pressure of 200 psia and 150$^{\circ F}$ were observed with a Cameca SX-50 electron microprobe. Additionally, its energy-dispersive X-ray spectrometry (EDS) allows qualitative chemical analysis of the observed material.

Conoco Cell Procedure

The laboratory techniques used in this study were developed to simulate and characterize the screen plugging that occurs during the initial completion of a horizontal well. These tests have allowed the quantification of the mechanism involved in the plugging of the screens. Testing procedures were developed by CEA 73 and were implemented by Burnett at Texas A&M.[19]

Conoco Inc.[5] developed a test device called a linear flow cell,[6,7] shown in Fig. 4. This cell was designed to measure the extent of metallic or pre-packed screen plugging in terms of regained permeability and to gauge a DIF's' capacity to form a thin, low-permeability filtercake.

Base Permeability Determination

Synthetic oil (SOLTROL-170™) was pumped through the whole assembly at 60 cc/min. The flow rate and pressure drops were measured. The initial flow capacity of the system (unconsolidated core/screen) was determined using Darcy's equation:

$$K_i = \frac{Q_o \times \mu_o \times L_{Core}}{A_{Core} \times \Delta P} \quad \text{......} (1)$$

Regained Permeability Study after Filtercake Cleanup Phase

The cleanup phase had the objective of removing the tested filtercake. Two chemical treatments were performed to evaluate the removal of the filtercake. In the first, 3% KCl was injected through the core to remove the filtercake under two different slot widths, 125μm and 250 μm. In the second, hydrochloric acid at 5% volume concentration was used to evaluate the ease with which the filtercake could be removed at two different temperatures, 150°F and 190°F.

$$K_r = \frac{Q_o \times \mu_o \times L_{Core}}{A_{Core} \times \Delta P} \quad \text{......} (2)$$

The regained-flow capacity (RFC) is determined as follows:

$$RFC = \frac{K_r}{Ki} \quad \text{......} (3)$$

The term K_r/K_i in Eq. 3 represents the fraction of permeability restored after removing the filtercake. Therefore, the higher the RFC, the higher the restored permeability of a given cleanup treatment. This relationship allows evaluating the cleanup efficiency of the filtercake formed by DIF's, both with and without drill solids, and the screen plugging after subsequent backflow through the residual filtercake.

Screen Permeabilities

Laboratory testing was performed to determine whether DIF filtercake could be produced through the metallic screen without reducing the permeability of the screen. The tests were performed on 3.24-cm-diameter disks of the metallic screens with two different slot widths to compare their performance.

Two approaches were used to determine the flow capacity of the metallic screen. The first approach was to flow lubricant oil (SAE 30) with a viscosity of 10 cp through the unplugged screens from the inside to the outside to obtain the initial permeability for each screen without unconsolidated cores. In the second approach lubricant oil was displaced through the plugged screen to determine the screen's permeability impairment. The permeabilities were calculated using Darcy's equation.

DISCUSSION AND RESULTS

The experimental laboratory work tested included screen slot width, DIF solid type, drill solid type, drill solids concentration, and PSD of the BWM, LCM, and drill solids.

Two different screen slot widths were used: 125 μm and 250 μm. DIF types included SCC and SS. Drill solid types were: clay and 75-μm sand. Both of these drill solids were used in concentrations of 2.5% wt and 5% wt.

At the onset of this research, it was still uncertain how the particle size distribution of the bridging and weighting material and drill solids affects the filtercake removal and screen plugging. Different combinations of BWM with simulated drill solids were analyzed.

Particle Size Distribution

The measurement of particle size distribution of the weighting and bridging agents that compose the DIF's as well as their mixture with simulated drill solids should, in principle, be indicative of the filtercakes' inclination to plug the metallic screen slots once it is dislodged. The objective of these PSD tests was to find some sort of correlation with the filtercake removal and the extent of plugging.

The potential damage of solids depends primarily on their size, dispersed character, and interaction with other DIF additives. Table 2 shows typical size ranges for various solids in this research. The most damaging sizes with respect to the screen plugging are the ultrafine size ranges, which are represented by particles smaller than 45μm in most sieve analyses.

By definition, the median particle size (D_{50}) is the one read at 50% on the cumulative mass percentage of particles larger than a certain diameter, which are graphed in a semi-logarithmic plot.

PSD of BWM and LCM of Sized-Salt DIF

As a first step, the PSD of the BWM and LCM used in both DIF's to be tested was determined by performing a dry sieve analysis. The SS DIF is made up of two types of solids: the BWM and the LCM. The mixture of these solid materials of the SS DIF was formed with the same proportion (50% wt) of each component.

Fig. 5 shows the PSD of the sized-salt BWM and LCM. The median particle sizes (D_{50}) for bridging, weighting and fluid-loss control materials and their mixture were determined to be 11 μm, 230 μm, and 38 μm, respectively. It should be pointed out that the BWM constitutes a high proportion of the solids that form the SS DIF, which provides most of the main characteristics of the filtercake.

A comparison between the ultrafine amount in these two ingredients of the SS DIF indicated that the BWM provides the highest value of the damaging size range (82%). However, in mixture with the LCM, this value decreased to 53%.

PSD of Clay as Drill Solids

The clay PSD is shown in Fig.6. The ultrafine content was about 31%. Clay has a wide particle-size distribution, and the median particle size (D_{50}) is 80 μm.

A comparison between both of the simulated drill solids indicates that the fines particles (45 to 75 μm) in clay constitute only 14%, whereas sand as solids consists almost totally of particles with a size of 75 μm, with neglected quantity of particles less than 45 μm. Therefore, the sand as drill solid constitutes mono-sized particles.

PSD of BWM and LCM of Sized-Salt DIF Containing Drill Solids

Fig 7 depicts the performance of the PSD of the BWM and LCM for the SS DIF with clay. The PSD did not change significantly when clay was added at 2.5% and 5% wt, and additionally it can be observed that the median grain size was slightly diminished from 38 μm to 35 μm.

The PSD of the solid materials of the SS DIF with 75-μm sand is shown in Fig. 8. A significant decrease in ultrafine content is noticeable, and the median size of the particle grains increased. The median size varied from 38 μm to 50 and 58 μm when the 2.5 % and 5% of 75-μm sand were added to the DIF. Also, the percentages of ultrafine material decreased from 53% to 43% and 36% with an increase of 75-μm sand of 2.5% and 5%, respectively.

PSD of BWM and LCM of Sized-Calcium Carbonate DIF Containing Drill Solids

Fig. 9 shows the PSD for BWM in the SCC DIF and clay mixture. Percentages of 2.5% or 5% clay were mixed with the SCC weighting and bridging agent to observe the performance of combined average PSD. The median size (D_{50}) decreased from 28 μm to 20 μm and 18 μm for 2.5% and 5% clay, respectively. Also, the BWM of SCC has a high content of ultrafine material (58%), which was increased by adding clay to 65% and 73% for 2.5 and 5%, respectively.

Fig. 10 shows the behavior of the PSD when 2.5 and 5% wt of 75-μm sand was added to BWM of SCC. Notice that an inflection point at 75 μm occurred, producing a reduction in ultrafine content. For 2.5% wt of sand, the median grain size was increased from the original 28 μm to 42 μm, and when the percentage of sand was increased to 5%, the average grain size increased from the original 28 μm to 52 μm. Also, the ultrafine material showed a decrease when 75-μm sand was added to the BWM; the original percentage was changed from 58% to 50% for 2.5% sand and to 42% for 5% sand.

