From: Hanson, Paul
Sent: Thu May 27 23:39:48 2010
To: Cowie, Jim; Robinson, Steve W (Alaska)
Cc: Chambers, Bryan D; MC252_Email_Retention
Subject: Project Spacer with Detailed Notes/Explanations
Importance: Normal
Attachments: Spacer Slide Packet with detailed notes.zip

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Jim and Steve,

Bryan and I have been collaborating on the attached slide packet which describes the work done to address Jim's "Project Spacer" ToR. If you open the slide presentation and go to "VIEW" and then "NOTES PAGE" you will be able to view detailed discussions of each slide's contents - basically a script for the slide. The level of detail is such that we believe that with a brief review a person could present what was done and what was learned with reasonable confidence.

Please review and let us know if this is useful and fulfills your needs with respect to understanding the spacer and it's capacity to cause pressure detection problems at the kill line and account for the high circulation pressures. This is not intended to replace the formal report, which we are in the process of finalizing over the next several days. If this is satisfactory, I'll ask Kimberly Teweleit to upload this to the Sharepoint and replace the presentation presently posted.

Best Regards,

Paul Hanson

Fluids Sector Specialist, Alaska Drilling and Wells

Bryan Chambers

Senior Advisor, Fluids, EPT

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Project Spacer

Rev 1.0
May 27th, 2010

Project spacer was initiated by James Cowie and detailed in the Project Spacer ToR document of 5/6/2010. In essence, the project was created to determine the physical properties of the Spacer used on the DW Horizon to displace SOBM from below the riser to seawater on 4/20/2010.

The actual spacer used was thought to be some combination of two LCM pills that were mixed but not used on April 6, 2010. At the initiation of the investigation it was understood that the two constituents were, for their application as LCM, pumped as a "Tandem pill" - FORM-A-SQUEEZE followed by FORM A SET AK, then chased by FORM A SQUEEZE. Initially, it was unknown as to volumes or the method by which these materials were pumped as spacer. Determination of these details were essential to progressing the investigation.

The real questions to be answered were:

What was actually pumped, and in what volume?

Could properties of the spacer cause or contribute to failures to detect pressure on the kill line?

Could physical properties of the spacer account for the large pump pressures observed to break circulation after the inflow test?

Additionally, this investigation identified samples from the deck of the Bankston which were recovered after the incident.

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Logic for the use of the spacer

- Mixture of Form-A-Set AK and Form-A-Squeeze.
- Not designed for the operation but to dispose of contingency lost circulation materials that had been mixed on the 6th April into separate tanks.
- This type of spacer had not been used previously.

  The spacer used was not in the program. It is believed that it was a change brought about by perceived expediency.

  The mud engineer's statement indicates that its use had been discussed on the rig and with the BP office based staff. The depth of the discussion is not completely clear, but there is no evidence that a risk assessment was performed.

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As stated previously, it was known that FA-SET AK and FA-SQUEEZE were known to be available on the Horizon, and early statements by the BP Fluids Engineer (John LeBleu) indicated that inquiries had been made to the GoM drilling team concerning using these materials as a spacer in order to facilitate their disposal via discharge.

This was not addressed in the approved drilling program, and the MI Swaco procedure refers to a "polymer spacer" consistent with the drilling program. Thus, this was a deviation from procedure for which there is no documented MoC, and no evidence that any risk assessment was done for substituting Lost Circulation Materials for spacers in any combination. In reality, this could be construed as "sham recycling", as a material was pumped downhole for a purpose it was not designed in order to change its status to exempt waste.

There was no apparent precedent for this action.

Engineering Design Criteria for the Spacer

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Well contained 14.0 ppg Rheliant SOBM that had to be displaced to seawater.

- A single spacer to be used using density and viscosity contrast to achieve efficient displacement of the Rheliant.
- A 16.0 ppg spacer was selected to give a 2.0 ppg contrast to the mud weight. There was no viscosity specification.
- Spacer volume was selected based on getting rid of remaining LCM. It appears that ~424 bbl was pumped to the well followed by 30 bbl fresh water and then seawater
- The mud engineers statements and procedure indicate that the intention was to leave the base of the spacer above the annular for the inflow test. (Calculation shows this to be 1188 ft above BOP)
- No statements have been found that considered the length of time expected for the In-flow test or what would happen to the 16.0 ppg spacer-seawater interface during this period.
- No evidence of compatibility testing could be found.

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After further investigation, it was determined that the intent was to pump a *single*, water-based spacer of sufficient density contrast to the 14 ppg Rheliant SOBM that was is the hole in preparation for swapping the well to seawater. Thus, the 14 ppg lost circulation materials were blended and weighted up to 16 ppg.

The total volume of 430 bbl, as indicated by the Pit Volume Totalizer data from pit 5 is used as the basis for determining the ratio of FA-SET AK to FA-SQUEEZE for the determination of physical properties. M-I SWACO-provided information indicates that the difference between spacer in the pits and pumped to the well was a volume of fresh water pumped ahead of the seawater.

The intent, as will be shown in slide 9 was to spot the pill above the upper annular preventer. No interview statements indicate that any consideration was given to what would happen to the pill over time, or, that any compatibility testing was done.

What are the materials used – Form-A-Set AK

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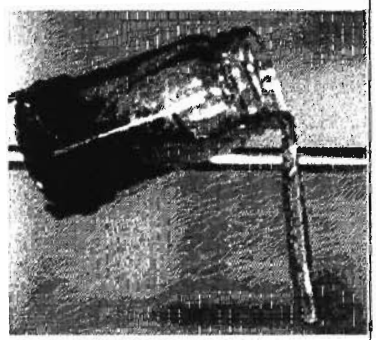
The components of the material are



- FORM-A-SET AK blend of PHPA (70% acrylamide) and fibre
- FORM-A-SET XL Cr(III) salt (acetate) cross-linker
- FORM-A-SET RET retards the system set time at higher temperature
- Duvois Xanthan gum viscosifier/suspension agent
- Rarely, In low temperature applications an accelerator may be used:
- FORM-A-SET ACC accelerator for low-temperature applications – not a part of this formulation

Charecteristics include:

- "tonguing" or 'ringing' gel when cross-linked
- Material will not X-link without Form-A-Set XL
- Contains fibrous LCM.

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This slide is offered to provide some understanding of what the individual constituents of the materials ultimately used as "SPACER" were. FORM-A-SET AK is a polymeric (PHPA) material that is mixed with fibrous LCM. It is designed to be cross linked with Chrome to make a rubber like material - with a controllable set-time based on temperature. Cross-linking creates a relatively rigid network of polymer strands.

Witness statements (surviving mud engineer, specifically) indicate that the cross-linker was not added to this pill. We have no way to prove or disprove this.

Even without the cross linker, this slurry would be expected to be very viscous - especially when a 14 ppg slurry is weighted up to 16 ppg.

Several things can be noted from the MI Swaco Product Bulletin concerning FA-SET AK:

16 ppg is the upper end of the recommended density for this material, and,

If one takes a 14 ppg FA-SET AK pill and weight it up with barite, the final concentration of both FA-SET AK and DUOVIS end up higher than the recommended 16 ppg concentration.

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What are the materials used – Form-A-Squeeze

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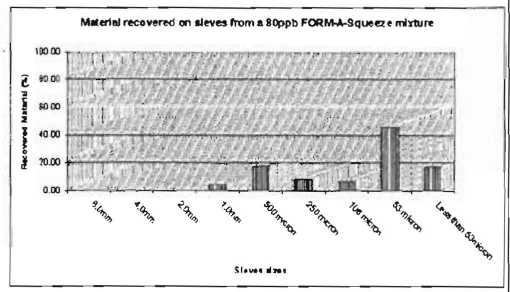
The only component of the material other than barite and water is Form-A-Squeeze. This is understood to be a blend of Diatomaceous earth and fibres. Under low differential pressures, it de-hydrates to form a thick cake The chart indicates the particle size distribution of Form-A-Squeeze.



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Likewise, Form-A-Squeeze is a high solids, high fluid loss pill designed to rapidly leak off to permeable zones, depositing a thick, solids-laden filter cake. Other than water and Barite, the only constituent is FORM-A-SQUEEZE - a blend of diatomaceous earth, fibrous LCM and polysaccharides (starch, most likely). The particle size distribution of the FA-SQUEEZE is shown in the graph.

It is important to reiterate that ALL published Mi Swaco bulletins, reports etc. present FORM-A-SET AK and FORM-A-SQUEEZE as LOST CIRCULATION MATERIALS, and no other applications (like spacers) are discussed.

Mixing of the Spacer on the Rig
Form -A Squeeze

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Material	M-I SWACO	Mud reports
Fresh water	175 bbl	Mud inventory reporting incomplete.
Form-a-Squeeze	175 * 80 lbs	
Barite	75 * 100 lbs	
Bbl mixed	249 @ 14.3 ppg	
Resultant formulation	Fresh water 0.70 bbl/bbl Form-A-Squeeze 56.22 ppb Barite 302 ppb	

The material was mixed into tank 3 on the 6th April

Note

M-I SWACO statements indicate 180 bbl was mixed at 14.0 ppg
When the final spacer was mixed, approximately 150 bbl of the contents of Pit 3 was transferred into Pit 5

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The formulation of the FA-Squeeze pill, as given in MI Swaco statements is shown above. This investigation has no reason to dispute these, as the formulation is consistent with published literature. However, our efforts to verify this using rig inventory adjustments in the time-frame that the pills were mixed were unsuccessful. It is theorized that, had the incident not have occurred, an end-of-well inventory adjustment might have caught the discrepancy.

This formulation was the basis of the laboratory work performed concerning FA-SQUEEZE.

Mixing of the Spacer on the Rig
Form –A-Set AK

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Material	M-I SWACO	Mud reports
Fresh water	175 bbl	Mud inventory reporting incomplete.
Form-A-Set AK	175 * 25 lbs	
Form-A Set AK Retarder	21 * 5 gal	
Duovis	3 * 55 lbs	
Barite	750 *100 lbs	
Mix Resultant formulation	242 bbl @ 14.0 ppg Fresh water 0.72 bbl/bbl Form-A-Set AK 18.08 ppb Form-A-Set AK Retarder 4.75 ppb Duovis 0.68 ppb Barite 310 ppb	

The material was mixed into pit 5 on the 6th April

Note

M-I SWACO statements indicate 200 – 210 bbl was mixed at 14.0 ppg
When the final spacer was mixed, the pit totaliser in pit 5 indicated a volume of 240 bbl

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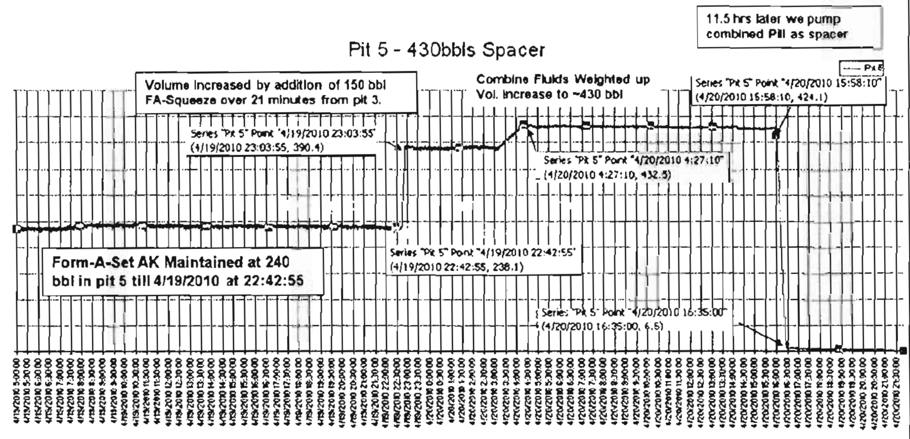
Likewise, with the FA-SET AK. It is worthwhile to note that the retarder concentration would be appropriate for temperatures in the range of >120 ° F, but < 150° F according to the product bulletin. Weighting a 14 ppg FA-SET AK to 16 ppg would dilute the retarder to the lower end of its temperature range.

