VARIATIONS IN CEMENT SLURRY CHARACTERISTICS

OF LIQUID ADDITIVES

by

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ABSTRACT

For nearly 50 years, admixtures of 50:50 Class H (or Class C): Pozzalon with 2% bentonite have functioned effectively worldwide as lightweight slurries for situations where heavier completion cements posed a risk of exceeding low fracture gradients in a particular wellbore. Pozzolanic materials are lightweight, and effectively combine with the calcium hydroxide that is liberated during the hydration of Portland cement. Historically, the 2% bentonite has been utilized to assist in the specification of relatively high water-to cement ratios, and therefore lighter slurry density, without the generation of excessive free water as the cement progresses though the setting process.

Though Bentonite has fulfilled the role quite well, it has two disadvantages: first, its presence in typical cement slurries reduces the effectiveness of a given concentration of most commercially available fluid loss additives. Second, while the 2% (by weight of cement) volume may seem of no consequence, the shipping costs associated with moving tons of the material over a long period of time can be significant.

A project was undertaken to determine whether or not there were other commercially available materials that could substitute for bentonite and yield improved slurry qualities at the same or reduced cost. Extensive testing of 50:50 slurries revealed that small quantities of sodium metasilicate (on the order of 0.5% by weight of cement) could effectively replace bentonite. Free water was controlled to the same degree, and a synergy with a commonly available fluid loss additive was discovered, allowing either a) less total fluid loss additive for a given fluid loss control tolerance, or, b) better fluid loss control for a given concentration of fluid loss additive.

CHAPTER I

INTRODUCTION

Bentonite has been used as an extender for years in the oil service industry. In recent years it has become of great concern to look into better quality control, cost savings, superior slurry performance, improved handling and logistics that could improve operations and generate savings.

In the industry today, the 50:50 Class H (or Class C): Pozzalon with 2% bentonite has been used predominantly for the control of excessive free water in cement systems. However, there has been the problem of bentonite reducing the effectiveness of fluid loss additives and the cost of having to transport this material to site has been a reason to look at better options or a substitute. The ability to control free water has been a major concern in the industry, especially with the Class H cement which has an inherent free water problem at higher water ratios. This project attempted to control free water in both class H and C, and also increase the functionality of fluid loss for given concentrations of additives.

More than ever before, increasing environmental concern is causing the industry to look for ways of minimizing the environmental impact of their operations. Waste disposal of unused cement is increasingly becoming the greatest limitation of the dry-additive blending system. Complete elimination of unused waste, as well as improved concentration tolerances of liquid additives systems through the development of closed-loop processes is making liquid-additive cement systems more suitable for even onshore cementing operations. This study provides basic cement slurry design data using a liquid-additive (sodium silicate) cement system for onshore surface casing cementing operations. Cost comparison results of different surface casing cementing scenarios for both liquid-additive (sodium silicate) and dry-additive blending (sodium metasilicate) are also presented.

Project Objectives

1. To investigate the effects of using sodium silicate by itself with Cemex Class C or H in small quantities to act as a substitute for bentonite in intermediate cementing to control free water and moderate extender on the thickening time rheology, free water, and compressive strength of class C cement. An objective of the project was to build the new slurry with the same control of free water as was observed in conventional slurries containing bentonite.
2. To determine the percentage salt per unit volume of water that will result in acceptable cement thickening time, rheology, free water, and compressive strengths of various weight of class C cement.
3. To suggest a set of new procedures for API Recommended practice for cementing operations if sodium silicate be used by itself with Cemex Class C and H in small quantities to act as an accelerator and moderate extender
4. What are the economics associated with switching from current surface pipe systems to a "C or H + sodium silicate" process? What is the fiscal value in making a switch? Are the intangible benefits substantial, and how do they compare to the tangible and measurable benefits?

5. To establish an interactive real time result posting system via the internet by the use of a fully automated cement consistometer unit at the mud laboratory, using Labview and other suite of hard wares

CHAPTER II

LITERATURE REVIEW

The use of liquid additives has become prevail in recent years in cementing operations this is mainly due to the increasing need to need the logistic problems of offshore cementing operations. A few studies have been conducted to investigate the use of field applicability liquid-additive systems for cement slurry control. Carrying out a thorough literature review on this subject matter is therefore quite challenging. The most salient work on this subject matter was done by Grant, Rutledge and Christy[2], in this work compares the performance of several liquid-additive cementing systems with those of dry-blending-additive systems. Cement-slurry thickening time, fluid loss, free water, and compressive strength are examined; sensitivity of the liquid-additive system to changes in slurry density was illustrated in this study. Laboratory data was used to demonstrate the liabilities of the liquid-additive system. Based on this study, a cost analysis comparing dry- and liquid-additive systems with equivalent design criteria shows that liquid-additive systems are generally more expensive and also more sensitive to changes in slurry density than dry-blended additives. The authors also pointed out that quality control and planning are the keys to successful cementing operations regardless of additive selection. The most important part of this work is that the authors were able to come out with a list of conditions under which the use of liquid-additive systems will be justified; these are listed as follows;

1) The mixing system is capable of maintaining a 0.1 Ibm/gal density
2) The metering system is tested for uniform and constant delivery of liquid-additive

3) A constant inventory of required and actual usage of mix water and liquid additives is maintained throughout the job
4) The dispersion of liquid additives throughout the mix water is verified
5) Liquid lingo-sulfonate retarders are avoided
6) Slurries are tested at 0.5 Ibm/gal above and below designed density to determine the effect of density variations
7) A monitoring package capable of continuously recording density is run and examined after job to ensure that the slurry is mixed to design specifications, and the scale for the density print out is small enough to detect small variations in density
8) The residual cement is significant
9) Cement delivery at different times is separated from any other cement
10) The cement, additive, and mix water used for the design and testing are the same materials used in the actual job.

Allen and Sands[3] investigated the importance of controlling cement slurry density, this paper is mainly concerned with slurry design and more particularly, the effects of deviations in mixed slurry density from the design point. The goal of this work to was to provide data and analysis to help clarify some of the existing density slurry properties relationships and therefore provide additional means to make rational decisions relative to density control specification.

The author pointed out that density as a slurry property is significant to wellbore hydrostatic pressure. However, deviations from design density may cause changes in all other slurry properties which may or may not cause future cementing problems. The relationships defining slurry properties dependence on slurry density are important when establishing meaningful density control limits. Lower control limit generally mean higher mixing system and operational cost, thus, there is an economic motivation for understating how deviations affect slurry properties. The knowledge of the cost to obtain specific density tolerance can be weighted against its benefit and hence more appropriate specifications can be developed to match job requirements. The authors tried to use this work to accomplish the following tasks; (1) define the significance of slurry properties variations with density deviations (2) present laboratory data which shows the property dependence on density, and (3) describe mathematical correlations for estimating the variation in slurry properties with density changes. Although the effects of using liquid-additive systems was not addressed in this work, the paper highlighted some of the benefits having a knowledge of the effects of density variation of slurry properties and the economic incentives associated with this.

Pollard et al[4] did a study on a new cement additive which improves slurry performance and reduce cost. The additive is a vitrified aggregate of calcium-magnesium aluminosilicate (CMAS) with potential cementitious reactivity. The authors mentioned that prior to the introduction of CMAS, lead slurry were lightens using liquid micro-silica, sodium silicate, bentonite or various combinations. Slurries with liquid micro-silica have high compressive strength but relatively high cost; meanwhile slurries using bentonite are economical but have low compressive strength. Slurries extended with sodium silicate are somewhat restricted by temperature, thus making a design cumbersome. CMAS is a powder; it is dry blended with cement at concentrations of 10% to 200% by weight of cement (bwoc) depending on the application. CMAS is applicable of neat and densified slurries to improve stability, fluid loss, free water, and compressive strength. Laboratory data and reaction chemistry revealed that CMAS and Portland cement have a synergistic relationship. CMAS hydrates by reacting with the undesired byproduct of cement –calcium hydroxide, thus improving a variety of properties.

Cementing technology is another major factor that has influenced additive selection, advances is metering and control technology can drastically improve concentration tolerances and hence improve slurry performance and project economics. Judge and Benge[5] illustrated how advance in technology can improve design and execution of foamed cement jobs. The paper describes the equipment and methods used to monitor and control nitrogen and liquid additives used in foamed cement slurries. Techniques to modify job parameters based on equipment performance parameters were also discussed in the paper. The authors stressed that precisely knowing the measuring the output of the cement unit, nitrogen unit, and additive pumps is critical to success of any foamed cement operation. The available metering technology for determination of volumetric flow rate of the gas and liquid component of foamed cement was classified into two major categories by the authors, these are; direct and indirect measurement. Direct measurement implies contact with the fluid being measured, and indirect measurement implies measuring flow without direct contact with fluid. Direct flow measurement devices include mass, turbine, vortex, target, and magnetic flowmeters. Indirect metering devices include ultrasonic meter and pump stroke counters. According to the authors, most common meters used in foamed cementing are mass and turbines, and many operators use only pump stroke counters to determine cement, nitrogen, and additive rates. Mass flow meters and magnetic flowmeters are appropriate for consideration in cement slurry measurement. Mass flowmeter have the advantage of measuring slurry density, but typically twice as expensive as magnetic flowmeters. Turbine meters do not withstand the abrasiveness of cement slurries very well. When using mass or magnetic flowmeter, the actual volumetric flowrate going through the meter is measured; resulting in the most accurate accounting of what is going downhole.

The authors also provided a definition of the concept of turndown, according to this paper; a meter's turndown ratio is the ratio of the maximum and the minimum ranges over which a meter is able to accurately measure a flowrate. For instance, if a meter has specific turndown of 10:1 and maximum flow rating of 10 gal/min., the minimum flowrate the meter can be used to measure accurately is 1 gal/min. Any flowrates outside the range of 1 to 10 gal/min cannot be accurately measured by this meter.

CHAPTER III

METHODOLOGY

This section of the project is sub-divided into three major categories: (1) Equipment selection, (2) Equipment calibration, and (3) test procedures. The testing procedures employed during this course of this study meet API 10B 22nd Edition, Dec 1997[6].

3.1 Equipment Selection

Equipment used in this study includes (1) Pressurized Consistometers (2) Rotor-bob type Rheometers (3) Atmospheric consistometer and Torque indicator (4) Compressive strength testing equipment (Bath and UCA) (5) Free water Test Apparatus (6) Fluid Loss filter press; the choice of these sets of equipment was informed by API regulations and standards. Compressive strength results from obtained from UCA were not used for analysis since this equipment has not been approved by API for compressive strength reporting.

3.2 Equipment Calibration

Laboratory calibrations were conducted on (1) Pressurized Consistometer, (2) Rotor-bob type Rheometers, and (3) Bath type compressive strength equipment. Some other calibrations were done outside the laboratory and will not be included in this section.

1) Voltage Calibration: Two pressurized consistometers were used for this study; Machine A, and Machine B, these two consistometers were calibrated for temperature and voltage. Voltage calibration was done to relate consistometer voltage reading to grams and grams to burden unit (Bc). Thickening time was set at 74Bc as required by API regulations, and the corresponding voltage reading was used to set the time alarm on each consistometer. Figure 1 and 2 below shows the calibration plots for both pressurized consistometers and the voltage reading corresponding to 74 Bc.