From the previous results, it is evident that the weighting and bridging agents make up a significant fraction of the DIF and even more of the filtercake. The DIF is a suspension of the solids (weighting, bridging and loss-control additives) into a water phase. When the DIF is displaced through a porous medium under a differential pressure, the majority of solid particles of the DIF are available to provide an optimal bridge or to seal a specific pore opening. These solids are too large to pass through the medium. Consequently, they become retained at the porous medium surface to form a filtercake. For this reason, the particle size distribution of the filtercake reflects the particle size distribution of the solids that compose the DIF. Therefore, the PSD plays a significant role in the performance of the filtercake developed by DIF's.

Logically, the physical properties of the BWM and LCM of the DIF's will exhibit a marked dependence on the broad PSD of the drill solids as well as on the concentration of these particles which will become suspended into the DIF and form part of the filtercake.

The PSD of the solid material of the filtercake shows that the SCC weighting material has an average grain size of 28 μm and a high percentage of ultrafine particles, 58%. Therefore, the DIF would tend to form a thick, impermeable filtercake because of the tighter packing of these small particles. Addition of clay to the SCC DIF would increase the ultrafine material content in the filtercake; thus, it will develop a tighter and harder filtercake than the one formed by the original SCC DIF with 0% drill solids.

In contrast, the filtercake formed by SCC with 75-μm sand added, the median grain size will be slightly increased and the ultrafine content substantially diminished. This filtercake will be much more permeable and less tight and hard.

The SS DIF may develop a more permeable and weaker filtercake because of its relatively large median size (38 μm) and relatively small percentage of ultrafine particles (53%). However, the presence of clay in the filtercake developed by SS increases the cohesive force among particles, producing a filtercake stronger than the one developed by the original SS DIF with 0% drill solids. The filtercake containing 75-μm sand would have larger permeability and decrease the cohesive force among particles because of the coarse sand particles.

The PSD of the filtercake depends on the PSD of the DIF solids; the finer the original size, the closer the particles will be packed. Under the same differential pressure, ultrafine particles tend to result in maximum packing of the particles, resulting in a filtercake with lower permeability and porosity than its coarse counterpart.

Finally, the wider particle size distribution of the clay has a larger effect on the PSD of the DIF solid components than mono-sized sand as solids. The more mono-sized the particle distribution, the higher the median size of the particles in the DIF solids and the lower the ultrafine material content.

Cake Texture Imaging

A scanning electron microscope observations were carried out so as to obtain a better understanding of the microscopic structure of the filtercakes, the effect of the different additives, and the variations of the cake structures versus the presence of simulated drill solids.

Sized-Calcium Carbonate Filtercake Texture

The SCC's BWM has the widest range of particles less than 45 μm (58%). These calcium carbonate particles are held together by the starches and biopolymers that are incorporated as solid material to control fluid loss in these DIF's.
A typical image of the original SCC filtercake (0% drill solids) is shown in Fig.11. Pore throats are clearly visible among $CaCO_3$ grains with some clusters of ultra- fine weighting material. The pore size varies from 2.5 μm to 5 μm that would restrict the flow of fluids through it. The size of the grains varies from 10 μm to 15 μm and the aggregates of ultrafine material having a size less than 5 μm are hold together by the starches and biopolymers that act as glue on the calcium carbonate particles.

The filtercake developed by a mixture of SCC DIF and clay is shown in Fig.12. This filtercake appears to be much more clustered together and the pore throats are visibly filled with ultrafine material. This filtercake has a structure similar to that observed in the original filtercake (0% drill solids), but the size of the pores was smaller.

The filtercakes formed by SCC DIF with 5% 75-µm sand are shown in Fig. 13. The pore throats are clearly visible among the $CaCO_3$ particles, clustered grains of ultrafine material form some bridges, which are embedded into the $CaCO_3$ network In general, the 75-µm sand as solids constitute a mono-sized particle distribution and the degree of infilled pores among the filtercake particles is relatively low, and high filtercake permeability is produced. The pore size is bigger than that formed by SCC filtercakes with clay. Furthermore, the filtercake with 75-µm sand resembles that developed by the original SCC.

Sized-Salt Filtercake Texture

The comparative SEM images of the filtercake formed by SS with and without drill solids were also investigated. The filtercake imaging of the original SS DIF shows that the SS filtercake is quite different from that of the SCC. In the SS filtercake, Fig. 14, large particles of LCM with sizes varying from 20 µm to 80 µm are in grain-to-grain contact and the pore structure is controlled by ultrafine particles of BWM that constitute about 60% of the solid material of the filtercake. As mentioned before, the SS BWM is a mixture of xanthan gum, starches, and sized sodium chloride with a high ultrafine content (82%) and an average median grain of 11 µm.

Fig. 15 shows an image of the filtercake developed by SS containing 5% clay. The clay has occluded pore throats of the filtercake. A thorough inspection of the filtercake with SEM showed similar results throughout the sample. The structure observed in the SS/clay filtercake seems to indicate that the behavior of calcium montmorillonite was affected by the ions of sodium and chloride present in the suspension of the DIF before the filtercake was formed. The flocculated clay is trapped into the framework of the SS particles, forming clusters in lumps. The appearance of the pore-lining flocculated clay is very different from that before addition to the SS DIF

Fig. 16 shows that the filtercake with 75-µm sand is more chaotic and clustered than for the cakes formed by the previous SS systems. This appears to be caused by many small weighting and bridging particles that are perpendicular to larger LCM and medium sand particles. This structure seems to have a larger contact area than the other filtercake structures because the sand grains were embedded among particles.

These microscopic observations confirm that the sizes of the particles present in both DIF's cover a broad range. While the majority of the particles are retained to form the filtercake, the ultrafine particles are retained into the cake. The rigidity of a cake depends on the amount of fines retained within the cake. Finer particles present in the SCC DIF system with clay tend to form tight, strong, impermeable filtercakes, whereas the coarse particles (sand drill solids) tend to form filtercakes that would not have as much cohesive strength because the ultrafine material decreased.

In all of the SS filtercakes, a strong link was observed between coarse and ultrafine particles produced by the presence of xanthan gum and starches.

SS filtercake containing calcium montmorillonite suggests that the clay particles suffered some alteration as a consequence of the action of sodium and chloride ions over the calcium of the clay particles, which seemed to have aggregated to increase the cohesive force among particles in this kind of filtercake.

The Effect of Screen Plugging Caused by Backflowing Filtercake

The primary objective of these laboratory tests was to investigate the plugging mechanism when a whole or residual filtercake with drill solids developed opposite an unconsolidated sandstone core is sandwiched between the core face and the sand-control metallic screen.

The tests focused on various responses of the filtercakes developed by the DIF's containing drill solids when they are either physically or chemically removed from the core.

The results derived from the regained permeability obtained after 3% KCl cleanup and subsequent backflow are illustrated and discussed in the following section.

Figs. 17 and 18 depict the regained flow capacity profile when SCC and SS filtercakes containing either clay or sand were backflowed through 125-µm or 250-µm screen. SCC results in significantly more regained flow capacity to unconsolidated sandstones when is compared to SS after 3% KCl treatment.

Fig. 17 shows the behavior when backflow was imposed through the SCC and SS filtercakes with and without clay as drill solids. When a SCC filtercake was backflowed through a screen-slot width of 125 µm, the regained-flow capacity was as high as 42%. When the clay concentration was increased to 2.5%, the regained-flow capacity decreased to 10.6%, whereas an increase to 5% clay reduced the regained-flow capacity to 3.2%.

