From: Kris Ravi
Sent: Mon Sep 20 14:51:44 2010
To: Thomas Roth
Subject: presentation
Importance: Normal
Attachments: Presentation2.pptx

Tommy:

Here is the presentation.

K. Ravi

(office): 1-281-871-4831

(cell): 1-281-224-8785

(fax): 1-281-871-5810

kris.ravi@halliburton.com <mailto:kris.ravi@halliburton.com>

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Cement Slurry Tests Completed

- **Base Slurry Mix-ability**
  - The slurry was easy to mix, on a scale of 1 to 5 (easy), it was 4.
- **Base Slurry Foam-ability**
  - The base slurry could be foamed in 8 seconds which indicated that it was easy to foam, resulting in a stable foam. The target is less than 15 seconds.
- **Foam Slurry Stability**
  - The foamed cement slurry was tested and was found to be stable
  - A column of cured foam cement slurry showed same density at top and bottom. The stability test confirms that the slurry had no free water and did not settle.
    - Free water – no free water
    - Settlement – no settling

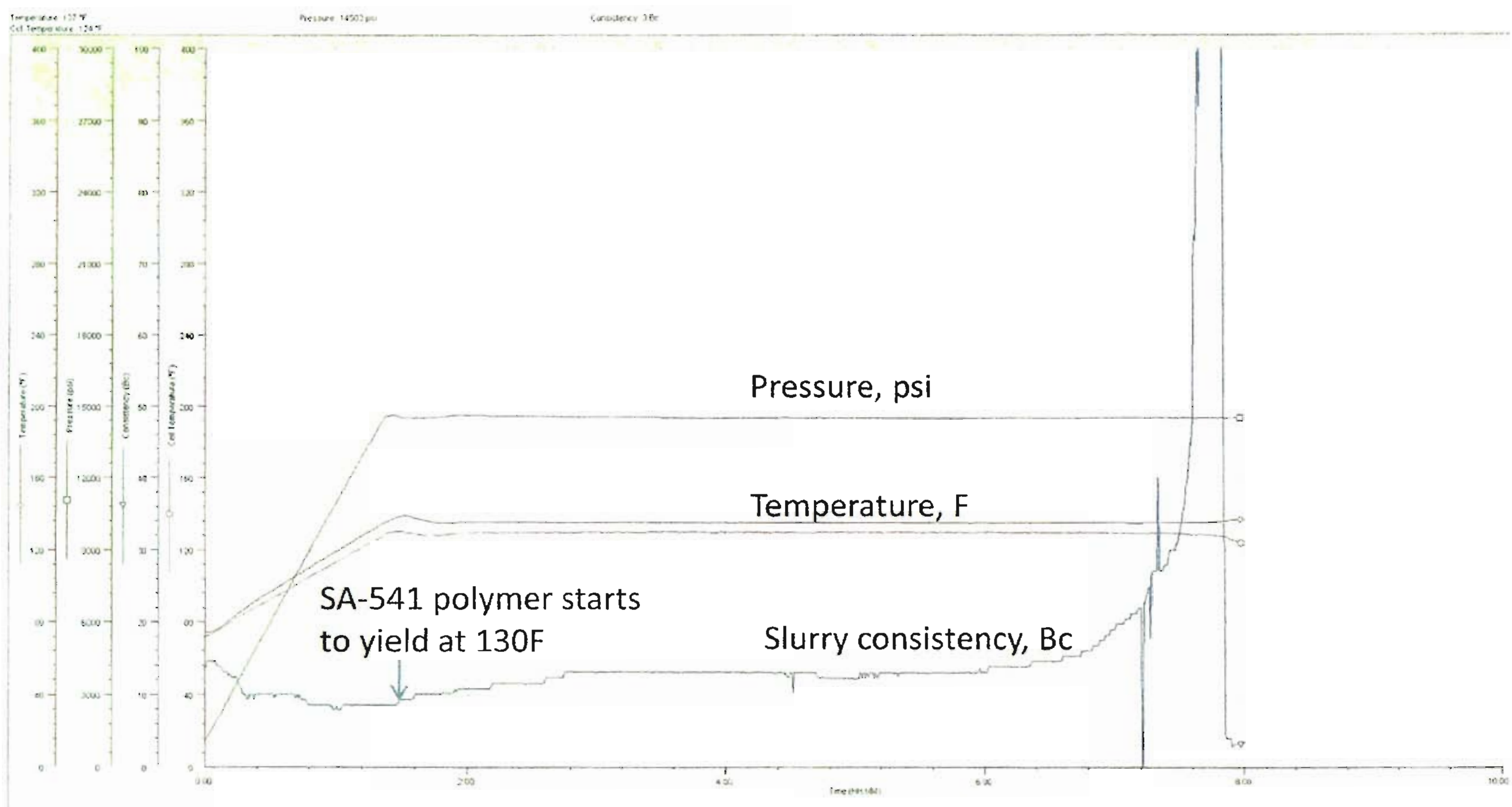
Cement Slurry Tests Completed

- **Fluid loss**
  - Fluid loss of foamed slurry is $1/5^{th}$ to $1/6^{th}$ of the base slurry
    - Microscopic nitrogen bubbles uniformly dispersed into the cement slurry acts as fluid loss additive
    - The lower fluid loss of foamed slurry is confirmed by the testing at CSI.
      - Fluid loss values reported by CSI: 302 cc for base slurry and 66 cc for foamed slurry.
- **Static gel strength; transition time and zero gel time**
  - Foam slurry is compressible and maintains hydrostatic pressure for an extended period of time when compared to a conventional cement slurry and prevents fluid influx from the formation (References: *SPE 124608, SPE 91002*)
- **Rheology**
  - Rheology of foamed and base slurry were measured and were optimal for placement and stability
- **Compatibility**
  - Spacer/mud/cement compatibility tests were conducted and were found to be compatible
    - There was no spike in rheology when spacer, mud and cement were brought in contact

Cement Slurry Tests Completed

- **Density**
  - Density of base slurry was measured using pressurized mud balance
    - Pressurized mud balance is used to measure the density of the slurry without the entrained air
  - Density of cured foam slurry was measured using Archimedes principle
    - Density of the cured foam slurry was same at the top and bottom
- **Thickening Time**
  - The thickening time of the base slurry was measured and had a pump time of 7 hrs and 37 min
    - This is the time it takes for the slurry to reach 70 Bc when the slurry is deemed non-pumpable
  - The slurry consistency rose from 30 Bc to 100 Bc in 14 min.