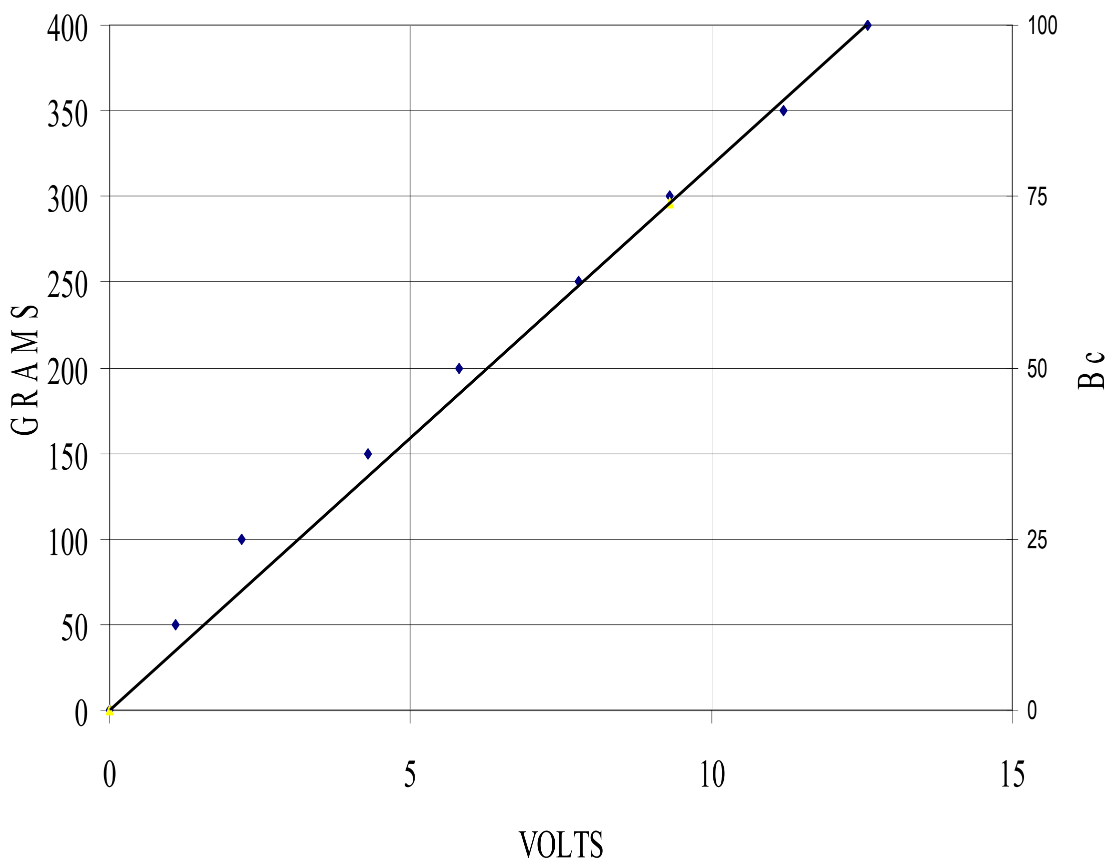

Figure 1. Calibration Plot for Machine A

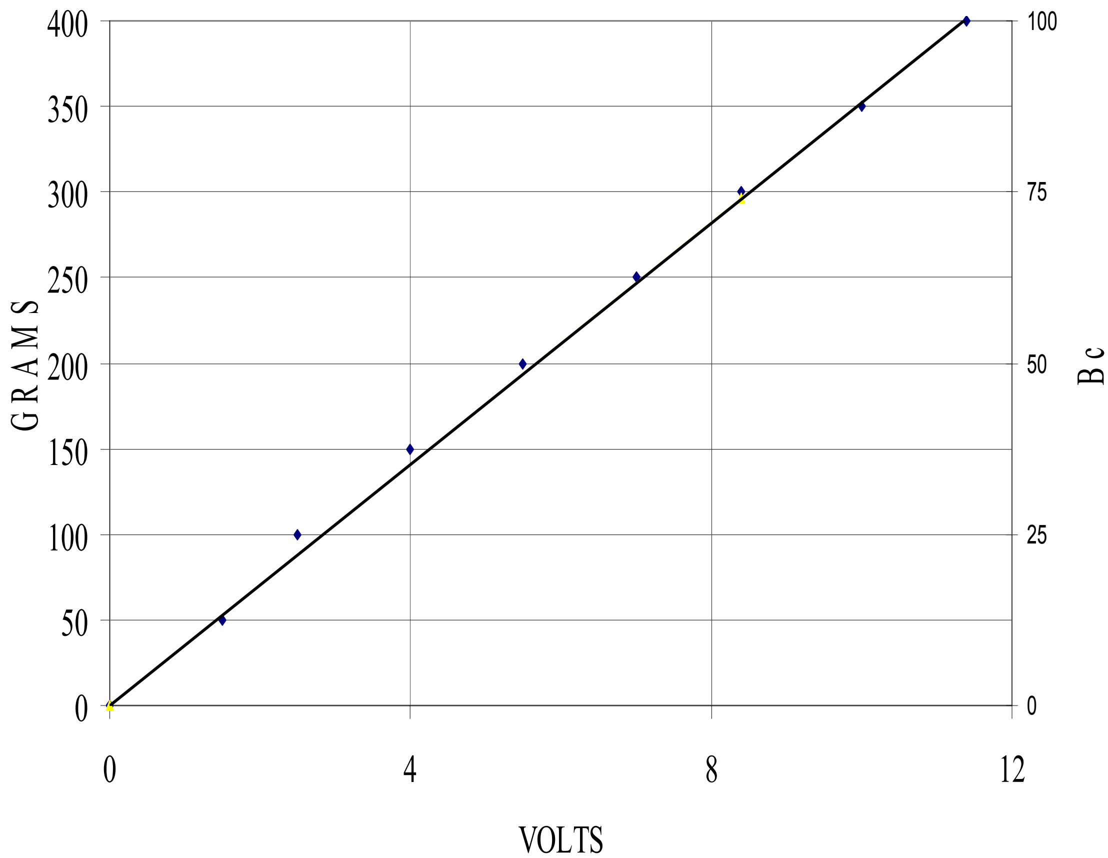

Figure 2. Calibration Plot for Machine B

2) Temperature Calibration: Temperature calibration was also performed of the two machines. This is to ensure that both machines are synchronized in terms of temperature readings. To achieve this, temperature readings from both machines were compared against that of a known standard. The deviation between the readings obtained form the machine and that of the known standard was then plotted (Figure 3). The resulting plot was then used as to relate the temperature obtained from both machine to the accurate temperature. Due to the fact that this study deals the development of slurries for surface pipe cementing operations, all laboratory testing were performed at 80^{o}F.

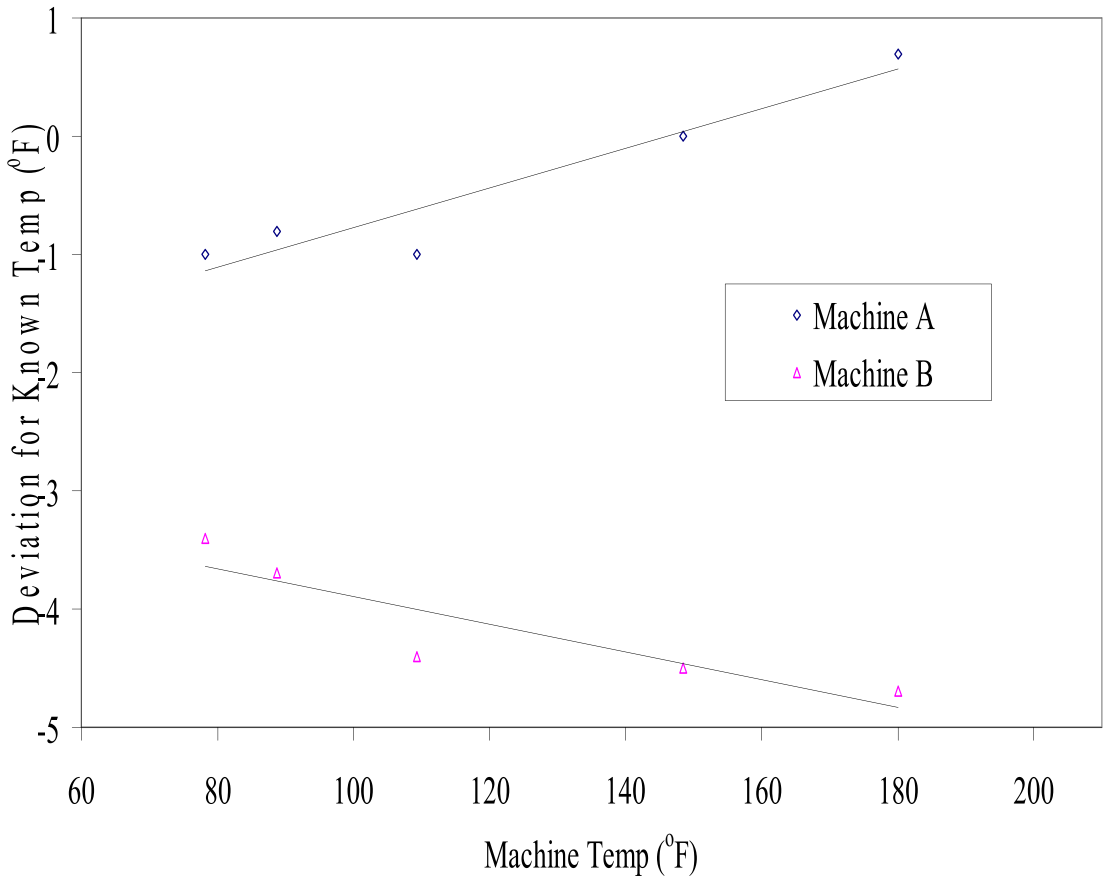

Figure 3. Temperature Correcting Plot for Machines A and B

3) RPM Calibration: To ensure through dispersion of additives and cement, we carried out a RPM calibration on the variable autotransformer. This calibration was done with the laser calibrator. 400RPM and 1600RPM marks were set of the apparatus for mixing before and after adding the cement to the mix water respectively.

4) Rotor-bob type Rheometer calibration: This was done with the calibrating oil according API standards. The temperature of the room was used to adjust

rheology reading obtained during the calibration. This temperature adjusted reading was then compared with manufacturer's standard for the calibrating oil.

3.3 Testing Procedures

All testing procedures were designed to satisfy both API and TRRC standards; however, during testing some circumstances required development of a reasonable and efficient testing procedure since that are not have not been included in both API and TRRC standard procedures. Some of these circumstances are listed below

a. A mix water containing 2% NaCl (bwow) was used as the final mixing system, to achieve this, a pre-calculated weight of NaCl was dissolved in water and the entire system is stirred until complete dissolution of the solid NaCl was achieved.
b. A calculated volume of the (Sodium MetaSilicate (SMS)) was added to the resulting water containing 2% NaCl (bwow), stirred for 5 seconds, and then the cement is added in 15 seconds.

All other testing procedures are as stated in API 10B 22nd Edition, Dec 1997[6].

CHAPTER IV

DEVELOPMENT

4.1 Design Contraints

Slurry development was governed by two main constraints; namely TRRC requirements and operational constraints.

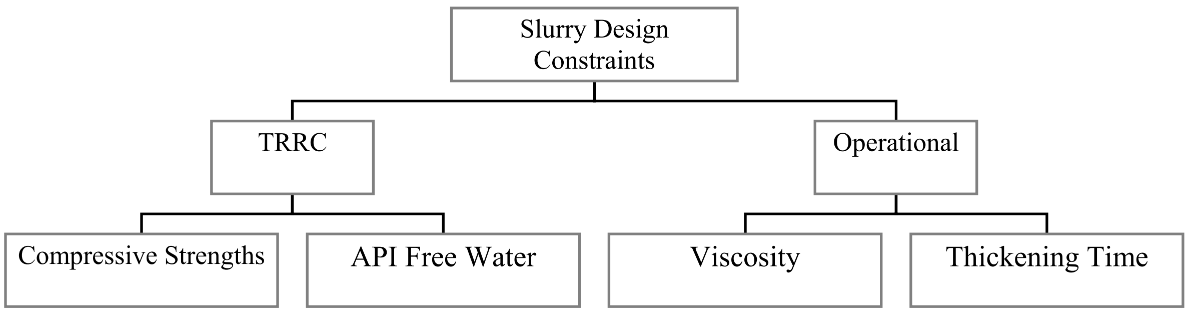

Figure 4. Chart of Slurry Design Constraints

a. TRRC Constraints

The TRRC constraints are critical for designing surface casing cement slurries. They are imposed mainly to ensure that the casing is securely anchored in the hole in order to effectively control the well at all times, and that all usable-quality freshwater zones be isolated and sealed off to effectively prevent contamination with other reservoir fluids in the wellbore trajectory. For surface and intermediate casing cementing operations, Rule 13 of the TRRC requirements classifies the bottom 20% or bottom 300 ft (whichever is greater) of the casing string as the "*zone of critical cement*". This zone may extend to the surface, but must not exceed 1000 ft. Cement slurries with volume extender may be used above the zone of critical cement to cement the casing from that point up to the ground surface. The TRRC cement quality requirements for cement slurries in these zones are shown in Table 1.

Table 1. TRRC Specifications, Rule13

Extender Slurry		
Duration (Hours)	12	24
Compressive Strength (Psi)	100	250
API Free Water (ml/2hrs)	6.0	
Tail Slurry		
Duration (Hours)	12	72
Compressive Strength (Psi)	500	1200
API Free Water (ml/2hrs)	6.0	

b. Operational Constraints

These are slurry design criteria imposed to optimize the cost and quality of the cement slurry in the field. Slurry viscosity, thickening time, and free water are the three major operational constraints employed in this project.

I. Slurry Viscosity: This shows the ease with which slurry can be pumped down hole. Slurries that are difficult to mix can result in operational problems in the field. Previous studies have indicated that rheologies greater than 40 at 6 rpm and 30 at 3 rpm may indicate the potential for field mixing problems. Rheologies less than 5 at 6 rpm and 4 at 3 rpm may indicate solids separation and excessive free water. The sodium metasilicate concentration impacts slurry viscosity. Figure 5 and 6 shows the effect of SMS on rheology of the cement slurry for class H and C respectively.

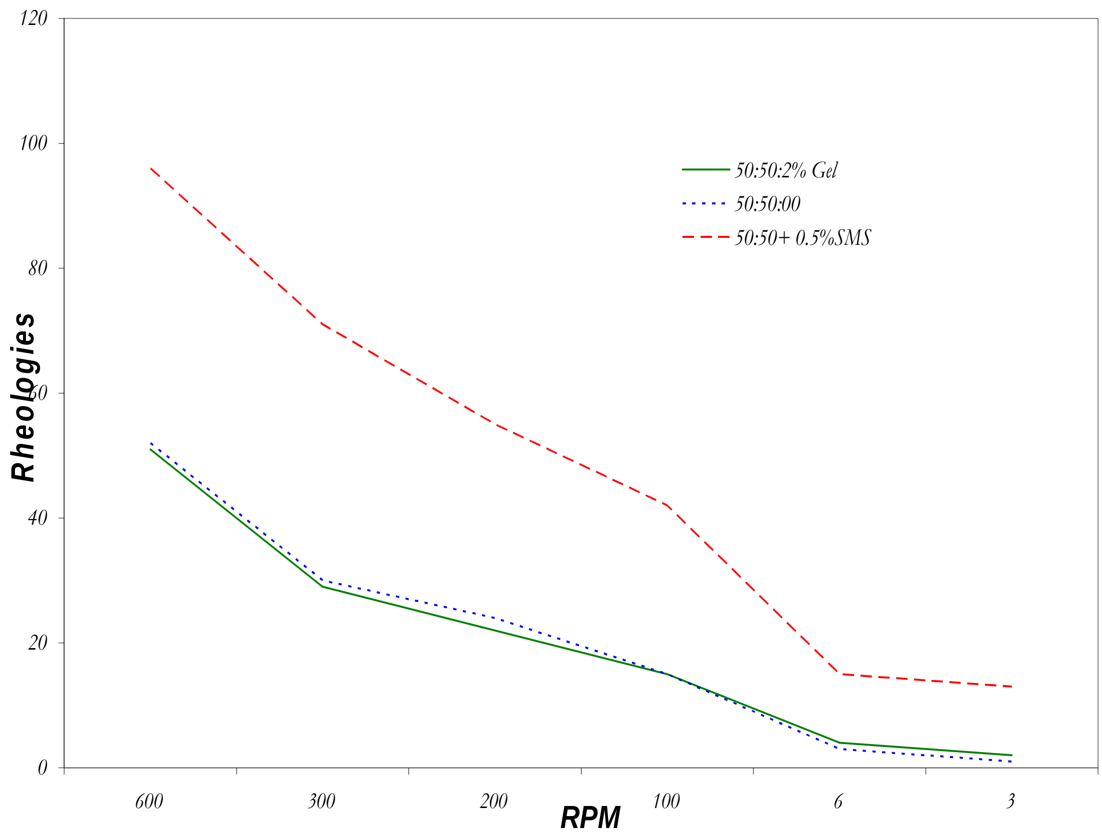

Figure 5. Correlation between SMS Concentration and Slurry Rheology
(API Class H, 12.0 ppg, Fresh Water Mixing system)