After the screen slot width was changed to 250 µm, new tests were carried out including backflow through the residual filtercakes. A reduction in flow capacity of 22% was observed when the original SCC formed the filtercake. When 2.5% clay was added, the regained-flow capacity decreased to 10.4%, whereas an increase of 5% clay reduced the regained-flow capacity to 4.9% .

The results obtained for the filtercake developed by the original SS were determined to be about 36.3% and 12.6% for the 125-µm and 250-µm screens, respectively.

During the backflow through the 125-µm screen, the regained-flow capacity profile obtained for the SS/clay filtercake can be summarized as follows: For 2.5% clay, the regained-flow capacity decreased to 9.2%. An increment in percentage of clay to 5% produced a reduction in the regained-flow capacity to 3.2%.

For the 250-µm screen and 2.5% of clay, the regained-flow capacity fell to 9.4%. An increase in the percentage of clay concentration to 5% caused a severe decrease in the regained-flow capacity to 1%.

For the following set of experiments, 2.5% and 5% wt 75-µm sand were added as drill solids to the SCC and SS DIF. Fig. 18 shows the regained-flow capacity obtained using 125-µm and 250-µm screens.

The chart shows that the regained-flow capacity was highest when the original SCC was displaced. Afterwards, there is a significant decrease in regained-flow capacity as a consequence of increasing sand concentration. Using the 125-µm screen, the regained-flow capacity when 75-µm sand was added to the SCC DIF at 2.5% and 5% was 43.6% and 25.9%, respectively.

The regained-flow capacity profile showed a reduction for the 250-µm screen when 2.5% and 5% 75-µm sand were added to SCC DIF. The regained-flow capacity was 16.6% and 11.5 %, respectively.

The addition of 75-µm sand as drill solids to the SS DIF resulted in reduction of regained-flow capacity when the filtercake was under backpressure through a 125-µm and a 250-µm screen as shown in Fig. 18.

When the percentage of sand was 2.5%, the regained-flow capacity was 14.2%. Sand percentage was increased to 5% and the regained-flow capacity decreased to 2%.

With the 250-µm screen, the regained flow capacities were calculated to be 9% and 1% when the sand concentration varied from 2.5% to 5%, respectively.

A simple inspection of Fig. 17 and 18 reveals a common characteristic between the behavior of the filtercake on the two screens. The reduction of regained-flow capacity is directly related with an increase of the suspended drill solids forming the filtercake. The presence of clay increases the content of ultrafine particles and decreases the median size of the particles, which makes the filtercake tight, compact, and hard to remove from the core.

The performance observed with the different SCC filtercakes when they are back flowed through 125-µm and 250-µm screens can be explained in terms of the retention capacity of those screens, which is basically a function of the relationship between particle size and screen-slot widths. The screen is supposed to retain particles larger than its slot width, but small particles can get through and plug the internal wraps of the screen.

During the backflow, oil (Soltrol-170™) is displaced through the core/filtercake/screen, the filtercakes both with and without drill solids are detached from the core completely as a consequence of the backpressure or minimum dislodging pressure (MDP), then the filtercake is totally or partially forced through the screen slots. This pressure behavior was observed in all tests performed to evaluate the 3% KCl cleanup and subsequent backflow of the filtercake.

Table-3 summarizes the MDP. It can noticed that MDP was generally lower in the system (core/filtercake/screen) exposed to original (0% drill solids) SCC and SS than the DIF containing clay. There is an inverse relationship between regained-flow capacity and MDP values. The smaller the particle size and the higher the concentration of ultrafine material, the higher the MDP and the lower the regained-flow capacity.

When sand as drill solids is added to the SCC DIFs, a similar behavior is observed during the backflow. Nonetheless, the numerical values of the MDP and stabilized pressure are much larger when clay is added to the DIF instead of sand as drill solids for the same concentration.

This performance indicates that the SCC filtercake with sand has weak cohesion among particles, but the increase of coarser particles causes an increase of the MDP for this kind of filtercake, which increases the screen plugging, reducing the regained-flow capacity of the system (core/filtercake/screen). On the other hand, sand as drill solids into the SS filtercake was embedded into the pore throats where it was held strongly by the glue formed by polymers and starches. Consequently, the cohesive force among SS filtercake particles was increased when sand made up the filtercake, increasing the MDP.

A comparison between SCC filtercakes and SS filtercakes indicated that the filtercakes developed by SS DIF's are affected by the presence of xanthan gum, which seems to increase the strength of the filtercake since the particles of salt and gum show tenacious cohesion. Therefore, the SS filtercakes are harder to remove from the core during backflow than their counterpart SCC filtercakes.

Screen Permeability Impairment

The impairment of screen permeability was established by determining the flow characteristic of the screens before and after backflowing of the filtercake. Two approaches were used to verify the screen-plugging mechanism. The following section describes the results.

Standard lubricating oil (SAE 30) was first circulated through the Poroplus™ metallic disks at 60 cm/min to establish the initial flow characteristics. Afterwards, either original SCC or SS were used to build up filtercake. Then, the core/filtercake/screen system was backflowed using Soltrol-170™. Once the screens were plugged and the unconsolidated core removed from the linear cell, SAE 30 oil was flowed through the filtercake/screen, and the flow rate and pressure were determined to evaluate the residual flow characteristics after screen plugging.

Fig. 19 shows the performance of the screen permeability with and without plugging. The metallic screen's initial permeabilities were determined to be 5,092 D for 125-µm screen and 4,160 D for 250-µm screen. Some variability in the permeability can be seen in the cases where the filtercakes were pushed into the screen slots by the high backpressures applied to displace the Soltrol through the core/filtercake.

As the screens retained the filtercake particles, their permeabilities were reduced. The permeabilities of the 125-µm screen after backflowing original SCC and SS filtercakes were reduced to 3,000 and 2,700 D, respectively. For 250-µm, the reductions in permeabilities were calculated to 2,800 and 1,700 D, respectively, when SCC and SS filtercakes were backflowed.

The screen behavior at the original SCC and SS filtercakes suggests that screen permeability was affected more severely by the SS filtercakes than by those with SCC. Additionally, the metallic screens allowed ultrafine particles from the filtercake to invade deeply as high MDP was applied. These phenomena are in good agreement with those observed in the previous tests.

Figs. 20 through 22 show microscopic observations of the metallic screen using an optical microscope at 180X magnification. The screens can be observed before and after flowback of the filtercake. A clean screen is shown in Fig. 20. This picture shows how the outer and inner wraps of the screen are completely free of solids, allowing a total flow. Fig. 22 shows how the solids got through the screen and how fines also plugged its external face.

Cleanup of Filtercake by Acidizing with 5% Hydrochloric Acid

The filtercake formed over the unconsolidated core or on the metallic screen can be highly impermeable because of its ultrafine material content. It has been demonstrated that ineffective removal occurs during the 3% KCl treatment and following backflow. Thereupon, some percentage of chemical agents (acids) may be necessary to remove the filtercake before production.

The laboratory tests used in this section were developed to evaluate the cleanup of the filtercake by displacement of 5% hydrochloric acid (HCl) at two different temperatures, $150^{O}F$ and $190^{O}F$ and afterwards, the residual filtercakes were backflowed through a 125-µm slot-width screen.

A number of different test procedures were carried out to investigate the effectiveness of the HCl acid in degrading the filtercake generated by the DIF's that included drill solids. These tests involved filtercake removal and core-screen backflow to determine the regained-flow capacity after acidizing the filtercake and to evaluate the screen plugging.

The first set of experiments was done by displacing 5% HCl acid over the filtercakes built up using SCC DIF containing clay.