Thickening Time Chart



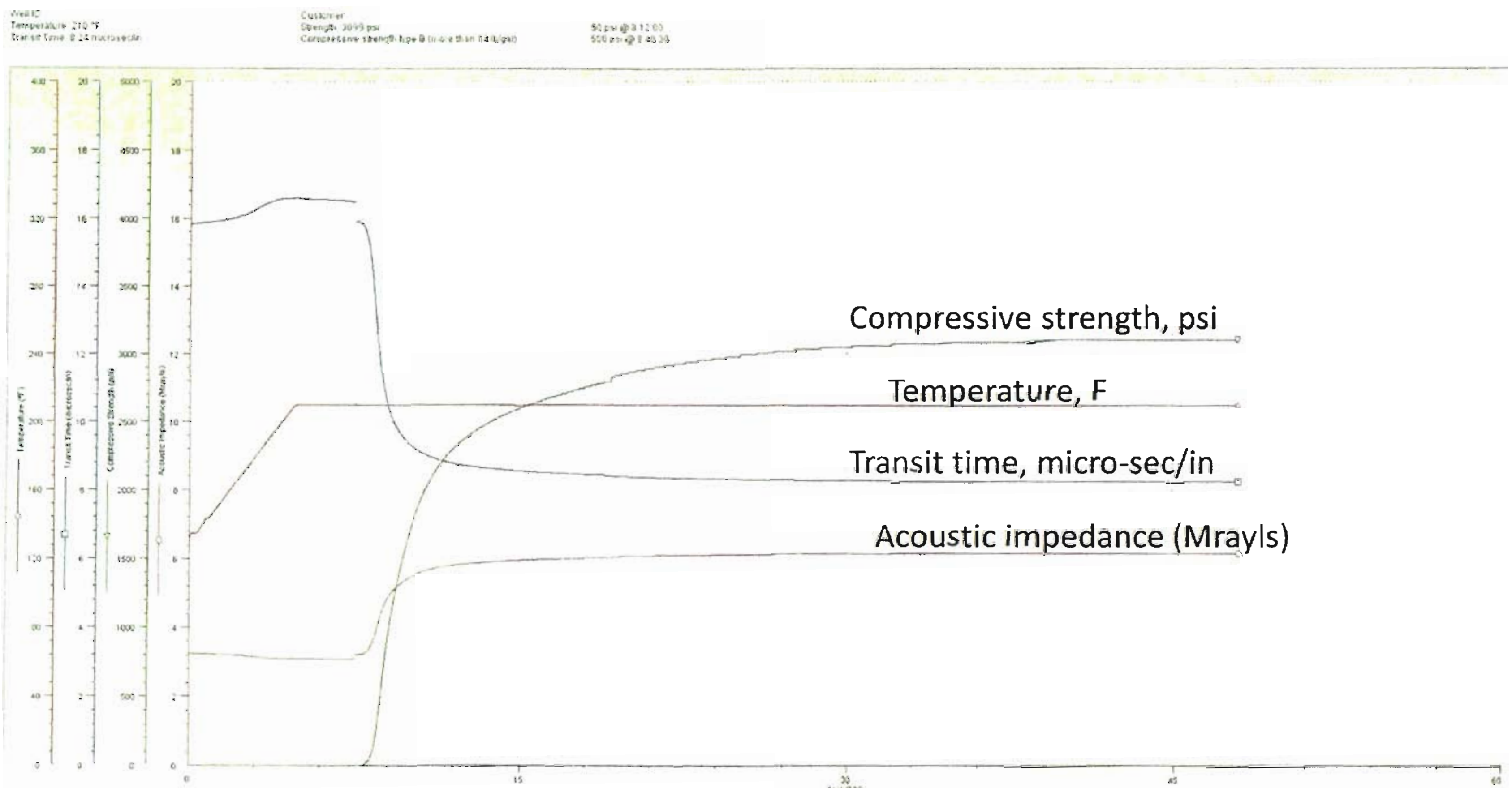
Fiber and Polymer were Added to Improve Stability

- SA-541 polymer was dry blended
  - SA-541 polymer starts to yield at 130F (shown in TT chart)
  - SA-541 improves slurry suspension as the slurry is pumped down the casing, due to the increase in temperature
  - SA-541 continues to yield as temperature increases and the maximum potential is obtained at 150F and beyond when the slurry goes static in the annulus
- WellLife 734 fibers were added to the slurry in the mixing tub
  - WellLife 734 not used in lab tests as this may interfere with the paddle used in lab testing and the fiber is inert
  - WellLife 734 improves rheology, slurry stability, decreases fluid loss and help prevent losses during placement

Cement Slurry Tests Completed

- **Strength**
  - Compressive strength of base slurry at downhole temperature (210 F) and pressure (14,458 psi) was determined in UCA (ultrasonic cement analyzer)
  - Compressive strength of foam slurry was measured by pouring cubes at *atmospheric pressure and 180F*
  - The relationship between compressive strength of foamed slurry and base slurry has been extensively studied and is well defined.
    - The compressive strength of foamed slurry at downhole pressure and temperature, with high amount of nitrogen, is approximately two-fifth to one-half the compressive strength of the base slurry measured at the downhole pressure and temperature (Reference: US Patent, 6345535, "Apparatus and Method for Estimating the Compressive Strength of Foam Cement", Fred L. Sabins, Voldi E. Maki, Jr.)
    - Extensive tests done by Halliburton shows that the compressive strength of foamed slurry with 20% nitrogen is about one-half of the compressive strength of base slurry.