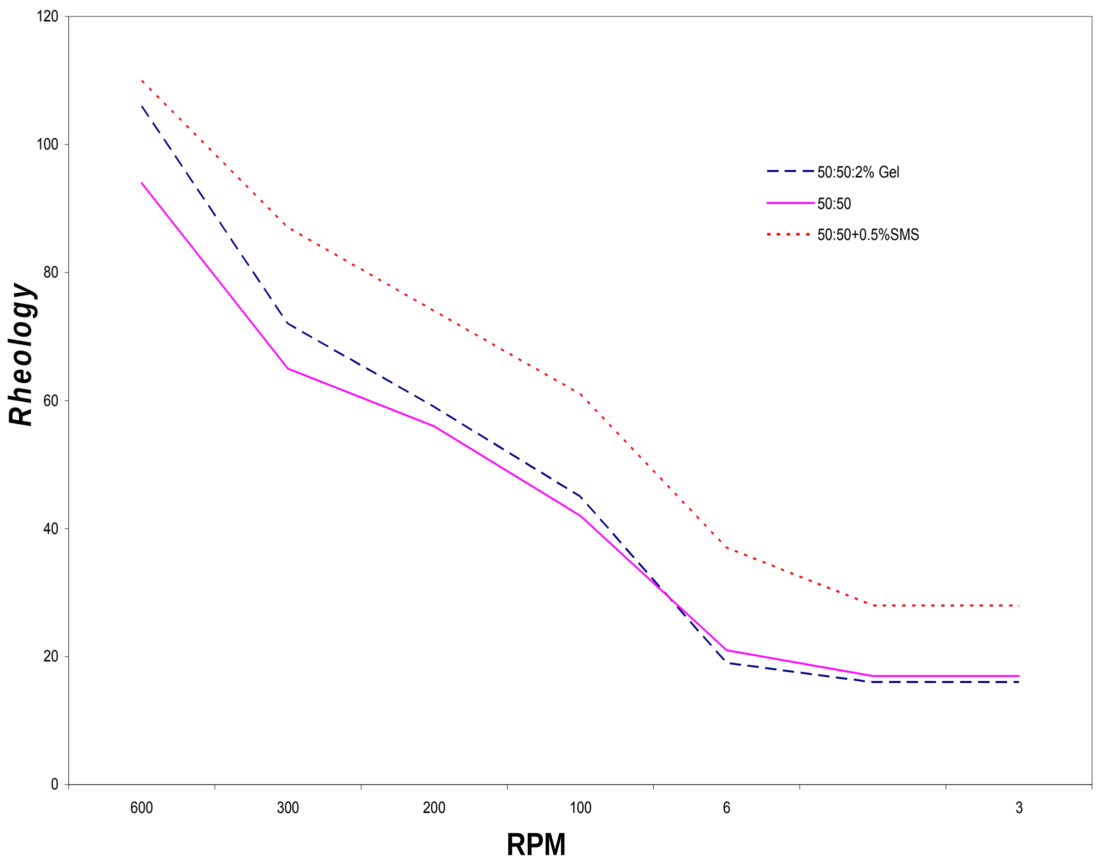

Figure 6. Correlation between SMS Concentration and Slurry Rheology
(API Class C, 12.0 ppg, Fresh Water Mixing system)

II. Thickening Time: Slurry thickening time must correlate to actual planned pumping time, and must fall within reasonable industry standards. It impacts both cost and cement quality. This study was able to match through the heat equation; reasonable temperature profiles of the two slurries with time using the consistometers, showing time required to thicken (this is shown in Fig 7). The Consistometer used was assumed to be at ambient temperature at the beginning of the test and gradual increase in the temperature was recorded to fit the desired profile expected from the correlation. The derivation of the heat equation and plot is also in the appendix. Thickening times less than 2 hours are generally too short, and can significantly increase the risk of premature cement setting prior to proper placement; while thickening times greater that 6 hours are generally to long, leading to extended compressive strength development and/or formation fluid migration problems.

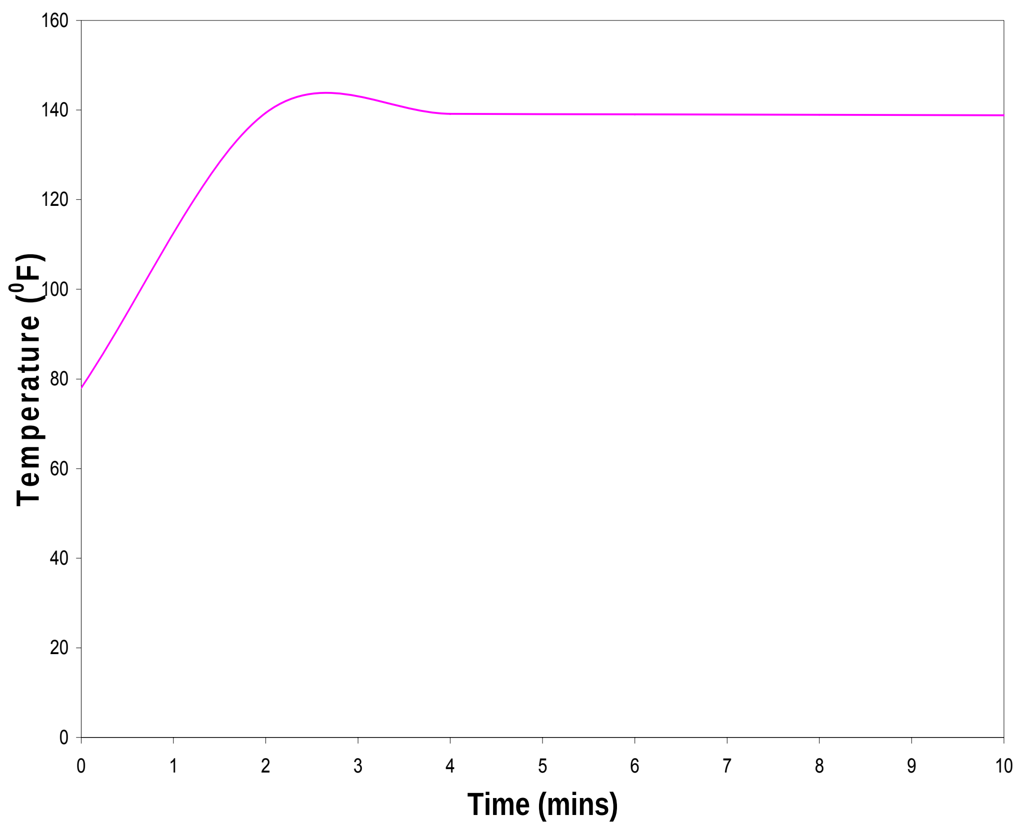

Figure 7. Variation of Temperature with Time

III. API Free Water: An objective of the project was to build the new slurry with the same control of free water as was observed in conventional slurries containing bentonite. Excessive free water can lead to "pockets" of water in the annular space between pipe and formation, and subsequent channeling and/or poor bonds.

IV. Fluid Loss: The rate at which slurry loses water to porous media at different pressures is important, as this allows for proper selection of slurries at different pressure and depths. A high fluid loss is often inversely proportional to the thickening time; when fluid leaks out of the slurry quickly, it viscosifies faster, and can lead to a shorter thickening time. Many fluid loss additive retard thickening time, and accelerators are often utilized in conjunction with these additives in order to shorten thickening time to an acceptable level at low bottomhole temperatures.

4.2 Design Objective

The Objective of this project is to optimize intermediate slurry development by using a commercially available additive to replace bentonite to form a new additive system. The goal of this system is to develop a system that (1) will not reduce or to a large extent not interfere with the effectiveness of a given concentration of most commercially available fluid loss additives. Second, while the 2% (by weight of cement) volume may seem of no consequence, the shipping costs associated with moving tons of the material over a long period of time can be significant, also to reduce the cost of intermediate cementing during drilling operations. Thirdly, to control free water to the same degree as the bentonite system, allowing less total fluid loss additive for a given fluid loss control tolerance, or, better fluid loss control for a given concentration of fluid loss additive.

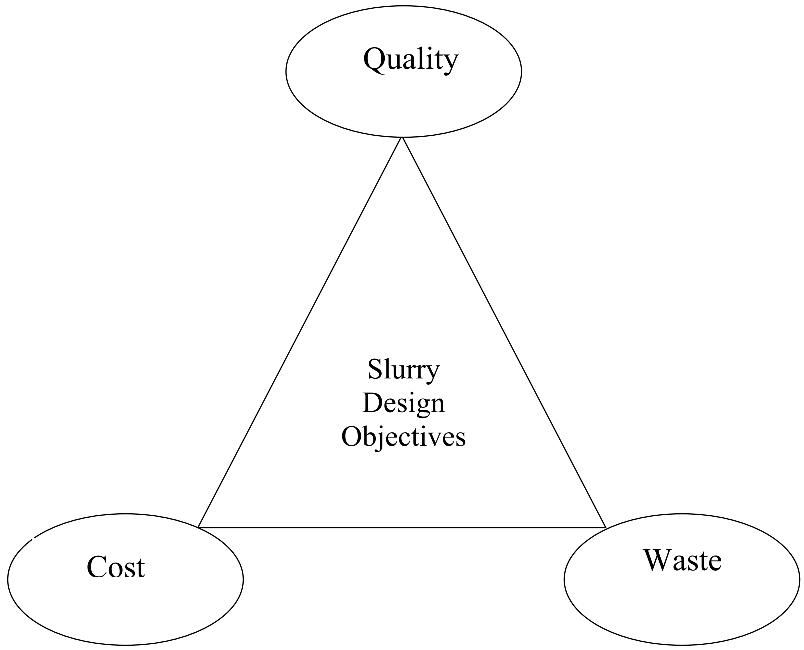

Figure 8. Slurry Design Objectives

4.3 Slurry Classification

The goal of this slurry design exercise is to design three sets of slurry type namely; lead/extended slurry, critical zone slurry and tail/non-extended slurry. The definition of these slurry types is based on the TRRC classification. The lead/extended slurry is design to minimally exceed the TRRC compressive and API Free Water requirements, while the critical zone slurry is design to be used in the zone of critical cement as define by Rule 13 of the TRRC requirements. The critical zone cement is design to minimally exceed the TRRC compressive strength requirements of the zone of critical cement. The tail/non-extended slurry is designed to radically exceed the TRRC compressive strength requirement for the zone of critical cement. Figure 7 below shows a diagram illustrating the various slurry types, their location in a typical surface pipe cementing operation.

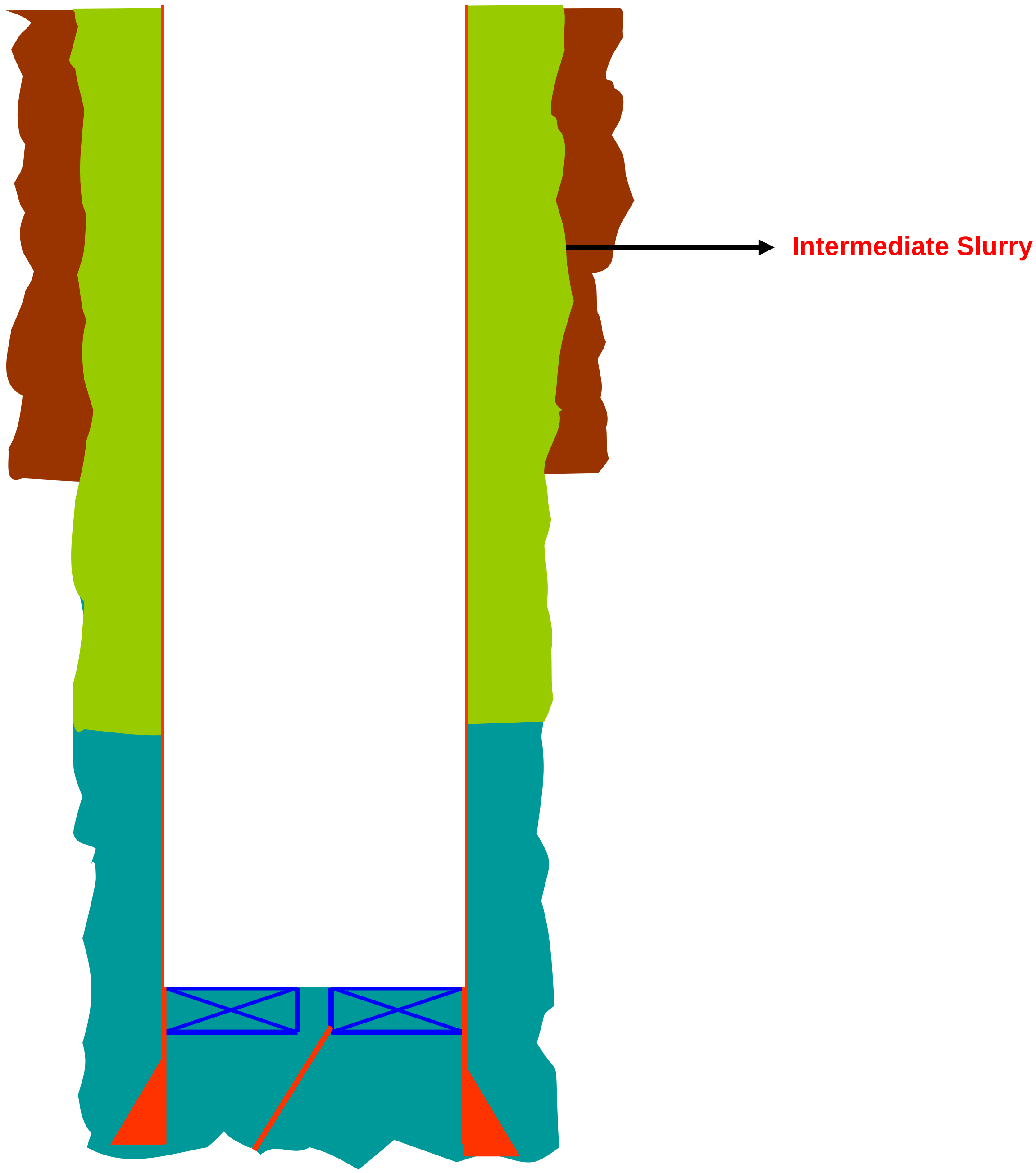

Figure 9. Layout of a Typical Intermediate Pipe Cementing.

4.4 History Of Development

The need for sulfate resistance and light weight slurries in the Permian and Mid-continent Basins has led to the dominant use of API Class C for shallow and intermediate-depth cementing operations, and was a major consideration in the selection of the cement class used in this project, though Class H was also tested for consistency and possibility of use at these same depths.

Initial testing reveals that use of API Class H + fresh water without sufficient concentrations of extender yields unacceptable free water and thickening times. Figs. 10 & 11 show the relationship between free water and SMS concentrations.

Subsequent tests reflect a free water level under the tolerance point of 5.0ml/2hrs. The main challenge in determining better slurry than the bentonitic slurry was to determine the amount of SMS that would yield the same or better properties and optimum results in terms of total system cost and quality than the original slurry. This was accomplished by trial and error, until the best concentration possible was determined. Fresh water was used along with 2% BWOW NaCl.

The class C cement tests are shown in figure 6. For different concentrations of the SMS, they were all below the tolerance value, but other tests carried out for thickening time, fluid loss, compressive strength and rheology shows 0.5% SMS having better values of this slurry properties than the bentonitic slurry.