Mixing of the Spacer on the Rig
Final blend



M I SWACO statements indicates that the contents of pit 3 were transferred to pit 5 and weighted up to 16.0 ppg and 2 further sacks of Duovis added. There was no viscosity determined as it was too thick to measure.

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This is the pit volume totalizer data from pit 5 plotted up in Excel for the time leading up to the displacement of the "spacer" to the wellbore. As one can see, there is roughly 240 bbl of what is now known to be FA-SET AK in Pit 5 until 22:43 on 4/19, at which time a (rapid) fluid transfer takes place bringing the total to 390 bbl. From the statements of the Mud Engineer, Leo Lindner, we "know" this to be a transfer of 150 bbl of FA-SQUEEZE from Pit 3, into Pit 5. At roughly 0:3:00 on April 20, the volume is slowly increased to ~430 bbl by the addition of barite and 2 sacks of Duovis (xanthan gum - polymer viscosifier). This operation was completed at 4:27. The "Spacer" was pumped 11.5 hours later.

The mud engineer reported that the spacer was "too thick to measure" the viscosity. Our testing, shown later, verifies this. It appears, however, that the pump was able to "pick up" the slurry, and no unusual/extreme pressures were noted during the displacement.

Placement of The Spacer

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- Mud Engineer's procedure clearly states, "Spacer should be above upper annular". Step 3 says "pump 425 bbl of WBM spacer…followed by seawater". Step 4 says, "pump 775 bbl or 6150 stks" – note that vol. and stks are consistent for pumping 775 bbl of seawater AFTER spacer. 352 bbl of sea water was actually pumped….leaving spacer across BOPE.

  After placement of the spacer, the theoretical heights of spacer in the various annuli were

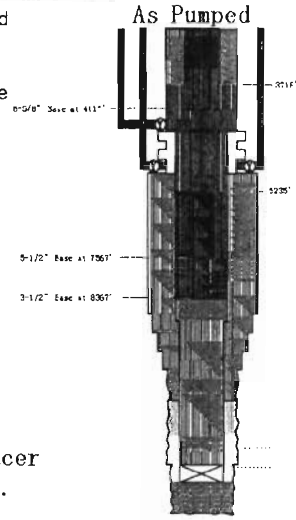
  399 ft 6.5/8" * 19.1/2"

  884 ft 5.1/2" * 19.1/2"

  53 ft 5.1/2" * 18.3/4"

  3 ft 5.1/2" * 18.1/2"

  188 ft 5.1/2" * 8.5/8"



Had procedure been followed, base of spacer would have ended up approx where top did.

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The displacement procedure drafted by Leo Lindner (in file) show that his intent was to place the spacer above the upper annular preventer. Step 3 displaces the planned 425 bbl spacer into the wellbore, and Step 4 is consistent with "chasing" that spacer with 775 bbl of seawater. This would have placed base of the spacer at roughly 3800' , and the top of the spacer at ~2500' . This would have left the base of the spacer approximately 1240' ABOVE THE KILL LINE. Unfortunately, only 352 of seawater was pumped - leaving the pill straddled across the BOPE.

The actual approximate spacer heights are shown (on the slide) below.

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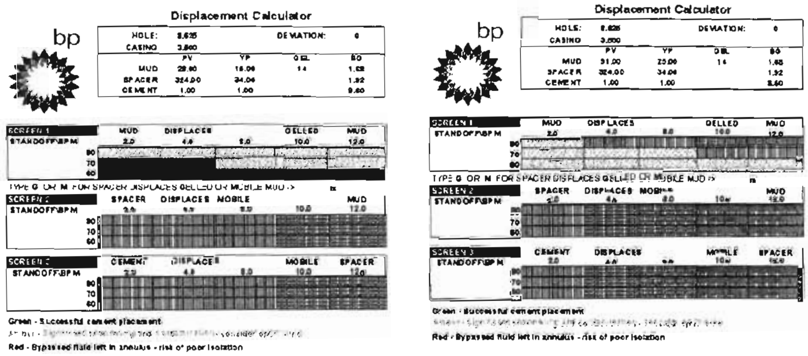
Efficiency of the Placement of The Spacer



Displacement modelled at ~ 600 gpm (14 bpm) for mud at 150F and BOP temperature of 45F.

Efficient displacement

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Using some assumed properties of the spacer and the known properties of the SOBM, data was input into BP's simple displacement model, which indicated that dynamically, the displacement would have been relatively clean although some channeling of spacer into the mud would be expected in the riser. However, there appears to be no good model readily available to predict the behavior after the spacer is in place (static). Logically, the interface between the spacer and the 14 ppg Rheliant SOBM would be reasonably stable initially. Likewise, it is assumed that the interface between 16 ppg spacer and 8.6 ppg seawater would be quite unstable - with the seawater tending to "swap" with the spacer. It is possible that with extended time, the dilution of the spacer weight with seawater could make the SOBM interface less stable. This can not be proved.

Inflow Test
What We Know and Assume

bp

Interaction with the kill line

- The kill line was over-displaced to the annulus ahead of pumping the spacer
- Circulating pressures pumping seawater and spacer were not reported as unusual
- Approximately 5 min after the cessation of pumping the spacer, the kill was opened to bleed off 1200 psi (residual "U" tube pressure). No indication of spacer into the kill line
- Between 7 and 12 minutes after the cessation of pumping the spacer, the kill line was closed. During this time, it is postulated that the well flowed 25 bbl, but no pressure observed at kill line
- Between 59 and 106 min after the cessation of pumping the spacer, the kill line was opened to the Halliburton unit. 700 psi was recorded with a flow of between 3 and 15 bbl into the line. The flow was reported
- Approximately 137 min after the cessation of pumping the spacer, the kill line was bled from 30 psi to 0 with the return of 0.2 bbl
- Approximately 175 min after the cessation of pumping the spacer, the kill line was closed

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We know that 106 bbl of seawater was pumped down the kill line. Volume of the kill line is ~100 bbl so it was over-displaced by 6 bbl. There was nothing unusual noted during this operation.

The remainder of this slide tracks the timeline established by the engineering team, and establishes that between 59 and 106 minutes after the cessation of pumping there was an opportunity for the annular contents - spacer and seawater(?) to be introduced into the kill line, and about 137 minutes after the cessation of pumping the kill line was bled from 30 to 0 psi with only 0.2 bbl of fluid bled off.

It is believed that this may be symptomatic of the kill line plugging, rendering it unable to transmit pressure.

Circulating out after the Inflow Test
What We Know and Assume

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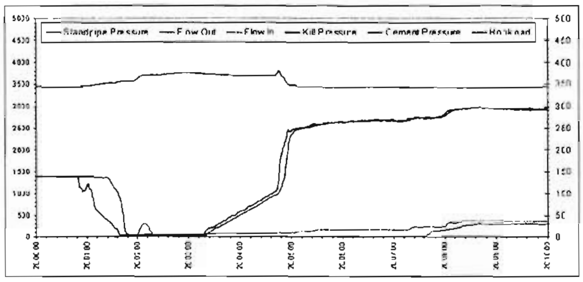
Pressure to resume circulation – Need 2700 psi to achieve Flow Out



Properties of returning spacer

- The spacer was reported as returning to surface on strokes. By this it is taken to be on strokes from where it was placed rather than were it was designed to be placed by the mud engineer.
- After 84 bbl had been returned to surface, pumping was shut down for the sheen test after which all returns were diverted over-board. There is no report of the density of the returning spacer or its properties. Greg Meche (M-I SWACO) makes no mention anything out of the ordinary about the spacer in his statements..

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As one can see from the plot, there is a significant lag between when pressure was ramped up and flow in was established (yellow) and the time that flow out was observed (pink). This is interpreted to be related to the gel strengths and/or minimum yield stress required to get the fluid moving. One could conclude that the spacer in the riser was exceptionally viscous to require such pressures to move. This is one of the factors we set out to determine.

The statement by the compliance engineer that the "spacer came back on strokes" is curious given that we know that it was under-displaced relative to the mud engineer's procedure. We surmise that when the compliance engineer came on tour he was told when to expect the spacer at surface based on the actual displacement - in other words, someone (possibly the driller or assistant driller) calculated the strokes to surface independent of the mud engineer and based on what was actually done.

After 84 bbl of the spacer had returned to surface, they shut down to conduct a static sheen test. This would have required the compliance engineer, Greg Meche (MI Swaco) to collect a sample of the returning spacer to check it for a sheen. In his interview, he makes no mention of anything unusual about the returning spacer. The spacer did not exhibit a sheen, and returns were diverted overboard (~21:14).

Design of The Initial Test Program

Initial objective was to establish the characteristics of the individual fluids and the spacer and then investigate the settlement properties as pumped and as contaminated with seawater.

Once completed, the work then moved to cross-linking possibilities

Properties of the Individual formulations and blend

Fluid rheology was to be tested using a Fann 35A viscometer using the standard R1B1 bob. Density was to be checked using an API Pressurized Mud Balance or gravimetrically. pH with electronic meter.

Tendency of the blends to separate

Since the spacer was positioned above the seawater in the annulus, and the density contrast was 1.86, the impact of seawater contamination on settling tendency was tested in gravity settling columns.

Tendency of the blends to deposit a thick filter cake

The ability of the fluid to dehydrate or inhibit the transmission of pressure under applied pressure was investigated using an API Filter press.

Resistance to contamination and tendency to cross-link

Tests conducted using an adapted cement compatibility test and a static shear test were used to appraise the effect of oil mud and x-linker on the spacer respectively.

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As stated previously, the main driver for this investigation was the need to understand the fluids in the well bore during events leading up to the incident. Emphasis was placed on the effects of settlement and stability due to the mechanics of the displacement and subsequent actions. To accomplish this, we set out to:

A. Determine the properties of the individual constituents of the spacer - FORM-A-SET AK and FORM-A-SQUEEZE and their combined properties. Rheology was to be measured using the standard Fann 35 viscometer at 45 and 120° F - 120° being the standard API mud test temperature, and 45° being the understood temperature at the inlet to the kill line (from the simulation group). Density was measured using an API pressurized balance or gravimetrically on a 3-position Mettler electronic balance (calibrated), and pH to be measured using a standard laboratory pH meter.

   As it turned out, measuring the rheology of the individual components was more difficult than anticipated, as the LCM in the FA-SQUEEZE fouled the viscometer. Since this information was so critical to the investigation, we ended up devising a way to approximate the rheology of the blend. This will be covered later.

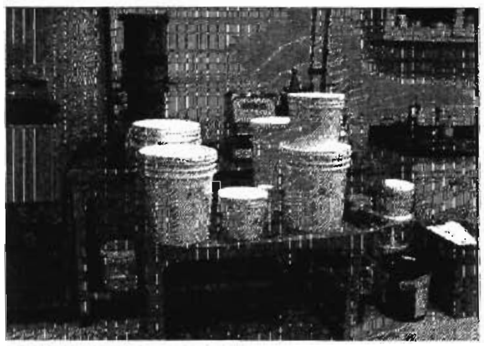
B. Settling tendency was appraised by placing 100% spacer, 50/50 seawater-to-spacer and 75/25 seawater-to-spacer blends into 1,000 ml graduated cylinder settling columns and monitoring settling over time. Experiments were conducted at room temperature, which averaged approximately 68 ° F.

