Ultra-Lightweight Cement

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Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report includes results from laboratory testing of ULHS systems along with other lightweight cement systems, including foamed and sodium silicate slurries. During this project quarter, a comparison study of the three cement systems examined the effect that cement drillout has on the three cement systems. Testing to determine the effect of pressure cycling on the shear bond properties of the cement systems was also conducted. This report discusses testing that will be performed for analyzing the alkali-silica reactivity of ULHS in cement slurries, as well as the results of Field Tests 1 and 2.

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Corrigendum

One of the cement types used in the project's tests has been inaccurately referred to as Class A in previous quarterly progress reports. The cement is actually Type I cement. Although Class A and Type I cements are very similar, they are different cements.

In previous progress reports, the "Class A" designation should be replaced with "Type I" when used to describe the cement being tested.

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The setting of cement in place serves three important functions: (1) it supports the casing in the hole, (2) it isolates various formations from one another, and (3) it controls fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required (1) to limit hydrostatic pressure on the formation, and (2) to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of the need for expensive remedial treatments. Lost circulation most commonly occurs in the upper sections of the well, where surface and intermediate casings are installed. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are low.

The minimum density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry's stability and set cement's strength and permeability are only marginally acceptable. Adding water to reduce the density of these conventional cements is impractical because additional water dilutes the cement, causing low strength and high permeability. Low temperatures, such as those in the upper well sections, delay strength development. To obtain a lower cement density or greater cement strength, ultra-lightweight materials must be mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water.

This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field testing.

Executive Summary

Laboratory testing during the eighth quarter was a continuation and extension of testing conducted previously. Tests were performed for comparing the performance of slurries containing ULHS to that of foamed and sodium silicate cement systems. Comparison studies examined shear bond strength after pressure-cycling conditions.

Two field tests were designed and conducted to test the slurry's performance in actual formations. The first field test was designed to ensure that the slurry could be easily blended, mixed, and pumped on location, in actual wells with little trouble. The second field test was designed to test the slurry's performance in a land-based well that closely resembled deepwater operations.

This report provides the following information:

- Field testing results
- Cement Quality –Control Program and QC program data (Appendix A)
- Description of the completed cement slurry software program used to calculate the amount of ULHS needed for specific densities
- Alkali-Silica Reactivity Testing description and procedures (Appendix E)
- On-Site Testing Summary of DOE Field Job 2 (Appendix B) and the Cement Testing Report for Field Job 2 (Appendix C)
- Preliminary Halliburton Job Recommendations (Appendix D)

Field Testing Result

The second field test was performed in the Rocky Mountains in a well operated by the DOE and Rocky Mountain Oilfield Testing Center (RMOTC) in Wyoming. The second field test well conditions were 5,765 ft TD, with a static temperature of 200°F and a bottomhole circulating temperature of 130°F. The previous well had been cemented with foam cement. These wells typically have problems with lost circulation and require high-strength cement and good zone isolation. This well required one hundred barrels of the ultra-lightweight cement slurry (using 3M 6K ULHS beads). The slurry was mixed and pumped with no problems, and the ULHS beads showed no breakage after one hour of conditioning at the surface. Complete fluid returns were observed during the entire cementing job. This was verified through density measurements every ten minutes. Tables 1 through 4 in Appendix B provide collected data.

Ultrasonic logs performed on the well after the cement operation showed good bonding to both pipe and formation (Fig. 1). In Figure 1, the callout entitled Good Pipe Bond shows that the amplitude of the ring of the pipe was very low indicating good coupling of the pipe. The second callout, Good Formation Bond, provides an estimation of the quality of the cement bond to the formation. In this case, the variable formation signal indicates a good cement formation bond. The third callout, High Impedence, High Compressive Strength, Good Bond, indicates that the impedance values of the cement measured were high as evidenced by the dark color (the darker the color, the higher the cement strength).

Figure 1—CBL and ultrasonic log for 10 lb/gal ULHS slurry

A summary of the field test parameters and results for Field Test 2 is shown in Table 1.

Table 1—Field Test 2 Parameters and Results	
County	Natrona County, Wyoming
TD	5,765 ft
Hole Size	8 3/4 in.
Production Casing	7 in.
Slurry Density	10 lb/gal
Lead Cement	ULHS w/ TXI Lightweight
Tail Cement	TXI Lightweight
Static Temperature	200°F
Bottomhole Circulating Temperature	130°F

Software Program

To assist in designing cement slurries made with ULHS, a software program was developed to calculate the amount of ULHS beads required for specific densities. The program does not simulate cement jobs and fluid dynamics. Instead, the program focuses on the static final placement of the fluids (i.e., the slurry composition and slurry properties such as yield and density).

The software program uses an inputted water requirement to calculate the amount of beads needed in the slurry.

The program has been distributed to the project participants. Fig. 2 through Fig. 5 show the screens included in the program interface.