A comparison between regained-flow capacity obtained by SCC and SS filtercakes with added drill solids indicates that the former are less soluble in 5% HCl than the latter. Figs. 23 and 24 show the profile of the regained-flow capacity obtained for SCC and SS filtercakes containing clay or sand. The cleanup of the filtercake seems to be related to the chemical composition of the filtercake, PSD, and concentration of solid particles that form the filtercake. Filtercakes with many coarse particles clean up better than filtercakes with more ultrafine particle sizes.

The 5% HCl provided high regained-flow capacities when the original SCC developed its filtercake. Notwithstanding, the regained flow capacities were low when drill solids formed an integral part of the filtercake. These values were substantially improved when the temperature was increased.

Another important observation of regained-flow capacity performance is related to the type of the drill solids. SCC/clay filtercakes have lower regained-flow capacity than those with 75-µm sand. The former has low interconnection among its pore throats, which prevents the acid from penetrating into the filtercake to reach total dissolution of the calcium carbonate, whereas the latter filtercake has much better connection among its pore throats, favoring the action of the acid.

The chemical composition of the filtercake has a marked influence on the performance of cleanup when HCl is used to degrade the filtercake. The SCC filtercake is a concentration of solids dominated by calcium carbonate that is highly soluble in HCl. This solubility is improved when the temperature of the reaction is increased

The 5% HCl restored the flow capacity as it reacted with $CaCO_3$, forming a soluble calcium chloride ($CaCl_2$) and carbon dioxide (CO_2). It is known that a volume of 1 cc of 5% HCl, at $60^{o}F$, can dissolve[20] 0.07 gm of calcium carbonate. This suggests that 200 cc of HCl can dissolve 14.1 gm of calcium carbonate in the SCC filtercake that included 63.3 gm of calcium carbonate. However, the reaction conditions at $150^{o}F$ and $190^{o}F$ were substantially improved as a consequence of temperature effects.

During the reaction, its rate decreased leaving a filtercake formed by residual $CaCO_3$ and the starches. On the other hand, the filtercakes including clay are not degraded completely by HCl. Gidley[20] noted that HCl is not appreciably reactive with sand (SiO_2) and clay (alumni-silicates). Consequently, calcium montmorillonite clay is not soluble in HCl but forms tough and impermeable filtercakes at higher concentrations, which decreases the efficiency of HCl cleanup.

Hamant[21] stated that during the dissolution of the $CaCO_3$, the number of drill solids particles surrounding each $CaCO_3$ grains increases, thus decreasing the effectiveness of acid and hindering dissolution, since most of the drill solids are insoluble particles in HCl.

As mentioned before, the SS DIF is formed by a blend of graded salt and polymers that make up the BWM. The presence of this additive seems to hinder filtercake degradation totally at $150^{o}F$ by using 5% HCl. The acid initially increased the filtercake permeability rapidly and thereafter reached a lower steady-state value. This behavior was attributed to the voids caused by rapid dissolution of graded salt (NaCl), but the polymeric particles cover part of the SS particles, hindering their total dissolution at $150^{o}F$.

At $60^{O}F$, a volume of 1 cc of 5% HCl can dissolve[20] 0.1 gm of NaCl, which means that 200 cc of HCl can dissolve 16.20 gm of salt. An increase of temperature improves the rate of reaction, as the acid attacks the SS filtercake by degrading the polymer. After sufficient degradation of the polymer, the remaining acid can dissolve the soluble BWM and LCM and the residual left on the core can be removed during the backflow.

The SS/75-μm sand filtercake cleanup was significantly improved by the 5% HCl treatment. This suggests that the high connection of the pore throats in the filtercake favor the acid reaction with the polymer, not only causing reaction with them but also dissolving the saturated SS particles. The acid probably dissolved the SS after reacting with the polymer coating, which is constituted mainly by xanthan gum. Xanthan dissolves in many acidic solutions, even in strong acids such as 5% sulfuric acid, 5% nitric acid, 10% hydrochloric acid.[22] The efficiency of 5% HCl to degrade the SS/sand filtercakes was increased with temperature.

The apparent high level of regained flow capacities for SS blended with drill solids either clay or 75-μm sand was probably caused by the relatively high proportion of coarse material in the filtercake itself, which creates good pore throats that favor the displacement of the acid.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This research presented experimental work to evaluate plugging mechanisms and cleanup techniques to remove the filtercakes before installation of production screens in horizontal wells. Tests used the Poroplus™ metallic screen and evaluated two existing DIF's with added drill solids. Both developed impermeable filtercakes that varied dependent on the simulated drill solids. The evaluations focused on PSD, concentration, and composition and their influence of the physical and chemical removal of the filtercakes from the unconsolidated core before they were backflowed through two screen slot widths.

The main conclusions drawn for this research are as follows:

1. The cleanup of the filtercakes is a function of many factors such as the chemical composition of the DIF, weighting and bridging agents, drill solids concentration, particle size distribution, and composition of the drill solids.
2. The plugging of the metallic screen is dependent on the minimum pressure dislodging applied to the whole or residual filtercake after clean up.
3. Bridging and weighting materials make up a significant fraction of the DIF's and even more of the filtercakes and have marked influence on the strength and the permeability of the filtercake developed by water-based SCC and SS.
4. The presence of clay as drill solids in the SCC filtercake reduced the initial particle size distribution of the bridging and weighting material. The percentage of the ultrafine material was substantially increased, causing a reduction in the median size grains, which decreased even more the paths into the filtercake. Clay also hinders effective contact between acid and the BWM particles, and reduces its potential for total dissolution.
7. The extent of the plugging of the screen by SCC/clay filtercakes was linearly dependent on the presence of ultrafine material and its concentration and inversely proportional to the median size of the particles that constitute the filtercake.
8. BWM and LCM of the SS with clay showed the particle size distribution was slightly lowered. However, increasing its concentration had a strong effect on the cleanup treatment and the plugging was severe since low regained flow capacities were obtained.
11. The calcium montmorillonite clay into the SS DIF could react as consequence of its chemical composition, which allowed cation exchange. This chemical reaction promotes the clay platelets to form aggregates.
12. When 75-μm sand was added to the SS solids, the fine material content decreased and the median size of the particles increased. High regained-flow capacities were measured after backflow through this filtercake.
13. Generalizing the plugging convention, it can be concluded that the screen slots are plugged by particles of the filtercakes containing clay or 75-μm sand when the ratio between the screen-slot width and the size of the particles is from 2 to 16 times smaller than the screen-slot widths.
14. The results based on the PSD and concentration of the drill solids showed three trends:
    - -The narrower-slot screen is less likely to be plugged, regardless of the filtercake DIF used.
    - -The wider-slot screen is more likely to be plugged, regardless of the filtercake used.
    - -Increasing the level of suspended solids able to get through the screen with a consequent reduction in the particle size to be retained increases the probability of the screen to be plugged.
    - - A decrease in the particle size decreases the plugging of the screen.

    The behavior of these different screen-slot widths is based on the difference between the screen permeabilities. The narrower screen has higher permeability than the wider screen and additionally, the selection capacity of the screen decreases when the slot width increases because the selection is a function of the relationship between particle size and screen-slot width.
15. The SCC filtercake is a network dominated by ultrafine materials that provides a strong external filtercake over the unconsolidated core. In such case, a high differential pressure (minimum dislodging pressure, MDP) is required to detach

the filtercake from the core. This pressure ranged from 20 psi to 150 psi. The maximum values were observed for SCC/clay filtercakes, indicating that the increase of ultrafine material developed a strong and rigid filtercake that is difficult to remove.