UCA Chart



Compressive strength, psi
Temperature, F
Transit time, micro-sec/in
Acoustic impedance (Mrayls)

Compressive Strength

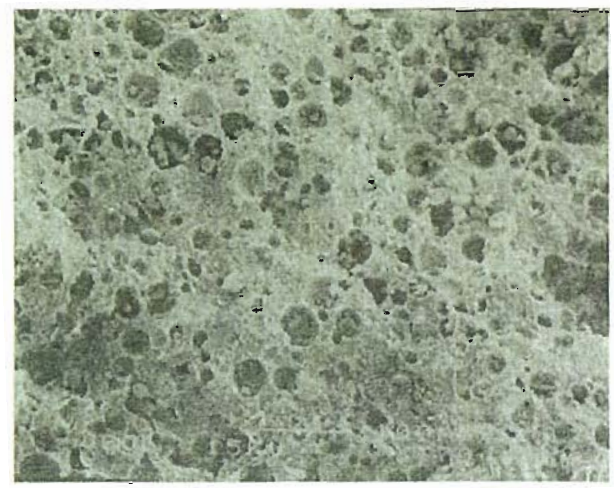
	8hrs:12min	8hrs:40min	12hrs	24hrs	48hrs
Base Slurry, from UCA Test; *210F & 14,458 psi*	50 psi	500 psi	2,301 psi	2,966 psi	3,099 psi
Foam Slurry, 2/5th of Base Slurry[1]; *210F & 14,458 psi*	20 psi	200 psi	920 psi	1,186 psi	1,240 psi
Foam Slurry, from cubes at *180F & atmospheric pressure*	-	-	-	-	1,590 psi

1 US Patent, 6345535, Apparatus and Method for Estimating the Compressive Strength of Foam Cement, Fred L. Sabins, Voldi E. Maki, Jr.)

What is Needed to Create Stable Foam Slurry

- Proven and tested Foamer and Stabilizer
  - Zonesealant 2000 is Halliburton proprietary foamer/stabilizer
  - Zonesealant 2000 is proven to yield stable and consistent foam slurries in a number of jobs around the globe under challenging conditions
- Foam generator in the field
  - Nitrogen atomizer
  - High energy to disperse microscopic bubbles of nitrogen uniformly into cement slurry

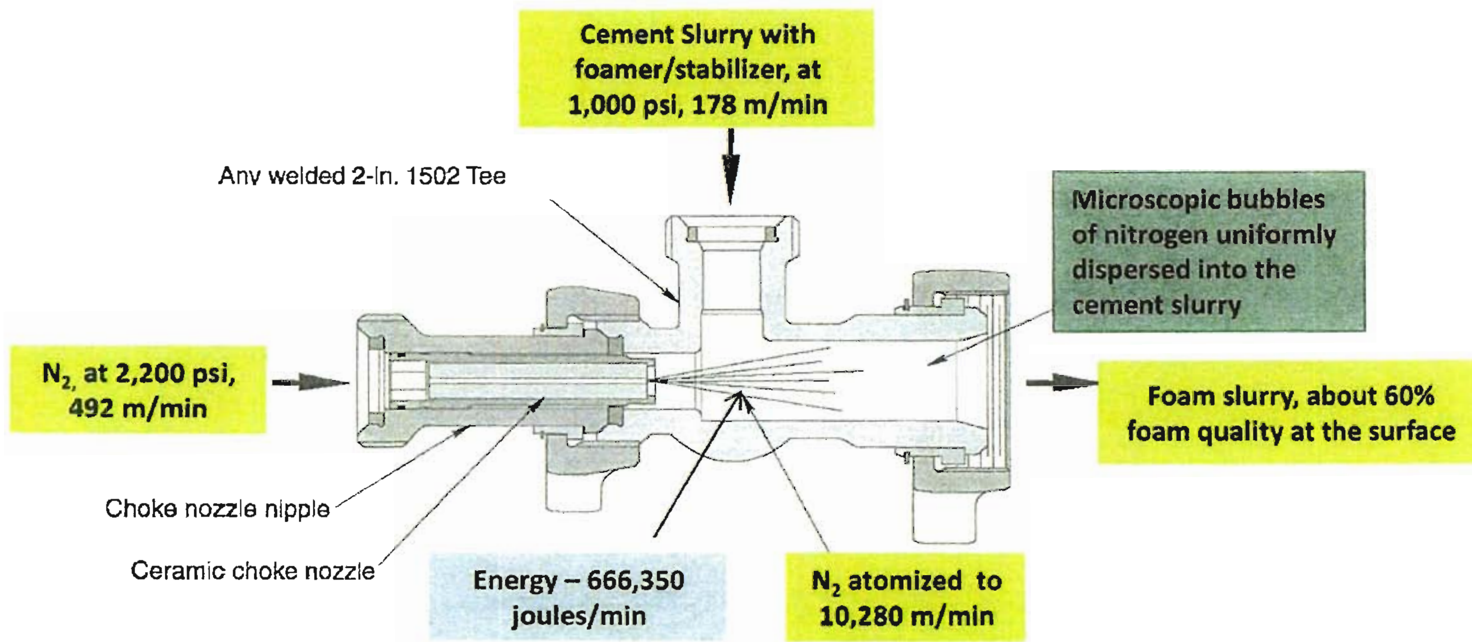
Well dispersed and stable nitrogen bubbles