C. Filtercake deposition for the base blends and 50/50 dilutions with seawater were appraised using a standard API filter press at 100 psi differential.

D. Contamination/compatibility with the Rheliant SOBM was evaluated using an adaptation of the API RP 10B cement/spacer compatibility procedure and the effect of X-linker was measured using a static shear tube procedure.

Results of the Test Program

Testing was conducted with the intent to match fluid ratios and properties as closely as possible. The "Fluid A 62:38 Spacer blend" referred to in the testing slides is a blend of FORM-A-SET AK and FORM-A-SQUEEZE at a 62:38 ratio respectively, which reflects the fluid transfers shown in SLIDE 8. "Fluid B 54:46 Spacer blend is similar, but reflects MI SWACO accounts of the displacement. Testing sought to recreate probable conditions in the wellbore on April 20, 2010 during the riser displacement to seawater.



Material for 55 bbl eq Provided on May 11 from MI Swaco

Confidentiality and release from liability in place May 13

All transfers covered by Chain of Custody and comply with subpoena.

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Basically, the Spacers were mixed at a 62:38 ratio of Set-to Squeeze to reflect the blending ratio supported by the pit 5 data : that 150 bbl of “14 ppg” FORM-A-SQUEEZE was added to 240 bbl of FORM-A-SET AK at ~14 ppg to make 390 bbl of the blended spacer (150 ÷ 390 = 0.38).

The 54:46 Set-to-Squeeze formulation reflects the mud engineer’ s assertion that 180 bbl of FORM-A-SQUEEZE was transferred from pit 3 to pit 5 - this is not supported by PVT data, so we feel that the 62:38 samples most likely represent the spacer actually used.

(180 ÷ 390 = 0.46)

The combined Spacers were then weighted up with barite and viscosified with additional Duovis to match what was understood to have occurred in the field.

MI provided enough of the FORM-A-SET AK and FORM-A-SQUEEZE materials to make 5 gallons, or ~55 laboratory barrel equivalents of each, and enough barite to weight the combined samples to 16 ppg.

Intertek Westport Laboratories were contracted to provide laboratory facilities and technicians, and all personnel involved were covered by confidentiality agreements.

Sample transfers were documented by Chain-of-Custody, and where applicable, sufficient sample was retained to permit duplicate testing in compliance with a Federal subpoena.

All testing was witnessed by BP

Spacer Rheology
62:38 and 54:46 Blends of FA-SET & FA SQUEEZE

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Challenges:

Complicated by coarse, fibrous LCM material

"Too viscous to test" (Mud Engineer, Leo Lindner)

- Too many solids and polymers
- Low Temperatures

Limitations of equipment – Fann 35 geometry

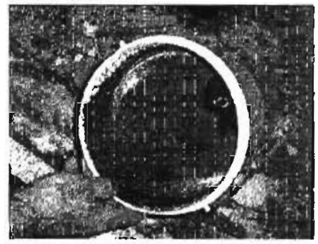
Solution:

Deconstruct the FA-SQUEEZE formulation (Scalp >425μ fibrous LCM)

Reconstruct at proper wt.% materials

Blend base fluids to "proper" ratios

Measure Rheology and assume Bingham Plastic model



Approach deemed reasonable, as the fibers represent about 8 wt% of a finished bbl of Form-A-Squeeze or <4 wt% of either blend A or B.

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Measuring the spacer rheology with the industry standard Fann 35 rotary viscometer proved to be challenging. In particular, The FORM-A-SQUEEZE rheology measurements were complicated by the fibrous LCM jamming the gap between the bob and sleeve of the Fann 35. Settling also caused measurements to be erratic and time dependent. In the blends of FA SET AK and FA SQUEEZE settling was not a problem, but viscometer "jamming" continued make reliable measurement impossible. Alternative bob sizes for the rheometer which may have solved this issue were not available.

After reviewing the known particle size distribution of the SQUEEZE material and comparing it with the gap dimension of the Fann 35 (1170 microns we decided to "scalp" the offending coarse LCM > 425 micron particles using a 40 mesh screen, and reformulate without that LCM. Since the final weight-percent of the very coarse LCM in the blends were small (<4%) we felt that the rheology measurements we could make would be somewhat optimistic (actual fluid thicker than our approximate formulation), but a reasonable and defendable approximation.

Spacer Rheology
62:38 and 54:46 Blends of FA-SET & FA SQUEEZE

bp

62:38 Blend at 45° F		54:46 Blend at 45° F	
$\varnothing_{600}$ = 682		$\varnothing_{600}$ = 530	
$\varnothing_{300}$ = 358	PV = 324	$\varnothing_{300}$ = 268	PV = 262
$\varnothing_{200}$ = 242	YP = 34	$\varnothing_{200}$ = 210	YP = 34
$\varnothing_{100}$ = 157		$\varnothing_{100}$ = 137	
$\varnothing_{6}$ = 39		$\varnothing_{6}$ = 32	
$\varnothing_{3}$ = 30		$\varnothing_{3}$ = 25	
Gels 10s/10min/30min 31/38/44		Gels 10s/10min/30min 25/34/39	

62:38 Blend at 120° F		54:46 Blend at 120° F	
$\varnothing_{600}$ = 203		$\varnothing_{600}$ = 210	
$\varnothing_{300}$ = 134	PV = 69	$\varnothing_{300}$ = 137	PV = 73
$\varnothing_{200}$ = 105	YP = 65	$\varnothing_{200}$ = 107	YP = 34
$\varnothing_{100}$ = 71		$\varnothing_{100}$ = 73	
$\varnothing_{6}$ = 18		$\varnothing_{6}$ = 18	
$\varnothing_{3}$ = 13		$\varnothing_{3}$ = 13	
Gels 10s/10min/30min 13/24/35		Gels 10s/10min/30min 15/35/40	

Comments: Numbers in red extrapolated from Bingham. Gels not as progressive as expected. Viscosity very high. Actual rheology w/o LCM adjustment would be higher

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The modified slurry rheology was measured using the Fann 35 at 45° and 120° F for both Spacer Formulations. It is important to note that the values in red are extrapolated values because the actual readings were off scale on the viscometer (dial reading only goes to 300) - they were extrapolated from a Bingham plastic curve fit. Both blends are very viscous at low temperature (45°), and are even very viscous at the standard API test temperature for drilling fluids (120°). Gels at low temperatures are high, but not progressive - meaning that there are not big increases in gel strength with time. As the fluid warms up, the Yield Point increases.

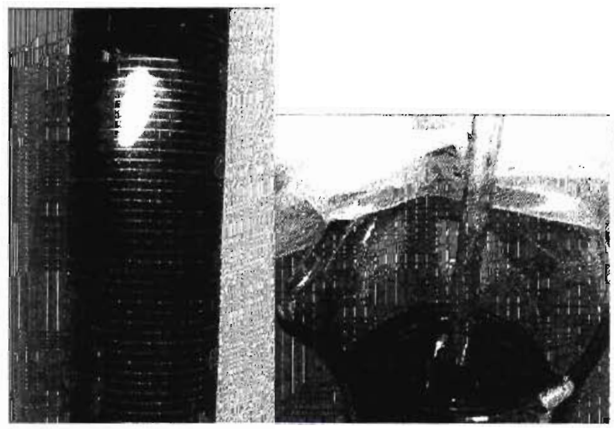
Again, it is important to stress that because of the removal of the coarsest LCM in the FA-SQUEEZE, these are optimistic results, and the actual rheology would be higher. However, we believe these data to be as good an approximation of the rheology as can be obtained with conventional oilfield viscometers.

Slurries and Spacer
Settlement with Seawater Dilution at Room Temperature

bp

Tested both blends at 100%, 50/50 and 75/25 Seawater to spacer:

- 100% - no settling
- 50/50 of blend A – density stratification began immediately. After two hours – densified fluid bed. Over night – clear separation of phases.
- 50/50 of Blend B – similar to A, but more rapid.
- 75/25 Sea water to spacer, A & B phase separation complete in 40 minutes.



Sea water comingling at lower interface accelerates settling/ phase separation.

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This slide pretty much speaks for itself. The base spacer slurries are so viscous that they exhibit no settling tendency over two days. However, as you blend increasing amounts of seawater with the spacer, as would happen at the lower interface, the settling tendency is pronounced. Significant settling could occur in a 50/50 or greater blend in the time-frame the spacer was static in the wellbore.

It should be noted also that these results may be optimistic relative to what would happen in a real wellbore. Our samples were homogenized in a laboratory mixer (Hamilton Beach). Thus, there was a significant amount of mixing energy put into these fluids prior to being tested for settling. Settling tendency is likely worse in the wellbore and kill line.

bp

Property	Blend A	Blend B
Suspended solids- ppb	425	427
Suspended solids - % volume	30.8	31.3

Suspended solids are expressed as an absolute volume%

Typical settling for even packed material could contain 30% void space. This would take the maximum settled height to around 40% of the original volume

If 203 ft of spacer drawn into the kill line (source incident animation)

Settled height of spacer as pumped 81 ft

Settled height of 50% diluted spacer 40 ft

Settled height of 75% diluted spacer 20 ft

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This slide attempts to give some insight into possible settled heights that could occur with various levels of dilution.

Even with 75% dilution of the spacer with seawater, a packed solids height of up to 20ft could occur assuming that 203 ft of fluid was pushed into the line.

It is not known if this could stop pressure transmission. However, you are in effect forming a barite plug.

Note also that these estimations are based on 4 bbl of "Spacer Material" being drawn into the kill line:

$(4.5^2)/1029 = 0.0197$ bbl/ft → 4 bbl÷ 0.0197 = 203 ft

Witness statements have suggested that this may be as much as 15 bb
Or 15 ÷ 0.0197 = 762 ft

Slurries and Spacer Settlement with Seawater Dilution

bp

- Sedimentation appraised using qualitative resistance to penetration using a solid glass rod.
- Sediment classified as dense, viscous fluid phase, to the extent that the rod at total depth is supported by dense phase
- Fluid at top of column not "slick" or viscous, indicating polymer remains with solids

Seawater dilution induces settling. Dense phase at bottom of column high in solids and polymer. Settling in Kill Line is probable and could contribute to plugging.

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Qualitative appraisals of the sediment beds were performed by inserting a glass rod down the length of the column and noting the changes in resistance (interpreted as changes in density or compaction).

One of the most interesting observations was that the rod did not seem "slick" with polymer when it came out - as if most of the polymers were associated with the sediments rather than the free fluid.

For the 75:25 Seawater to Spacer blends, the pack at the bottom of the cylinders could be classified as firm.

Slurries and Spacer
API Fluid loss control ("filterability")

What happens when one mixes a high-viscosity, high polyr content LCM pill (FAS-AK) with high fluid loss, high soli LCM (FA-SQUEEZE)?

Blend A – 62:38 Set-to-Squeeze 100%

API 30-min Fluid Loss at 50 psi 3.8 ml

API 30-min Fluid Loss at 100 psi 5.2 ml

Blend A – 62:38 Set-to-Squeeze 50/50 dil.