16. The SS filtercakes composed by xanthan gum, derivatized starch, and sized NaCl are very stable and resistant to break-up during backflow as consequence of the presence of polymers and starches that develop a strong adhesion between the filtercake and core. Consequently, a high MDP is achieved before the flow begins through the filtercake/core sandstone. These pressures ranged from 40 psi to 185 psi. Additionally, the presence of drill solids worsened the removal of the filtercake from the core.
17. As mentioned previously, the SCC filtercakes and SS filtercakes differ in respect to their reaction to the MDP applied to detach the filtercake and begin production. The former detaches completely from the formation core at relatively low MDP, but the latter tends to rupture because it requires a high MDP due to the strength of its filtercake, which is strongly adhered to the core face. Once the oil makes its way to be produced, the pressure through the system (core/filtercake/screen) is stabilized. These two effects explain the mechanism of the plugging of the screen during the backflow. When the oil is allowed to flow through the system once the filtercake is pulled out, all or part of it falls down on the screen. The ultrafinest and finest particles are separated from the bulk of the filtercake and transported towards the screen. The screen retains some of these particles but others, mainly fine and ultrafine material, are allowed to migrate into the middle and inner layers of the screen. These are retained, causing a reduction of the screen permeability, and an impermeable filtercake forms along the internal screen slots. In unconsolidated sandstones, when drawdown occurs and oil production begins, the formation sandstone and filtercake collapse on the screen and exacerbate the screen plugging.
18. SCC seems less damaging than SS, as a consequence of the MDP. The high MDP reached during the dislodging of the SS filtercake seems to favor the encrustation of a large amount of solid material into the screen slots, which further reduces the screen permeability and the flow capacity of the system (core/screen).
19. When the acid is spent to dissolve the BWM, the ratio of the drill solids to BWM increases. This means that the number of drill solid particles (insoluble in HCl) surrounding the weighting and bridging agents increases, thus decreasing the capacity of the HCl and hindering dissolution.
21. The presence of drill solids affected SCC cleanup more than SS systems.

Recommendations for Further Study

1. A better model of filtercake clean up is needed.
2. Newer cleanup techniques need to be tested.
3. The study of the filtercake developed under simulated circulation of the DIF's could be required to evaluate the erosion of the filtercake during circulation. This is an important fact because the filtercake thickness as well as its hardness can be varied by the velocity of the erosion in front of the unconsolidated sandstone.
4. A PSD of the filtercake could be carried out to make a comparison between the initial PSD of the solids to form the DIF and the solids present in the filtercake.

REFERENCES

1. Browne, S.V. and Smith, P.S.: "Mud Cake Cleanup to Enhance Productivity of High-Angle Wells," paper SPE 27350 presented at the 1994 International Symposium on Formation Damage Control, Lafayette, LA, 7-10 February.
2. Browne, S.V., Ryan, D.F., Chambers, B.D., Gilchrist, J.M., and Bamforth, S.A.: "Simple Approach to the Cleanup of Horizontal Wells with Pre-Packed Screen Completions," paper SPE 30116 presented at the 1995 European Formation Damage Conference, The Hague, The Netherlands, 15-18 May.
3. Ryan, D.F., Browne, S. V., and Burnham, M.P.: "Mud Clean-Up in Horizontal Wells: A Major Joint Industry Study," paper SPE 30528 presented at the 1995 SPE Annual Technical Conference and Exhibition, Dallas, 22-25 October.
4. Fraser, L.J., Reid, P., Williamson, D., and Enriquez, F.: "Mechanistic Investigation of the Formation Damaging Characteristics of Mixed Metal Hydroxide Drill-In Fluids and Comparison with Polymer-Based Fluids," paper SPE 30501 presented at the 1995 Annual Technical Conference and Exhibition, Dallas, 22-25 October.
5. Hodge, R.M., Mackinlay, W.M., and Landrum, W.R.: "The Selection and Application of LCM's to Minimize Formation Damage in Gravel Packed Completions for a North Sea Field," paper SPE 30119 presented at the 1995 European Formation Damage Conference, The Hague, The Netherlands, 15-18 May.
6. Burnett, D.B. and Hodge, R.M.: "Laboratory and Field Evaluation of the Role of Drill Solids in Formation Damage and Reduced Horizontal Well Productivity," paper SPE 37125 presented at the 1996 International Conference on Horizontal Well Technology, Calgary, Canada, 18-20 November.
7. Burnett, D.B.: "Wellbore Cleanup in Horizontal Wells: An Industry Funded Study of Drill-in Fluids and Cleanup Methods," paper SPE 39473 presented at the 1998 International Symposium on Formation Damage Control, Lafayette, LA, 18-19 February.

8. Halliday, W.S.: "Drill-In Fluids Control Formation Damage," *World Oil* (Dec. 1994), 43-47.
9. Moore, W.R. and Syed, A.A.: "Formation Damage Removal Through the Application of Enzyme Breaker Technology," paper SPE 31084 presented at the1996 SPE International Symposium on Formation Damage Control, Lafayette, LA, 14-15 February.
10. Hale, A. H., Lau, H.C., Bernardi, L.A., and Albreecht, M.S.: "Selection and Qualification of Drill-In Fluids for Horizontal Wells in Unconsolidated Sands," paper SPE 37077 presented at 1996 Conference on Horizontal Well Technology, Calgary, Canada, 18-20 November.
11. Bayley, L., Meeten, G., Way, P., and L'Alloret, F.: "Filtercake Integrity and Reservoir Damage," paper SPE 39429 presented at the 1998 SPE International Symposium on Formation Damage Control, Lafayette, LA, 18-19 February.
12. Tien, C., Bai, R., and Ramarao, B.V.: "Analysis of Cake Growth in Cake Filtration; Effect of Fine Particle Retention," *AIChE Journal* (Jan. 1997) **43,** No. 1, 33-44.
13. Darley, H.C. and Gray, G.R.*: Composition and Properties of Drilling and Completion Fluids*, Fifth Edition, Gulf Publishing Company, Houston, TX.
14. Poroplus™, Puralator Products Company, Greensboro, NC.
15. Spurlock, J. W. and Demski, D. B.: " A New Approach to the Sand Control Problem- A Multi-Layer, Wire Wrapped Sand Screen," paper SPE 4014 presented in 1972 at the 47th Annual Fall Meeting of the Society of Petroleum Engineers of AIME, San Antonio, TX, 8-11 October.
16. Markesta, P., Christie, O., Espedal, A., and Rorvick, O.: "Selection of Screen Slot Width to Prevent Plugging and Sand Production," paper SPE 31087 presented at the 1996 SPE Formation Damage Control Symposium, Lafayette, LA, 14-15 February.
17. Tiffin, D.L., King, G.E., Larese, R.E., and Britt, L.K.: "New Criteria for Gravel and Screen Selection for Sand Control," paper SPE 39437 presented at the 1998 SPE International Symposium on Formation Damage Control, Lafayette, LA, 18-19 February.
18. Garcia, G.S.: "Laboratory Evaluation of Filtercake Cleanup Techniques and Metallic Screen Plugging Mechanism in Horizontal wells," MS thesis, Texas A&M., College Station, TX (May 1999).
19. Burnett, D. B. Personal Communication. Texas A&M U. College Station, TX (June 1997).
20. Williams, B.B., Gidley, J.L., and Schechter, R.S.: *Acidizing Fundamentals*, Monograph Volume 6, SPE, New York (1979).
21. Hemant, K.J, Mehmet, P., Price-Smith, C., Lindsay, J., Fraser, L.J., and Syed, A.A.: "Mechanisms of Sand Control Screen Plugging from Drill-In Fluid and Its Cleanup Using Acid, Oxidizers, and Enzyme Breakers." paper SPE 39439 presented at 1998 International Symposium on Formation Damage Control, Lafayette, LA, 18-19 February.
22. Kang, K.S. and Petitt, D. J.: *Xanthan, Gellan, Welan, and Rhamsan*, Kelco Division of Merck and Co. Inc., San Diego (1993).