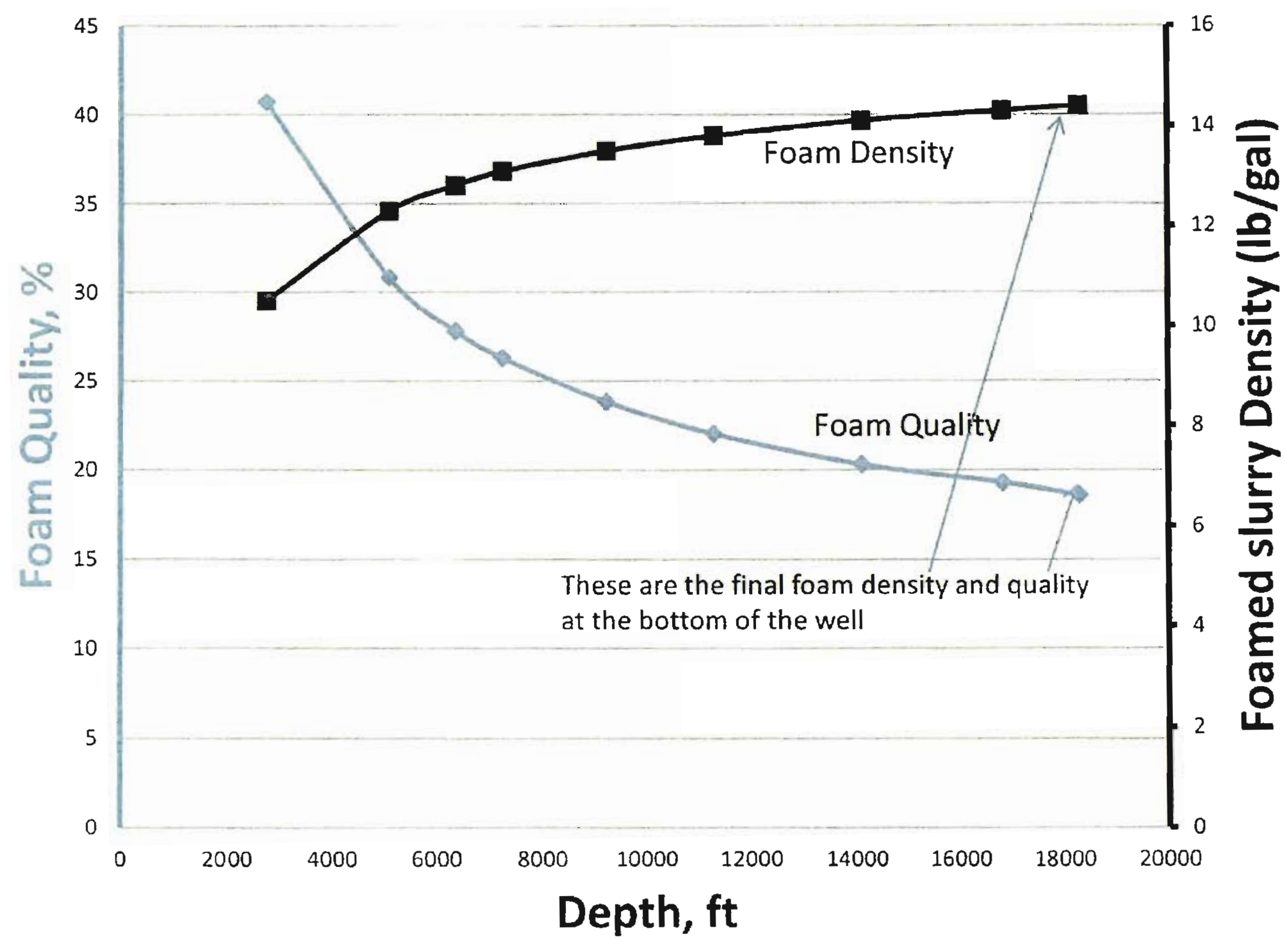
SEM Photo of Cured Foamed Cement Slurry that was Pumped into the Well and Returned to the Mudline. The sample was taken after the well was abandoned[1]

1 IADC/SPE 87194: "Foam Cement Engineering and Implementation for Cement Sheath Integrity at High Temperature and High Pressure" ; J.E. Griffith, G. Lende, K. Ravi, Halliburton, A. Saasen, N. Nodland, O. Jordal, Statoil ASA