A basic cement slurry design specification for intermediate cementing operations was developed using a SMS system. Table 2 shows the complete slurry design data. The Class C Cement shows very good results for all the tests carried out on for the SMS slurry, making it comparable to the bentonite system, it gives a better thickening time, compressive strength, rheology and free water for the tests carried out. The class H cements shows the SMS system having better controlled free water than the bentonitic system, and showed better thickening time and compressive strength.

The economics of using any of this system, either for class C or H is strongly dependent on the type of job being done. But generally, the SMS system has proved to be economically more viable than the Bentonite system.

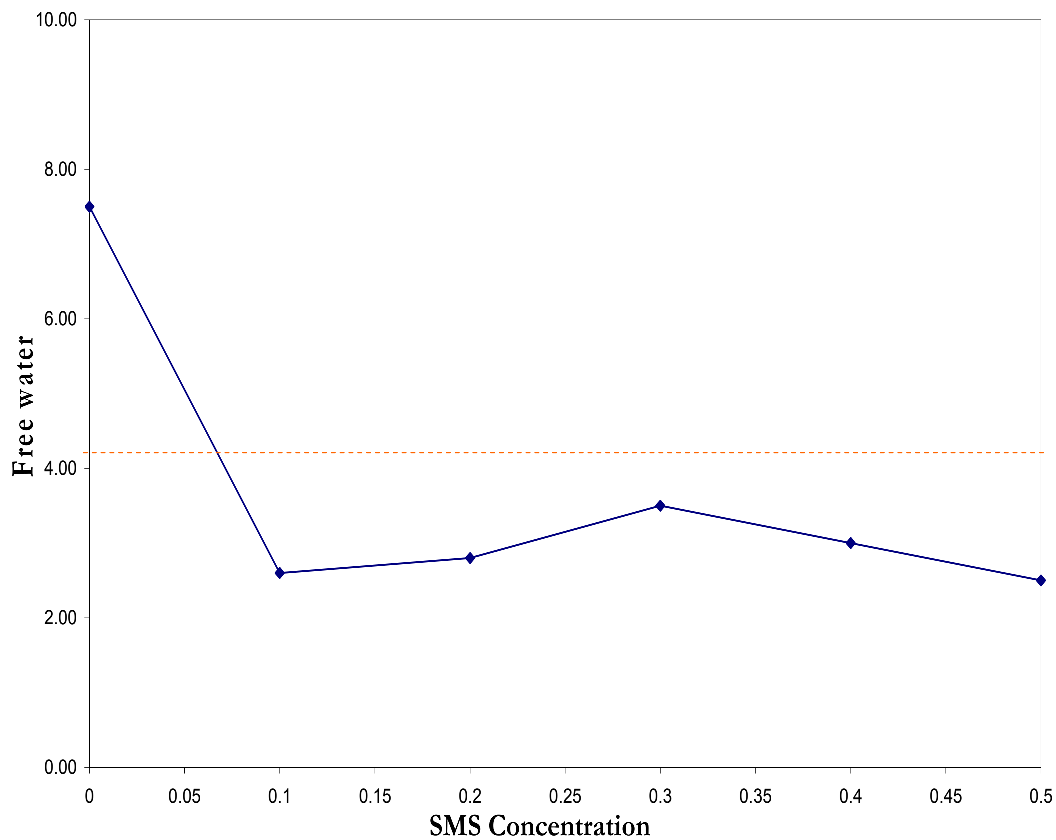

Figure 10. Correlation between SMS Concentration and API Free Water
(API Class H, 12.0 ppg, Salt Water Mixing system)

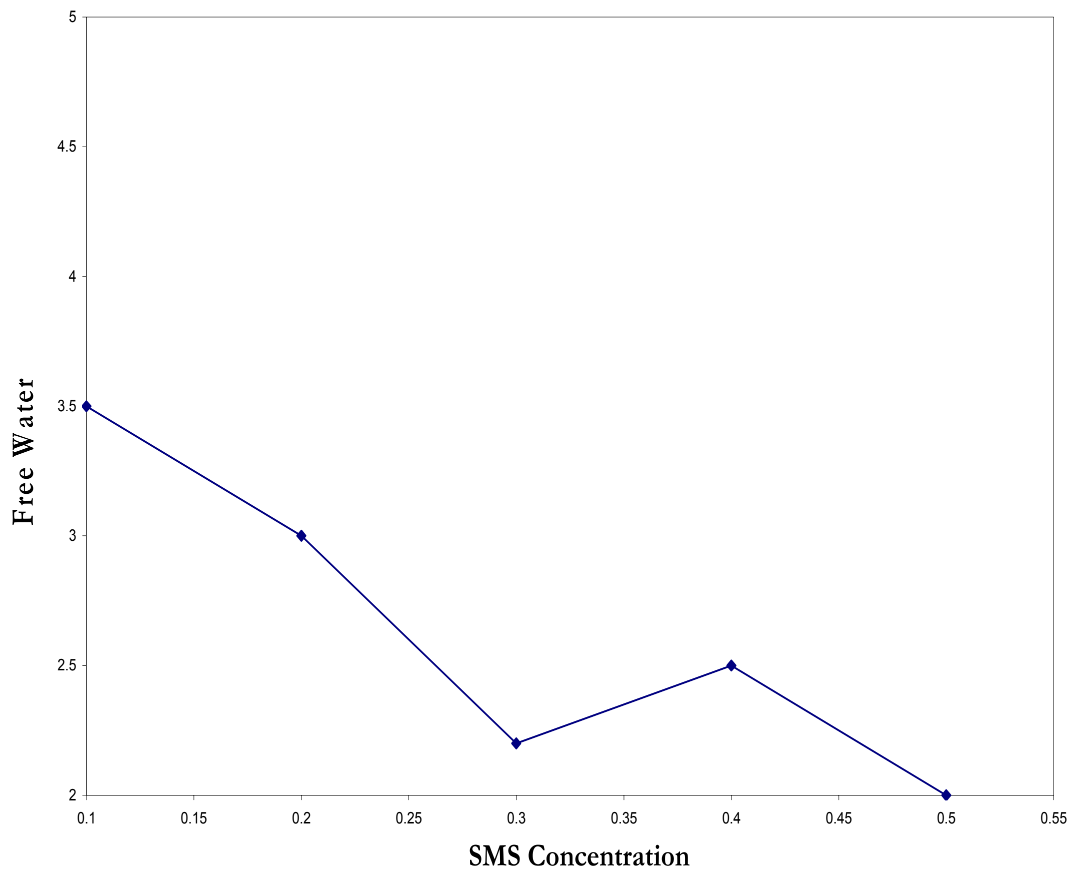

Figure 11. Correlation between SMS Concentration and API Free Water
(API Class C, 12.0 ppg, Salt Water Mixing system)

A decision was made to develop a system more similar to Bentonite slurries, which are high in chlorides. To accomplish this; chlorides were artificially introduced into the mix water. The main challenge was to determine the percentage salt (by weight of mix water) that would yield optimum results in terms of total system cost and quality. Different systems of varying concentrations of NaCl were developed. The mixture 5% NaCl (by weight of mix water) and sodium Metasilicate system resulted in a noticeable precipitation. A system of API Class C + 2%$CaCl_2$ (by weight of mix water) + sodium

Metasilicate could be found to give acceptable values for all imposed operating constraints, but this was not tested.

Having arrived at favorable mix water, further testing was conducted that imposed different operational and TRRC constraints for both the critical and extender cement slurries. Optimum slurry weight and SMS concentrations for were obtained by a trail and error approach. The critical cement slurry required more trials than the extender slurry, because compressive strength criteria were the most difficult constraint to meet.

CHAPTER VI

RESULTS

Table 2. Slurry Design Data

Class C Cement		
	50:50 2% Gel	**50:50: 0. 5% SMS**
Slurry Specification	**API Class C,14.2ppg + 14.2ppg + 2% NaCl**	**API Class C , 14.20ppg + 14.2ppg (SMS) + 2% NaCl**
600rpm	102	110
300rpm	72	87
200rpm	59	74
100rpm	45	61
6rpm	19	37
3rpm	16	28
API Free Water, ml/2hrs	2.1	2.0
Thickening Time (74Bc)	3hrs, 36mins	3hrs, 19mins
8hrs	N/A	N/A
12hrs	60psi	0psi
24hrs	750psi	1938psi
Fluid Loss, cc/30mins	I335	368
Class H Cement		
	50:50 2% Gel	**50:50: 0. 5% SMS**
Slurry Specification	**API Class H,14.2ppg + 14.2ppg + 2% NaCl**	**API Class H , 14.20ppg + 14.2ppg (SMS) + 2% NaCl**
600rpm	51	96
300rpm	29	71
200rpm	22	55
100rpm	15	42
6rpm	4	15
3rpm	2	13
API Free Water, ml/2hrs	6.5	2.5
Thickening Time (74Bc)	5hrs, 53mins	4hrs, 11mins
8hrs	N/A	N/A
12hrs	0psi	263psi
24hrs	737psi	921psi
Fluid Loss cc/30mins	1697.14	1009.09

5.1 Slurry Specifications

A basic cement slurry design specification for intermediate pipe cementing operations was developed using a Sodium Metasilicate system. Table 2 shows the complete slurry design data.

5.2 Comparative Cost Analysis

Prices Estimate: The pricing data contained in this project reflect only estimates and may vary depending on the work actually being performed. Pricing does not include federal, state, and local taxes or royalties. Service charges may vary depending of the service company and some other factors. Equipment price estimates are based of the average price for equipment purchase and rental and this is subject to available and the prevailing price of crude oil. Freight cost associated with transportation of waste cement, remediation cost associated with cleanup operations, additional cost associated with equipment modification, extra manpower and possible rental of specialized equipment are not included in this cost analysis due to lack of existing field experience regarding these cost items. A typical 50:50 Class C + Poz + 0.5% sodium metasilicate + 0.5% dispersing fluid loss additive, mixed at 14.2 lb/gal; in order to match the fluid loss performance of the system, a conventional 50:50 Class C + 2% bentonite, would need an additional 0.3% dispersing fluid loss additive. Under many circumstances, this additional amount would also retard the slurry so much that the long thickening times would be unacceptable and the designer would probably add a small amount of salt to lower thickening time a bit.

February 2005 typical costs for 785 ft3 for Class C of wet slurry for the bentonitic system would be $9,578.64, and for the sodium metasilicate system, $8,748.92. This is approximately 9.5% more for the bentonitic system, showing a sharp reduction in cost.

For class H, the savings are similar $9,593.19 compared to for the SMS with $8,764.14; which again equates to a about a 9.5% differential.

Table 3. Product Material Price Estimates

PRODUCT DESCRIPTION	UNIT AMOUNT
Class C Cement	$7.51/sack
Class H Cement	$7.56/sack
Calcium Chloride	$0.37/Ibs
Sodium MetaSilicate	$4.53/gal
Bentonite	$0.14/Ibs
Poz (Fly Ash)	$4.0/sack
Sodium Chloride	$0.14/Ibs
Cement Plug, Rubber, Top 13-3/8 in	$340.0 each
FP-13L	$52.13/gal

Table 4. Service/ Equipment Price Estimate

SERVICE/EQUIPMENT DESCRIPTION	UNIT PRICE
Employee Incentive Bonus – Cement Svc	$50 each
Bulk Material Service Charge	$1.17/cu ft
Cement Pump Casing	$178/hr
Data Acquisition, Cement, Standard	$352/ job
Mileage, Heavy Vehicle	$2.2/mile
Mileage, Auto, Pick-up or Treating Van	$1.33/mile
Freight charges (Bulk Delivery, Dry Products)	$0.74/ton-mile

Table 5. Volumetric Slurry Cost Comparison

Systems for lead and tail slurries	Weight (lb/gal)	Cost/ft3 (dollars)
Class C + 2% NaCl + 2% Bentonite	14.2	12.20
Class H + 2% NaCl + 2% Bentonite	14.2	12.22
Class C + 2% NaCl +0.5% SMS	14.2	11.14
Class H + 2% NaCl + 0.5% SMS	14.2	11.14

5.3 Discussion

The slurry specifications arrived at in this study achieved our technical objective of developing a slurry system of comparable performance to that of the conventional system using a Sodium Metasilicate system. However, our economic objective of developing the slurry system at a cheaper cost was not too significant but would be imperative to note that this would be of importance over a long period of time, Table 5 shows that volumetric slurry cost for a SMS system is comparable to that of the conventional system. Our initial choice of Class C cement was informed by the fact that we expect the early compressive strength development behavior of this class of cement to result in significant economic gains in this project. We believe that the addition of SMS additive slows down the compressive strength development of Class C cement at early time, as a result of this the minimum slurry density that will satisfy the TRRC 8 Hours compressive strength requirement was found to be 14.20ppg. Offshore field application of the liquid-additive system utilizes seawater as the mix system. The failure of fresh water mixing system for onshore application of the liquid additive system introduces the extra challenge of onsite development of a salt water system. The extra cost associated with material purchase ($CaCl_2$) and transportation resulted in higher than expected cost of onshore application of the liquid-additive system for slurry development. Further studies are planned to investigate the use of customized bland of Class H cement with a right amount of tricalciumaliminate for sulfate resistance instead of Class C, this might result in lower cost per unit volume of the lead slurry. Also the extra cost due to the purchase of $CaCl_2$ can be eliminated by investigating the use of different brine samples to establish a permissible concentration tolerance that could serve as a mix system for liquid-additive systems. This will lower the cost per unit volume of the resulting slurry as well as improve the overall mixing logistic of the liquid-additive system.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

Conclusions

The following conclusions were arrived at:

1) Extensive testing of 50:50 slurries revealed that small quantities of sodium metasilicate (in the order of **0.5%** by weight of cement) could effectively replace bentonite.
2) Economics of using SMS is **9.5%** less than current Bentonite Systems.
3) Economics of using SMS when cementing large casing down drill pipe can be highly cost-effective.
4) In almost all cases there are improved properties using SMS compared to Bentonite.
5) Additive concentration tolerances are improved when SMS additives are used.
6) Free water was controlled to the same degree, and a synergy with a commonly available fluid loss additive was discovered, allowing better fluid loss control for a given concentration of fluid loss additive.
7) Basic slurry design data are presented.