Table 1
Composition and Additives of the SS and SCC DIF's

Type of Fluid	Composition
Sized-Salt	500 cc H_2O, 170 gm NaCl, 104 gm Bridgesal™, 64.5 gm Plugsal™, 6.40 gm Fl-7 Plus, 1.44 cc Defoam
Sized-Calcium Carbonate	376 cc H_2O, 24 gm KCl, 120 gm NaCl 63.6 gm Carbwate™, 0.75 gm Visplus™, 8.25 gm FL-7 Plus, 2 gm pH buffer, 1.14 cc Defoam

Additives	Description	Function
Carbwate™	Super fine (53 microns) $CaCO_3$ and 0.5% by weight of crystalline silica (SiO_2)	Bridging and weighting material
FL-7 Plus™	Derivatize starch	Fluid-loss control additive
Visplus™	Biopolymer	Viscosifier
PH Buffer	Alkaline metal salt	Buffer to maintain alkaline pH (8-12)
Bridgesal™	Salt/polymer blend	Bridging and weighting
Plugsal™	Sized NaCl	Fluid-loss control additive
Defoam	Water/ miscible glycol mixture	Reduce foaming action

Table 2
Size Range Classification

Classification	Size Range, μm
Medium	75-300
Fine	45-75
Ultra Fine	2-45

Table 3
Minimum Dislodging Pressure (MDP) Behavior during Filtercakes Backflow

Concentration of Drill solids, %wt	$MDP_{(SCC\ DIF)}$	$MDF_{(SS\ DIF)}$
0.0	20	38
2.5 (clay)	46	70
5.0(clay)	150	180
2.5 (75 μm sand)	18	60
5.0 (75 μm sand)	35	130