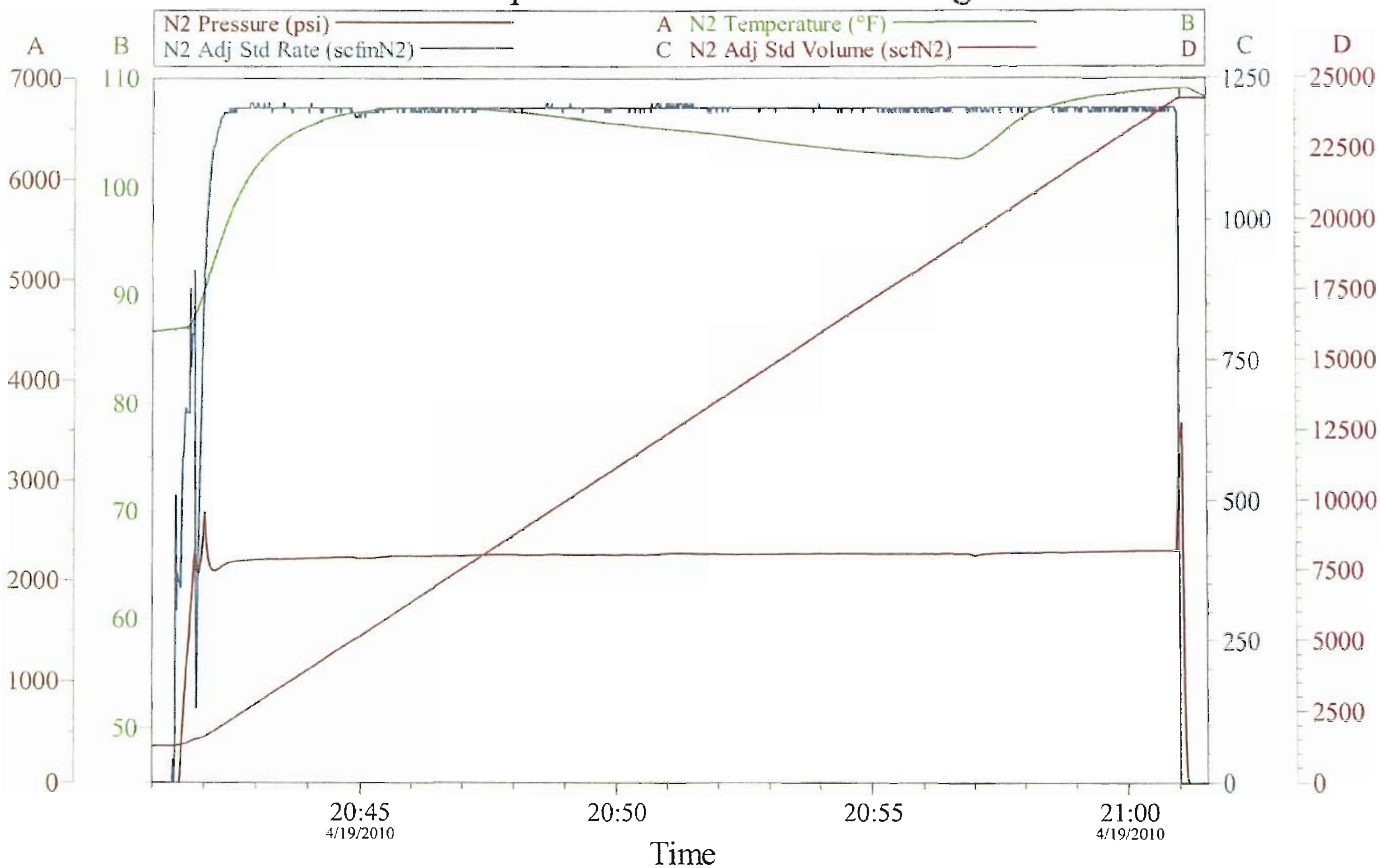
Foam Generator in the Field



Foam Quality and Density



N2 Graph - 9 7/8" X 7" Prod Casing



Customer: Well Desc:	Job Date: UWI:	Ticket #:

HALLIBURTON
CemWin v1.7.2
19-Sep-10 12:27

Jobs Done for BP in the GoM

Jobs Done for BP in the Gulf of Mexico at Similar Conditions

Depth	BHST	BHCT	Water Depth	Single or Dual Plug	Bump Plug	Floats Held	Base Oil ahead (bbls)
18669	174	125	6929	Dual	**No**	No	0
18141	215	185	6435	Dual	Yes	Yes	0
17422	170	125	6929	Dual	Yes	Yes	0
12346	162	125	5598	Dual	Yes	Yes	0
17330	196	165	6741	Dual	**No**	Yes	150

In these two jobs, the pressure tests were done successfully against the foam cement in the shoe track as the plugs did not bump

Jobs Done in Norway

Foam Testing

- Foam slurry stability was tested with the field cement blend and rig water sample as early as April 17, 2010
  - A column of cured foam cement slurry showed same density at top and bottom. The stability test confirms that the slurry had no free water and did not settle.
- Amount of nitrogen is calculated and metered to yield 14.5 lb/gal foam slurry at downhole conditions
- Nitrogen density at the surface is about 1 kg/m^3 and is about 620 kg/m^3 at 14,500 psi and 210F
- To foam 16.7 lb/gal slurry to 14.5 lb/gal at the surface, xx% nitrogen is needed
- To foam 16.7 lab/gal slurry to 14.5 lb/gal at downhole conditions, about 18.5% nitrogen is needed
- Engineering program calculates the amount of nitrogen needed, in realtime and adjusts the amount of nitrogen added
- API cooperative testing shows that a cement slurry can be successfully foamed to between 10% to 60% quality in multiple blade blender
  - The stability test shows that the set cement column is stable from top to bottom (Reference: Foam Cement Workgroup, 2000 API Annual Meeting, Los Angeles, June 19-22, 2000)

Foam Testing

- Tests done as a part of API cooperative testing for the "API Foam Workgroup" clearly showed that foam slurries (up to 60% foam quality) are stable when mixed in multiple blade blender and may <u>not</u> be stable when mixed in single blade blender. (Foam Cement Workgroup, 2000 API Annual Meeting, Los Angeles, June 19-22, 2000)
- Zonesealant 2000 is Halliburton proprietary foamer/stabilizer.
- Multiple blade blender is used in Halliburton labs
- Energy applied in the field, through the foam generator, to foam the cement slurry is closer to the multiple blade blender
- Energy from single blade blender is about 1/3rd that of the multiple blade blender
- Reviewing the results shown in Appendix K:
  - Representative foamer/stabilizer was <u>not</u> used
  - Most of the tests were conducted using single blade blender

D-Air

- Field blend foamed in 8 sec, foamed slurry was stable, density was same at the top and the bottom
  - The field blend contained D-Air for the purpose of removing entrained air in the base slurry before foaming it
  - The D-Air is important to achieve the correct base slurry density
  - The base slurry is held in the 25 barrel tank of RCM for 13 minutes and then pumped through 120 feet before it reaches the foam generator
    - Base slurry reaches the foam generator 15 minutes after mixing
- PS Lite Halliburton field bulletin – recommends adding D-Air to slurries that entrain air during mixing, in order to achieve correct base slurry density before foaming