Cement Slurry
File Edit View Window

Data File - C:\MEI\Cement Slurry\test1.cs1

Well and Other Data Lead Cement and Additives Tail Cement and Additives

By Length By Volume

Last Casing ID: 10.000 in
 Last Casing Depth: 400.0 ft
 Current Casing OD: 7.000 in
 Open Hole Diameter: 8.000 in
 Excess Annular Volume: 10.0 %
 Total Well Depth (M/D): 4466.0 ft
 Length of Spacer: 600.0 ft
 Length of Lead Cement: 1999.9 ft
 Length of Tail Cement: 1620.3 ft
 Mud Density: 10.00 ppg
 Spacer Density: 12.00 ppg

Figure 2—General well information

Cement Slurry
File Edit View Window

Data File - C:\MEI\Cement Slurry\test1.cs1

Well and Other Data **Lead Cement and Additives** Tail Cement and Additives

Lead Cement

Pressure at Bottom of Lead Cement: 1542.2 psi Cement: Class H
 ULHS Type: 8K Water Requirement: 4.29 gal/sk
 ULHS Specific Gravity: 0.460 Specific Gravity: 3.15
 Target Slurry Density: 10.00 ppg Sack Weight: 94 lb/sk

Additives	Name	Concentration	Units	Specific Gravity	Water Requirement
1					
2					
3					
4					

Insert Delete

Figure 3—Lead cement parameters

Cement Slurry
File Edit View Window

Data File - C:\MEI\Cement Slurry\test1.cs1

Well and Other Data Lead Cement and Additives **Tail Cement and Additives**

Tail Cement

Pressure at Bottom of Tail Cement: 2384.7 psi Cement: TX Lightweight

ULHS Type: 6K Water Requirement: 5.45 gal/sk

ULHS Specific Gravity: 0.460 Specific Gravity: 2.8

Target Slurry Density: 10.00 ppg Sack Weight: 75 lb/sk

Additives	Name	Concentration	Units	Specific Gravity	Water Requirement
1	HR-5	0.30	%bwoc	1.60	
2	Bentonite	6.00	%bwoc	2.65	0.690
3	Holod-14	1.19	%bwoc	1.31	
4	D-Air-1	0.10	%bwoc	1.35	

Insert Delete

Figure 4—Tail cement parameters

Cement Slurry
File Edit View Window

Output

Lead Cement

ULHS Concentration: 30.10 %bwoc

Target Density: 10.00 ppg

Water Requirement: 7.69 gal/sk

Yield of Slurry: 2.49 #3/sk

Tail Cement

ULHS Concentration: 23.10 %bwoc

Target Density: 10.00 ppg

Water Requirement: 10.63 gal/sk

Yield of Slurry: 2.50 #3/sk

Depth of Mud: 245.8 ft

Figure 5—Output screen containing job design requirements

Alkali-Silica Testing

Approval was made for a continuation of the current cooperative agreement with DOE. This agreement consisted of a new task to study the long-term effects of the Alkali-Silica Reaction (ASR) in ULHS cements. The goal of this task is to determine procedures and methods from the construction industry that are applicable to oil well cements, and conduct long-term tests to verify if ASR is occurring and when and how it manifests itself. Appendix D provides the proposed testing program.

Conclusions

1. A field job was successfully completed using the ULHS in Natrona County, Wyoming.
2. Ultrasonic and sonic logs performed on the well after the cement operation showed good cement bond to pipe, good cement bond to formation, and high compressive strengths.
3. A computer program was developed to assist in slurry design of ULHS cement systems.
4. A recommended procedure and testing protocol was developed for Alkali-Silica Reactivity of ULHS slurries.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
CaCl₂—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H₂O—chemical formula for water
hr—hour
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
OD—outer diameter
psi—pound per square inch
rev—revolution
rpm—revolutions per minute
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. API Recommended Practice 10B: “Recommended Practices for Testing Well Cements,” 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.