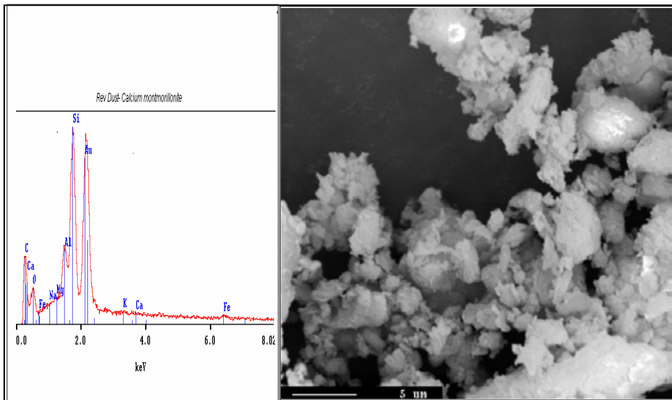

Figure 1 – Calcium Montmorillonite Clay Chemical Composition and Structure

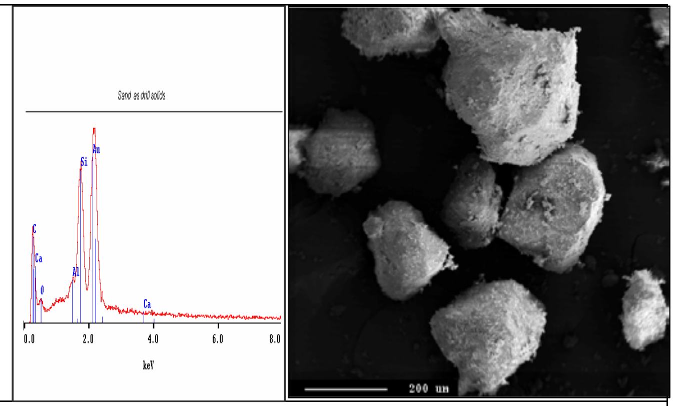

Figure 2 – Sand As Drill Solids Chemical Composition

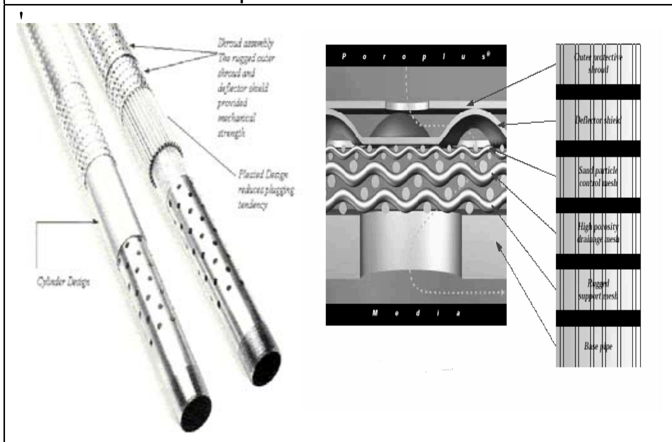

Figure 3 – Poroplus™ Metallic Screen (Courtesy of Halliburton

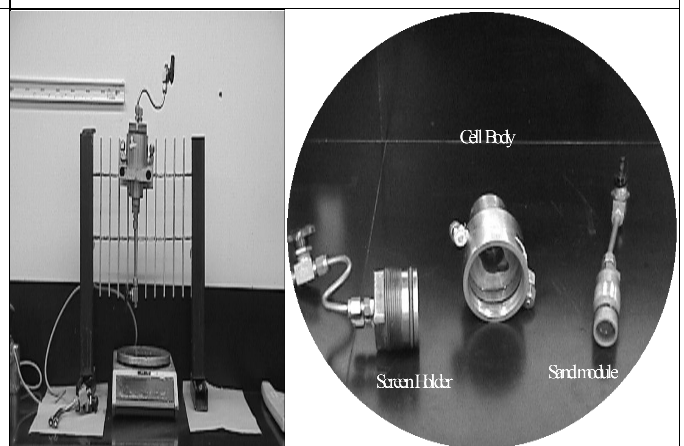

Figure 4 – Conoco Cell

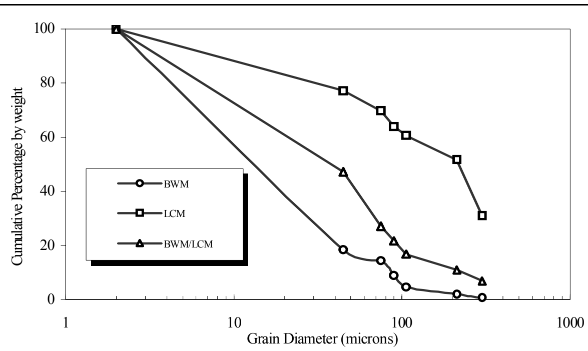

Figure 5 – Particle Size Distribution of BWM and LCM of SS DIF

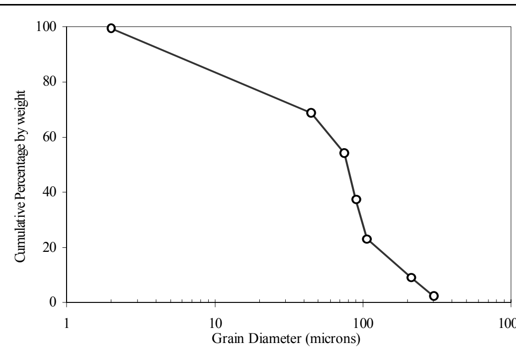

Figure 6 – Particle Size Distribution of Clay

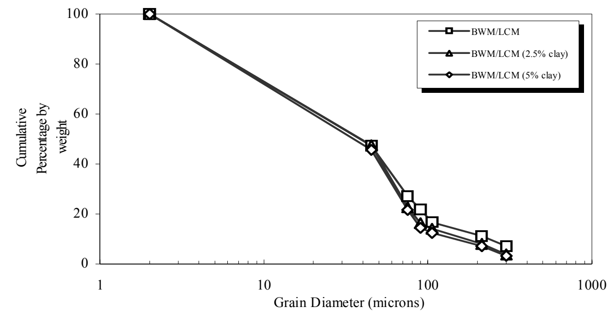

Figure 7 – Particle Size Distribution of BWM and LCM of SS DIF Plus Clay

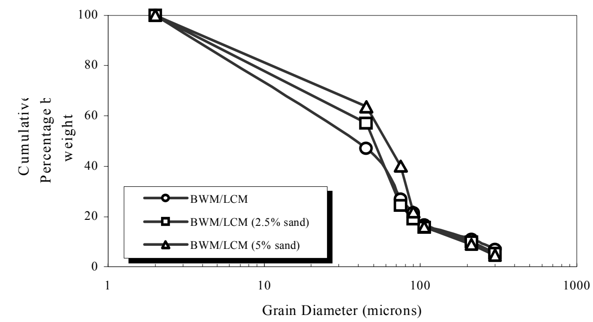

Figure 8 – Particle Size Distribution of BWM and LCM of SS DIF Plus 75- μm Sand

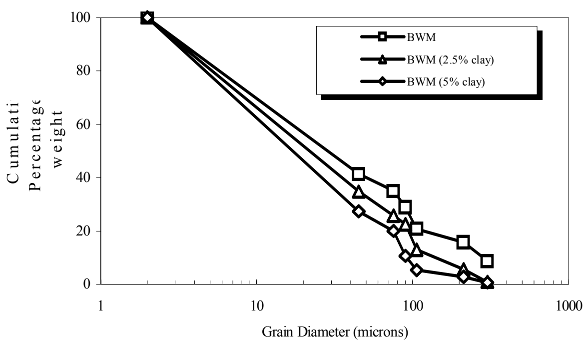

Figure 9 – Particle Size Distribution of BWM of SCC DIF Plus Clay

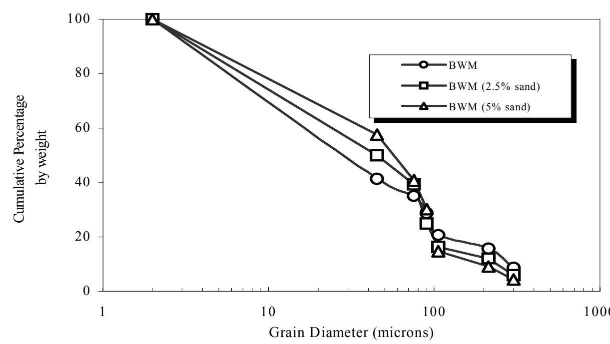

Figure 10 – Particle size distribution of BWM of SCC DIF plus 75-μm sand

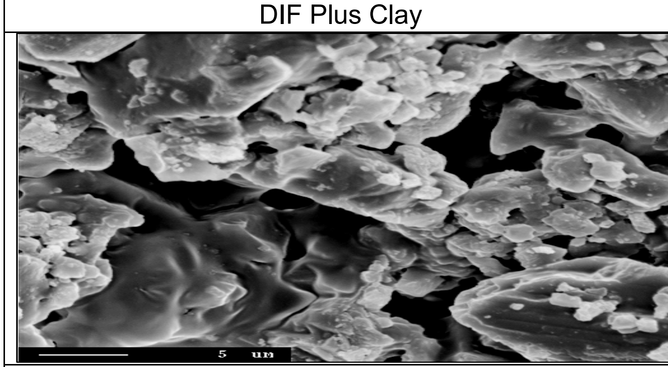

Figure 11 – Texture of Filtercake Surface of SCC-2,500X

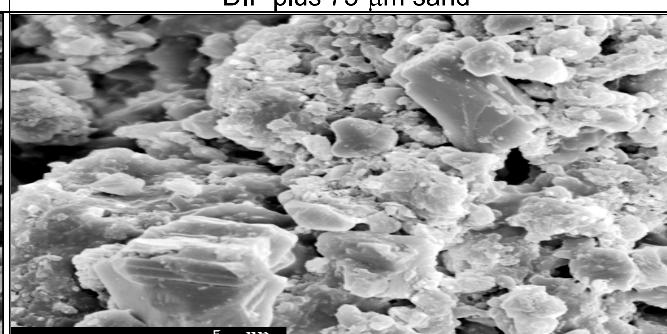

Figure 12 – Texture Of Filtercake Surface of SCC and Clay-2,500X

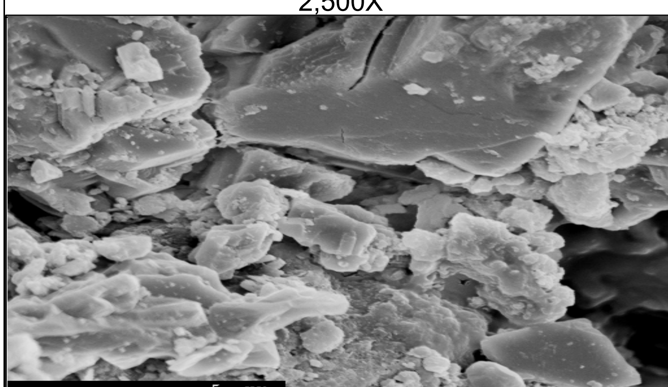