Centralization

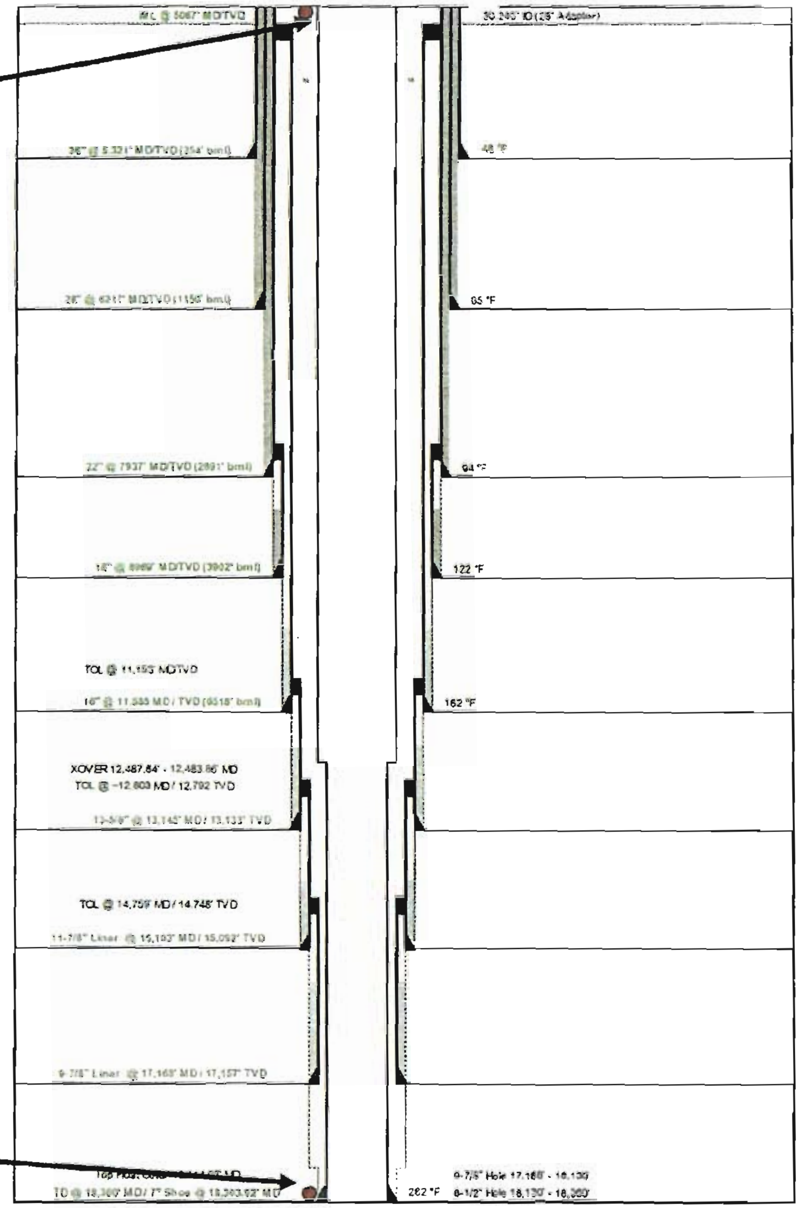
- BP used only 6 centralizers
- 3 Centralizers used around the shoe, covering one bottom primary reservoir sand, out of four primary reservoir sands
- This should have helped in achieving good cement around the shoe
- Poor centralization across the other three primary reservoir sands
- This would have left mud channel and hence flow path from the formation around the top three reservoir sands
- With good cement around the shoe, the fluid from formation would have entered the annulus through the mud channel and flowed up the annulus

Circulation and Gas in the Mud

- Indications of gas to the surface while circulating bottoms-up prior to running the casing (Reference: xxx)
- Circulated only 1/3rd bottoms up total
- Circulated only 1/10th bottoms up after going static for one hour and half to convert the floats
  - Industry recommendation is a minimum of one full bottoms up and preferably two bottoms up
- Hook load change – 63,000 K while circulating mud prior to cement job

Bottom-up mud after cement in place. Total volume pumped = 1110 bbls, total calculated volume of anulus = 1089 bbls. Difference of 21 bbls.

Very likely that the gas that entered into the mud was not circulated out before setting casing seal assembly



Mud on bottom before circulating 110 bbls of mud and cement job.

Casing Seal Assembly

- At the time of incident the casing seal assembly was not mechanically locked (page 38)
- On Page 38 it shows that the casing seal could be uplifted if sufficient forces were applied
  - Even with cement 100% bonded to casing the forces were close to uplift the casing seal (BP estimation, page 38)
  - With casing and cement not bonded, need only 258 psi to unseat the 9 7/8 inch casing from the hanger/ seal assembly (BP calculation, Appendix M, page 19)
    - Due to improper centralization, most likely the mud was not removed from the entire annulus and hence the cement is not fully bonded to the casing

Other

- Page 36: 1,000 feet cement of above the sand and centralization 100 feet above the top sand – BP did not follow their own best practices
- Page 36: Halliburton did communicate the risk of channeling
  - BP did order 15 additional centralizers but did not install them
- Page 35 – no discussion was held with Halliburton on logging
- Page 37: Shoe track cement is not intended to be a barrier (see next page for definition)

Shoe Joint

- “The space between the float or guide shoe and the landing or float collar. The principal function of this space is to ensure that the shoe is surrounded in high-quality cement and that any contamination that may bypass the top cement plug is safely contained within the shoe track.”

Reference: http://www.glossary.oilfield.slb.com

Shoe Joint

- "The distance between the float collar and float shoe (usually 1-3 joints) is called the shoe track. Per Sluman[1] this spacing between guide or float shoe and float collar provides a chamber to contain mud contaminated cement after cementing has been completed. This practice helps to assure placement of good quality cement outside the bottom few joints of casing to help prevent backoff of bottom joints during drill out of floating equipment."