Recommendations for Further Investigation

1) The use of sodium Metasilicate at very low concentrations for acceleration in critical zone cements rather than the addition of conventional salts such as calcium chloride or sodium chloride.
2) Investigation of the use of Class H cement with a right amount of tricalciumaliminate for sulfate resistance instead of Class C
3) API Water Analysis of about 150 brine samples in the Permian Basin

4) Establishment of a brine concentration tolerance window suitable for liquid additive application in onshore locations
5) Substitution of NaCl for $CaCl_2$ – examination of multiple fresh waters with various salts.
6) The use of sodium silicate as an extender in casing strings subsequent to the surface pipe
7) Closer examination of process control issues – issues associated with the modification of existing cementing equipment to easily handle the pumping of liquid additives.

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APPENDIX A

WORK SHEETS AND LABORATORY RESULTS

Test Number: 529411901 Test Date: 12/16/2002
Report Number:

WELL INFORMATION

Operator:	BJ Services	County:	NA
API #:		State:	TX
Well Name:	Texas Tech University	Requested By:	Doug Walser
Slurry Type:		TVD:	1 MD: 1
Blend Type:	Lab	District:	Odessa
Comments:			

TEST DATA AND SCHEDULE

Time To Temp (min):	13.00	Mud Density (lb/gal):	8.34
Initial Press (psi):	250	Mix Water Density (lb/gal):	8.34
Final Press (psi):	700	Mix Water Type:	Tap Water
BHST (deg F):	80	Surf Temp (deg F):	80
BHCT (deg F):	80	Job Type:	N/A
Comments:			

SLURRY AND TEST RESULTS

Vendor: Southdown
Slurry: Class 'C' + 0.7 gps Liquid Sodium Silicate + 2.0% Calcium Chloride + 0.004 gps FP-6L

Density:12.5 lb/gal	Pump Time (50 Bc):
Yield:2.163 CuFt/sk	Pump Time (70 Bc):
Mix Water:11.77 gal/sk (104.5%)	Pump Time (100 Bc):
Total Mix Liquid: 12.48 gal/sk	
Fluid Loss: cc/30 min	Free Water (ml): (Tested at 90 Degrees)

Compressive Strength

Temp	Time	Strength	Type
80	8	108	Bath
80	12	265	Bath
80	24	388	Bath

Rheology (PL=Power Law, BP= Bingam Plastic)

Temp	600	300	200	100	6	3

Comments:

Test Number:529411899 Test Date: 12/16/2002
Report Number:

WELL INFORMATION

Operator:	BJ Services	County:	NA
API #:		State:	TX
Well Name:	Texas Tech University	Requested By:	Doug Walser
Slurry Type:		TVD:	1 MD: 1
Blend Type:	Lab	District:	Odessa
Comments:			

TEST DATA AND SCHEDULE

Time To Temp (min):13.00	Mud Density (lb/gal): 8.34
Initial Press (psi):250	Mix Water Density (lb/gal):8.34
Final Press (psi):680	Mix Water Type:Tap Water
BHST (deg F):80	Surf Temp (deg F): 80
BHCT (deg F):80	Job Type: N/A
Comments:	

SLURRY AND TEST RESULTS

Vendor: Southdown
Slurry: Class 'C' + 0.65 gps Liquid Sodium Silicate + 2.0% Calcium Chloride + 0.004 gps FP-6L

Density:13.5 lb/gal	Pump Time (50 Bc):
Yield:1.74 CuFt/sk	Pump Time (70 Bc):
Mix Water:8.656 gal/sk (76.8%)	Pump Time (100 Bc):
Total Mix Liquid: 9.31 gal/sk	
Fluid Loss: cc/30 min	Free Water (ml): (Tested at 90 Degrees)

Compressive Strength

Temp	Time	Strength	Type
80	12	500	Bath
80	24	850	Bath
80	72	1469	Bath

Rheology (PL=Power Law, BP= Bingam Plastic)

Temp	600	300	200	100	6	3

Comments:

Test Number:529411901 Test Date: 12/16/2002

Report Number:

WELL INFORMATION

Operator:	BJ Services	County:	NA
API #:		State:	TX
Well Name:	Texas Tech University	Requested By:	Doug Walser
Slurry Type:		TVD:	1 MD: 1
Blend Type:	Lab	District:	Odessa
Comments:			

TEST DATA AND SCHEDULE

Time To Temp (min):	13.00	Mud Density (lb/gal):	8.34
Initial Press (psi):	250	Mix Water Density (lb/gal):	8.34
Final Press (psi):	700	Mix Water Type:	Tap Water
BHST (deg F):	80	Surf Temp (deg F):	80
BHCT (deg F):	80	Job Type:	N/A
Comments:			

SLURRY AND TEST RESULTS

Vendor: Southdown

Slurry: Class 'C' + 0.2 gps Liquid Sodium Silicate + 2.0% Calcium Chloride + 0.004 gps FP-6L

Density:14.5 lb/gal	Pump Time (50 Bc):
Yield:1.425 CuFt/sk	Pump Time (70 Bc):
Mix Water:6.746 gal/sk (104.5%)	Pump Time (100 Bc):
Total Mix Liquid: 6.950 gal/sk	
Fluid Loss: cc/30 min	Free Water (ml): (Tested at 90 Degrees)

Compressive Strength

Temp	Time	Strength	Type
80	12	699	Bath
80	72	2422	Bath

Rheology (PL=Power Law, BP= Bingam Plastic)

Temp	600	300	200	100	6	3

Comments:

Table A.1 Worksheet for 0.5% SMS +Class H Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.341		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.038		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class H	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	336.96	Fresh	0.1199	Ab. Vol.
GPS	6.034	Poz:		265.27	Sea	0.1169	0.1199
%	59.914	Slag/Other:		0.00	COMMENTS		
				602.23			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.83*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.5	0	1	sodium silicate	3.01	*2.1508*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	360.82			

Table A.2 Slurry Information for 0.5% SMS +Class H Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.3 Worksheet for 0.4% SMS +Class H Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.341		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.041		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class H	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.10	Fresh	0.1199	Ab. Vol.
GPS	6.037	Poz:		265.37	Sea	0.1169	0.1199
%	59.945	Slag/Other:		0.00	COMMENTS		
				602.47			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.84*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.4	0	1	sodium silicate	2.41	*1. 713*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	361.15			

Table A.4 Slurry Information for 0.4% SMS +Class H Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.5 Worksheet for 0.3% SMS +Class H Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.340		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.045		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class H	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.23	Fresh	0.1199	Ab. Vol.
GPS	6.041	Poz:		265.48	Sea	0.1169	0.1199
%	59.976	Slag/Other:		0.00	COMMENTS		
				602.71			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.85*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.3	0	1	sodium silicate	1.81	*1.2915*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	361.48			

Table A.6 Slurry Information for 0.3% SMS +Class H Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.7 Worksheet for 0.2% SMS +Class H Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.340		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.048		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class H	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.37	Fresh	0.1199	Ab. Vol.
GPS	6.044	Poz:		265.59	Sea	0.1169	0.1199
%	60.007	Slag/Other:		0.00	COMMENTS		
				602.95			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.86*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.2	0	1	sodium silicate	1.21	*0.8614*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	361.82			

Table A.8 Slurry Information for 0.2% SMS +Class H Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.9 Worksheet for 0.1% SMS +Class H Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.339		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.051		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class H	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.50	Fresh	0.1199	Ab. Vol.
GPS	6.047	Poz:		265.69	Sea	0.1169	0.1199
%	60.039	Slag/Other:		0.00	COMMENTS		
				603.19			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.87*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.1	0	1	sodium silicate	0.60	*0.4309*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.02			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	362.15			

Table A.10 Slurry Information for 0.1% SMS +Class H Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.11 Worksheet for 2% Bentonite +Class H Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.358		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.092		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class H	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	332.94	Fresh	0.1199	Ab. Vol.
GPS	6.088	Poz:		262.10	Sea	0.1169	0.1199
%	60.449	Slag/Other:		0.00	COMMENTS		
				602.23			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.80*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.0	0	1	sodium silicate	3.01	*2.1508*		
2	0	2	Gel	11.9			
0.5		3	fl-25	2.98			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.23			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	359.69			

Table A.12 Slurry Information for 2% Bentonite +Class H Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.13 Worksheet for 0.5% SMS + Class C Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.341		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.038		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class C	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	336.96	Fresh	0.1199	Ab. Vol.
GPS	6.034	Poz:		265.27	Sea	0.1169	0.1199
%	59.914	Slag/Other:		0.00	COMMENTS		
				602.23			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.83*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.5	0	1	sodium silicate	3.01	*2.1508*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	360.82			

Table A.14 Slurry Information for 0.5% SMS +Class C Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.15 Worksheet for 0.4% SMS + Class C Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.341		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.041		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class C	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.10	Fresh	0.1199	Ab. Vol.
GPS	6.037	Poz:		265.37	Sea	0.1169	0.1199
%	59.945	Slag/Other:		0.00	COMMENTS		
				602.47			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.84*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.4	0	1	sodium silicate	2.41	*1. 7213*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	361.15			

Table A.16 Slurry Information for 0.4% SMS +Class C Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.17 Worksheet for 0.3% SMS + Class C Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.340		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.045		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class C	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.23	Fresh	0.1199	Ab. Vol.
GPS	6.041	Poz:		265.48	Sea	0.1169	0.1199
%	59.976	Slag/Other:		0.00	COMMENTS		
				602.71			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.85*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.3	0	1	sodium silicate	1.81	*1.2915*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	361.48			

Table A.18 Slurry Information for 0.3% SMS +Class C Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.19 Worksheet for 0.2% SMS + Class C Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.340		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.048		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class C	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.37	Fresh	0.1199	Ab. Vol.
GPS	6.044	Poz:		265.59	Sea	0.1169	0.1199
%	60.007	Slag/Other:		0.00	COMMENTS		
				602.95			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.86*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.2	0	1	sodium silicate	1.21	*0.8614*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	361.82			

Table A.20 Slurry Information for 0.2% SMS +Class C Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	100lbs/ft^2		hrs:mins		hrs:mins
9:				500lbs/ft^2		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.21 Worksheet for 0.1% SMS + Class C Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.339		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.051		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class C	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.50	Fresh	0.1199	Ab. Vol.
GPS	6.047	Poz:		265.69	Sea	0.1169	0.1199
%	60.039	Slag/Other:		0.00	COMMENTS		
				603.19			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.87*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.1	0	1	sodium silicate	0.60	*0.4309*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.02			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	362.15			

Table A.22 Slurry Information for 0.1% SMS +Class C Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	$100 lbs/ft^2$		hrs:mins		hrs:mins
9:				$500 lbs/ft^2$		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.23 Worksheet for Pozzalon + Class C Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.339		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.054		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class C	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	337.64	Fresh	0.1199	Ab. Vol.
GPS	6.050	Poz:		265.80	Sea	0.1169	0.1199
%	60.070	Slag/Other:		0.00	COMMENTS		
				603.43			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.88*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.0	0	1	sodium silicate	0.00	*0.000*		
0	0	2	Gel	0.00			
0.5		3	fl-25	3.01			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.24			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	362.48			

Table A.24 Slurry Information for Pozzalon +Class C Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	71			
Pressure (psi)				200	55			
Free H20 (mls)			*2.5*	100	42			
Temperature (°F)			110	6	15			
Angle (°deviation)			90	3	13			
FL Temp °F			*Fluid Loss*	600	96			
SFL Temp °F			cc's/30mins:1009.09	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	$100 lbs/ft^2$		hrs:mins		hrs:mins
9:				$500 lbs/ft^2$		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:	263.12	psi	Critical Zone Slurry					
24 hr:	921.1	psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.25 Worksheet for 2% Bentonite + Class C Cement Intermediate Zone Slurry

		14.20			600	Project#	02-06-0470
	Yield (cu ft/sk)	1.358		Slurry SG	1.703	District:	TTC
	Total Fluid (gps)	6.092		Total Fluid %	#REF!	Analyst:	olu fasesan
Cement Brand:			Cemex class C	Grams	Mix H20 Ab. Vol.		Desired Mix H20
Cement Mix H20		Cement:	50/50	332.94	Fresh	0.1199	Ab. Vol.
GPS	6.088	Poz:		262.10	Sea	0.1169	0.1199
%	60.449	Slag/Other:		0.00	COMMENTS		
				602.23			
%NACL:		*By weight of water*		*0.00*			
%KCL:	3	*By weight of water*		*10.80*			
% bwoc	gal/sk	Add #	Additive	Grams	Volume (cc)		
0.0	0	1	sodium silicate	3.01	*2.1508*		
2	0	2	Gel	11.9			
0.5		3	fl-25	2.98			
		4		0.00			
		5		0.00			
		6		0.00			
		7		0.00			
	0.004	8	fp-6l	0.23			
		9		0.00			
		10		0.00	*60%*		
			Fresh H20:	359.69			

Table A.26 Slurry Information for 2% Bentonite +Class C Cement Intermediate Zone Slurry

Temperature (°F)				Rheology (RPM)		°F		°F
Ramp (hrs:mins)				300	72			
Pressure (psi)				200	59			
Free H20 (mls)			*1.2*	100	45			
Temperature (°F)			110	6	19			
Angle (°deviation)			90	3	16			
FL Temp °F			*Fluid Loss*	600	106			
SFL Temp °F			cc's/30mins:	*Gel Str @*		°F		°F
Ramp hrs:mins				10 sec				
1:		Blow Out Values		10 min				
4:		min:sec	cc's	$100 lbs/ft^2$		hrs:mins		hrs:mins
9:				$500 lbs/ft^2$		hrs:mins		hrs:mins
16:		*Gas Model*		*Settling@*		°F		Press
25:		Temp °F		Top		Densities lb/gal		Bottom
30:		Pass / Fail						
UCA / Compressive Strength @				°F			Pressure (psi)	
50psi:		hrs:mins	Final Time:		Final Strength:			
500psi:		hrs:mins						
8 hr:	N/A	psi	*Comments*					
12 hr:		psi	Critical Zone Slurry					
24 hr:		psi						
48 hr:	N/A	psi						
72 hr:	N/A	psi						

Table A.27 Summary of Test results for Class C Cement

TEXAS TECH UNIVERSITY
SMS COOPERATIVE RESEARCH PROJECT

Rheologies and Free Waters should be run first to ensure the slurry is field mixable and does not contain excessive Free Water.