Appendix A—Quality Control Testing

Class A

TXI Provided Information		CSI Information			CSI Thickening Time						Pass/ Fail
Cmt Class	Mill Production Run Date	Date Received	CSI Log #	Bucket Opened	Test Date	% H ₂ O	Sch #	Int Bc	15'-30' Bc	100 Bc	
Type I	9/25 to 9/27/00	11/06/00	C-113 A-1	11/09/00	11/15/00	46.0	4	9	10	2:17	Pass
Type I	9/25 to 9/27/00	11/06/00	C-113 A-2	11/20/00	01/05/01	46.0	4	8	11	2:21	Pass
Type I	9/25 to 9/27/00	11/06/00	C-113 A-3	12/04/00	01/09/01	46.0	4	4	ran	out	of sample
Type I	9/25 to 9/27/00	11/06/00	C-113 A-4	01/09/01	01/17/01	46.0	4	4	6	2:09	Pass
Type I	9/25 to 9/27/00	11/06/00	C-189-A-8	07/11/01	08/15/01	46.0	4	6	8	1:50	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-17	08/30/01	09/12/01	46.0	4	6	8	2:00	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-6	10/16/01	10/16/01	46.0	4	7	11	1:41	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-6	10/16/01	11/13/01	46.0	4	7	13	1:53	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-6	10/16/01	12/21/01	46.0	4	6	11	1:46	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-11	01/17/02	01/14/02	46.0	4	8	15	1:42	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-12	02/17/02	02/11/02	46.0	4	15	17	1:40	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-13	02/28/02	03/04/02	46.0	4	14	12	2:10	Pass
Type I	9/25-9/27/00	11/06/00	C-189-A-14	03/27/02	04/02/02	46.0	4	21	19	1:46	Pass
Type I	4/19-4/21/02	05/02/02	C-418-A	05/02/02	05/03/02	46.0	4	27	28	2:15	Pass
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	06/25/02	46.0	4	32	30	2:00	Pass
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	07/24/02	46.0	4	29	28	1:59	Pass
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	08/08/02	46.0	4	29	28	1:57	Pass
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	09/24/02	46.0	4	29	28	1:59	Pass

Lightweight

TXI Provided Information			CSI Information				CSI Thickening Time						
Cmt	Mill Production		Date	CSI	Bucket	Test	%	Sch	Int	70	100	Pass/	
Class	Run Date	Grind	Received	Log #	Opened	Date	H ₂ O	#	Bc	Bc	Bc	Fail	
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-1	11/07/00	11/15/00	75.0	5	6	2:02	2:20		
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-2	12/05/00	01/05/01	75.0	5	5	2:00	2:17		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-12	07/03/01	08/14/01	75.0	5	7	2:03	2:22		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-7	09/05/01	09/10/01	75.0	5	6	1:57	2:17		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-14	09/24/01	10/16/01	75.0	5	4	2:07	2:26		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-14	09/24/01	11/13/01	75.0	5	5	2:05	2:25		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-14	09/24/01	12/21/01	75.0	5	7	2:03	2:22		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-13	12/04/01	01/11/02	75.0	5	8	1:58	2:12		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-15	01/22/02	02/08/02	75.0	5	7	2:05	2:15		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	03/04/02	75.0	5	13	2:11	2:27		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	04/09/02	75.0	5	23	1:54	2:16		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-16	05/15/02	05/16/02	75.0	5	19	2:00	2:12		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	06/26/02	75.0	5	24	1:53	2:10		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	07/26/02	75.0	5	23	1:59	2:09		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	08/22/02	75.0	5	23	2:05	2:15		
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	09/12/02	75.0	5	23	2:00	2:10		

Class H

TXI Information				CSI Information				CSI Thickening Time						CSI 8hr				CSI 8hr Strengths					
Cmt Class	Prod. Date	Date Received	CSI Log #	Date Bucket Opened	Test Date	% H ₂ O	Sch #	Int	Bc	out	of sample	Pass/Fail	Time Hrs	Temp °F	Old	Str psi	Pass/Fail	Time Hrs	Temp °F	Old	Str psi	Pass/Fail	
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	38.0	5	15	20	13	2:03	Fail	8	100	335	524	Pass	8	140	1334	2087.71	Pass	
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/29/00	38.0	5	12	13	13	1:54	Pass	8	100	307	480	Pass	8	140	1437	2248.91	Pass	
H	9/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	38.0	5	7	13	13	1:54	Pass	8	100	768	1201.92	Pass	8	140	1255	1964.08	Pass	
H	9/27/00	11/06/00	C-108 A-2	11/06/00	01/12/01	38.0	5						8	100	664	1039.16	Pass	8	140	1122	1755.93	Pass	
H	9/27/00	11/06/00	C-108 A-2	11/06/00	02/12/01								8	100	271	424	Pass	8	140	1097	1716.81	Pass	
H	9/27/00	11/06/00	C-108 A-1	11/06/00	02/22/01													8	140		1617	Pass	
H	9/27/00	11/06/00	C-108 A-3	02/22/01	02/22/01													8	140		1567	Pass	
H	9/27/00	11/06/00	C-108 A-1	11/06/00	02/22/01													8	140		1550	Pass	
H	9/27/00	11/06/00	C-108 A-3	02/22/01	02/22/01													8	140		1580	Pass	
H	9/27/00	11/06/00	C-108 A-6	07/20/01	08/13/01	38.0	5	15	20	17	1:50	Pass											
H	9/27/00	11/06/00	C-108 A-7	08/27/01	09/06/01	38.0	5	19	17	17	2:00	Pass											
H	9/27/00	11/06/00	C-108 A-3	02/22/01	10/09/01	38.0	5	12	15	15	1:53	Pass											
H	9/27/00	11/06/00	C-108 A-3	02/22/01	11/13/01	38.0	5	13	20	20	1:50	Pass											
H	9/27/00	11/06/00	C-108 A-3	02/22/01	12/20/01	38.0	5	14	21	21	1:45	Pass											
H	9/27/00	11/06/00	C-108 A-3	02/22/01	01/11/02	38.0	5	13	17	17	2:00	Pass											
H	9/27/00	11/06/00	C-108 A-8	01/14/02	02/08/02	38.0	5	28	19	19	1:55	Pass											
H	9/27/00	11/06/00	C-108 A-8	01/14/02	03/05/02	38.0	5	18	18	18	1:55	Pass											
H	9/27/00	11/06/00	C-108 A-8	01/14/02	04/04/02	38.0	5	24	27	27	2:00	Pass											
H	9/27/00	11/06/00	C-108 A-8	01/14/02	05/15/02	38.0	5	22	22	22	1:50	Pass											
H	9/27/00	11/06/00	C-108 A-10	06/11/02	06/25/02	38.0	5	26	27	27	1:50	Pass											
H	9/27/00	11/06/00	C-108 A-10	06/11/02	07/25/02	38.0	5	24	28	28	1:49	Pass											
H	9/27/00	11/06/00	C-108 A-10	06/11/02	08/09/02	38.0	5	24	28	28	1:45	Pass											
H	9/27/00	11/06/00	C-108 A-10	06/11/02	09/19/02	38.0	5	24	28	28	1:52	Pass											