Reference: IADC/SPE 62751, pg 1-2

Shoe Joint

- The shoe joint is not designed to provide flow barrier
- In the Macondo well there were problems in converting the floats
  - It is possible that the floats were damaged in the process
- Mud in rat hole

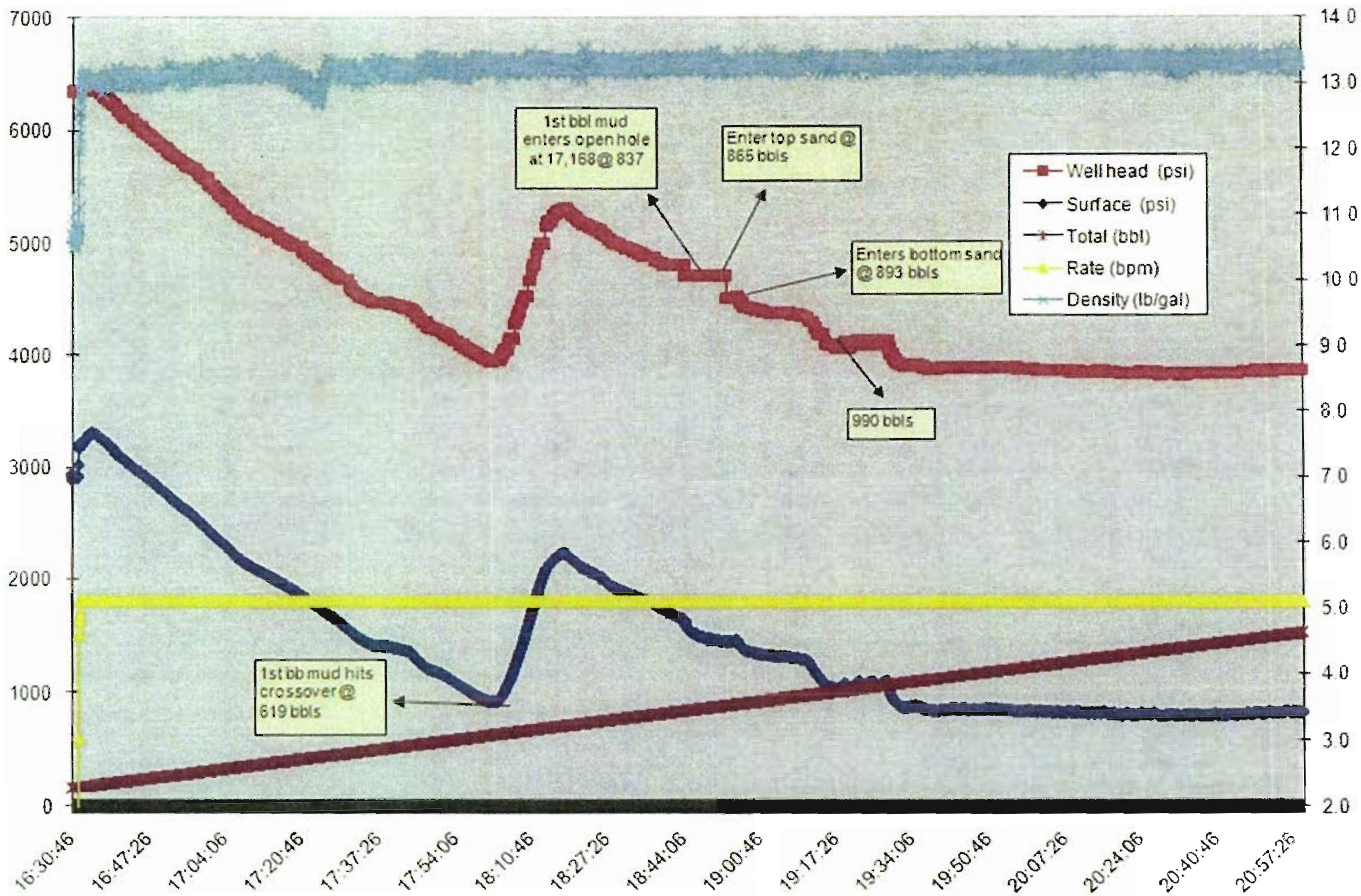
Cap and Shoe Cement

- As per the design, Cap Cement, pumped ahead of the foam cement, does not cover any gas bearing zones
  - Hence, fluid loss control is not needed in this slurry
- As per the design, the shoe slurry, pumped behind the foam cement, is not a flow barrier
  - Hence, fluid loss control is not needed in this slurry
- The cap, foam and shoe slurries are isolated from mud and base oil by mechanical barriers and spacer in the casing and spacer in the annulus

OLGA and Static Kill Analysis

- From our preliminary analysis of data from August 4, 2010, seem to indicate all or a large portion of the fluid during static kill went through the annulus – this is in contrast to conclusion in Page 37.