START-UP TEST MATRIX

CLASS C + RHEOLOGIES, FREE WATER AND FLUID LOSS, THICKENING TIMES AND COMPRESSIVE STRENGHTS TESTS

Density	Yield	Mix H2O	Slurry	SMS	Rheology							Free Water	Fluid loss	Thickening Times @ 110 F			Compressives @ 130F			
(PPG)	cuft/sx	gal/sx	**System**	(% BWOC)	600	300	200	100	6		3	Mls/2 Hr	cc/30 min	Departure	mins	74 Bc	8 hr	12 hr	24 hr	72 hr
14.2			**50/50/2%**		**106**	**72**	**59**	**45**	**19**	**16**	**16**	**1.20**						60	543.75	
14.2			**50/50**		**94**	**65**	**56**	**42**	**21**	**17**	**17**	**0.00**						**0**	**362.5**	
14.2			**50/50/2%**	0								**2.10**						60	543.75	
14.2			**50/50 + 0.5% SMS**	0.5	**110**	**87**	**74**	**61**	**37**	**28**	**28**	**2.00**						0	**750**	
14.2			**50/50 + 0.4% SMS**	0.4								**2.50**								
14.2			**50/50 + 0.3% SMS**	0.3								**2.20**								
14.2			**50/50 + 0.2% SMS**	0.2								**3.00**								
14.2			**50/50 + 0.1% SMS**	0.1								**3.50**								
14.2			**50/50/2 + 0.5% FI-25**	0									**1335**		216				750	
14.2			**50/50 + 0.5% SMS +0.5% FI-25**	0.5									**368**		199				**1937.5**	
14.2																				
14.2																				
14.2																				
14.2																				
14.2																				
Maximum									40		30	5.0 ml/2hr								
Minimum									5		4	None								

Table A.28 Summary of Test results for Class H Cement

TEXAS TECH UNIVERSITY
SMS COOPERATIVE RESEARCH PROJECT

Rheologies and Free Waters should be run first to ensure the slurry is field mixable and does not contain excessive Free Water.

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START-UP TEST MATRIX

CLASS H + RHEOLOGIES, FREE WATER AND FLUID LOSS, THICKENING TIMES AND COMPRESSIVE STRENGHTS TESTS

Density	Yield	Mix H2O	Slurry	SMS	Rheology							Free Water	Fluid loss	Thickening Times @ 110 F			Compressives @ 130F			
(PPG)	cuft/sx	gal/sx	**System**	(% BWOC)	600	300	200	100	6		3	Mls/2 Hr	cc/30 min	Departure	mins	74 Bc	8 hr	12 hr	24 hr	72 hr
14.2			**50/50/2%**		**56**	**31**	**23**	**16**	**3**	**16**	**2**	**6.50**						0	375	
14.2			**50/50**		**52**	**30**	**24**	**15**	**3**	**17**	**1**	**4.50**						**0**	**362.5**	
14.2			**50/50/2%**	0								**7.50**								
14.2			**50/50 + 0.5% SMS**	0.5								**2.50**								
14.2			**50/50 + 0.4% SMS**	0.4								**3.00**								
14.2			**50/50 + 0.3% SMS**	0.3								3.50								
14.2			**50/50 + 0.2% SMS**	0.2								2.80								
14.2			**50/50 + 0.1% SMS**	0.1								2.60								
				0								7.50								
14.2			**50/50/2 + 0.5% Fl-25**	0	51	29	22	15	4		2		1697.14			353		0	736.8421	
14.2			**50/50 + 0.5% SMS +0.5% Fl-25**	0.5	96	71	55	42	15		13		1009.09			251		263.1579	921.0526	
14.2																				
14.2																				
14.2																				
14.2																				
14.2																				
Maximum									40		30	5.0 ml/2hr								
Minimum									5		4	None								

Table A.29 Calculation Sheet for 0.5% SMS+ Class H Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.42	0.0856	0.036	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.739228
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.934	
KCL=	1.510		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.327		6.034	
Grand Total lb/sk =	142.49	Total gal/sk =	10.035	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.30 Calculation Sheet for 0.4% SMS+ Class H Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.336	0.0856	0.029	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.741922
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.926	
KCL=	1.511		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.354		6.037	
Grand Total lb/sk =	142.44	Total gal/sk =	10.031	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.31 Calculation Sheet for 0.3% SMS+ Class H Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.252	0.0856	0.036	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.739228
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.919	
KCL=	1.511		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.380		6.041	
Grand Total lb/sk =	142.38	Total gal/sk =	10.027	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.32 Calculation Sheet for 0.2% SMS+ Class H Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.168	0.0856	0.014	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.739228
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.912	
KCL=	1.511		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.406		6.044	
Grand Total lb/sk =	142.32	Total gal/sk =	10.023	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.33 Calculation Sheet for 0.1% SMS+ Class H Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.084	0.0856	0.007	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.750018
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.905	
KCL=	1.513		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.433		6.047	
Grand Total lb/sk =	142.26	Total gal/sk =	10.019	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.34 Calculation Sheet for 0.5% SMS+ Class C Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.42	0.0856	0.036	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.739228
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.934	
KCL=	1.510		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.327		6.034	
Grand Total lb/sk =	142.49	Total gal/sk =	10.035	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.35 Calculation Sheet for 0.4% SMS+ Class C Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.336	0.0856	0.029	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.741922
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.926	
KCL=	1.511		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.354		6.037	
Grand Total lb/sk =	142.44	Total gal/sk =	10.031	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.36 Calculation Sheet for 0.3% SMS+ Class C Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.252	0.0856	0.036	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.739228
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.919	
KCL=	1.511		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.380		6.041	
Grand Total lb/sk =	142.38	Total gal/sk =	10.027	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.37 Calculation Sheet for 0.2% SMS+ Class C Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.168	0.0856	0.014	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.739228
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.912	
KCL=	1.511		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.406		6.044	
Grand Total lb/sk =	142.32	Total gal/sk =	10.023	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.38 Calculation Sheet for 0.1% SMS+ Class C Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0.084	0.0856	0.007	
Cacl2	0	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.750018
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.65497918		3.905	
KCL=	1.513		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.433		6.047	
Grand Total lb/sk =	142.26	Total gal/sk =	10.019	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.39 Calculation Sheet for 2% Bentonite + Class C Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0	0.0856	0.000	
Cacl2	1.68	0.0612	0.103	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.6587121
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	91.91497918		4.000	
KCL=	1.523		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.777		6.088	
Grand Total lb/sk =	142.22	Total gal/sk =	10.156	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.40 Calculation Sheet for 2% Bentonite + Class H Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0	0.0856	0.000	
Cacl2	1.68	0.0612	0.103	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.6587121
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	91.91497918		4.000	
KCL=	1.523		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.777		6.088	
Grand Total lb/sk =	142.22	Total gal/sk =	10.156	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.41 Calculation Sheet for Pozzalon + Class C Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0	0.0856	0.000	
Cacl2	0.00	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.75272215
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.23497918		4.000	
KCL=	1.514		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.459		6.050	
Grand Total lb/sk =	142.21	Total gal/sk =	10.015	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

Table A.42 Calculation Sheet for Pozzalon+ Class H Intermediate Zone Slurry

Calculations

Material	Wt	ab vol gal/lb	vol gal/sk	
Cmt	84	0.0428	3.60	
sodium silicate	0	0.0856	0.000	
Cacl2	0.00	0.0612	0.000	
fl-25	0.42	0.0881	0.037	
Gel	5.781013807	0.0452	0.261	6.75272215
fp-6l	0.032976092	0.1213	0.004	
NACL% of Liquid Adds =	0.0000		0.000	
KCL% of Liquid Adds =	0.0010		0.000	
Subtotal H20 unknown =	90.23497918		4.000	
KCL=	1.514		0.067	
NACL=	0.000		0.000	
H20 Fresh or Sea =	50.459		6.050	
Grand Total lb/sk =	142.21	Total gal/sk =	10.015	

Calculation Check

Density =	14.20	Slurry SG =	1.703
Yield =	1.34	Grams of Slurry =	1021.58

APPENDIX B

PUBLICATIONS

SOUTH WEST PETROLEUM SHORT COURSE

Cost-effective Application & Incremental Improvements in 50:50 Poz Cementing Yields Enhanced Properties.

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Abstract

For nearly 50 years, admixtures of 50:50 Class H (or Class C): Pozzalon with 2% bentonite have functioned effectively worldwide as lightweight slurries for situations where heavier completion cements posed a risk of exceeding low fracture gradients in a particular wellbore. Pozzolanic materials are lightweight, and effectively combine with calcium hydroxide that is liberated during the hydration of Portland cement. Historically, the 2% bentonite has been utilized to assist in the specification of relatively high water-to cement ratios, and therefore lighter slurry density, without the generation of excessive free water as the cement progresses though the setting process. Though the bentonite has fulfilled the role quite well, it has two disadvantages: first, its presence in typical cement slurries reduces the effectiveness of a given concentration of most commercially available fluid loss additives. Second, while the 2% (by weight of cement) volume may seem of no consequence, the shipping costs associated with moving tons of the material over a long period of time can be significant.

A project was undertaken to determine whether or not there were other commercially available materials that could substitute for bentonite and yield improved slurry qualities at the same or reduced cost.

Extensive testing of 50:50 slurries revealed that small quantities of sodium metasilicate (on the order of 0.5% by weight of cement) could effectively replace bentonite. Free water was controlled to the same degree, and a synergy with a commonly available fluid loss additive was discovered, allowing either a) less total fluid loss additive for a given fluid loss control tolerance, or, b) better fluid loss control for a given concentration of fluid loss additive.

The testing is summarized, and relative economics associated with the systems are discussed

Introduction

Bentonite has been used as an extender for years in the oil service industry. In recent years it has become of great concern to look into better quality control, cost savings, superior slurry performance, improved handling and logistics that could improve operations and generate savings.

In the industry today, the 50:50 Class H (or Class C): Pozzalon with 2% bentonite has been used predominantly for the control of excessive free water in cement systems, However, there has been the problem of bentonite reducing the effectiveness of fluid loss additives and the cost of having to transport this material to site has been a reason to look at better options or a substitute. The ability to control free water has been a major concern in the industry, especially with the Class H cement which has an inherent free water problem at higher water ratios. This project attempted to control free water in both class H and C, and also increase the functionality of fluid loss for given concentrations of additives.

Operational Constraints: These are slurry design criteria imposed to optimize the cost and quality of the cement slurry in the field. Slurry viscosity, thickening time, fluid loss and free water are the three major operational constraints employed in this project.

1. **Slurry Viscosity**: This shows the ease with which slurry can be pumped down hole. Slurries that are difficult to mix can result in operational problems in the field. Previous studies have indicated that rheologies greater than 40 at 6 rpm and 30 at 3 rpm may indicate the potential for field mixing problems. Rheologies less than 5 at 6 rpm and 4 at 3 rpm may indicate solids separation and excessive free water. The sodium metasilicate concentration impacts slurry viscosity. Figure 3 shows the effect of sodium silicate on the rheology of the cement slurry for class H and figure 4 shows for class C.
2. **Thickening Time**: Slurry thickening time must correlate to actual planned pumping time, and must fall within reasonable industry standards. It impacts both cost and cement quality. This study was able to match through the heat equation; reasonable temperature profiles of the two slurries with time using the consistometers, showing time required to thicken (this is shown in Fig 6 of the appendix). The Consistometer used was assumed to be at ambient temperature at the beginning of the test and gradual increase in the temperature was recorded to fit the desired profile expected from the correlation. The derivation of the heat equation and plot is also in the appendix. Thickening times less than 2 hours are generally too short, and can significantly increase the risk of premature cement setting prior to proper placement; while thickening times greater that 6 hours are generally to long, leading to extended compressive strength development and/or formation fluid migration problems.
3. **Fluid Loss:** The rate at which slurry loses water to porous media at different pressures is important, as this allows for proper selection of slurries at different pressure and depths. A high fluid loss is often inversely proportional to the thickening time. When fluid leaks out of the slurry quickly, it viscosifies faster, and can lead to a shorter thickening time. Many fluid loss additive retard thickening time, and accelerators are often utilized in conjuction with these additives in order to shorten thickening time to an acceptable level at low bottomhole temperatures.
4. **Free water**: An objective of the project was to build the new slurry with the same control of free water as was observed in conventional slurries containing bentonite. Excessive free water can lead to “pockets” of water in the annular space between pipe and formation, and subsequent channeling and/or poor bonds.

Testing Equipment

The testing equipment used meets API 10B 22nd Edition, Dec 1997, and includes:

1. Pressurized Consistometer Unit
2. Rotor-bob type Rheometers
3. Free water testing apparatus
4. Compressive strength testing equipment
5. Atmospheric Pressure Consistometer Torque indicator
6. Fluid loss filters Press.

History of Development and Results

The need for sulfate resistance and light weight slurries in the Permian and Mid-continent Basins has led to the dominant use of API Class C for shallow and intemediate-depth cementing operations, and was a major consideration in the selection of the cement class used in this project, though Class H was also tested for consistency and possibility of use at these same depths.

Initial testing reveals that use of API Class H + fresh water without sufficient concentrations of extender yields unacceptable free water and thickening times. Figs. 2 & 5 show the relationship between free water and SMS concentrations.

Subsequent tests reflect a free water level under the tolerance point of 5.0ml/2hrs. The main challenge in determining better slurry than the bentonitic slurry was to determine the amount of SMS that would yield the same or better properties and optimum results in terms of total system cost and quality than the original slurry. This was accomplished by trial and error, until the best concentration possible was determined. Fresh water was used along with 2% BWOW NaCl.

The class C cement tests are shown in figure 5. For different concentrations of the SMS, they were all below the tolerance value, but other tests carried out for thickening time, fluid loss, compressive strength and rheology shows 0.5% SMS having better values of this slurry properties than the bentonitic slurry.

A basic cement slurry design specification for intermediate cementing operations was developed using a SMS system. Table 2 shows the complete slurry design data. The Class C Cement shows very good results for all the tests carried out on for the SMS slurry, making it comparable to the bentonite system, it gives a better thickening time, compressive strength, rheology and free water for the tests carried out. The class H cements shows the SMS system having better controlled free water than the bentonitic system, and showed better thickening time and compressive strength.

The economics of using any of this system, either for class C or H is strongly dependent on the type of job being done. But generally, the SMS system has proved to be economically more viable than the Gel system.

Fiscal Comparison

A typical 50:50 Class C:Poz + 0.5% sodium metasilicate + 0.5% dispersing fluid loss additive, mixed at 14.2 lb/gal; in order to match the fluid loss performance of the system, a conventional 50:50 Class C + 2% bentonite, would need an additional 0.3% dispersing fluid loss additive. Under many circumstances, this additional amount would also retard the slurry so much that the long thickening times would be unacceptable and the designer would probably add a small amount of salt to lower thickening time a bit.

February 2005 typical costs for 785 ft3 of wet slurry for the bentonitic system would be $9,578.64, and for the sodium metasilicate system, $8,748.92. This is approximately 9.5% more for the bentonitic system, showing a sharp reduction in cost.

For class H, the savings are similar $9,593.19 compared to for the SMS with $8,764.14; which again equates to a about a 9.5% differential.

