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Macondo M252
Cement Analysis

BP Investigation Team
24-June-2010

EXHIBIT # 336

WIT: _____

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Scope of this document

This report is to support conclusions made in several Engineering Critical Factor Conclusions and any other data relevant to the cementing analysis. This report will provide details about calculations for the cement analysis in the event a future engineer needs to understand the BP excel spreadsheets used for cement analysis.

Summary and Conclusions

The cement job was pumped as planned.

1377 bbls of mud was pumped after converting the float equipment, which would place any hydrocarbons above the wellhead after cementing operations. The shoe to wellhead volume = 1109 bbls and the shoe to RKB volume = 2764 bbls. The volumes pumped eliminate the possibility of trapped hydrocarbons in the annulus or wellhead that were there prior to pumping the cement job.

Operations went well however the float collar took 9 attempts to try to convert from the open to the closed position. It is possible that the floats never converted. A separate investigation is looking into this issue. The top plug was bumped at 1150 psi (750 psi over final circulating pressure). Pressure was bled to 0 psi and 5 bbls was reported bled back to check the floats. U-tube pressure was ~ 21 psi therefore it would be difficult to test the floats with close to zero u-tube pressure.

The actual displacement volume of 885 bbls indicates that the plug bumped at the correct volume when considering up to 13 bbls of compression occurred with the synthetic oil based mud at this depth. Theoretical displacement without mud compression is 878 bbls (7 bbls less than actual). Displacements indicated by plug pressure increases across the 7" x 9-7/8" crossover indicate that the volume of cement between the top and bottom plug had a slight variance from plan (actual = 54 bbls vs plan = 60.4 bbls).

A separate document should be referenced for lost returns analysis. In summary no losses were observed during displacement and only 0-3 bbls of cement were likely lost (based on pits volumes).

Displacement calculations indicate that 7 bbls of class H cement are in the shoe track out of a 7 bbls capacity. The shoe did not have a float and it is possible that rat hole mud (14.17 ppg ESD) could have swapped with the 16.7 ppg class H cement in the shoe track. If this occurred a wet shoe track would be possible. No pill was spotted in the rat hole during the clean out run prior to casing running.

6 centralizers were reported run, which did not cover the shallowest hydrocarbon zones. Based on pre-plan simulation analysis (April 18th report) there could have been channeling above the top centralizer, which could reduce the quality of cement and increase the top of cement. The drilling team was only aware of the 13.01 ppg sand (17788') prior to the cement job and designed the top of cement assuming this was the shallowest hydrocarbon sand. The 14.15 ppg sand (17451') was identified in post well operations.

Excluding the transition time of the cement, the first time the well was under balanced was during the negative test. From cement placement (4/19 20:37) to the negative test (4/20 17:00) was ~20 hrs. The unfoamed 16.74 ppg base slurry has a 2,301 psi compressive strength after 12 hrs per the Halliburton lab test dated April 12, 2010.

Specific Data or Information Gaps:
A cement bond log may have indicated actual top of cement depth and the extent of channeling.

Returns to the cement unit are not recorded and therefore cement returns while checking floats cannot be confirmed with digital data.

The line volume from the cement unit to the drill pipe side entry sub is not verified with actual data. The plan indicates a line volume of 3.0 bbls, however if this volume is less then the shoe track could be contaminated with spacer.

Simulations and lab tests need to be done to confirm the following:

1) compressive strength of the foam cement at downhole conditions
2) test float equipment
3) test float equipment seal rating with low positive and negative differential pressure (< +/- 100 psi)
4) possible swapping of rat hole mud and shoe track cement
5) Nitrogen migration after pumping cement
6) Possible cement contamination with hydrocarbon zone, spacer, and mud.
7) Cement foam stability

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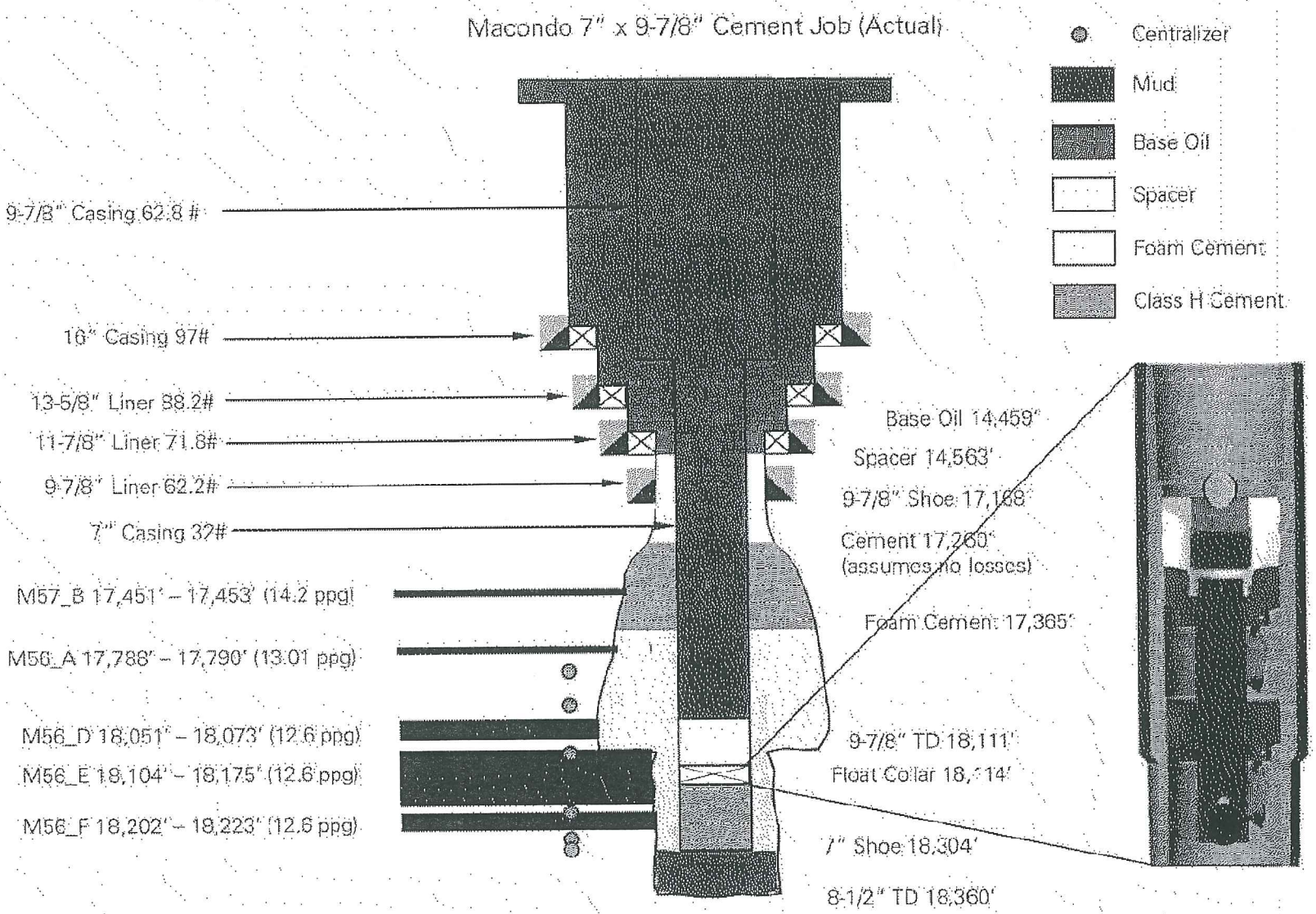
Well Schematic



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Daily Operation Report - Cement Details per Open Wells

Cement operations reported by the daily drilling report in Open Wells have the following sequence.