Appendix B—On-Site Testing Summary of DOE Field Job #2

A 10 ppg, TXI Lightweight ULHS lead cement slurry was pumped as the lead slurry. The Tail slurry was a 13.5 ppg TXI Lightweight cement slurry mixed with 1% HALAD- 9. As seen in Table1, no changes in rheological properties occurred except for an increase in temperature after the slurry began to mix inside the RCM. The slurry was mixed on the RCM for an hour and rheologies were taken initially every five minutes; but after no change was noticed the sampling time was extended to every 10 minutes. The consistent rheologies indicated that no shearing of ULHS had occurred.

The rheologies shown in Tables 1 through 4 are much lower than the rheologies shown in Halliburton's lab report in Appendix C. We are uncertain of what caused this discrepancy.

Table 1.

Summary of Viscosity Change as a Result of Shearing in RCM												
<u>Lead: TXI Lightweight Cement + 25% ULHS + 0.3% HR-5 + 0.5% HALAD-9 + 7.57gps Water + 0.20%CFR-3</u>												
<u>Time (minutes)</u>	<u>Temperature (°F)</u>	<u>Rheological Properties</u>										
		<u>300</u>	<u>200</u>	<u>100</u>	<u>60</u>	<u>30</u>	<u>20</u>	<u>10</u>	<u>6</u>	<u>3</u>	<u>PV</u>	<u>YP</u>
0	91.7	86	60	34	26	18	14	12	10	10	78	8
5	93.5	100	70	40	28	18	14	12	10	10	90	10
15	93.5	96	64	38	26	18	16	10	10	10	87	9
20	94.1	90	64	40	28	18	14	10	10	8	75	15
30	94.5	92	62	36	24	16	14	10	10	8	84	8
40	94.3	90	62	38	26	18	14	10	10	8	78	12
50	94.2	82	60	36	26	18	14	10	10	8	69	13
60	94.3	86	60	38	26	16	14	10	10	8	72	14

Table 2 below lists the rheological properties of lead slurry sampled in the flow line as it was being pumped into the well. The slurry was pumped at a rate of 4 bpm. The slurries viscosity remained the same as those samples taken from the RCM through the first 10 minutes of sampling.

Table 2

Summary of Viscosity Change as Slurry was Pumped into Well												
<u>Lead: TXI Lightweight Cement + 25% ULHS + 0.3% HR-5 + 0.5% HALAD-9 + 7.57gps Water + 0.20% CFR-3</u>												
<u>Time (minutes)</u>	<u>Temperature (°F)</u>	<u>300</u>	<u>200</u>	<u>100</u>	<u>60</u>	<u>30</u>	<u>20</u>	<u>10</u>	<u>6</u>	<u>3</u>	<u>PV</u>	<u>YP</u>
0	90.1	96	70	42	30	20	20	16	14	14	81	15
5		90	64	36	20	16	14	10	10	8	81	9
10	87.8	72	50	30	22	16	14	10	10	8	63	9
15	90.9	76	42	30	24	16	14	10	10	10	69	7

Pressurized Mud Balance was used during the job to verify density and record any changes that might occur during blending and agitation. Table 3 indicates time required to mix cement and achieve density of 10.0 ppg.

Table 3

Time	Density
16:15	10.6 ppg
16:25	10.1 ppg
16:40	10.0 ppg

Table 4 indicates time in blender agitating prior to pumping slurry downhole.

Table 4.