Conclusions

The following conclusions were arrived at:

1. Economics of using SMS are relatively comparable to current use of Bentonite system for most jobs.
2. Basic slurry design data are presented.
3. Additive concentration tolerances are improved when SMS additives are used.

Recommendations for Further Investigation

1. Examination of multiple waters with various salts.
2. The use of sodium silicate as an extender in casing strings subsequent to the intermediate pipe. (Phase 3)
3. Closer examination of process control – (Phase 3)
4. Substitution of NaCl with $CaCl_2$

Nomenclature

t = Time of heat dispersion, sec

L = Length of rod, meters

K_1 = *temperature of rod at first end,* ^{0}C

K_2 = *temperature of rod at end,* ^{0}C

k = Thermal conductivity of rod, cal/cm - sec - ^{0}C

ρ = Density of rod, g/cm^3

c = Thermal Capacity of rod, cal/g ^{0}C

References

1. Specification for Materials and Testing for Well Cements. API Specification 10 (Spec 10) Fourth Edition, August 1,1988
2. Casing, Cementing, Drilling, and Completion Requirements. TRRC Rule 13, August 13, 1991
3. Grant, W.H., Rutledge, J.R., and Christy, R.H. "Field Limitations of Liquid-Additive Cementing Systems" SPE 18616, 1989
4. Gerke, R.R., "A Study of Bulk Cement Handling and Testing Procedures" SPE 14196, Las Vegas, September 1985
5. Liquid Sodium Silicate Cement Research Project, Texas Tech University, "Liquid Additives Control Cement Slurry Properties" SPE 2003.December, 2002

Appendix A

The consistometer is made up of Homogenous material with a
laterally insulated (1-D flow in the x-direction) medium and thin rod (Temperature $U(x,t)$)at all pints of the cross-section is constant and using the Parabolic Heat Equation. With Conditions at the boundary being:

$$U_t = \alpha^2 U_{xx}$$

$$\alpha^2 = \kappa / c\rho$$

$$U(0,t) = \kappa_1 \qquad 0 < t < \infty$$

$$U(L,t) = \kappa_2$$

Initial Condition

$$U(x,0) = \psi(x) \qquad 0 \le x \le L$$

The given system is a composite heat flow and consisting of the general solution which can be expressed as the sum of the steady state system and the transient state system.

$$U(x,t) = w(x) + u(x,t) \ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots..1$$

Where

$U(x,t)$ = The general solution to the given composite system
$w(x)$ = The steady state component of the general solution
$u(x,t)$ = The transient state component of the general solution

$$w(x) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$U(x,t) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L} + u(x,t)$$

The given PDE, boundary conditions, and initial conditions have been transformed into the following PDE and boundary conditions:

$$u(0,t) = 0 \qquad 0 < t < \infty$$

$$u(L,t) = 0$$

And the initial Condition becomes

$$u(x,0) = \psi(x) - w(x) \qquad 0 \le x \le L$$

Solving for the transient part gives:

$$u(x,t) = \kappa_1 \exp\left(-\frac{\alpha^2 \lambda^2 t}{L^2}\right) * \left(B_1 \sin\left(\frac{\lambda x}{L}\right) + B_2 \cos\left(\frac{\lambda x}{L}\right)\right)$$

$$u(x,t) = \exp\left(-\frac{\alpha^2\lambda^2 t}{L^2}\right) * \left(B\sin\left(\frac{\lambda x}{L}\right) + C\cos\left(\frac{\lambda x}{L}\right)\right)$$

Applying the Boundary conditions gives:

$$u(x,t) = \sum_{n=1}^{\infty} \exp\left(-\frac{\alpha^2 n^2 \pi^2 t}{L^2}\right) * B_n \sin\left(\frac{n\pi x}{L}\right)$$

And applying initial conditions gives

$$u(x,t) = \sum_{n=1}^{\infty} B_n \sin\left(\frac{n\pi x}{L}\right) = \phi(x) - w(x)$$

Using Fourier Orthogonality properties

$$B_n = 2\int_0^L (\psi(x) - w(x))\sin\left(\frac{n\pi x}{L}\right)dx$$

From Equation 1

$$U(x,t) = w(x) + u(x,t)$$

$$U(x,t) = w(x) + \sum_{n=1}^{\infty} \exp\left(\frac{\alpha^2 n^2 \pi^2 t}{L^2}\right) * B_n \sin\left(\frac{n\pi x}{L}\right)$$

Where

$$B_n = 2\int_0^L (\psi(x) - w(x))\sin\left(\frac{n\pi x}{L}\right)dx$$

$$w(x) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L}$$

Table 1: TRRC Specifications, Rule13

Extender Slurry		
Duration (Hours)		
Compressive Strength (Psi)		
Tail Slurry		
Duration (Hours)		
Compressive Strength (Psi)		

API Free Water (ml/2hrs)	6

Table 2: Slurry Design Data

Class C Cement		
	50:50 2% Gel	**50:50: 0. 5% SMS**
Slurry Specification	**API Class C,14.2ppg + 14.2ppg + 2% NaCl**	**API Class C , 14.20ppg + 14.2ppg (SMS) + 2% NaCl**
600rpm	102	110
300rpm	72	87
200rpm	59	74
100rpm	45	61
6rpm	19	37
3rpm	16	28
API Free Water, ml/2hrs	2.1	2.0
Thickening Time (74Bc)	3hrs, 36mins	3hrs, 19mins
8hrs	N/A	N/A
12hrs	60psi	0psi
24hrs	750psi	1938psi
Fluid Loss, cc/30mins	I335	368
Class H Cement		
	50:50 2% Gel	**50:50: 0. 5% SMS**
Slurry Specification	**API Class H,14.2ppg + 14.2ppg + 2% NaCl**	**API Class H , 14.20ppg + 14.2ppg (SMS) + 2% NaCl**
600rpm	51	96
300rpm	29	71
200rpm	22	55
100rpm	15	42
6rpm	4	15
3rpm	2	13
API Free Water, ml/2hrs	6.5	2.5
Thickening Time (74Bc)	5hrs, 53mins	4hrs, 11mins
8hrs	N/A	N/A
12hrs	0psi	263psi
24hrs	737psi	921psi
Fluid Loss cc/30mins	1697.14	1009.09

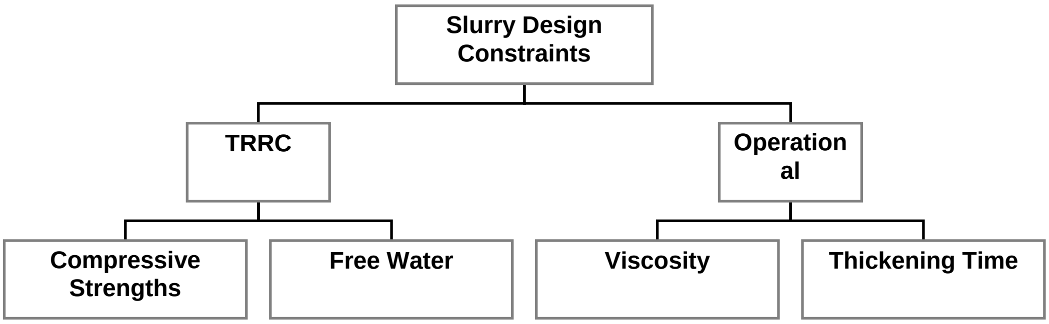

Figure 1. Chart of Slurry Design Constraints

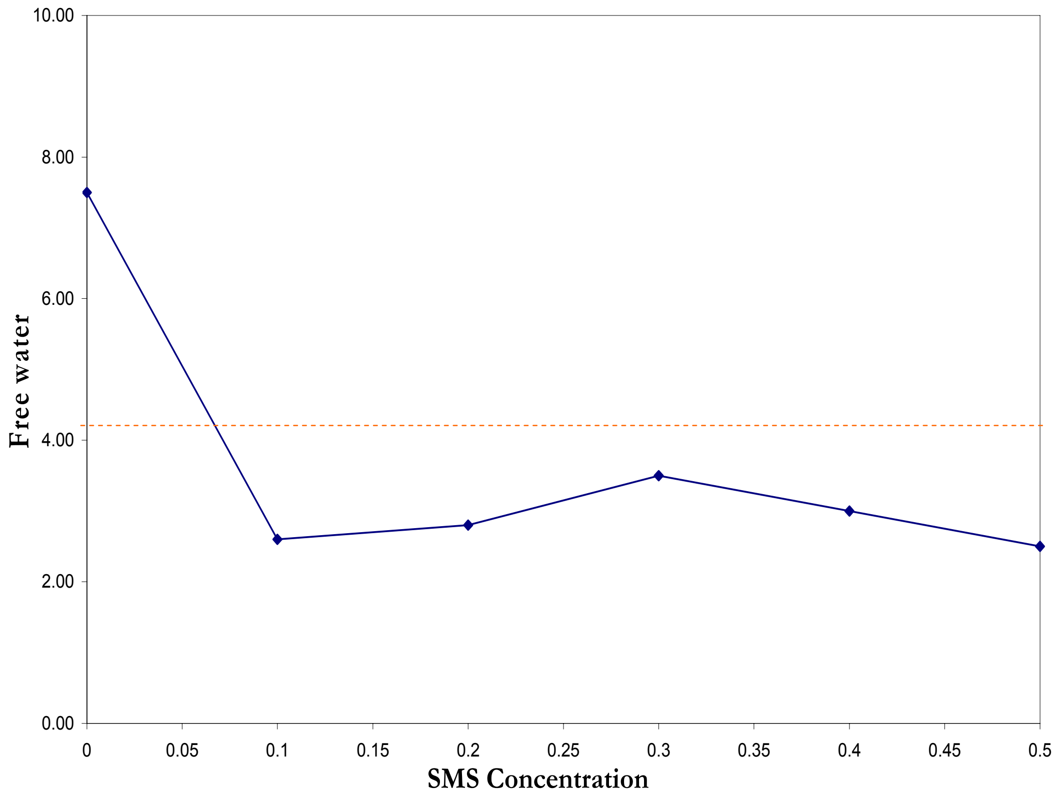

Figure 2 Curve of Free Water vs SMS Concentration
API Class H 14.2ppg) fresh water mixing

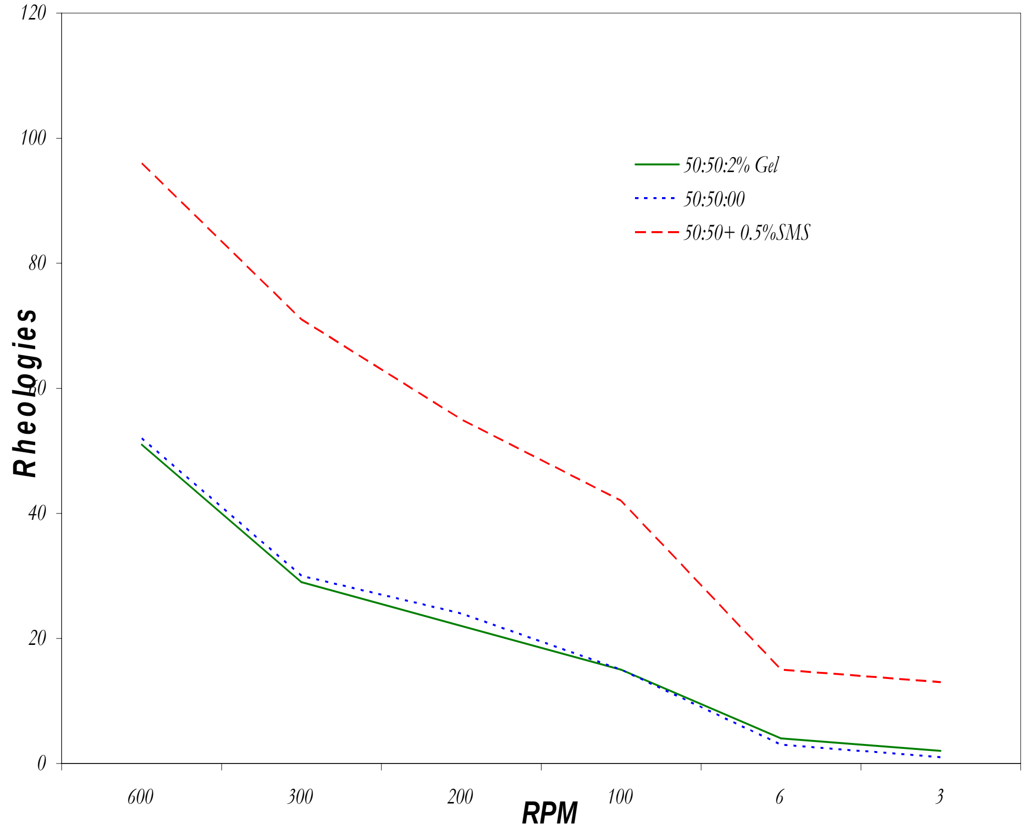

Figure 3 Correlations between Slurry Rheology and RPM
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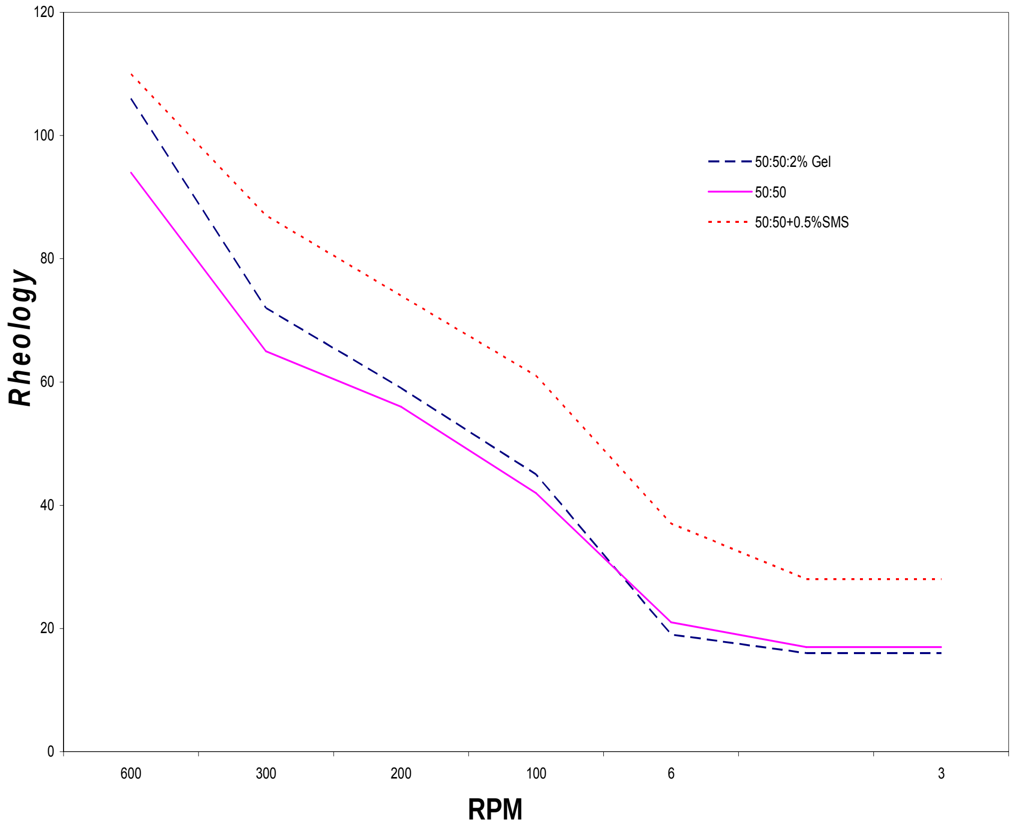