Cement Operations (from Open Wells operations report)

Item	Weight	Volume	Yield cf / sx	Rate	
	ppg	bbl		bpm	
base oil	6.7	7			
spacer	14.3	10			
spacer	14.3	62		4	
Class H cmt	16.7	4	1.37	2	
drop dart #1					
Class H cmt	16.7	4	1.37	2	
N2 Foam cmt	14.5	48	1.69		39 bbl cmt & 48 bbls once foamed
Class H cmt	16.7	4	1.37		
spacer	14.3	0			3 bbls displace surface lines from cmt unit to wellhead
drop dart #2					
spacer	14.3	20			(3 bbls to clear lines + drop dart + 17 bbls per DIMS)
mud	14.0	133			with cement unit
bottom dart to diverter					43 bbls to diverter, 3500 psi sheared
bottom dart to DTD					150 bbls to DTD, 3250 psi sheared
no indication of bottom plug shear					
top dart to diverter					100 bbls to diverter, 3200 psi sheared
top dart to DTD					109 bbls pumped, 3400 psi sheared
top dart to plug					119 bbls, 3300 psi sheared
switch to rig pumps					
mud	14	727		4	530 psi circ rate
bottom plug to XO					469 bbls at 830 psi
top plug to XO					523 bbls at 590 psi
bottom plug landed FC					673 bbls at 2932 psi
top plug to land FC					727 bbls at 740 psi over circ press

Cement Volumes

The slight discrepancies from the Halliburton post well report dated April 20, 2010 vs analysis of real time data are listed here. The main unknown that could change the volumes of lead, foam, and tail is the line volume from the cement unit to the side entry sub on the drill pipe. The drilling engineer reported that the N2 was connected directly to the side entry sub therefore no additional line volume should be considered from normal cementing operations.

The post well report and drilling engineer's plan used a 3 bbls line volume, which has been assumed in this analysis. If the line volume is less than 3 bbls then it is possible that spacer would have been left in the shoe track.

The green column in the table below was used to calculate cement tops.

Macondo - 7" x 9-7/8" cement job								
			18-Apr	19-Apr	19-Apr	20-Apr	20-Apr	Comment
			Plan	Digital	Digital	HES post report	DIMS	
	line volume assumption		3	0	3	3	7	the planning team assumed 3 bbls line vol
sequence			bbls	bbls	bbls	bbls	bbls	
1	mud			347.0	347.0			only 111 bbls reported in DIMS
2	mud			6.1	6.1	7.0		
3	base oil			6.6	6.6	5.0	7.0	
4	spacer		72.0	76.0	76.0	72.0	72.0	
5	lead			4.2	4.2		4.0	
6	drop bottom dart							
7	lead		5.3	4.0	4.0	5.3	4.0	
8	foam cement (liquid base)			0.7	3.7			
9	foam cement (liquid base)		38.9	39.3	35.9	38.9	39.0	
10	tail		6.9	4.2	7.2	6.9	4.0	possible foam in shoe track
11	spacer			3.0			3.0	possible spacer in shoe track
12	drop top dart							
13	spacer		20.0	18.1	21.0	20.0	17.0	
14	mud (cmt unit)			131.3	131.3	133.0	133.0	
15	mud (rig)			735.0	735.0	729.0	727.0	13 bbls SOBM compression
(surface)	Total Cement Volume		51.1	52.4	52.4	51.1	51.0	No N2 included in vol
(downhole)	Total Cement Volume		60.0	51.6	61.6	60.0	60.0	foam = 1.23 x class H vol
	Total Circulation Vol			1376	1376			shoe to wellhead volume = 1109 bbls
	shoe track (class H)		7.0	4.0	7.0	7.0	4.0	
	shoe track (foam cmt)		0.0	3.0	0.0	0.0	0.0	
	shoe track (spacer)		0.0	0.0	0.0	0.0	3.0	

Nitrogen Volumes

Using the real time cement data 23758 scf (4235 bbls) of nitrogen was pumped over 19.4 minutes.

Average conditions were 1120 psi, 110 degF, and 1175 scfpm over 19.4 minutes. Using averages (19.4 min * 1175 scfpm = 22795 scf) the volume is lower than summing the raw data (integrating like calculation). The post well job report from the 20th shows an injection temperature of 110 deg F.

The non-ideal gas law was used for volume calculations of nitrogen.

$$\frac{P_1 \times V_1}{Z_1 \times T_1} = \frac{P_2 \times V_2}{Z_2 \times T_2}$$

Where:
P= Pressure [psi] = x psi + 14.7
V=Volume
Z=Compressibility Factor
T=Absolute Temperature [deg Rankin] = x deg F + 459

Event	Pressure (psi)	Temperature °F	Compressibility Factor**	Volume of Nitrogen (bbls)
Standard	0	60	1	4235
Injection	1120	110	1	60.0
TD	13490*	135	1.87	9.8

* injection pressure at TD = hydrostatic plug + friction pressure
** compressibility factor from Schlumberger's i-handbook.

Injection volume calculations:
Where Z2 = 1.0
14.7 psi * 23758 scf / (60 deg F + 459 deg F) = (1120 psi + 14.7 psi)*V2 / (110 deg F + 459 deg F)
V2 = 337 ft^3 = 60.0 bbls (surface injection N2 volume)
surface N2 cement quality = 60.0 bbls / (60.0 + 40.0 bbls) = 60.0%
The reason this volume is important is that the active pits should gain 60.0 bbls above the base cement volume due to nitrogen injection. The active system should gain volume equal to all the fluids pumped from the cement unit plus the volume of nitrogen.

Downhole volume calculations:
Where Z3 = 1.87
V2 = 56.8 bbls (surface injection N2 volume)
(1120 psi + 14.7 psi)*60.0 bbls / (110 deg F + 459 deg F) = (13490 psi + 14.7 psi)*V3 / (1.87*(135 degF + 459 degF))
V3 = 9.84 bbls (downhole N2 volume)
downhole N2 cement quality = 9.84 / (9.84 + 40.0) = 19.7%

Formation Depths

Formation Tops provided by GOM:

The 13.01 ppg sand was the shallowest hydrocarbon sand provided to the drilling engineering team prior to the cement job. The 14.15 ppg sand at 17451' was identified post well operations.