API 30-min Fluid Loss at 100 psi 7.9 ml

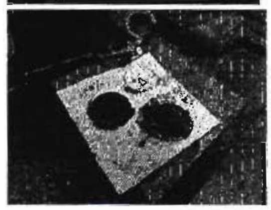
Blend B – 54:46 Set-to-Squeeze 100%

API 30-min Fluid Loss at 100 psi 6.1 ml

Blend B – 54:46 Set-to-Squeeze 50/50 dil.

API 30-min Fluid Loss at 100 psi 9.1 ml

Filtrate



Filter Cakes

Combined fluid have good fluid loss control properties (impermeable), which would impede pressure transmission. No real "spurt loss" noted.

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An API Fluid Loss cell is a metallic chamber with a filter media at the bottom that is used to compare the filtration and filter cake building characteristics of drilling fluids. The cell holds approximately 1 laboratory barrel equivalent or 350 ml. Test are run at ambient conditions with 100 psi differential applied. Filtrate is collected over 30 minutes and recorded as ml filtrate/30 minutes.

The most interesting result of the API Fluid Loss tests on 100% Spacer and 50/50 Seawater blends is that the combination of a highly polymeric LCM material FA-SET AK and a high fluid loss LCM FA-SQUEEZE results in a low fluid loss, impermeable material. Thus, under differential pressure, one can visualize a pack or column of fluid becoming increasingly less permeable with the application of differential pressure.

For reference under a similar test carried out previously by BP for other work looking at Form-A-Squeeze only, the test cell was evacuated entirely in 65 seconds (~ 250 ml).

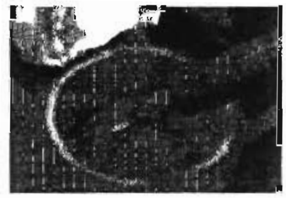
Spacer
Contamination w/ 14 ppg Rheliant SOBM

bp

Spacer formulations A and B were exposed to 5% SOBM contamination using modified cement compatibility test to look for:

- Flocculation
- Gelation
- Clabbering
- Unusual behavior

No unusual behavior was observed. The only change noted was the color of the spacer.



Good displacement of SOBM - little interface. No evidence that SOBM in spacer would be detrimental.

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The effect of Rheliant SOBM on the Spacer was evaluated by placing 380 ml of spacer (A & B) into a circulating cooling bath and lowering the temperature to 45° F. 20 ml of Rheliant SOBM collected from the Damon Bankston was added slowly via a syringe while carefully stirring the mud into the spacer and noting any reactions.

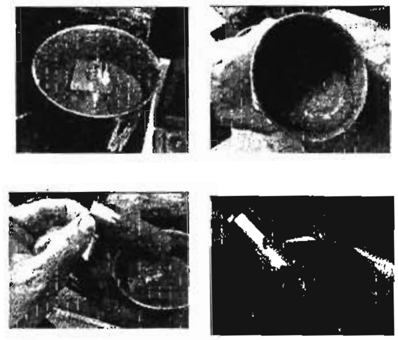
This is an adaptation of the API RP 10B cement/spacer compatibility tests.

No unusual behavior was observed, and it is believed that no detrimental interactions occurred.

Cross-Linking
Causes for the Kill line Not To see Well Pressure

bp

Blend A Blend B



2 bbl-eq of Blend A and B were mixed on a blender.

3.75 #/bbl FORM-A-SET XL (cross-linker was added)

Mixture was blended for 5 minutes

Static shear measurements were taken at 30 min. intervals.

A_0 = 25.88g. A_{30} = 25.88 g. A_{60} =25.88 g.

B_0 = 28.88g. B_{30} = 78.88 g. B_{60} =98.88 g

Note that A did NOT X Link, B showed significant X Linking. B contains more FA-Squeeze, which dilutes retarder concentration.

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22

From the onset of this investigation, we thought it unlikely that cross-linking agent had been added to the Spacer prior to pumping. Part of this was motivated by the fact that adding the X-linker would make the pill very unpredictable, and it would also incur unnecessary expense for properties that were not desired (the XL is the most expensive additive in the FA-SET AK package). Additionally, the original FA-SET AK pill had been retarded to set at down-hole conditions, so it was unlikely that cross-linking could occur at the temperatures in the riser. Because it was impossible to prove that it was not added, we elected to see if it would have any affect.

To do this, we mixed 2 bbl equivalents of the 62:38 and 54:46 blends weighted to 16 ppg and added 3.75 lbs/bbl equivalent of the XL cross-linker to each (the recommended treatment). These were mixed on a Hamilton Beach mixer for 5 minutes to simulate to quick addition of x linker prior to pumping down hole.

Static shear measurements were taken at T= 0 min., 30 min., and 60 min.

The Static Shear Test involves taking a shear tube of known weight and dimensions and measuring the weight required to force the tube into the fluid to a known depth (inscribed line on the tube).

The net result was that the 62:38 blend spacer showed no sign of cross-linking, whereas the 54:46 blend spacer showed significant cross-linking.

It is possible that because the 54:46 blend has more “SQUEEZE” in it, that it dilutes the retarder enough to allow cross-linking.

Cross-Linking
Causes for the Kill line Not To see Well Pressure

bp

X-Linking as a mechanism is difficult to prove.

- MI SWACO reports that it wasn't X-linked (Leo Lindner)
- No unusual properties were noted by Greg Meche for static sheen
- Formulation A is the closest to what we believe was pumped – it did not X-link with the correct amount of commercial x-linker.
- Circulation might not have been possible after X-linking

What might account for X-linking?

- Addition of XL unknown to Mud Engineers (TO pit watcher thinking we always add this blue-green stuff before we pump these?) Can't prove.
- External source of x-linker ? Difficult to rationalize how to get enough. Requires "creative" chemistry

X-Linking as a mechanism for plugging is unlikely, given what we know but requires further verification testing

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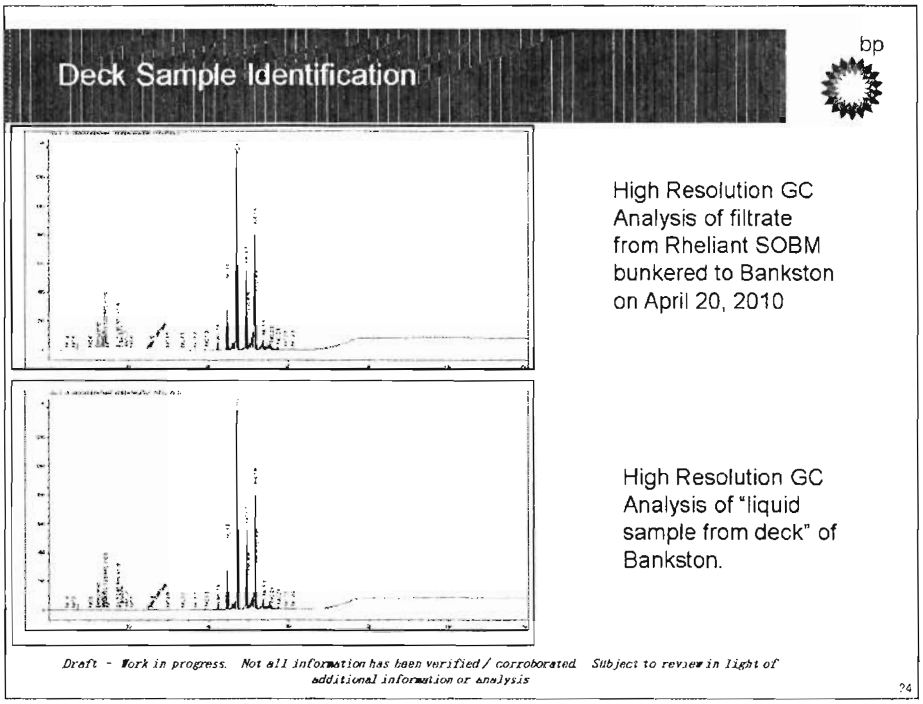
Despite the fact that X-linking was observed in the 54:46 blend, the case for cross-linking is weak and unproven for the reasons on this slide.

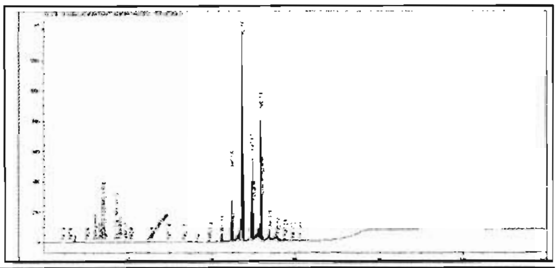


This slide is a comparison of the Gas Chromatography "fingerprint" of SOBM filtrate collected in a HTHP Filter Press (run at 150°F to protect the oil) and a liquid sample collected from the deck of the Bankston. They are virtually identical, supporting that the "ejecta" from the well which landed on the Bankston after the incident was SOBM.

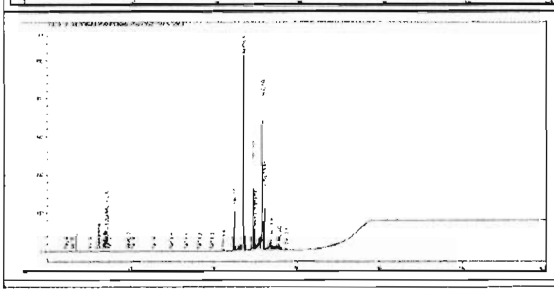
The lack of any peaks for petroleum hydrocarbons (crude) in either samples indicates that any possible crude oil was below the detection limits of the GC.

Deck Sample Identification

bp



High Resolution GC Analysis of filtrate from Rheliant SOBM bunkered to Bankston on April 20, 2010



High Resolution GC Analysis of "Bulk Mud from Deck" from Bankston.

d Subject to review in light of

25

Likewise, the sample collected from the deck of the Bankston labeled "Bulk Mud" was consistent with the SOBM, and did NOT have detectable levels of crude oil either.

Deck Sample Identification Conclusions

- Organics in both samples were clearly derived from SOBM.
- GC signatures indicative of synthetic oil only – no sign of hydrocarbon contaminant in whole mud bunkered to the Bankston prior to the incident on April 20 or the samples recovered from the deck of the Bankston after the incident.
- XRD (X-Ray Diffraction) Minerology of "Liquid" and "Bulk Mud" showed substantial quantities of Barite, supporting drilling fluids origin.
- Microscopy also showed presence of particles of material described as "concrete", "metal", and "scale/corrosion product". No speculation was made as to origin.