16:55	9.9 ppg
17:05	10.0 ppg
17:10	10.0 ppg
17:20	10.0 ppg
17:30	10.0 ppg
17:45	10.0 ppg
17:50	10.0 ppg
18:00	10.0 ppg
18:15	10.0 ppg
18:30	10.0 ppg
18:35	10.0 ppg
18:45	10.0 ppg

The cement remained in the blender for 1 hour and 50 minutes prior to pumping without any change in density. Aeration of slurry caused loss of prime to centrifugal pump twice

during agitation period. This is a normal phenomenon when no additive is used to prevent foaming of slurry.

Job Log

Job Log				TICKET # 1953511	TICKET DATE 10/18/02
REGION NORTH AMERICA LAND		NWA / COUNTRY WESTERN		BDA / STATE DENVER, CO		COUNTY NATRONA	
MBU ID / EMPL #		H.E.S. EMPLOYEE NAME		PSL DEPARTMENT ZONAL ISOLATION			
LOCATION CASPER, WY		COMPANY RMOTC		CUSTOMER REP / PHONE CLAUD DICKEY			
TICKET AMOUNT		WELL TYPE		API/UWI #			
WELL LOCATION NATRONA, WY		DEPARTMENT CEMENTING SERVICES 10003		JOB PURPOSE CODE			
LEASE / WELL # DOE		Well No. 41-2-X-3		SEC / TWP / RNG			
Date mo/dy/yr	Time	Rate (bpm)	Volume (bbl)(gal)	N2 Rate (scfm)	Pressure (psi) tbq/csg bkcd		Job Description / Remarks
7-19-02	1400						ARRIVE ON LOCATION
	1420						BLOW OFF CEMENT INTO FIELD BIN
	1500						RIG UP SWEDGE AND CIRCULATE WITH 9.0 PPG MUD
	1545						RIG UP HES EQUIPMENT
	1630						MIX AND CIRCULATE 94 BBLs LEAD CEMENT
	1745						SAFET MEETING WITH RIG CREW
	1800						REMOVE SWEDGE AND STAB PLUG CONATINER
	1823	5			4000		PRESSURE TEST LINES
	1826	5	10		200		PUMP WATER SPACER
	1828	5	20		200		PUMP SUPERFLUSH
	1832	5	10		250		PUMP WATER SPACER
	1835	5	94		250		PUMP LEAD CEMENT 10 PPG 2.11 CUFT/SK 7.57 GAL/SK
	1844	2	27		150		CATCH CEMENT SAMPLE
	1850	2	55		100		CATCH CEMENT SAMPLE
	1855	2	80		150		CATCH CEMENT SAMPLE
	1900	5	119		290		PUMP TAIL CEMENT 13.5 PPG 1.25 CUFT/SK 6.06 GAL/SK
	1922						WASH PUMPS AND LINES
	1923						DROP TOP PLUG
	1924	7	226		90		PUMP DISPLACEMENT

Job Chart

Appendix C—Halliburton Cement Test Report

HALLIBURTON

**CEMENT TEST REPORT
HALLIBURTON ENERGY SERVICES
ROCKY MOUNTAIN NWA LABORATORY
EVANSVILLE, WY**

Date: 19 Jul 02

Report: RMOTC/CSI, C02-0211

To: Brian Carty
- Halliburton Energy Services
- Casper, Wyoming

PURPOSE

The purpose of this work was to determine the thickening times and rheologies of the submitted slurry pilot designs and bulk plant blends using the conditions listed below.

SCOPE AND PROCEDURE

All tests were performed according to modified API Spec 10.
Re: worksheet # 1077, 1078, 1082, 1083

WELL INFORMATION AND TESTING CONDITIONS

Company	-	RMOTC/CSI
Well Name	-	DOE 41-2-X-3
Job Type	-	Casing
District	-	Casper
State	-	Wyoming
Depth	-	5700 feet
BHST	-	200 degrees F
BHCT	-	130 degrees F
BHP	-	3500 psi

Respectfully submitted,

Nancy K. Lang
HALLIBURTON ENERGY SERVICES

CC: Casper Cementing

LEAD PILOT DESIGN #1

TXI Lightweight	#/sk	75.00
ULHS Beads	#/sk	18.75
Halad 9	% bwc	0.50
CFR-3	% bwc	0.20
HR-5	% bwc	0.30

Lab Tap Water	gal/sk	7.57
Slurry Weight	#/gal	10.00
Slurry Volume	ft3/sk	2.11

THICKENING TIME TEST

Initial Viscosity:	13 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	5:28

RHEOLOGY TESTS

RPM	SURF.
600	350
300	216
200	140
100	84

LEAD BULK PLANT BLEND #3

TXI Lightweight	#/sk	75.00
ULHS Beads	#/sk	18.75
Halad 9	% bwc	0.50
CFR-3	% bwc	0.20
HR-5	% bwc	0.30

Submitted Water	gal/sk	7.57
Slurry Weight	#/gal	10.00
Slurry Volume	ft3/sk	2.11

THICKENING TIME TEST

Initial Viscosity:	25 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	6:25

RHEOLOGY TESTS

RPM	SURF.	110 F	130 F
600	460	370	366
300	282	240	228
200	198	160	156
100	110	88	86

TAIL PILOT DESIGN #2

TXI Lightweight	#/sk	75.00
Halad 9	% bwc	1.00
Submitted Water	gal/sk	6.02
Slurry Weight	#/gal	13.50
Slurry Volume	ft3/sk	1.25