		LWD		Wireline		
Sand Name	pore press	top	bottom	top	bottom	
	ppg	md	md	md	md	
M57B	14.15	17451.0	17453.0	17467.0	17469.0	identified as hydrocarbon June 2010 not a measured pressure
M57C	14.15	17684.0	17692.5	17700.0	17708.5	Not hydrocarbon zone per GOM petrophysical review
M56A	13.01	17788.0	17790.5	17804.0	17806.5	MDT
M56D	12.6	18051.0	18073.0	18067.0	18089.0	MDT
M56E	12.6	18104.0	18175.0	18120.0	18191.0	MDT
M56F	12.6	18201.5	18222.5	18217.5	18238.5	not measured

Note: All data comes from BP petrophysical review done on 25-May-2010.

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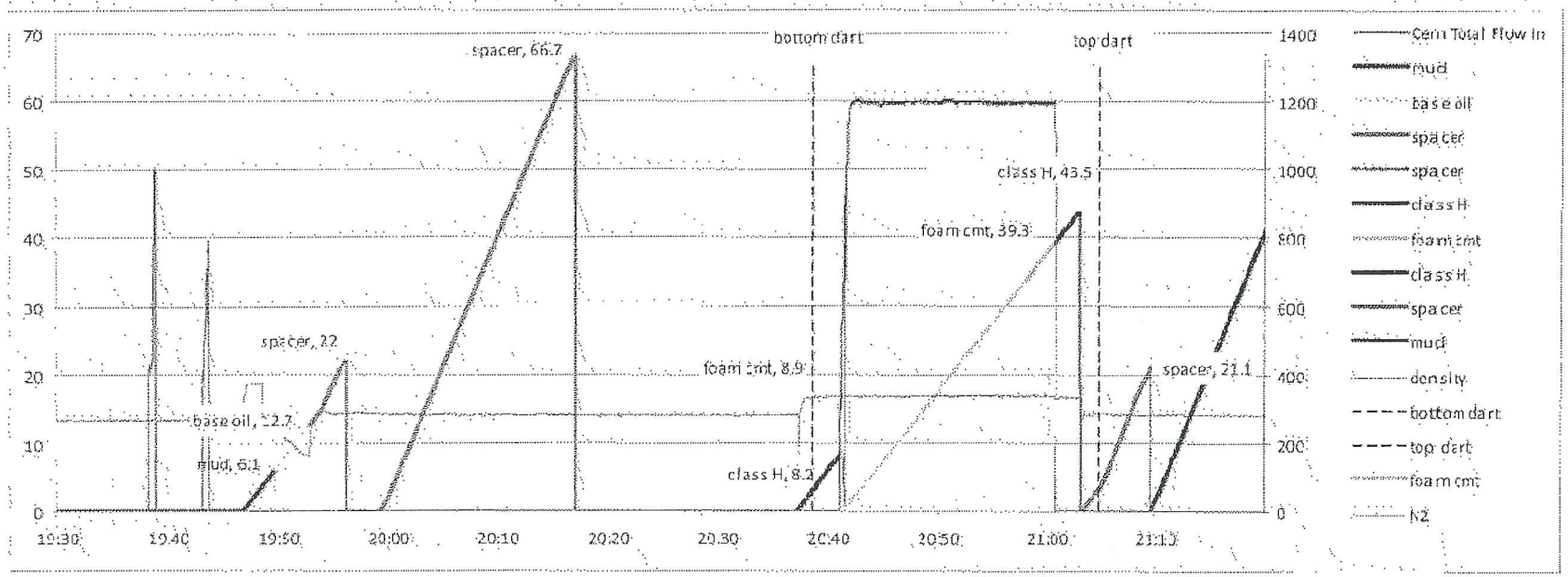
Real Time Cement Data

The real time data was used to determine the actual volumes pumped. The volume counter for each phase was set by the cementer on the job, however lines volumes and densities need to be considered. For example the 1st phase was a total of 22 bbls (19:45 - 19:55). Of those 22 bbls on the counter 6.1 bbls were mud, 6.6 bbls were base oil (12.7 - 6.1), and 9.3 bbls were spacer (22 - 12.7). In addition since the line volumes were reported to be 3 bbls (this has not been verified with hard data) the last 3 bbls pumped before turning off the nitrogen unit would not have been nitrified. The tail pumped after turning off nitrogen would be 43.5 bbls - 39.3 bbls = 4.2 bbls. 3 bbls in the line must be added to this to get the total class H tail 7.2 bbls (4.2 + 3).



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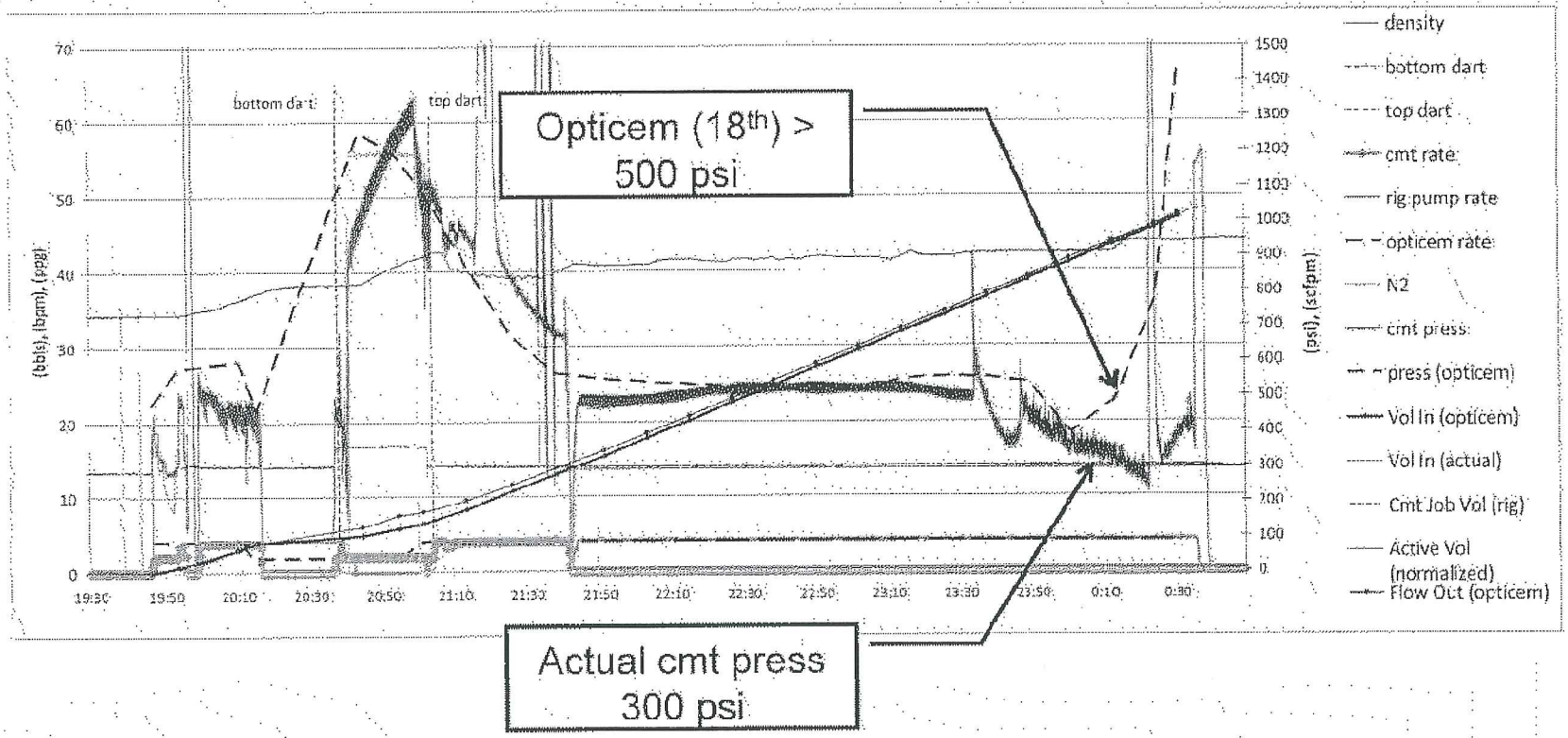
Pump Pressure - Actual vs Model