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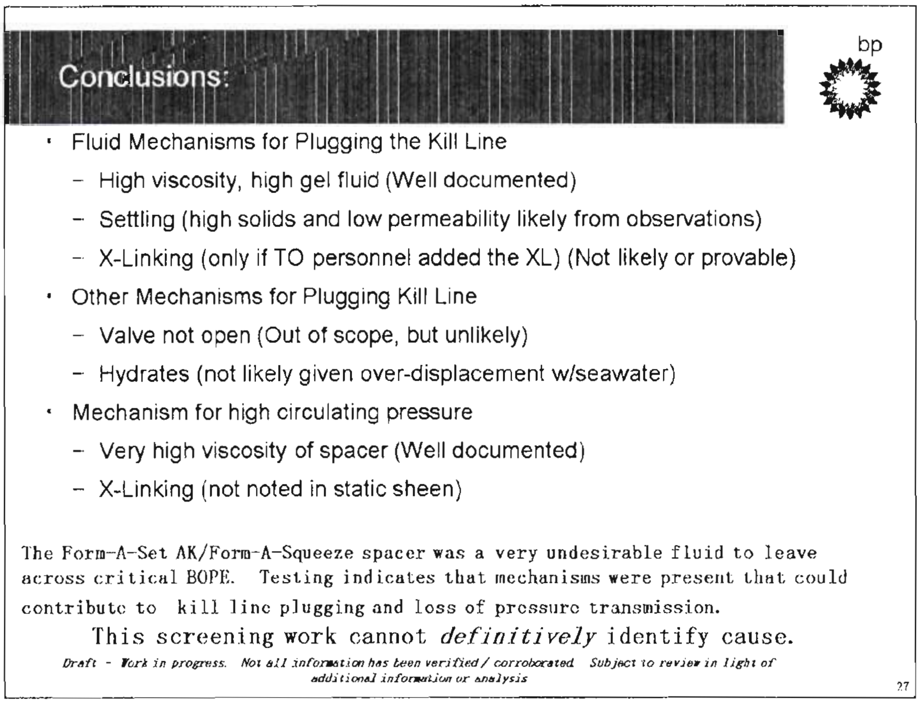
The bulk solids extract from the deck mud appears to be a mixture of barite, drilled solids and carbonate bridging material. The drilling mud report of the 19th April (Report 79) indicates that the solids content of the fluid corrected for salt was 26.2%. Taking this figure, it is possible to work back to a theoretical concentration of these materials in the drilling fluid

Barite	298 ppb
Bridging material	34 ppb
Drilled solids 50 ppb	

This equates to a drilling fluid with a density of around 14.0 ppg. This information verifies that the bulk mud deck sample is very likely to be drilling fluid



In conclusion, there are a number of mechanisms present which could account for both the plugging of the kill line and the high pressure required to break circulation after the inflow test.

With respect to kill line plugging, high viscosity high gel strength 100% spacer could ultimately cause plugging. SET and SQUEEZE are designed to be lost circulation treatments designed to plug fractures and vugs. However, it is likely that swapping and comingling began almost immediately at the interface between the seawater and the spacer. This would favor settling and compaction as a mechanism for plugging. Fluid loss data show that under differential pressure even dilute mixtures develop a low permeability "cake" rapidly.

As far as the "other" mechanisms for plugging or lack of pressure transmission at the kill line, these are beyond the scope of the investigation, but hydrates seem unlikely.

The very high viscosity exhibited by these spacer formulations could account for the high pump pressures. Also, it is conceivable that the upper part of the spacer could remain intact and viscous while the trailing edge at the spacer-seawater interface could be strung out and prone to settling.

We don't think anyone can argue that a FA-SET AK/FA-SQUEEZE Spacer would have undesirable properties if left across BOPE.

Future Actions:

- Rheology characterization
  - More sophisticated rheometrics
- Sedimentation
  - Larger settling columns and a method to place the fluids without comingling
  - Instrumentation to non-invasively measure density
  - Packing and permeability work
- Cross linking Fann 70 as used by M-I SWACO

Some of this work could done in BP Research facility or major drilling fluids company research facility but would require time to fabricate test equipment.

It is not thought possible that this work could be completed at Westport

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We recognize that the testing performed has its limitations, and most of them have been pointed out within the presentation. The real intent of this work was to identify likely mechanisms which could explain the failure of the kill line to transmit pressure and the high pump pressures observed while breaking circulation. We believe we've done that. To take this further will require more advanced testing as outlined on this slide.

bp

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Subject to review in light of additional information or analysis

Project Spacer

Rev 1.0
May 27th, 2010

Logic for the use of the spacer

- Mixture of Form-A-Set AK and Form-A-Squeeze.
- Not designed for the operation but to dispose of contingency lost circulation materials that had been mixed on the 6th April into separate tanks.
- This type of spacer had not been used previously.

The spacer used was not in the program. It is believed that it was a change brought about by perceived expediency.

The mud engineer's statement indicates that its use had been discussed on the rig and with the BP office based staff. The depth of the discussion is not completely clear, but there is no evidence that a risk assessment was performed.

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Engineering Design Criteria for the Spacer

Well contained 14.0 ppg Rheliant SOBM that had to be displaced to seawater.

A single spacer to be used using density and viscosity contrast to achieve efficient displacement of the Rheliant.

A 16.0 ppg spacer was selected to give a 2.0 ppg contrast to the mud weight. There was no viscosity specification.

Spacer volume was selected based on getting rid of remaining LCM. It appears that ~424 bbl was pumped to the well followed by 30 bbl fresh water and then seawater

The mud engineers statements and procedure indicate that the intention was to leave the base of the spacer above the annular for the inflow test. (Calculation shows this to be 1188 ft above BOP)

No statements have been found that considered the length of time expected for the In-flow test or what would happen to the 16.0 ppg spacer-seawater interface during this period.

No evidence of compatibility testing could be found.

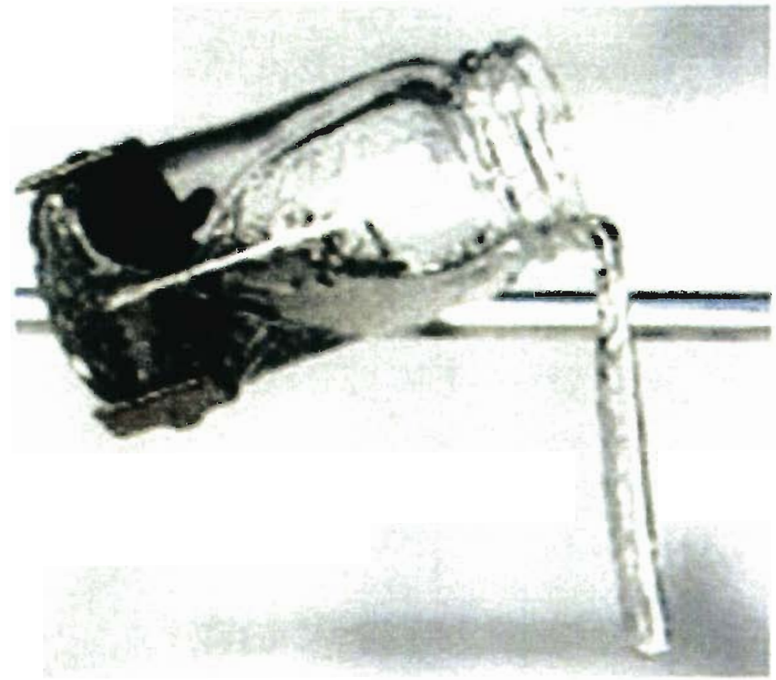
What are the materials used – Form-A-Set AK

The components of the material are

- FORM-A-SET AK blend of PHPA (70% acrylamide) and fibre
- FORM-A-SET XL Cr(III) salt (acetate) cross-linker
- FORM-A-SET RET retards the system set time at higher temperature
- Duvois Xanthan gum viscosifier/suspension agent
- Rarely, in low temperature applications an accelerator may be used:
- FORM-A-SET ACC accelerator for low-temperature applications – not a part of this formulation

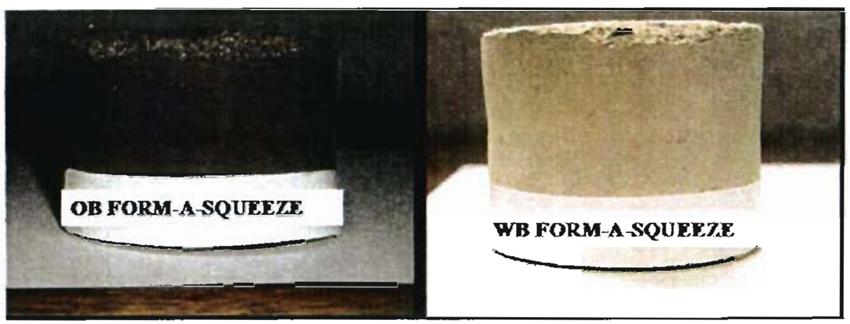
Charecteristics include:

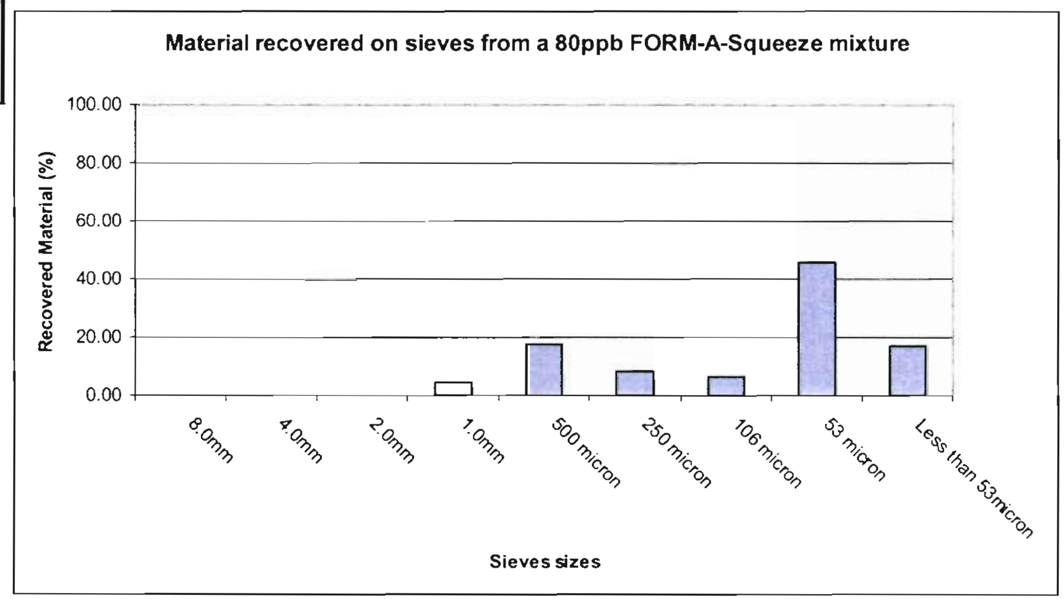
- "tonguing" or "ringing" gel when cross-linked
- Material will not X-link without Form-A-Set XL
- Contains fibrous LCM.



What are the materials used – Form-A-Squeeze

The only component of the material other than barite and water is Form-A-Squeeze. This is understood to be a blend of Diatomaceous earth and fibres. Under low differential pressures, it de-hydrates to form a thick cake The chart indicates the particle size distribution of Form-A-Squeeze.