THICKENING TIME TEST

Initial Viscosity:	8 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	3:24

RHEOLOGY TESTS

RPM	SURF.
600	214
300	124
200	94
100	60

TAIL BULK PLANT BLEND #4

TXI Lightweight	#/sk	75.00
Halad 9	% bwc	1.00
CFR-3	% bwc	0.40
Submitted Water	gal/sk	6.02
Slurry Weight	#/gal	13.50
Slurry Volume	ft3/sk	1.25

THICKENING TIME TEST

Initial Viscosity:	4 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	3:39

RHEOLOGY TESTS

RPM	SURF.	110 F	130 F
600	154	138	126
300	92	84	80
200	66	60	56
100	40	36	34

This report is based on sound engineering practices, but because of variable well conditions and other information which must be relied upon, Halliburton makes no warranty, express or implied, as to the accuracy of the data or of any calculations or opinions expressed herein. You agree that Halliburton shall not be liable for any loss or damage whether due to negligence or otherwise arising out of or in connection with such data, calculation or opinions.

Appendix D—Preliminary Halliburton Job Recommendations

Appendix D contains the preliminary recommendation received from Halliburton. The well data and slurry composition shown in this appendix are different than what was actually performed on the job. Although this information is preliminary, it provides the details for volume calculations and critical well parameters. In addition, the well number shown below is wrong and should be DOE 41-2-X-3.

HALLIBURTON

Job Information

Tensleep Completion

DOE 25-1-X-14

Surface Casing	0 - 725 ft (MD)
Outer Diameter	9.625 in
Inner Diameter	8.921 in
Linear Weight	36 lb/ft
Casing Grade	J-55
Job Excess	0 %

Tensleep Production Hole	725 - 5900 ft (MD)
Inner Diameter	10.540 in
Job Excess	10 %

Tensleep Production Casing	0 - 5900 ft (MD)
Outer Diameter	7.000 in
Inner Diameter	6.366 in
Linear Weight	23 lb/ft
Casing Grade	J-55
Job Excess	0 %

Mud Weight	0 lbm/gal
BHCT	0 degF

Calculations**Tensleep Completion**

Spacer:		
151.00 ft * 0.3387 ft ³ /ft * 10 %	= 56.25 ft ³	
Total Spacer	= 56.15 ft ³	
	= 10.00 bbl	
Spacer:		
301.00 ft * 0.3387 ft ³ /ft * 10 %	= 112.13 ft ³	
Total Spacer	= 112.29 ft ³	
	= 20.00 bbl	
Spacer:		
151.00 ft * 0.3387 ft ³ /ft * 10 %	= 56.25 ft ³	
Total Spacer	= 56.15 ft ³	
	= 10.00 bbl	
Cement : (1515.00 ft fill)		
1515.00 ft * 0.3387 ft ³ /ft * 10 %	= 564.37 ft ³	
Total Lead Cement	= 564.37 ft ³	
	= 100.52 bbl	
Sacks of Cement	= 270 sks	
Cement : (1748.00 ft fill)		
1748.00 ft * 0.3387 ft ³ /ft * 10 %	= 651.17 ft ³	
Tail Cement	= 651.17 ft ³	
	= 115.98 bbl	
Shoe Joint Volume: (44.00 ft fill)		
44.00 ft * 0.221 ft ³ /ft	= 9.73 ft ³	
	= 1.73 bbl	
Tail plus shoe joint	= 660.90 ft ³	
	= 117.71 bbl	
Total Tail	= 530 sks	
Total Pipe Capacity:		
5900.00 ft * 0.221 ft ³ /ft	= 1304.11 ft ³	
	= 232.27 bbl	
Displacement Volume to Shoe Joint:		
Capacity of Pipe - Shoe Joint	= 232.27 bbl - 1.73 bbl	
	= 230.54 bbl	

Job Recommendation**Tensleep Completion**

Fluid Instructions

Fluid 1: Water Spacer

Water Spacer

Fluid Density: 8.34 lbm/gal

Fluid Volume: 10 bbl

Fluid 2: Spacer Sweep

Super Flush

42 lbm/bbl Fresh Water (Base Fluid)

Fluid Density: 9.20 lbm/gal

Fluid Volume: 20 bbl

Fluid 3: Water Spacer

Water Spacer

Fluid Density: 8.34 lbm/gal

Fluid Volume: 10 bbl

Fluid 4: Lead Cement

TXI Lightweight

75 lbm/sk TXI Lightweight (Cement-api)
25 % Spherelite (Light Weight Additive)
0.2 % Halad(R)-9 (Low Fluid Loss Control)