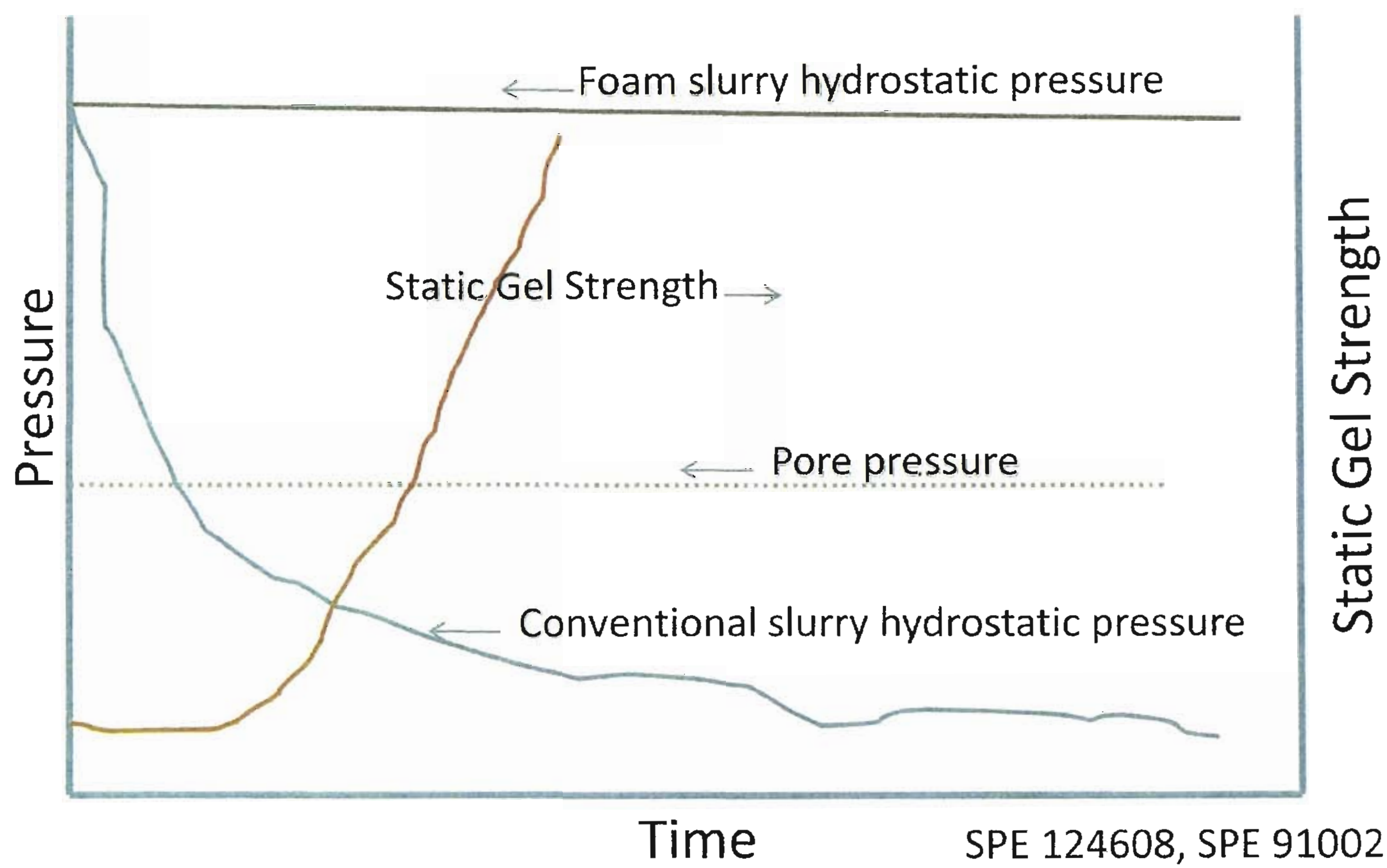
Static Kill Chart



Other

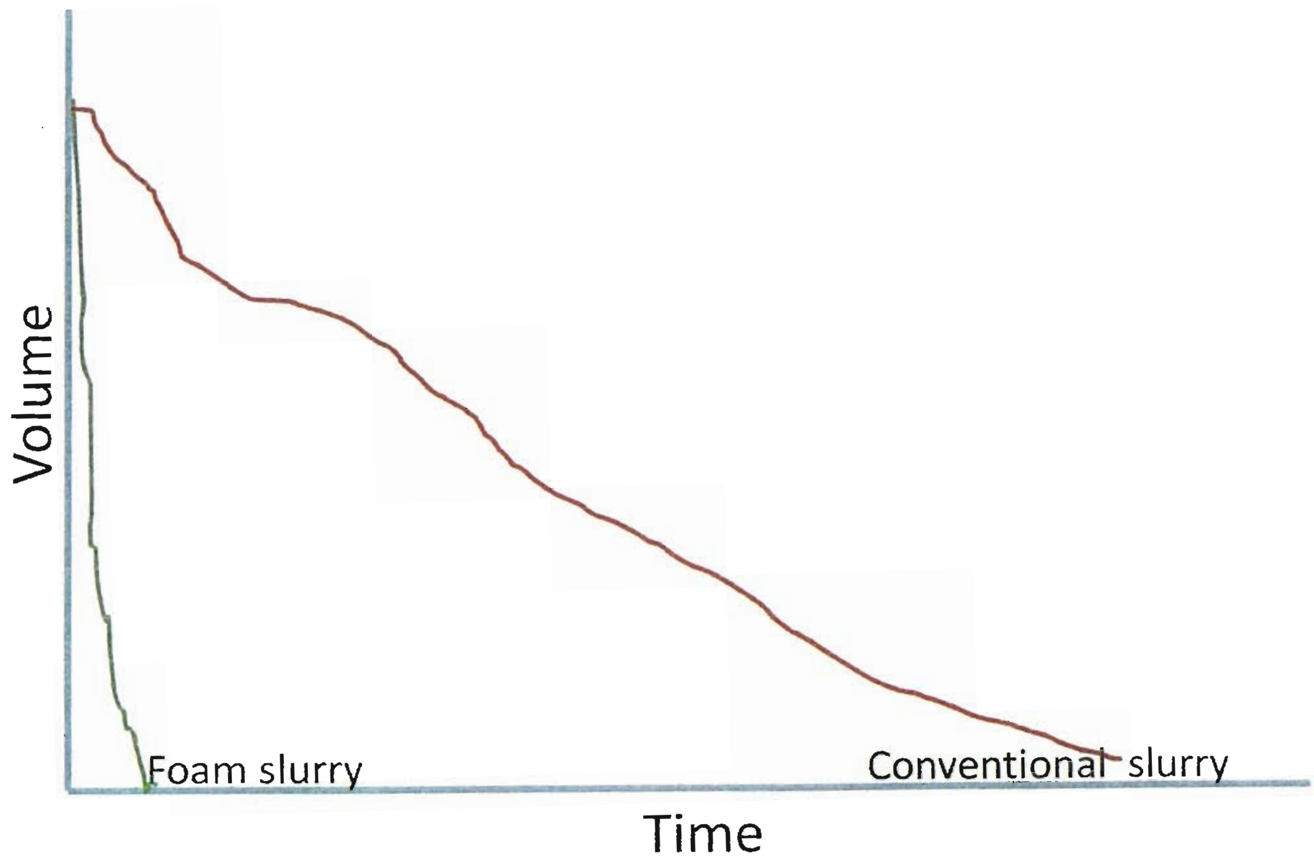
- No indication that hydrocarbons entered the wellbore prior to or during cement job (page 33)
  - Bottoms-up not conducted to verify
- Yield point (page 34)
- Small volume
  - Specified by BP
- Base oil, spacer contamination
  - Mechanically separated

Hydrostatic Pressure



SPE 124608, SPE 91002

Fluid Loss



Hydrostatic Pressure and Fluid Loss