Mixing of the Spacer on the Rig
Form -A Squeeze

Material	M-I SWACO	Mud reports
Fresh water	175 bbl	Mud inventory reporting incomplete.
Form-a-Squeeze	175 * 80 lbs	
Barite	75 * 100 lbs	
Bbl mixed	249 @ 14.3 ppg	
Resultant formulation	Fresh water 0.70 bbl/bbl Form-A-Squeeze 56.22 ppb Barite 302 ppb	

The material was mixed into tank 3 on the 6th April

Note

M-I SWACO statements indicate 180 bbl was mixed at 14.0 ppg

When the final spacer was mixed, approximately 150 bbl of the contents of Pit 3 was transferred into Pit 5

Mixing of the Spacer on the Rig Form –A-Set AK

Material	M-I SWACO		Mud reports
Fresh water	175 bbl		Mud inventory reporting
Form-A-Set AK	175 * 25 lbs		
Form-A Set AK Retarder	21 * 5 gal		
Duovis	3 * 55 lbs		
Barite	750 *100 lbs		
Mix	242 bbl @ 14.0 ppg		
Resultant formulation	Fresh water	0.72 bbl/bbl	
	Form-A-Set AK	18.08 ppb	
	Form-A-Set AK Retarder	4.75 ppb	
	Duovis	0.68 ppb	
	Barite	310 ppb	

The material was mixed into pit 5 on the 6th April

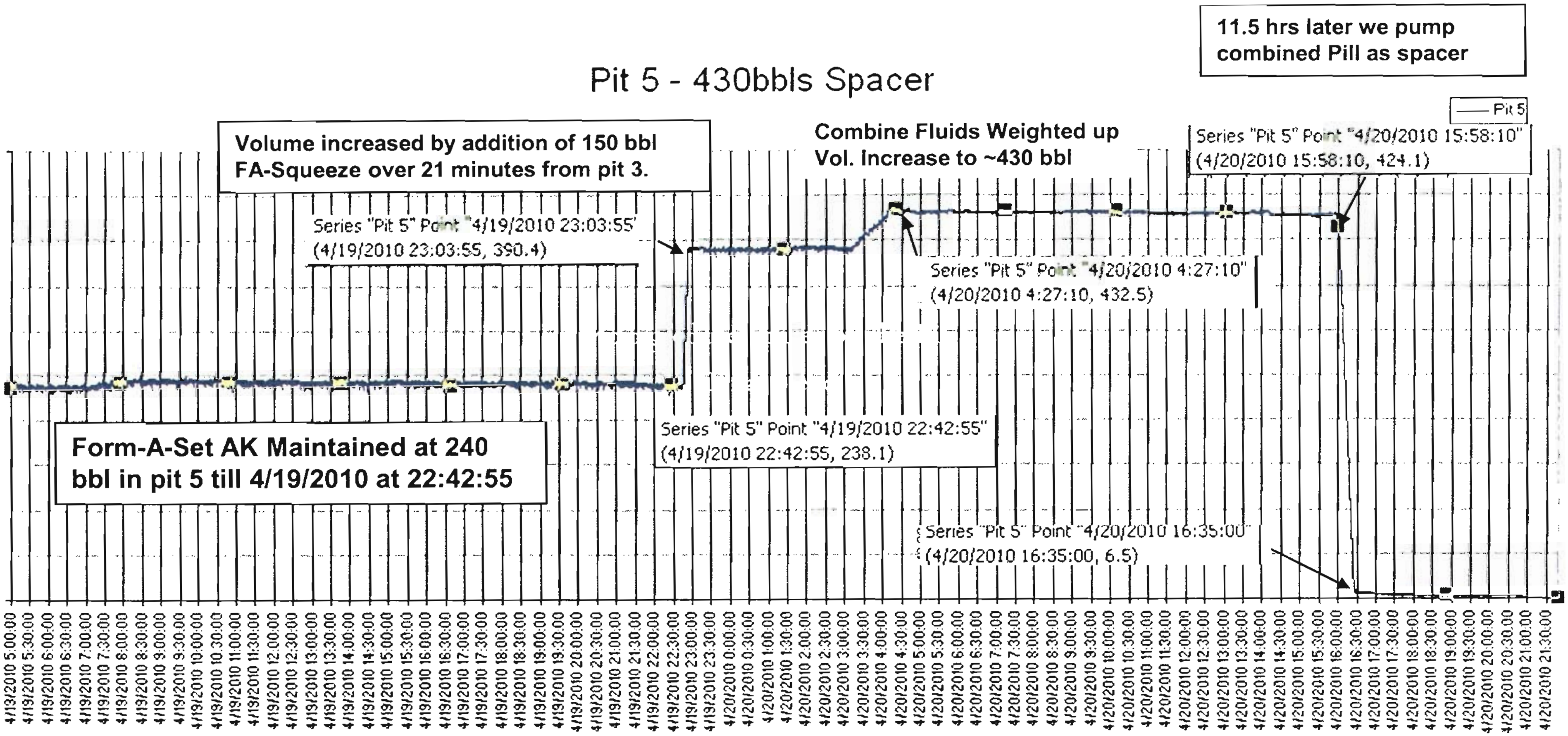
Note

M-I SWACO statements indicate 200 – 210 bbl was mixed at 14.0 ppg

When the final spacer was mixed, the pit totaliser in pit 5 indicated a volume of 240 bbl

Mixing of the Spacer on the Rig

Final blend



M-I SWACO statements indicates that the contents of pit 3 were transferred to pit 5 and weighted up to 16.0 ppg and 2 further sacks of Duovis added. There was no viscosity determined as it was too thick to measure.

Placement of The Spacer

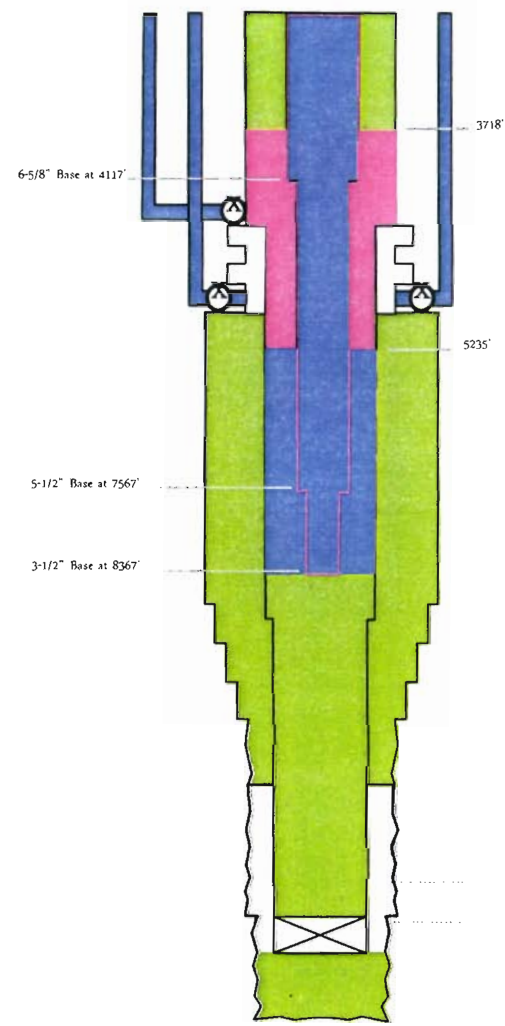
- Mud Engineer's procedure clearly states, "Spacer should be above upper annular". Step 3 says "pump 425 bbl of WBM spacer…followed by seawater". Step 4 says, "pump 775 bbl or 6150 stks" – note that vol. and stks are consistent for pumping 775 bbl of seawater AFTER spacer. 352 bbl of sea water was actually pumped….leaving spacer across BOPE.

  After placement of the spacer, the theoretical heights of spacer in the various annuli were

399 ft	6.5/8" *	19.1/2"
884 ft	5.1/2" *	19.1/2"
53 ft	5.1/2" *	18.3/4"
3 ft	5.1/2" *	18.1/2"
188 ft	5.1/2" *	8.5/8"

Had procedure been followed, base of spacer would have ended up approx where top did.

As Pumped



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Efficiency of the Placement of The Spacer

Displacement Calculator

HOLE:	8.625		DEVIATION:	0
CASING	3.500			
	PV	YP	GEL	SG
MUD	28.00	15.00	14	1.68
SPACER	324.00	34.00		1.92
CEMENT	1.00	1.00		8.60

SCREEN 1	MUD	DISPLACES		GELLED	MUD
STANDOFF\BPM	2.0	4.0	8.0	10.0	12.0
80					
70					
60					

TYPE **G** OR **M** FOR SPACER DISPLACES GELLED OR MOBILE MUD -> m

SCREEN 2	SPACER	DISPLACES	MOBILE		MUD
STANDOFF\BPM	2.0	4.0	8.0	10.0	12.0
80					
70					
60					

SCREEN 3	CEMENT	DISPLACES		MOBILE	SPACER
STANDOFF\BPM	2.0	4.0	8.0	10.0	12.0
80					
70					
60					

Green - Successful cement placement
Amber - Significant channelling and contamination - consider optimising
Red - Bypassed fluid left in annulus - risk of poor isolation

Displacement Calculator

HOLE:	8.625		DEVIATION:	0
CASING	3.500			
	PV	YP	GEL	SG
MUD	91.00	25.00	14	1.68
SPACER	324.00	34.00		1.92
CEMENT	1.00	1.00		8.60

SCREEN 1	MUD	DISPLACES		GELLED	MUD
STANDOFF\BPM	2.0	4.0	8.0	10.0	12.0
80					
70					
60					

TYPE **G** OR **M** FOR SPACER DISPLACES GELLED OR MOBILE MUD -> m

SCREEN 2	SPACER	DISPLACES	MOBILE		MUD
STANDOFF\BPM	2.0	4.0	8.0	10.0	12.0
80					
70					
60					

SCREEN 3	CEMENT	DISPLACES		MOBILE	SPACER
STANDOFF\BPM	2.0	4.0	8.0	10.0	12.0
80					
70					
60					

Green - Successful cement placement
Amber - Significant channelling and contamination - consider optimising
Red - Bypassed fluid left in annulus - risk of poor isolation

Displacement modelled at ~ 600 gpm (14 bpm) for mud at 150F and BOP temperature of 45F.

Efficient displacement

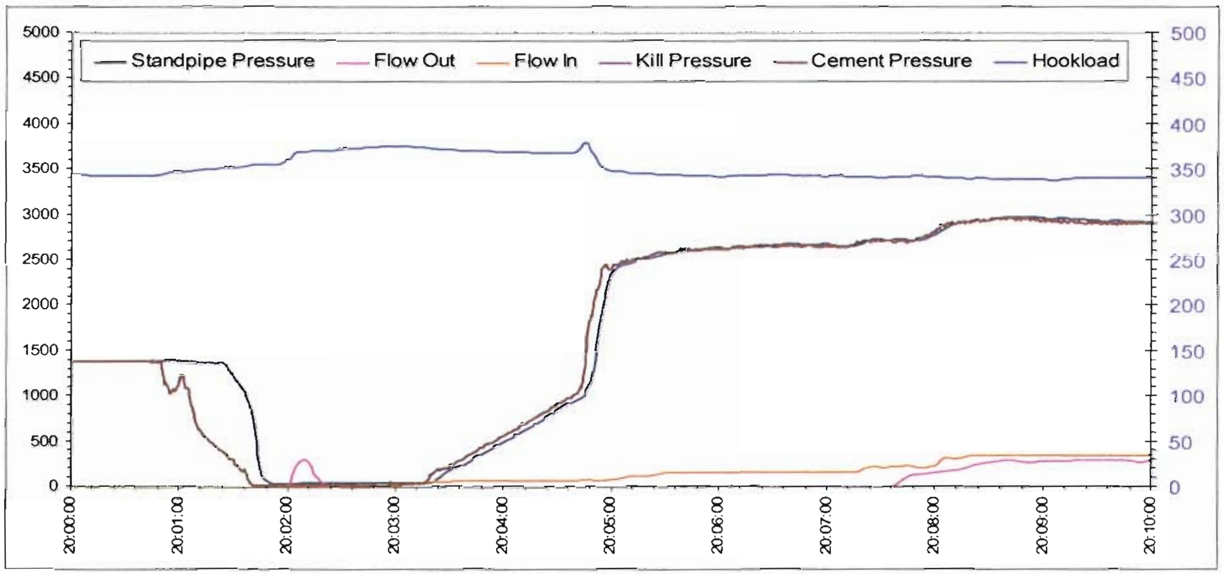
Inflow Test
What We Know and Assume

Interaction with the kill line

- The kill line was over-displaced to the annulus ahead of pumping the spacer
- Circulating pressures pumping seawater and spacer were not reported as unusual
- Approximately 5 min after the cessation of pumping the spacer, the kill was opened to bleed off 1200 psi (residual "U" tube pressure). No indication of spacer into the kill line
- Between 7 and 12 minutes after the cessation of pumping the spacer, the kill line was closed. During this time, it is postulated that the well flowed 25 bbl, but no pressure observed at kill line
- Between 59 and 106 min after the cessation of pumping the spacer, the kill line was opened to the Halliburton unit. 700 psi was recorded with a flow of between 3 and 15 bbl into the line. The flow was reported
- Approximately 137 min after the cessation of pumping the spacer, the kill line was bled from 30 psi to 0 with the return of 0.2 bbl
- Approximately 175 min after the cessation of pumping the spacer, the kill line was closed

Circulating out after the Inflow Test
What We Know and Assume

Pressure to resume circulation – Need 2700 psi to achieve Flow Out



Properties of returning spacer

- The spacer was reported as returning to surface on strokes. By this it is taken to be on strokes from where it was placed rather than were it was designed to be placed by the mud engineer.
- After 84 bbl had been returned to surface, pumping was shut down for the sheen test after which all returns were diverted over-board. There is no report of the density of the returning spacer or its properties. Greg Meche (M-I SWACO) makes no mention anything out of the ordinary about the spacer in his statements..