This graph analyzes the planned HES Opticem Model (rev April 18th) pump pressure vs the actual data. It should be noted that the pressures diverges at 24:00 hrs before the bottom plug bumps the float collar. CSI is running OptiCem models to understand the lower pump pressure vs actual.



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Displacements

Actual vs Theoretical

The real time cement unit pressure data was used to determine if the plugs crossed known constrictions at correct volumes of displacement. The table summarizes the volumes vs theoretical. Compressibility was not considered in the theoretical volumes.

Displacements		Actual		
	theo	bottom dart	top dart	comment
launch to diverter	120.5	118	119	
vol from plug to XO	536.4	n/a	542	didn't see bottom dart at hanger
vol from XO to FC	203.2	206	208	
total displacement	878	887	885	
		Actual (net)		
	theo	bottom dart	top dart	
launch to diverter		-2.5	-1.5	
vol from plug to XO			5.6	
vol from XO to FC		2.8	4.8	
total displacement		9	7	

note: compressibility can be up to 13 bbls at this depth with SOBM, which will affect displacement volumes. compressibility not considered here.

Capacity Calculations

To calculate the cement volumes and tops of fluids the following capacities were used.

Item	Weight lb/ft	ID in	OD in	Top ft	Bottom ft	Length ft	Capacity bbl/ft	Close Ended Displacement bbl/ft	Cap Vol bbl
Riser		19.5		0	5067	5067	0.369		1872
22"		18.375		5067	5227	160	0.328		52
16" Casing	97	14.92		5227	11585	6358	0.216		1375
13-5/8" Liner	88.2	12.375		11153	13145	1992	0.149		296
11-7/8" Liner	71.8	10.711		12803	15103	2300	0.111		256
9-7/8" Liner	62.8	8.625		14759	17168	2409	0.072		174
9 7/8" Casing	62.8	8.598	9.875	5067	12487	7420	0.072	0.095	
7" Casing	32	6.143	7	12487	18304	5817	0.037	0.048	
9-7/8" Open Hole			9.875	17168	18111	943	0.095		89
8.5" Open Hole			8.5	18111	18360	249	0.070		17
6-5/8" DP	40		6.625	0	5057	5057	0.0272	0.043	138

Note: the 7" casing average measured ID was 6.143" ID (API = 6.094") and the 9-7/8" average measured ID was 8.598" (API = 8.625").

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Volume Calculations

The following volumes were used for annulus capacity and displacement volumes. Caliper data was used for the open-hole volumes.

	bbl / ft	Length ft	Vol bbl	%excess
Shoe Track	0.037	190	7.0	
rat hole	0.072	56	4.0	
7" csg x 8.5" OH Annulus (gauge)	0.023	193	4.4	
7" csg x 9-7/8" OH Annulus (gauge)	0.047	943	44.4	
7" csg x (8-1/2"OH) - caliper	0.026	193	5.0	16%
7" csg x (9-7/8"OH) - caliper	0.057	944	53.6	21%
7" csg x 9-7/8" Liner	0.025	2409	59.4	
7" csg x 11-7/8" Liner	0.064	1956	124.9	
7" csg x 13-5/8" Liner	0.101	316	32.0	
9-7/8" csg x 13-5/8" Liner	0.054	1334	72.1	
9-7/8" csg x 16" Liner	0.122	5926	720.1	
9-7/8" csg x 22" Liner	0.233	160	37.3	
7" XO to FC	0.037	5627	206.3	
WHD to XO	0.072	7420	532.9	
WHD to FC			739.1	
6-5/8" DP to WHD	0.0272	5079	138.1	
WHD to RKB (riser)	0.327	5067	1655.7	
annulus volume (cmt bottom to whd)		1109	bbls	
btm up vol (shoe to RKB)		2764	bbls	

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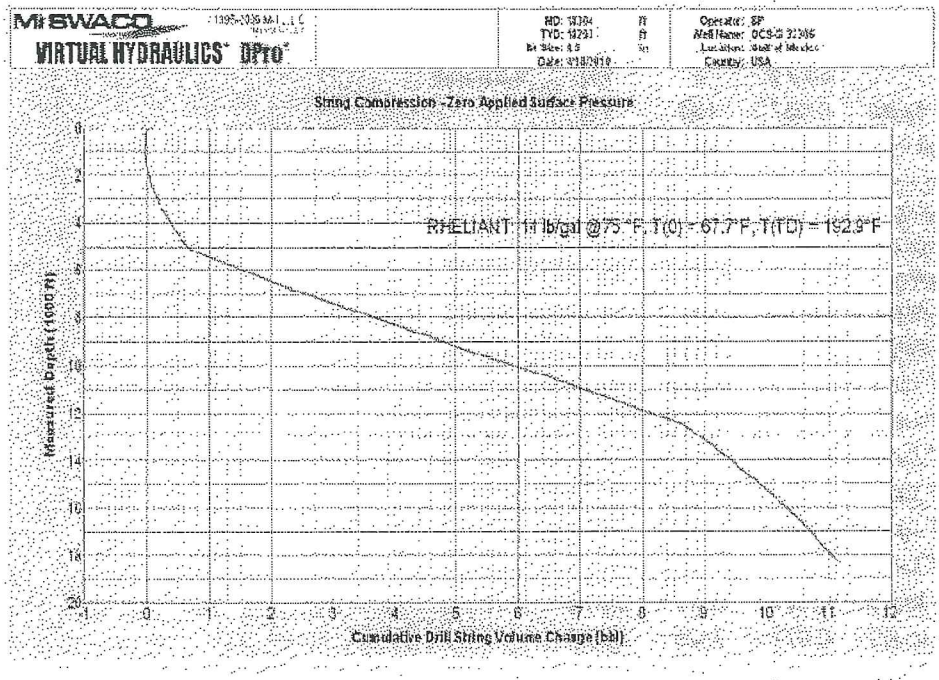
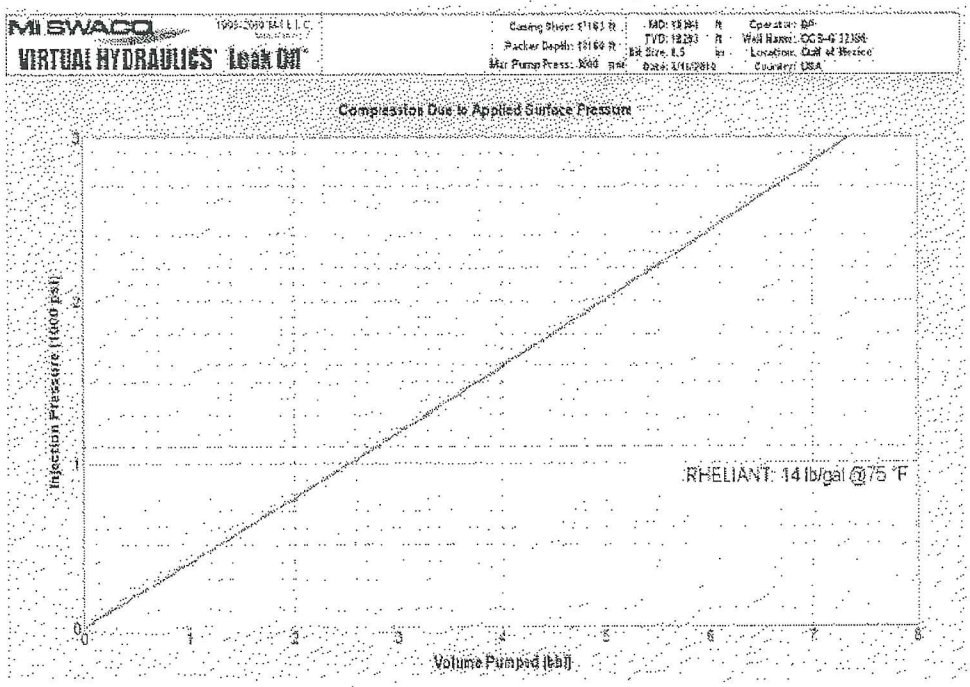
SOBM Compressibility Model (Pre-job analysis)