Fluid Weight 10 lbm/gal

Slurry Yield: 2.09 ft³/sk

Total Mixing Fluid: 7.57 Gal/sk

Top of Fluid: 2637 ft

Calculated Fill: 1515 ft

Volume: 100.51 bbl

Calculated Sacks: 270 sks

Proposed Sacks: 270 sks

Fluid 5: Tail Cement

TXI Lightweight

75 lbm/sk TXI Lightweight (Cement-api)
0.2 % Halad(R)-9 (Low Fluid Loss Control)

Fluid Weight 13.50 lbm/gal

Slurry Yield: 1.25 ft³/sk

Total Mixing Fluid: 6.10 Gal/sk

Top of Fluid: 4152 ft

Calculated Fill: 1748 ft

Volume: 117.71 bbl

Calculated Sacks: 530 sks

Proposed Sacks: 530 sks

Fluid 6: Water Spacer

Fresh Water Displacement

Fluid Density: 8.34 lbm/gal

Fluid Volume: 230.54 bbl

The Cement and Hollow Beads will be Customer Supplied.

Appendix E—Alkali-Silica Reactivity (ASR) Testing

Objective

The goals of this project are to study the long-term effects of the alkali-silica reaction in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR.

Alkali-silica reactivity (ASR) is a chemical reaction that occurs between alkali and reactive silica present in cement and concrete mixes. When this reaction occurs, a gel is formed that absorbs available water and increases internal pressure, eventually causing the cement to fracture. This fracturing renders the cement vulnerable to several hazardous materials that can severally weaken the structure of the cement matrix causing it to fail.

Testing Procedures

A variation of the Length Change of Hardened Hydraulic-Cement Mortar and Concrete (ASTM C157-93) methods was used to test expansion in the slurries. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496-90) methods were used to determine a change in the tensile strength of specimens as a result of ASR. A tensile strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and 6 months. For statistical purposes, nine replicates of each slurry are made.

Test Slurry Composition

As a baseline for testing, neat Class H cement with a density of 16.4 lb/gal and TXI Lightweight cement with a density of 13.5 lb/gal will be used. Ultra-light hollow sphere (ULHS) slurries with similar bead concentrations and a density of 9.0 lb/gal will also be used. Several 0.5% sodium chloride slurries will be used to evaluate accelerated ASR.

Neat Slurries (Baseline)

- Class H cement mixed with 4.3 gal of fresh water per sack to achieve a density of 16.4 lb/gal
- TXI Lightweight cement mixed with 6.0 gal of fresh water per sack to achieve a density of 13.5 lb/gal

Ultra-Light Hollow Sphere (ULHS) Slurries

- Class H cement plus 42.14% BWOC 3M 6K (6,000 psi) beads mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal

- TXI Lightweight cement plus 37.19% BWOC 3M 6K (6,000 psi) beads mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Salt Slurries

- Class H cement plus 0.5% BWOC NaCl mixed with 4.3 gallons of fresh water sack for a density of 16.4 lb/gal
- TXI Lightweight cement plus 0.5% BWOC NaCl mixed with 6.0 gallons of fresh water per sack for a density of 13.5 lb/gal
- Class H cement with 42.14% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal
- TXI Lightweight cement with 37.19% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Testing Conditions

- Application No. 3 – 128°F / 174°F (BHCT/BHST)
- Slurries were tested for a minimum of 200 days.

Mixing Procedures

Prepare a ULHS slurry as follows.

1. Weigh the appropriate amounts of the cement sample, additives, water, and ULHS into separate containers.
2. Mix the cement slurry according to Appendix A of API RP 10B.
3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.
4. Place this slurry in a Waring blender and mix at 4,000 rpm for 15 seconds. Then, return each specimen to lime-saturated water.

Alkali-Silica Reactivity (ASR) Testing for Expansion

Curing the Specimens

One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made. Cure each test specimen in a heated, circulating water bath containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
 - Never strike or jar a specimen during removal.
 - Never exert pressure directly against the gage studs.
 - Make sure the gage stud holder remains attached to the stud during specimen removal.

Important—To avoid damaging the specimens during removal from the molds, it may be necessary to leave the specimens in the molds for more than 24 hours. This is especially true for certain slow-hardening cements. If the curing schedule must be extended, make sure that the same curing time is used for all other specimen to be compared, and that all comparison specimens are within $\pm 1/2$ hour of the same age at the time the initial comparator reading is performed.

2. Mark specimens for identification or positioning as required with a soft graphite pencil, a graphite liquid that deposits graphite without binder, or waterproof, indelible ink. Never use any other writing instrument.
3. Place the specimens in lime-saturated water maintained at $73.4 \pm ^\circ\text{F}$ ($23.0 \pm 0.5^\circ\text{C}$) for a minimum of 15 min. This helps minimize variation in length measurements due to variation in temperature of the specimens.
4. When the specimens are $24 \pm 1/2$ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and immediately take a comparator reading. Then, return each specimen in lime-saturated water.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, ± 300 mg/L.