Design of The Initial Test Program

bp

Initial objective was to establish the characteristics of the individual fluids and the spacer and then investigate the settlement properties as pumped and as contaminated with seawater.

Once completed, the work then moved to cross-linking possibilities

Properties of the individual formulations and blend

Fluid rheology was to be tested using a Fann 35A viscometer using the standard R1B1 bob. Density was to be checked using an API Pressurized Mud Balance or gravimetrically. pH with electronic meter.

Tendency of the blends to separate

Since the spacer was positioned above the seawater in the annulus, and the density contrast was 1.86, the impact of seawater contamination on settling tendency was tested in gravity settling columns.

Tendency of the blends to deposit a thick filter cake

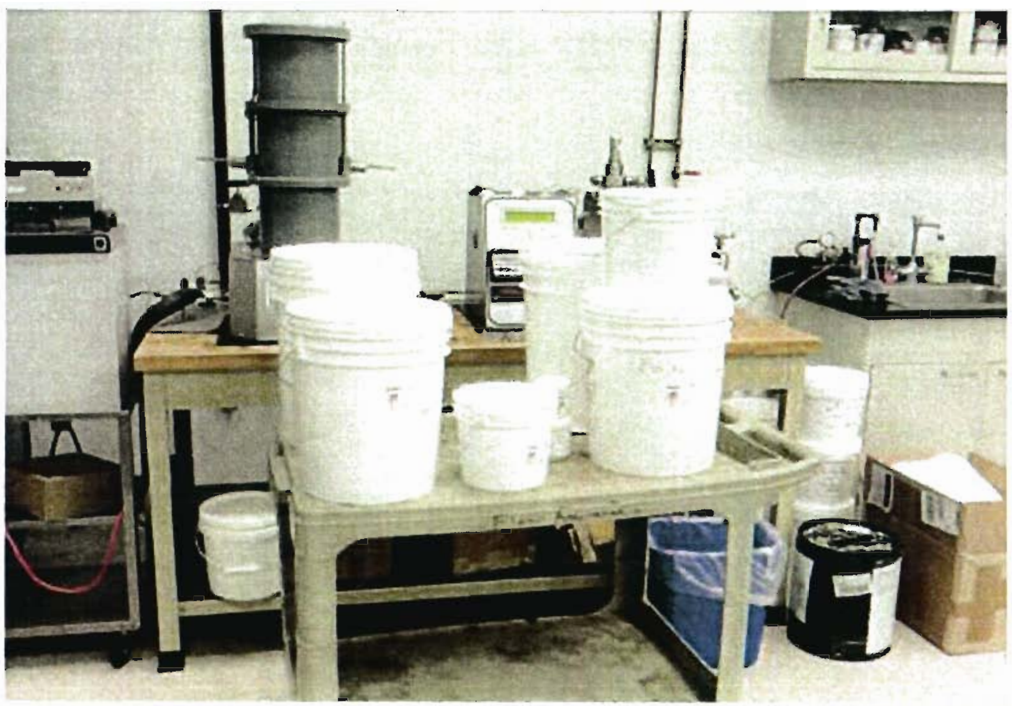
The ability of the fluid to dehydrate or inhibit the transmission of pressure under applied pressure was investigated using an API Filter press.

Resistance to contamination and tendency to cross-link

Tests conducted using an adapted cement compatibility test and a static shear test were used to appraise the effect of oil mud and x-linker on the spacer respectively.

Results of the Test Program

Testing was conducted with the intent to match fluid ratios and properties as closely as possible. The "Fluid A 62:38 Spacer blend" referred to in the testing slides is a blend of FORM-A-SET AK and FORM-A-SQUEEZE at a 62:38 ratio respectively, which reflects the fluid transfers shown in SLIDE 8. "Fluid B 54:46 Spacer blend is similar, but reflects MI SWACO accounts of the displacement. Testing sought to recreate probable conditions in the wellbore on April 20, 2010 during the riser displacement to seawater.



Material for 55 bbl eq Provided on May 11 from MI Swaco

Confidentiality and release from liability in place May 13

All transfers covered by Chain of Custody and comply with subpoena.

Spacer Rheology
62:38 and 54:46 Blends of FA-SET & FA SQUEEZE

Challenges:

Complicated by coarse, fibrous LCM material

"Too viscous to test" (Mud Engineer, Leo Lindner)

- Too many solids and polymers
- Low Temperatures

Limitations of equipment – Fann 35 geometry

Solution:

Deconstruct the FA-SQUEEZE formulation (Scalp >425μ fibrous LCM)

Reconstruct at proper wt.% materials

Blend base fluids to "proper" ratios

Measure Rheology and assume Bingham Plastic model

Approach deemed reasonable, as the fibers represent about 8 wt% of a finished bbl of Form-A-Squeeze or <4 wt% of either blend A or B.

Spacer Rheology
62:38 and 54:46 Blends of FA-SET & FA SQUEEZE

62:38 Blend at 45° F

$Ø_{600}$ = 682

$Ø_{300}$ = 358   PV = 324

$Ø_{200}$ = 242   YP = 34

$Ø_{100}$ = 157

$Ø_{6}$ = 39

$Ø_{3}$ = 30

Gels 10s/10min/30min 31/38/44

62:38 Blend at 120° F

$Ø_{600}$ = 203

$Ø_{300}$ = 134   PV = 69

$Ø_{200}$ = 105   YP = 65

$Ø_{100}$ = 71

$Ø_{6}$ = 18

$Ø_{3}$ = 13

Gels 10s/10min/30min 13/24/35

54:46 Blend at 45° F

$Ø_{600}$ = 530

$Ø_{300}$ = 268   PV = 262

$Ø_{200}$ = 210   YP = 34

$Ø_{100}$ = 137

$Ø_{6}$ = 32

$Ø_{3}$ = 25

Gels 10s/10min/30min 25/34/39

54:46 Blend at 120° F

$Ø_{600}$ = 210

$Ø_{300}$ = 137   PV = 73

$Ø_{200}$ = 107   YP = 34

$Ø_{100}$ = 73

$Ø_{6}$ = 18

$Ø_{3}$ = 13

Gels 10s/10min/30min 15/35/40

Comments: Numbers in red extrapolated from Bingham. Gels not as progressive as expected. Viscosity very high. Actual rheology w/o LCM adjustment would be higher

Slurries and Spacer
Settlement with Seawater Dilution at Room Temperature

Tested both blends at 100%, 50/50 and 75/25 Seawater to spacer:

100% - no settling

50/50 of blend A – density stratification began immediately. After two hours – densified fluid bed. Over night – clear separation of phases.

50/50 of Blend B – similar to A, but more rapid.

75/25 Sea water to spacer, A & B phase separation complete in 40 minutes.

Sea water comingling at lower interface accelerates settling/ phase separation.

Other Physical Properties of the Spacer

Property	Blend A	Blend B
Suspended solids- ppb	425	427
Suspended solids - % volume	30.8	31.3

Suspended solids are expressed as an absolute volume%

Typical settling for even packed material could contain 30% void space. This would take the maximum settled height to around 40% of the original volume

If 203 ft of spacer drawn into the kill line (source incident animation)

Settled height of spacer as pumped 81 ft

Settled height of 50% diluted spacer 40 ft

Settled height of 75% diluted spacer 20 ft

Draft – Work in progress. Not all information has been verified / corroborated. Subject to review in light of additional information or analysis

Slurries and Spacer
Settlement with Seawater Dilution

Sedimentation appraised using qualitative resistance to penetration using a solid glass rod.

Sediment classified as dense, viscous fluid phase, to the extent that the rod at total depth is supported by dense phase

Fluid at top of column not "slick" or viscous, indicating polymer remains with solids

Seawater dilution induces settling. Dense phase at bottom of column high in solids and polymer. Settling in Kill Line is probable and could contribute to plugging.

Draft – Work in progress. Not all information has been verified / corroborated. Subject to review in light of additional information or analysis

Slurries and Spacer
API Fluid loss control ("filterability")

What happens when one mixes a high-viscosity, high polyr
content LCM pill (FAS-AK) with high fluid loss, high soli
LCM (FA-SQUEEZE)?

Blend A – 62:38 Set-to-Squeeze 100%

API 30-min Fluid Loss at 50 psi 3.8 ml

API 30-min Fluid Loss at 100 psi 5.2 ml

Blend A – 62:38 Set-to-Squeeze 50/50 dil.

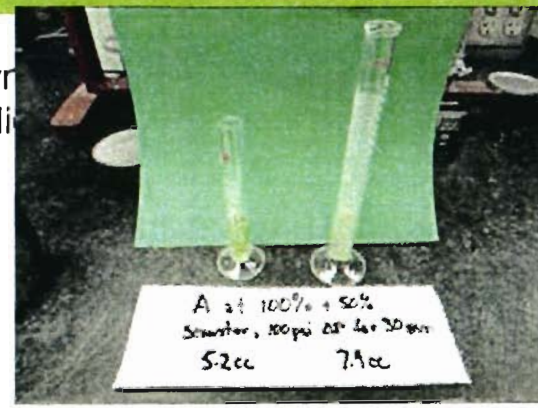
API 30-min Fluid Loss at 100 psi 7.9 ml

Blend B – 54:46 Set-to-Squeeze 100%

API 30-min Fluid Loss at 100 psi 6.1 ml

Blend B – 54:46 Set-to-Squeeze 50/50 dil.

API 30-min Fluid Loss at 100 psi 9.1 ml



Filtrate

Filter Cakes

Combined fluid have good fluid loss control properties (impermeable), which would impede pressure transmission.

No real "spurt loss" noted.

Spacer
Contamination w/ 14 ppg Rheliant SOBM

Spacer formulations A and B were exposed to 5% SOBM contamination using modified cement compatibility test to look for:

- Flocculation
- Gelation
- Clabbering
- Unusual behavior

No unusual behavior was observed. The only change noted was the color of the spacer.

Good displacement of SOBM – little interface. No evidence that SOBM in spacer would be detrimental.

Cross-Linking
Causes for the Kill line Not To see Well Pressure

2 bbl-eq of Blend A and B were mixed on a blender.

3.75 #/bbl FORM-A-SET XL (cross-linker was added)

Mixture was blended for 5 minutes

Static shear measurements were taken at 30 min. intervals.