This graph shows the extra volume needed (over calculated capacity) to fill the landing string and Casing due to synthetic compression at temperature and hydrostatic pressure (with zero applied surface pressure).



This graph shows the extra volume needed to bump the plug due to APPLIED SURFACE PRESSURE.
Read the pump pressure near plug bump on the left. The two graphs values must be added to obtain the total volume needed to bump the plug over calculated drill string capacity



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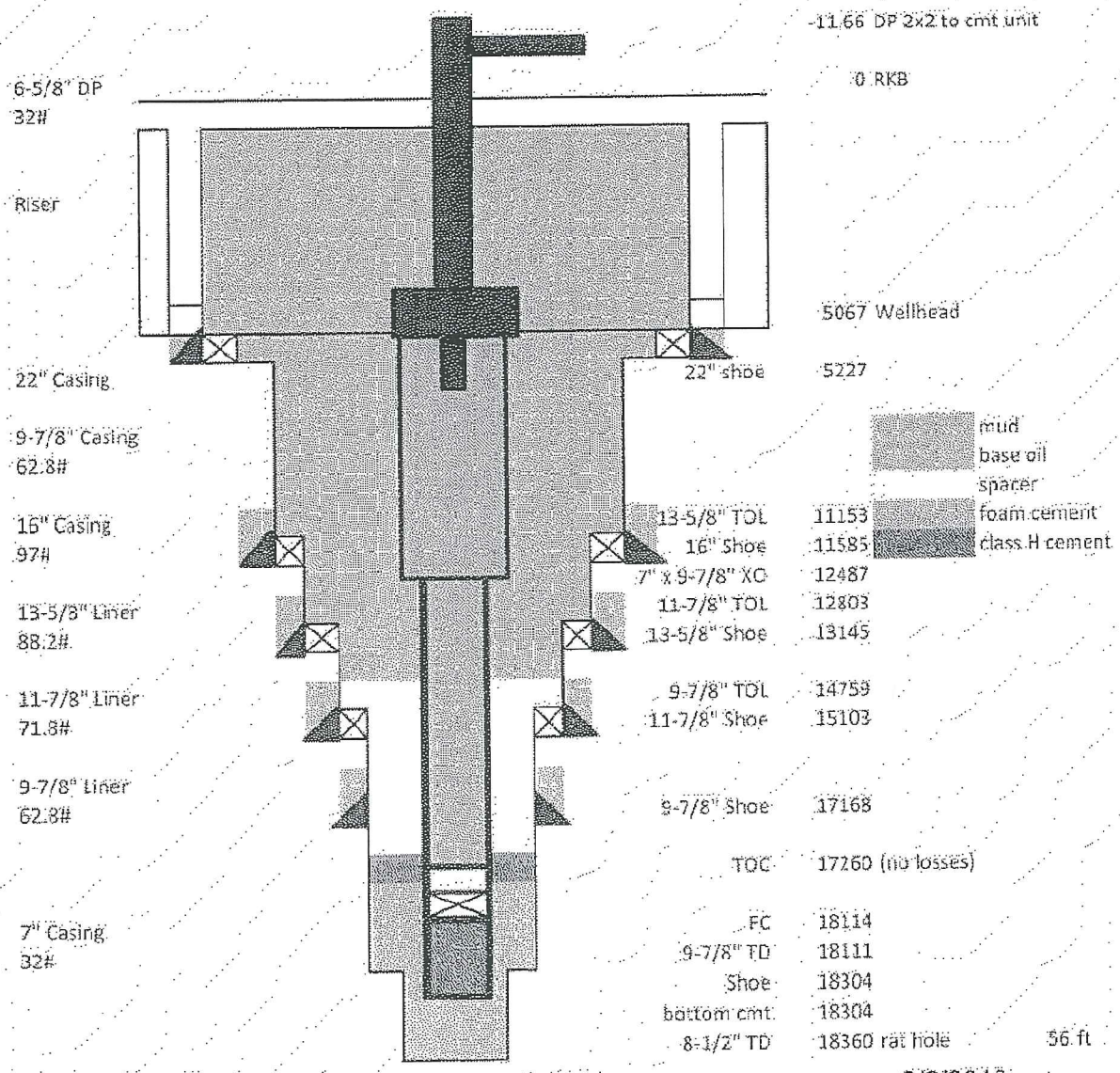
Cement Placement - no losses

These calculations for fluid depths assume no losses.

based on digital data (3 bbl cement lines)

Sequence		Total Volumes	Vol bbl	losses bbl	net vol bbl
	1	base oil	6.6		
	2	spacer	76		
	3	Class H	5.2	0	5.2
	4	N2 Foam Cmt	49.2	0	49.2
	5	Class H	7.2		
	6	spacer	0		
	7	spacer	21.1		
	8	mud	131.3		
	9	mud	735		

Macondo 7" x 9-7/8" Cement Job (actual)



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Without losses the tops of fluids are:

Annulus		Top	Bottom	Vol	bb/ft	Length	ESD (ppg)	Hydrostatic
	mud	0	14459			14459	14.17	10654
11-7/8" Liner	base oil	14459	14563	6.6	0.064	103	6.7	10690
11-7/8" Liner	spacer	14563	14759	12.5	0.064	196	14.3	10836
9-7/8" Liner	spacer	14759	17168	59.4	0.025	2409	14.3	12628
9-7/8" OH	spacer	17168	17260	4.1	0.044	92	14.3	12696
9-7/8" OH	class H	17260	17365	5.2	0.050	105	16.7	12787
9-7/8" OH	foam cement	17365	18111	44.4	0.059	746	14.5	13350
8-1/2"OH	foam cement	18111	18295	4.8	0.026	184	14.5	13489
8-1/2"OH	class H	18295	18304	0.2	0.026	9	16.7	13496
8-1/2" OH	mud	18304	18360	4.0	0.072	56	14.17	13538

Inside Casing		Top	Bottom	Vol	Length	ESD (ppg)	Hydrostatic
	mud	0	17568	866.3	17568	14.17	12945
	spacer	17568	18114	20.0	546	14.3	13351
FC		18114	18114				13351
	class H	18114	18304	7.0	190	16.7	13516
Shoe		18304	18304				
						u-tube press	21

annulus volume (cmt bottom to whd)	1109	bbls
btm up vol (shoe to RKB)	2764	bbls

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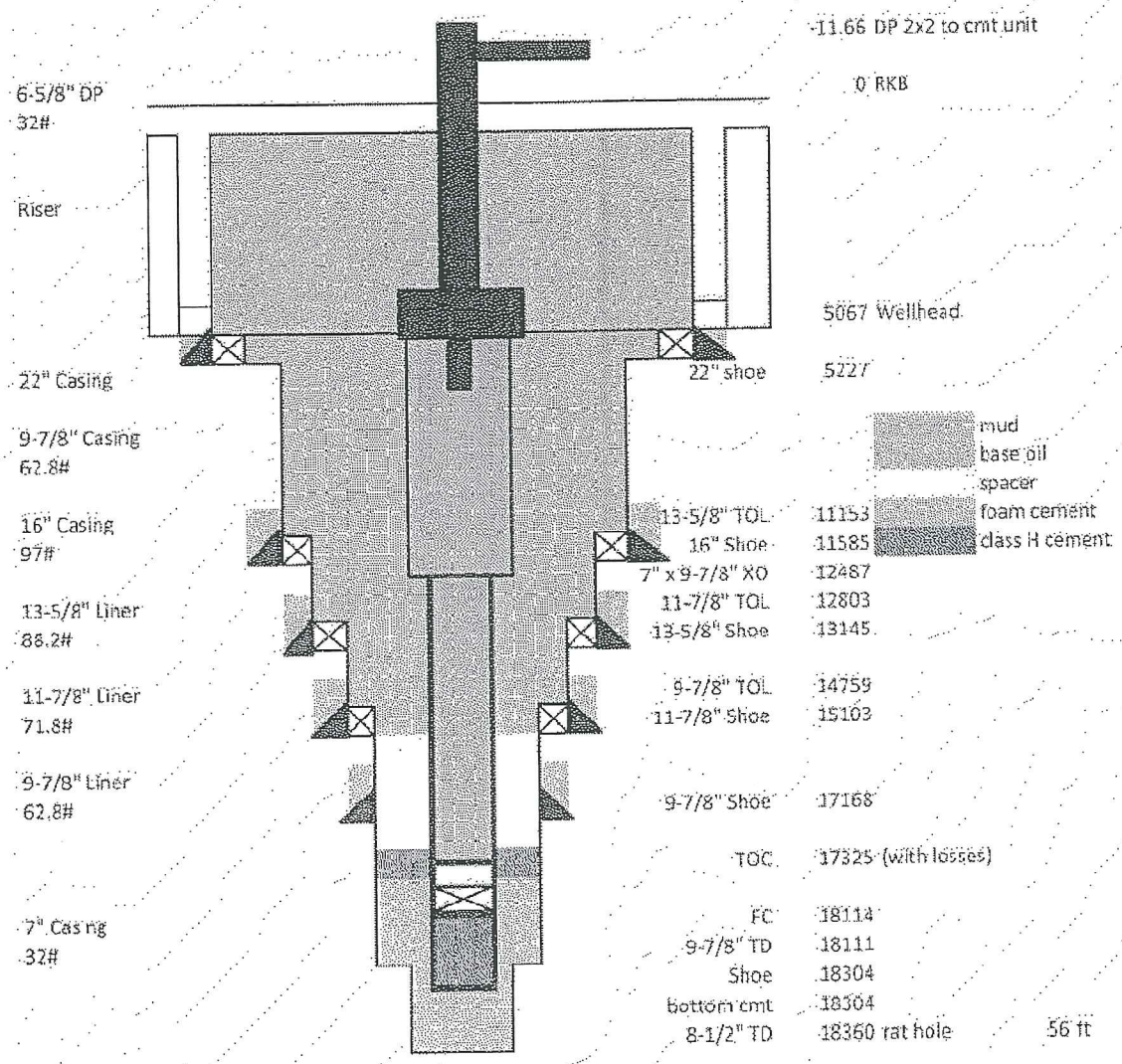
Cement Placement - with losses

3 bbls cement losses were assumed based on pit data.
Note: flow data shows 9.7 bbls in cement losses, however pit data is considered more accurate.

Sequence	Total Volumes	Vol bbl	losses bbl	net vol bbl
1	base oil	6.6		
2	spacer	76		
3	Class H	5.2	0	5.2
4	N2 Foam Cmt	49.2	3	46.2
5	Class H	7.2		
6	spacer	0		
7	spacer	21.1		
8	mud	128.3		
9	mud	735		

Macondo 7" x 9-7/8" Cement Job (actual)



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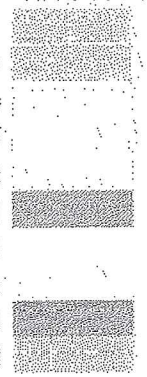
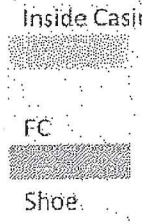
With 3 bbls losses the tops of fluids are:



	Top	Bottom	Vol	bb/ft	Length	ESD (ppg)	Hydrostatic
mud	0	14656			14656	14.17	10799
base oil	14656	14759	6.6	0.064	103	6.7	10835
spacer	14610	14759	9.5	0.064	149	14.3	10946
spacer	14759	17168	59.4	0.025	2409	14.3	12737
spacer	17168	17325	7.1	0.045	157	14.3	12854
class H	17325	17421	5.2	0.054	96	16.7	12937
foam cement	17421	18111	41.4	0.060	690	14.5	13458
foam cement	18111	18295	4.8	0.026	184	14.5	13596
class H	18295	18304	0.2	0.026	9	16.7	13604
mud	18304	18360	4.0	0.072	56	14.17	13646