Apparatus

Molds for cement specimen curing have one section and are constructed as shown in Fig. 6. Molds for test specimens used in determining the length change of cement pastes and mortars produce $1 \times 1 \times 11 \frac{1}{4}$ -in. prisms with a 10-in. gage length. The gage length is the nominal length between the innermost ends of the gage studs. The parts of the molds should fit tightly and firmly together when assembled, and their surfaces should be smooth and free of pits.

The molds are made of steel not readily attacked by the cement paste, mortar, or concrete. The sides of the molds should be sufficiently rigid to prevent spreading or warping. For the molds shown in Fig. 6, the tolerance on dimension A is ± 0.03 in. Each end plate of the mold is equipped to hold properly in place during the setting period.

The gage studs are of American Iron and Steel Institute (AISI) 3 Type 316 stainless steel. To prevent restraint of the gage studs before the specimen is removed, the device for holding the gage studs in position is arranged such that it can be partially or completely released after the slurry compacts in the mold. The gage studs are set so their principal axes coincide with the principal axis of the test specimen. For the molds shown in Fig. D-1, gage studs extend into the specimen 0.625 ± 0.025 in. and the distance between the inner ends of the gage studs is 10.00 ± 0.10 in.. Ten inches is the gage length for calculating length change.

Test Measurement

The comparator for the molds shown in Fig. D-1 features a dial micrometer or other measuring device graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at

least 0.3 in.) in the measuring device to allow for small variations in the actual length of specimens. The terminals of the comparator are plane, polished, and heat-treated, and are fitted with collars held in place with set screws. The collars extend 0.062 ± 0.003 in. beyond the plane face of the terminal and have an inside diameter 0.02 in. greater than the average diameter of the portion of the gage studs that must fit into the collars.

The comparator must allow the checking of the measuring device against a reference bar at regular intervals. The reference bar has an overall length of $11 \frac{5}{8} \pm \frac{1}{8}$ in. for the specimen in use. The bar is made of a steel alloy with a coefficient of thermal expansion not greater than two millionths per degree Celsius. Each end of the reference bar is fitted with heat-treated, hardened, and polished tips machined to the same shape as the contact end of the gage studs used in test specimens.

Reference Bar

Place the reference bar (Fig. D-2) in the instrument in the same position each time a comparator reading is taken. Check the dial gage setting of the measuring device by taking a comparator reading of the reference bar at least at the beginning and end of a series of specimen readings to span no more than a half-day, provided the apparatus is kept in a room maintained at constant temperature.

To obtain a comparator reading, perform the following steps.

1. Clean the hole in the base of the comparator into which the gage stud on the lower end of the bar fits.
2. Read and record the comparator indication of the length of the reference bar.
3. Take one bar out of immersion, blot the pins, place the bar in the comparator, read, and record the indication.
4. Return the bar to immersion and clean the hole in the base of the comparator.
5. Repeat the procedure with second and subsequent bars until all bars have been read, returned to immersion, and the readings recorded.
6. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar indication. Blot only around the pins.

Calculate the specimen length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} \times 100$$

Where:

L = change in length at x age, %

L_x = comparator reading of specimen at x age minus comparator reading of reference bar at x age;

L_i = initial comparator reading of specimen minus comparator reading of reference bar at that same time

G = nominal gage length, 10 in.

Figure D-1—Test specimen mold schematics

Figure D-2—Reference bar

Alkali-Silica Reactivity (ASR) Testing for Tensile Strength

The testing method used is similar to that described in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the slurry is placed in a 1.5 × 5-in. mold sealed at both ends.

Curing the Cement Specimens

One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made.

Prepare the molds as follows.

1. Place slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Stir the remaining slurry by hand and place into additional molds and repuddle it.

3. Seal the molds and place them upright in a heated, circulating water bath at the appropriate curing temperature.
4. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.

Important—To avoid damaging the specimen during removal, it may be necessary to leave specimens in the molds for more than 24 hours. This is especially true for certain slow-hardening cements. If the curing schedule must be extended, make sure that the same curing time is used for all other specimen to be compared, and that all comparison specimen are within $\pm 1/2$ hour of the same age at the time the initial comparator reading is performed.

Test Measurement

After curing, the sample is extracted from the mold and cut into 1-in. $\pm 1/8$ in. sections in length. The density of each sample is measured before it is measured for tensile strength.

A 1/4-in. section of the top surface of the sample is cut first. Next, the three 1-in. sections to be measured are cut. Each 1-in. $\pm 1/8$ in. section is identified as top, middle, and bottom and is measured for tensile strength in the test machine. The remaining sample pieces are discarded. Fig. D-3 shows a general schematic of how each specimen is oriented on its side during testing. The force applied to the specimens is automatically controlled and applied at a constant rate of approximately 0.025mm/hr. This testing is carried out at Westport Technology Center.

Figure D-3—Tensile strength Crush Diagram