Figure 13 – Texture of Filtercake Surface of SCC and sand-2,500X

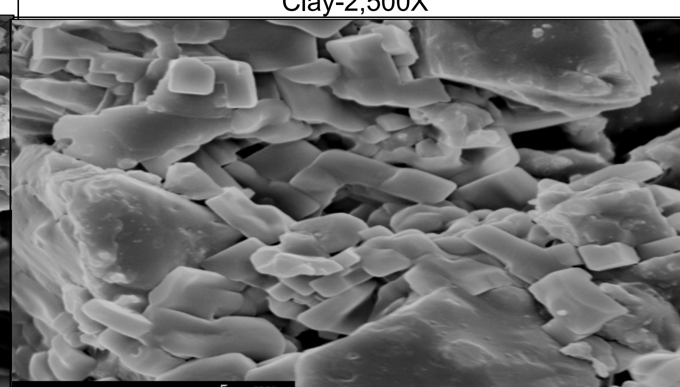

Figure 14 – Texture of Filtercake surface of SS-2,500X

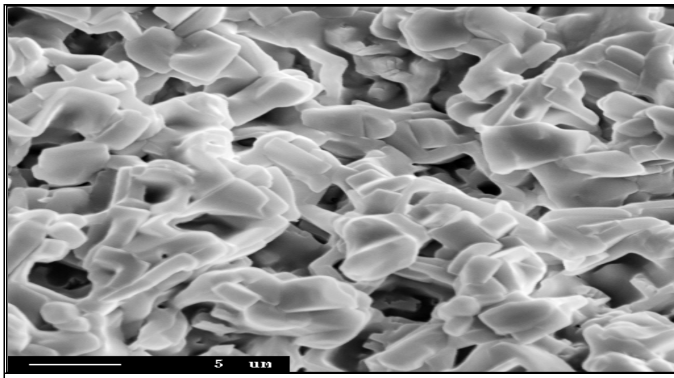

Figure 15 – Texture of Filtercake Surface of SS and Clay-2,500X

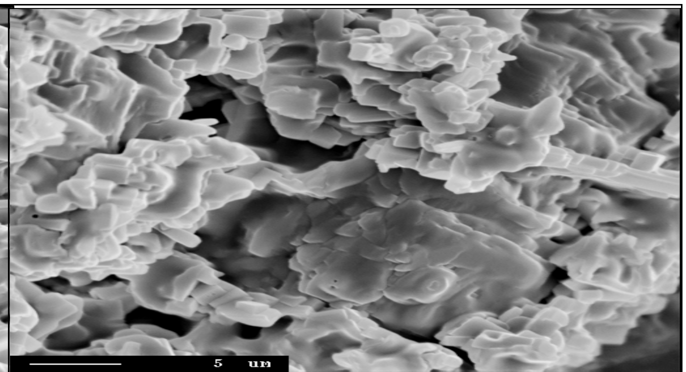

Figure 16 – Texture of Filtercake Surface of SS and Sand-2,500X

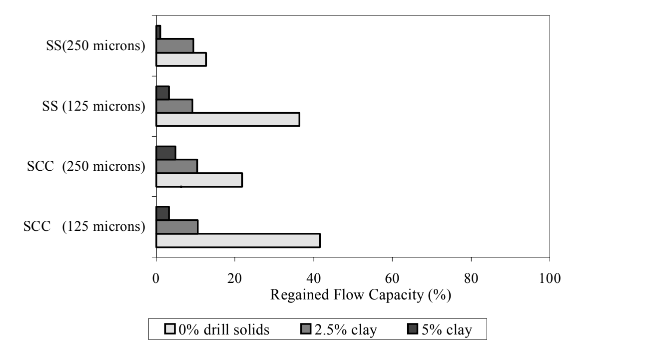

Figure 17 – Regained Flow Capacity Profile of SCC and SS Filtercakes Plus Clay after 3% KCl Treatment

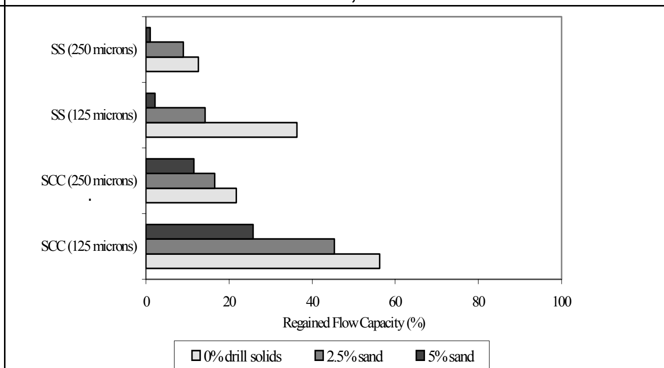

Figure 18 – Regained Flow Capacity Profile of SCC and SS Filtercakes Plus Sand After 3% KCl Treatment

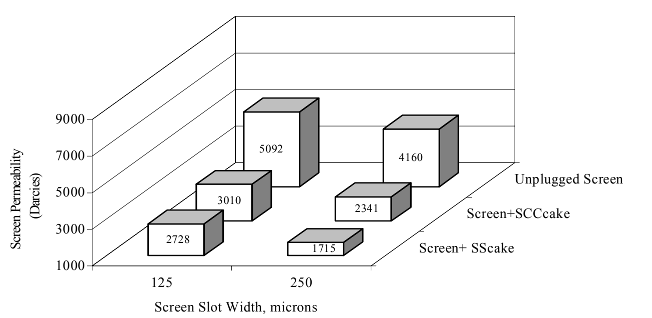

Figure 19 – Screen Permeability Performance 180X

Figure 20 – Initial Condition of the Screen-180X

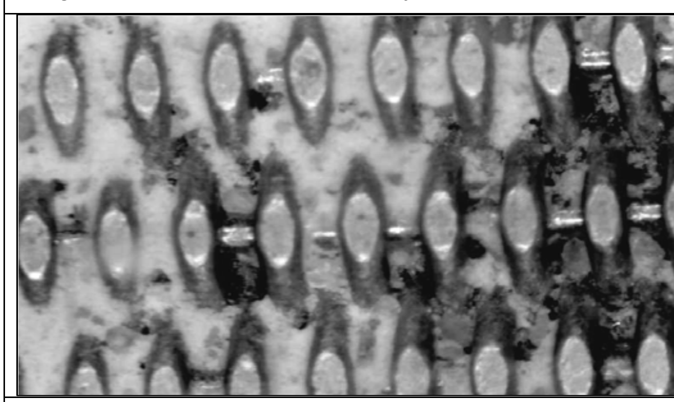

Figure 21 – Internal Face of the Screen Plugged by filtercake after backflow-180X

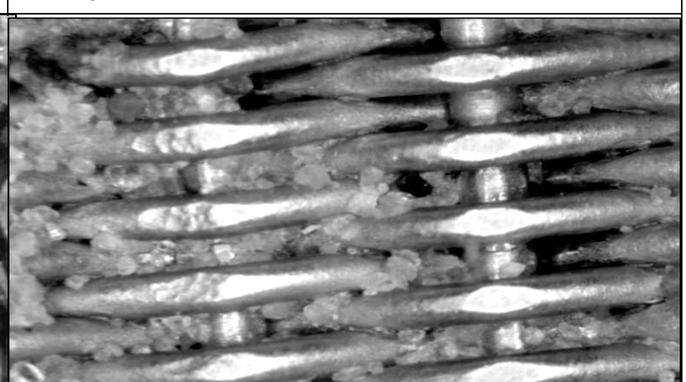

Figure 22 – External Face of the Screen Plugged by Filtercake After Backflow-180X

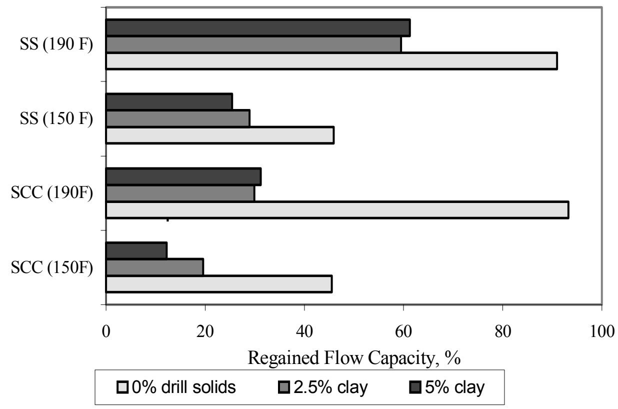

Figure 23 – Regained Flow Capacity Profile of SCC and SS Filtercakes Plus Clay after 5% HCl Treatment

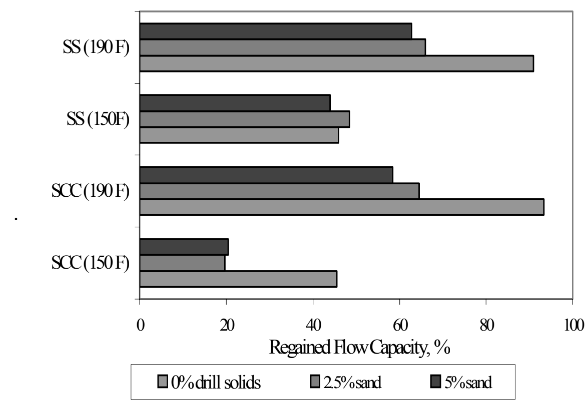

Figure 24 – Regained Flow Capacity Profile of SCC and SS Filtercakes Plus Sand fter 5% HCl Treatment