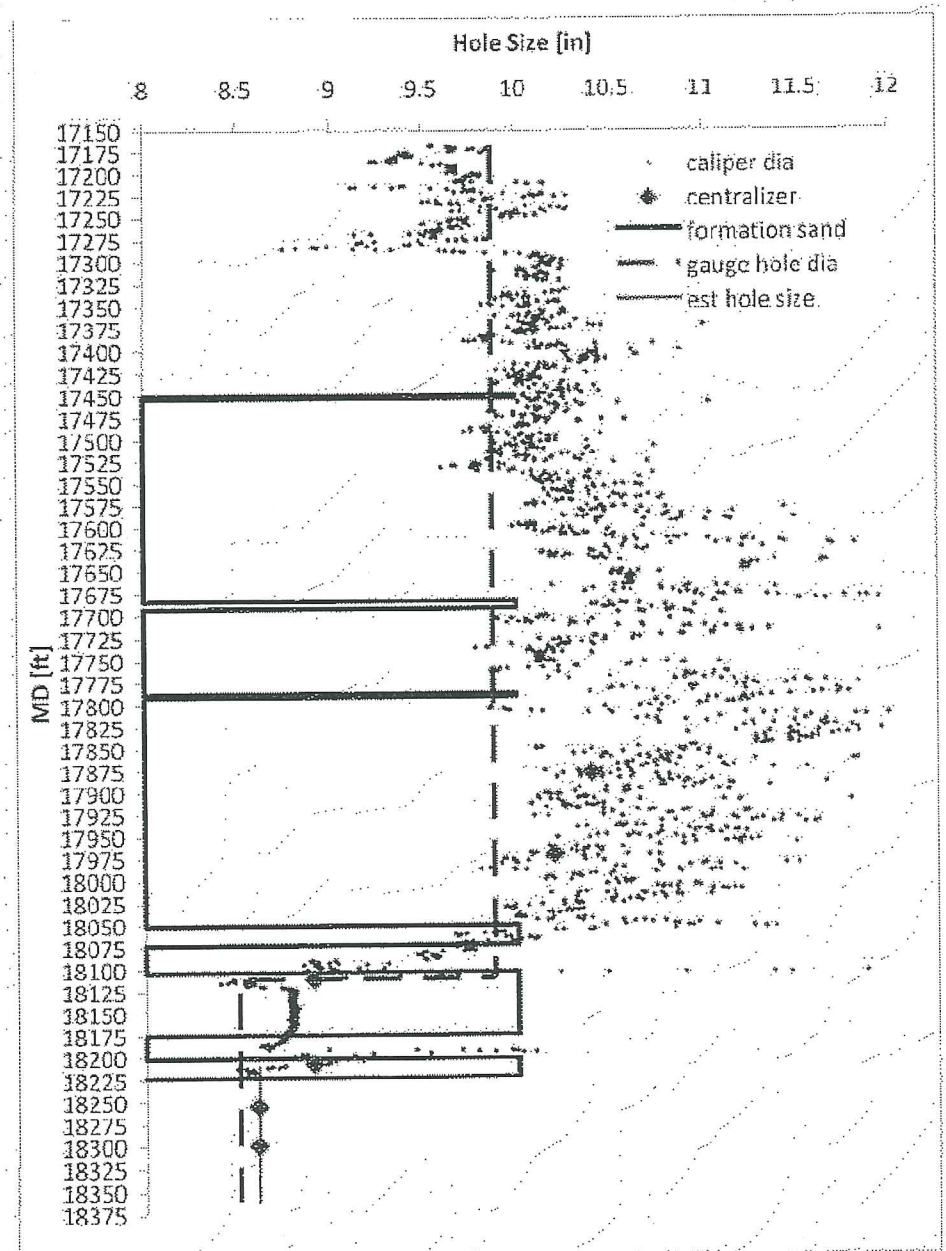
	Top	Bottom	Vol	Length	ESD (ppg)	Hydrostatic
mud	0	17568	863.3	17568	14.17	12945
spacer	17568	18114	20.0	546	14.3	13351
	18114	18114				13351
class H	18114	18304	7.0	190	16.7	13516
	18304	18304				
					u-tube press	129

annulus volume (cmt bottom to whd)	1109	bbls
btm up vol (shoe to RKB)	2764	bbls

Centralizer Placement

Six (6) 10.75" bow spring centralizer subs were run. Emails from the operations team state the centralizers were placed on the bottom of the joints. The following centralizer depths have been estimated based on the tally.

Estimated centralizer mid point			
	C Depth	spacing	OH Caliper
1	18299	5	8.6
2	18255	44	8.6
3	18208	48	8.9
4	18111	97	8.9
5	17972	139	10.2
6	17879	93	10.4



Cement lost returns analysis

Refer to the separate report on called "Cement Lost Returns Analysis_21Jun10.doc" for details.

Bottoms-Up Summary

The volume circulated from the time the floats were converted to the time the top plug was bumped was 1377 bbls, which is greater than the bottoms up required (1109 bbls) to the wellhead. This confirms that any hydrocarbons in the open hole prior to cement operations would have been circulated into the riser above the wellhead.