A_0 = 25.88g. A_{30} = 25.88 g. A_{60} =25.88 g.

B_0 = 28.88g. B_{30} = 78.88 g. B_{60} =98.88 g

Blend A

Blend B

Note that A did NOT X-Link, B showed significant X-Linking. B contains more FA-Squeeze, which dilutes retarder concentration.

Cross-Linking
Causes for the Kill line Not To see Well Pressure

X-Linking as a mechanism is difficult to prove.

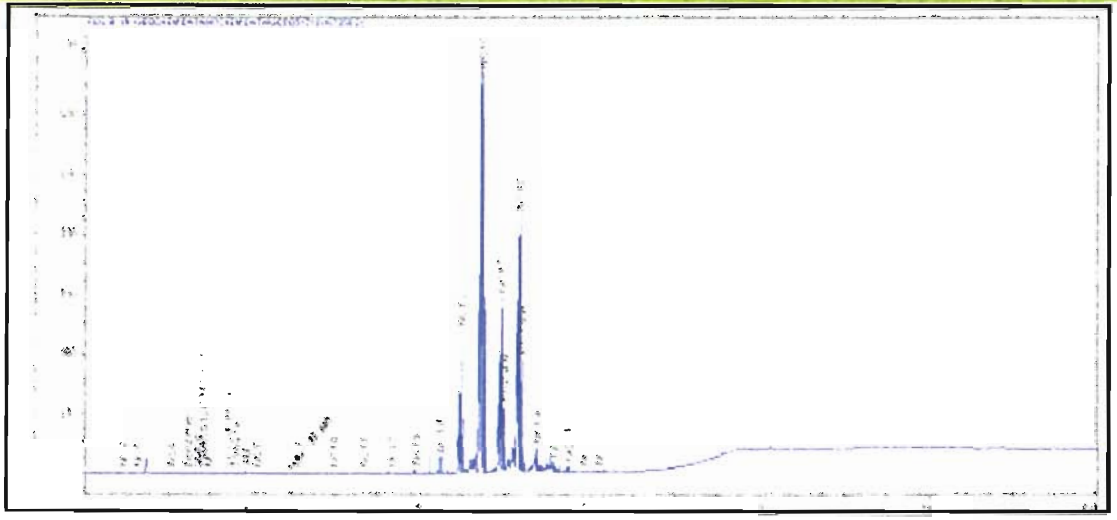
- MI SWACO reports that it wasn't X-linked (Leo Lindner)
- No unusual properties were noted by Greg Meche for static sheen
- Formulation A is the closest to what we believe was pumped – it did not X-link with the correct amount of commercial x-linker.
- Circulation might not have been possible after X-linking

What might account for X-linking?

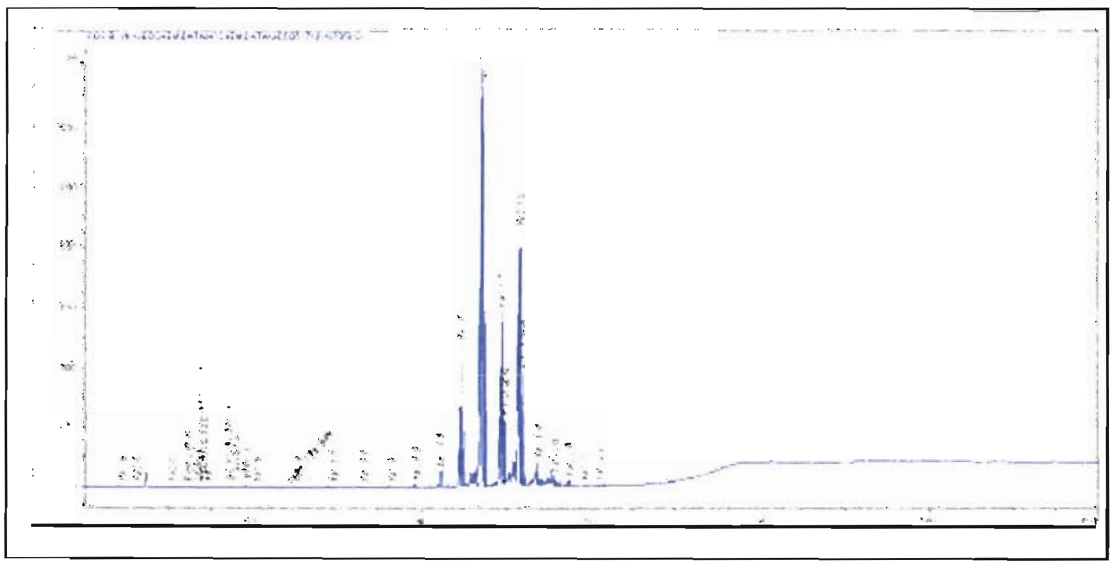
- Addition of XL unknown to Mud Engineers (TO pit watcher thinking we always add this blue-green stuff before we pump these?) Can't prove.
- External source of x-linker ? Difficult to rationalize how to get enough. Requires "creative" chemistry

X-Linking as a mechanism for plugging is unlikely, given what we know but requires further verification testing

Deck Sample Identification

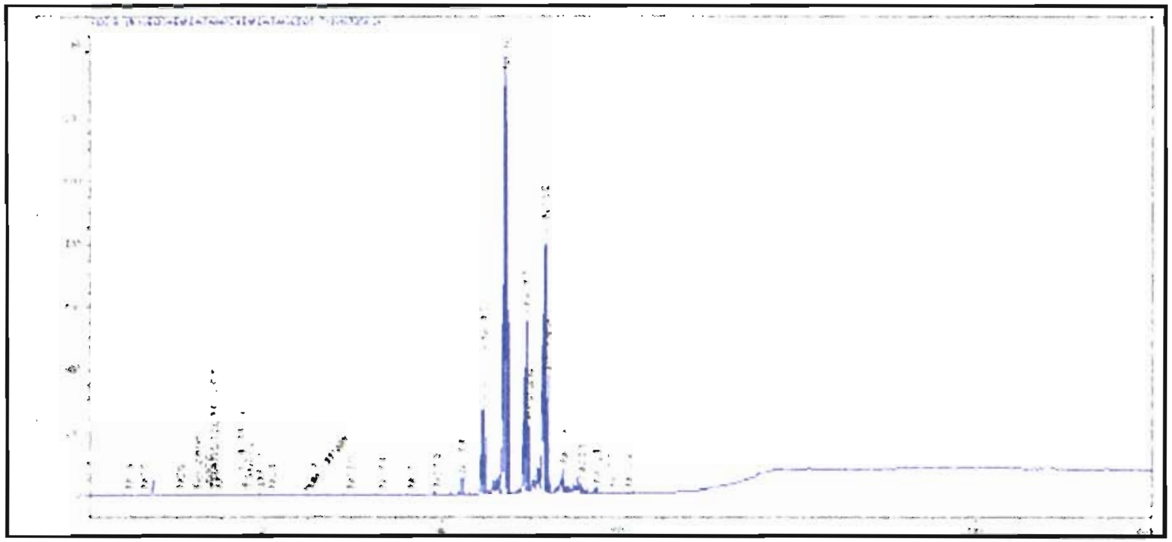


High Resolution GC Analysis of filtrate from Rheliant SOBM bunkered to Bankston on April 20, 2010

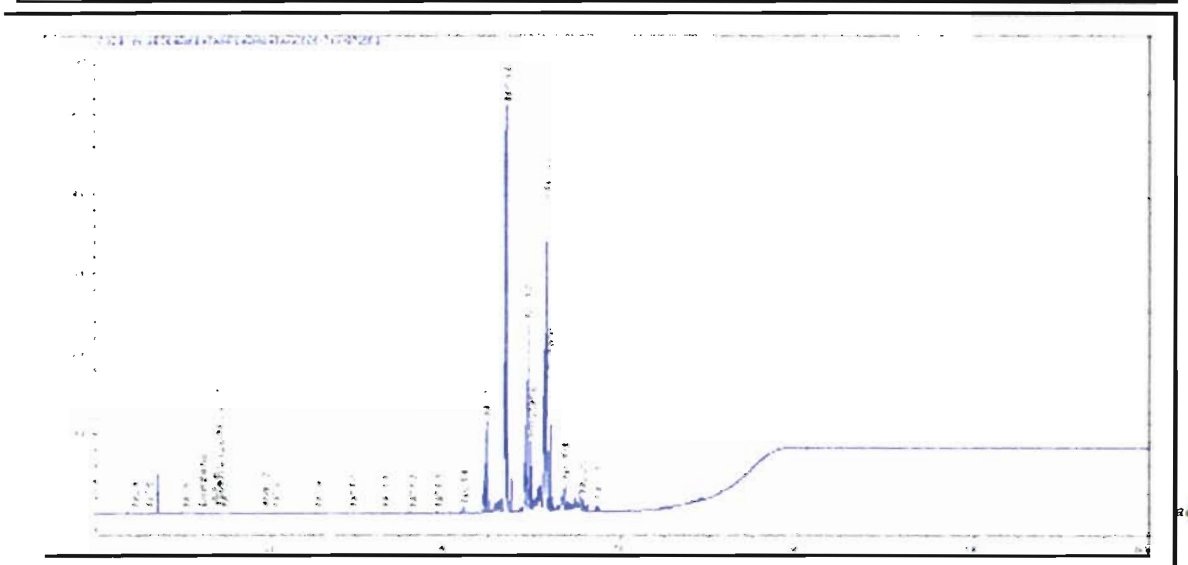


High Resolution GC Analysis of "liquid sample from deck" of Bankston.

Deck Sample Identification



High Resolution GC Analysis of filtrate from Rheliant SOBM bunkered to Bankston on April 20, 2010



High Resolution GC Analysis of "Bulk Mud from Deck" from Bankston.

additional information or analysis

Deck Sample Identification Conclusions

- Organics in both samples were clearly derived from SOBM.
- GC signatures indicative of synthetic oil only – no sign of hydrocarbon contaminant in whole mud bunkered to the Bankston prior to the incident on April 20 or the samples recovered from the deck of the Bankston after the incident.
- XRD (X-Ray Diffraction) Minerology of “Liquid” and “Bulk Mud” showed substantial quantities of Barite, supporting drilling fluids origin.
- Microscopy also showed presence of particles of material described as “concrete”, “metal”, and “scale/corrosion product”. No speculation was made as to origin.

Conclusions:

- Fluid Mechanisms for Plugging the Kill Line
  - High viscosity, high gel fluid (Well documented)
  - Settling (high solids and low permeability likely from observations)
  - X-Linking (only if TO personnel added the XL) (Not likely or provable)
- Other Mechanisms for Plugging Kill Line
  - Valve not open (Out of scope, but unlikely)
  - Hydrates (not likely given over-displacement w/seawater)
- Mechanism for high circulating pressure
  - Very high viscosity of spacer (Well documented)
  - X-Linking (not noted in static sheen)

The Form-A-Set AK/Form-A-Squeeze spacer was a very undesirable fluid to leave across critical BOPE. Testing indicates that mechanisms were present that could contribute to kill line plugging and loss of pressure transmission.

This screening work cannot *definitively* identify cause.

Future Actions:

- Rheology characterization
  - More sophisticated rheometrics
- Sedimentation
  - Larger settling columns and a method to place the fluids without comingling
  - Instrumentation to non-invasively measure density
  - Packing and permeability work
- Cross linking Fann 70 as used by M-I SWACO

Some of this work could done in BP Research facility or major drilling fluids company research facility but would require time to fabricate test equipment.

It is not thought possible that this work could be completed at Westport