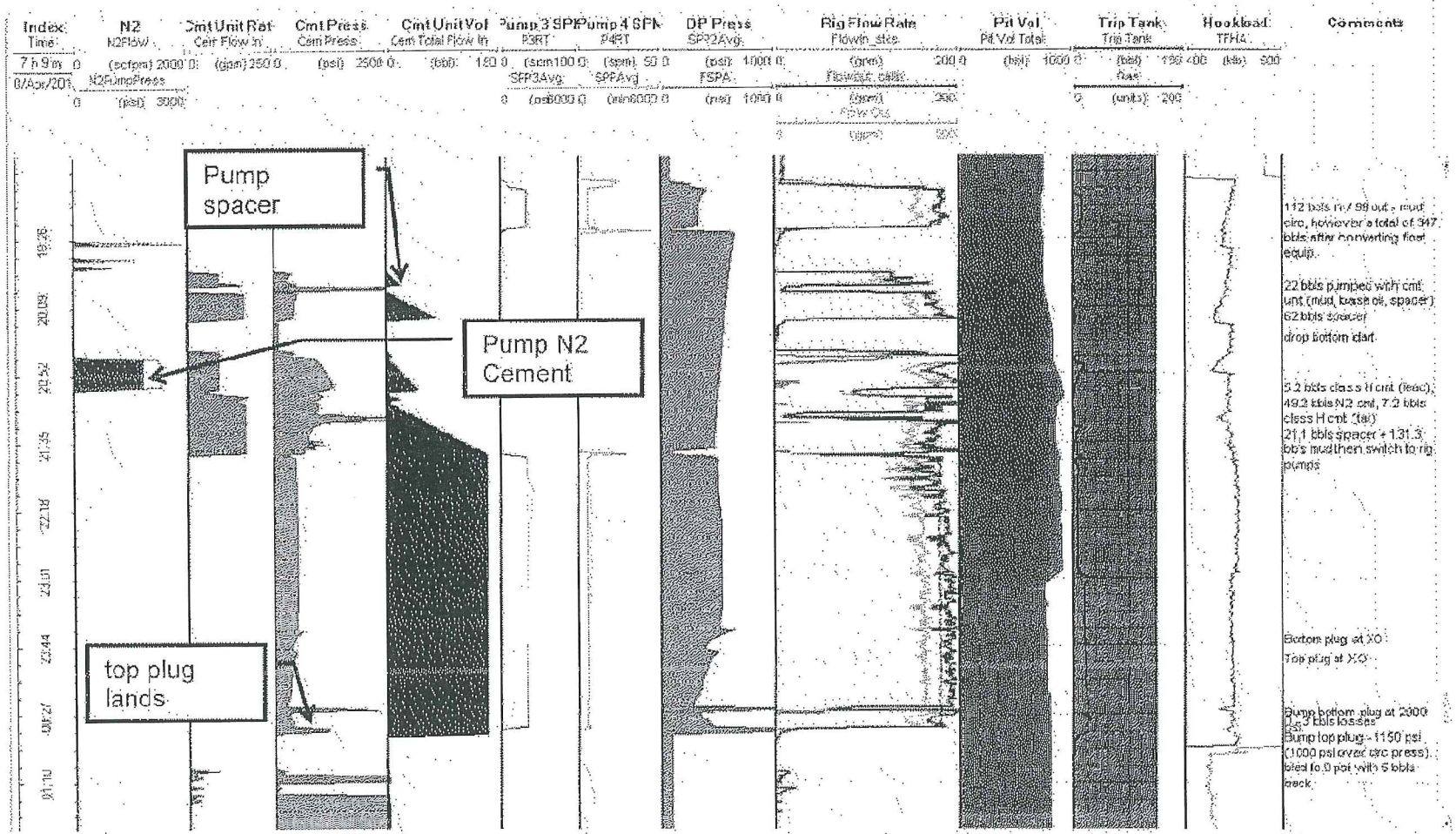
	Vol in (bbls)	time
pre cmt circ	347	16:17 - 19:23
base oil	7	
spacer	76	
cement job	61.4	
spacer	21	21:05 (begin)
displacement	865	00:37:00 (end)
total	1377.4	

Calculated Btms Up Vol	(bbls)
annulus volume (cmt bottom to whd)	1109
btm up vol (shoe to RKB)	2764

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

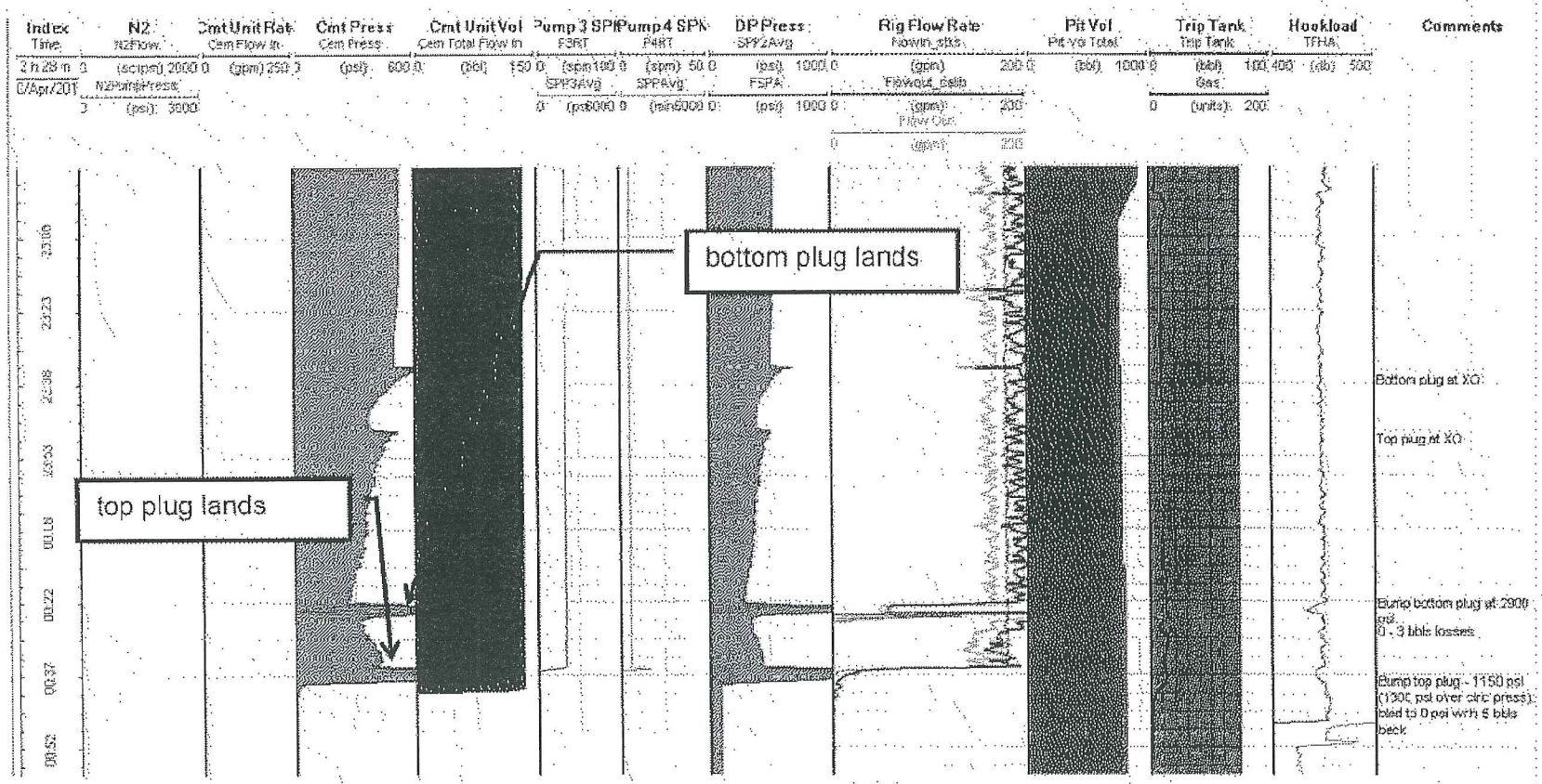
Cement Real Time Mud Log Data

Flowout has been calibrated based on pit data. See the lost returns analysis document for more details.



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

Both plugs bumped at the correct displacements and 5 bbls were bled to the cement unit after checking the floats with 0 psi on the drill pipe. Since there is no digital pit volume data on the cement unit the float check returns cannot be verified.



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

Lift Pressure

Actual lift pressure was 190 psi (232 psi circulating pressure increased to 422 psi). Calculated u-tube pressure was 21 psi. Since the cement and mud weights are very close (14.5ppg cement vs 14.17 ppg MW) lift pressure is not a good indication of channeling or losses. The pumps were never slowed prior to landing the top plug therefore the lift pressure will largely measure frictional pressure increases at 4 bpm due to N2 cement vs spacer rheology differences.