Figure 4 Correlations between Slurry Rheology and RPM
API Class C 14.2ppg fresh water mixing

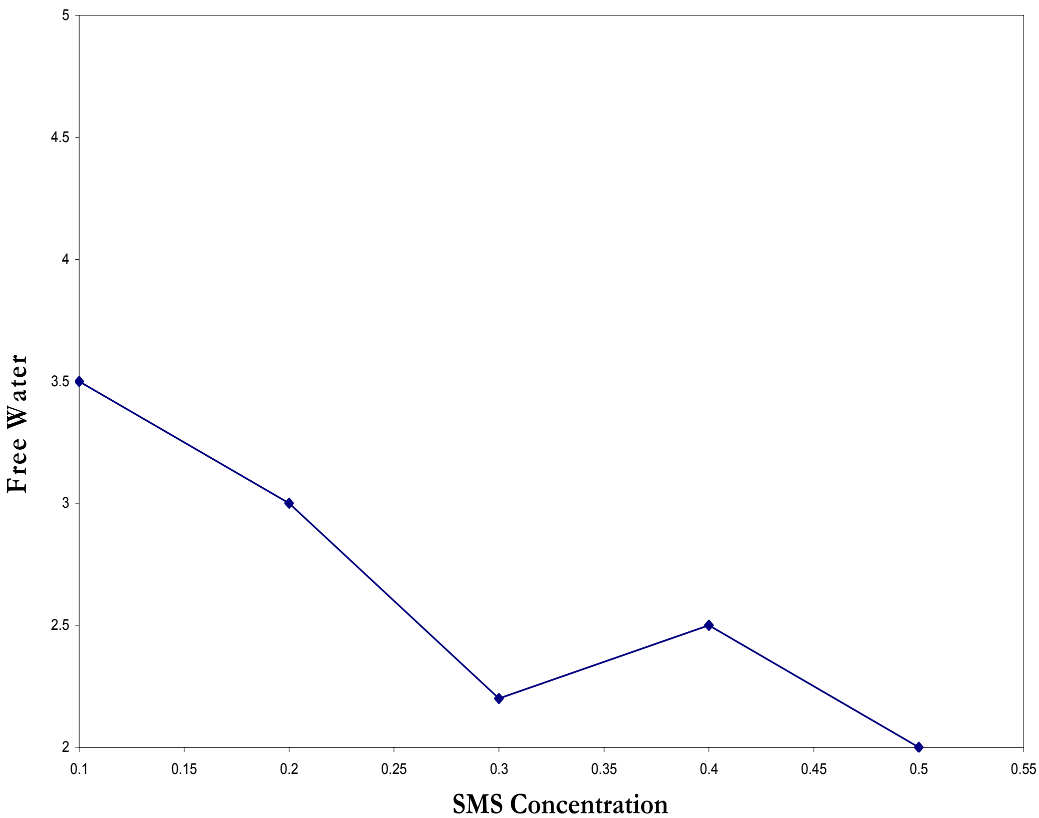

Figure 5: Curve of Free Water vs SMS Concentration
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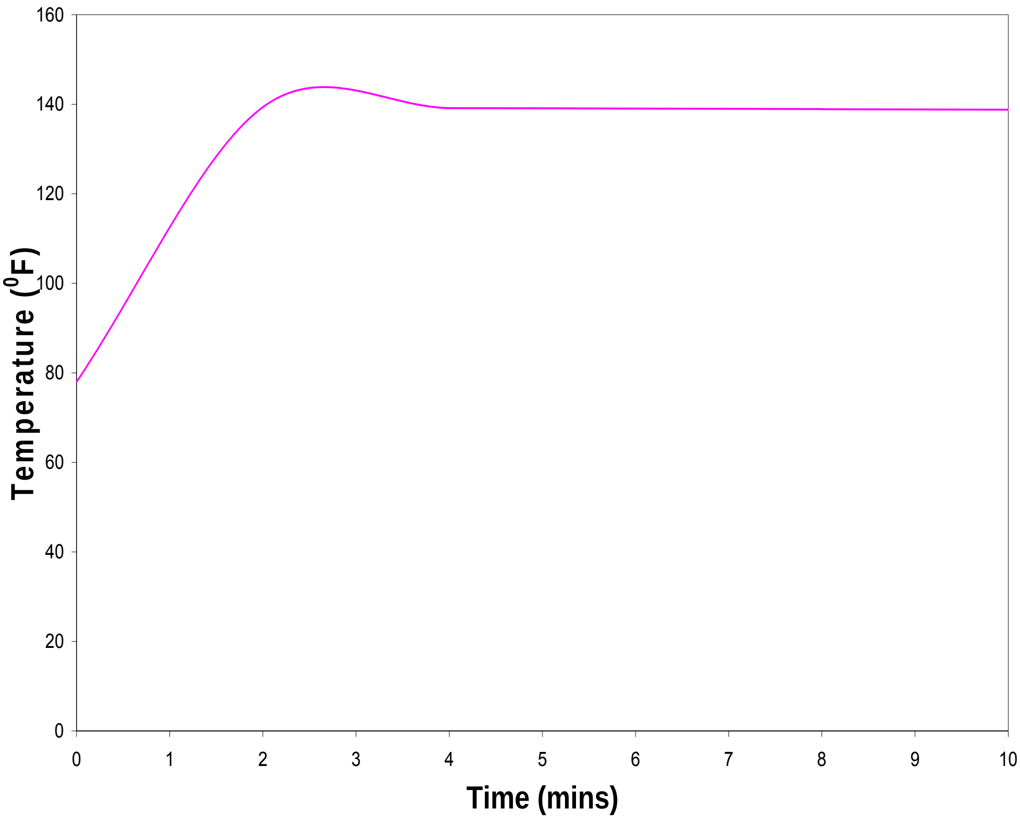

Figure 6 Variation of Temperature with Time

SPE 94327

Incremental Improvements in 50:50 Poz Cementing Yields Enhanced Properties & Cost-effective Application.

Fasesan, O.A, Heinze, L.R Texas Tech University, SPE;
Walser, D.W B.J. Services USA, SPE

This paper was prepared for presentation at the 2005 SPE Production and Operations Symposium held in Oklahoma City, OK, U.S.A., 17 – 19 April 2005.

Abstract

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A project was undertaken to determine whether or not there were other commercially available materials that could substitute for bentonite and yield improved slurry qualities at the same or reduced cost.

Extensive testing of 50:50 slurries revealed that small quantities of sodium metasilicate (on the order of 0.5% by weight of cement) could effectively replace bentonite. Free water was controlled to the same degree, and a synergy with a commonly available fluid loss additive was discovered, allowing either a) less total fluid loss additive for a given fluid loss control tolerance, or, b) better fluid loss control for a given concentration of fluid loss additive.

The testing is summarized, and relative economics associated with the systems are discussed

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concentration impacts slurry viscosity. Figure 3 shows the effect of sodium silicate on the rheology of the cement slurry for class H and figure 4 shows for class C.

2. **Thickening Time**: Slurry thickening time must correlate to actual planned pumping time, and must fall within reasonable industry standards. It impacts both cost and cement quality. This study was able to match through the heat equation; reasonable temperature profiles of the two slurries with time using the consistometers, showing time required to thicken (this is shown in Fig 6 of the appendix). The Consistometer used was assumed to be at ambient temperature at the beginning of the test and gradual increase in the temperature was recorded to fit the desired profile expected from the correlation. The derivation of the heat equation and plot is also in the appendix. Thickening times less than 2 hours are generally too short, and can significantly increase the risk of premature cement setting prior to proper placement; while thickening times greater that 6 hours are generally to long, leading to extended compressive strength development and/or formation fluid migration problems.
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2. Rotor-bob type Rheometers
3. Free water testing apparatus
4. Compressive strength testing equipment
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6. Fluid loss filters Press.

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The need for sulfate resistance and light weight slurries in the Permian and Mid-continent Basins has led to the dominant use of API Class C for shallow and intemediate-depth cementing operations, and was a major consideration in the selection of the cement class used in this project, though Class H was also tested for consistency and possibility of use at these same depths.

Initial testing reveals that use of API Class H + fresh water without sufficient concentrations of extender yields unacceptable free water and thickening times. Figs. 2 & 5 show the relationship between free water and SMS concentrations.

Subsequent tests reflect a free water level under the tolerance point of 5.0ml/2hrs. The main challenge in determining better slurry than the bentonitic slurry was to determine the amount of SMS that would yield the same or better properties and optimum results in terms of total system cost and quality than the original slurry. This was accomplished by trial and error, until the best concentration possible was determined. Fresh water was used along with 2% BWOW NaCl.

The class C cement tests are shown in figure 5. For different concentrations of the SMS, they were all below the tolerance value, but other tests carried out for thickening time, fluid loss, compressive strength and rheology shows 0.5% SMS having better values of this slurry properties than the bentonitic slurry.

A basic cement slurry design specification for intermediate cementing operations was developed using a SMS system. Table 2 shows the complete slurry design data. The Class C Cement shows very good results for all the tests carried out on for the SMS slurry, making it comparable to the bentonite system, it gives a better thickening time, compressive strength, rheology and free water for the tests carried out. The class H cements shows the SMS system having better controlled free water than the bentonitic system, and showed better thickening time and compressive strength.

The economics of using any of this system, either for class C or H is strongly dependent on the type of job being done. But generally, the SMS system has proved to be economically more viable than the Gel system.

Fiscal Comparison

A typical 50:50 Class C:Poz + 0.5% sodium metasilicate + 0.5% dispersing fluid loss additive, mixed at 14.2 lb/gal; in order to match the fluid loss performance of the system, a conventional 50:50 Class C + 2% bentonite, would need an additional 0.3% dispersing fluid loss additive. Under many circumstances, this additional amount would also retard the slurry so much that the long thickening times would be unacceptable and the designer would probably add a small amount of salt to lower thickening time a bit.

February 2005 typical costs for 785 ft3 of wet slurry for the bentonitic system would be $9,578.64, and for the sodium metasilicate system, $8,748.92. This is approximately 9.5% more for the bentonitic system, showing a sharp reduction in cost.

For class H, the savings are similar $9,593.19 compared to for the SMS with $8,764.14; which again equates to a about a 9.5% differential.

Conclusions

The following conclusions were arrived at:

1. Economics of using SMS are relatively comparable to current use of Bentonite system for most jobs.
2. Basic slurry design data are presented.
3. Additive concentration tolerances are improved when SMS additives are used.

Recommendations for Further Investigation

1. Examination of multiple waters with various salts.
2. The use of sodium silicate as an extender in casing strings subsequent to the intermediate pipe. (Phase 3)
3. Closer examination of process control – (Phase 3)
4. Substitution of NaCl with $CaCl_2$

Nomenclature

t = Time of heat dispersion, sec

L = Length of rod, meters

K_1 = *temperature of rod at first end,* ^{0}C

K_2 = *temperature of rod at end,* ^{0}C

k = Thermal conductivity of rod, cal/cm - sec - ^{0}C

ρ = Density of rod, g/cm^3

c = Thermal Capacity of rod, cal/g ^{0}C

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Appendix A

The consistometer is made up of Homogenous material with a
laterally insulated (1-D flow in the x-direction) medium and thin rod (Temperature $U(x,t)$)at all pints of the cross-section is constant and using the Parabolic Heat Equation. With Conditions at the boundary being:

$$U_t = \alpha^2 U_{xx}$$

$$\alpha^2 = \kappa / c\rho$$

$$U(0,t) = \kappa_1 \qquad 0 < t < \infty$$

$$U(L,t) = \kappa_2$$

Initial Condition

$$U(x,0) = \psi(x) \qquad 0 \le x \le L$$

The given system is a composite heat flow and consisting of the general solution which can be expressed as the sum of the steady state system and the transient state system.

$$U(x,t) = w(x) + u(x,t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where

$U(x,t)$ = The general solution to the given composite system
$w(x)$ = The steady state component of the general solution
$u(x,t)$ = The transient state component of the general solution

$$w(x) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$U(x,t) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L} + u(x,t)$$

The given PDE, boundary conditions, and initial conditions have been transformed into the following PDE and boundary conditions:

$$u(0,t) = 0 \qquad 0 < t < \infty$$

$$u(L,t) = 0$$

And the initial Condition becomes

$$u(x,0) = \psi(x) - w(x) \qquad 0 \le x \le L$$

Solving for the transient part gives:

$$u(x,t) = \kappa_1 \exp\left(-\frac{\alpha^2\lambda^2 t}{L^2}\right) * \left(B_1 \sin\left(\frac{\lambda x}{L}\right) + B_2 \cos\left(\frac{\lambda x}{L}\right)\right)$$

$$u(x,t) = \exp\left(-\frac{\alpha^2\lambda^2 t}{L^2}\right) * \left(B\sin\left(\frac{\lambda x}{L}\right) + C\cos\left(\frac{\lambda x}{L}\right)\right)$$

Applying the Boundary conditions gives:

$$u(x,t) = \sum_{n=1}^{\infty} \exp\left(-\frac{\alpha^2 n^2 \pi^2 t}{L^2}\right) * B_n \sin\left(\frac{n\pi x}{L}\right)$$

And applying initial conditions gives

$$u(x,t) = \sum_{n=1}^{\infty} B_n \sin\left(\frac{n\pi x}{L}\right) = \phi(x) - w(x)$$

Using Fourier Orthogonality properties

$$B_n = 2\int_0^L (\psi(x) - w(x)) \sin\left(\frac{n\pi x}{L}\right) dx$$

From Equation 1

$$U(x,t) = w(x) + u(x,t)$$

$$U(x,t) = w(x) + \sum_{n=1}^{\infty} \exp\left(\frac{\alpha^2 n^2 \pi^2 t}{L^2}\right) * B_n \sin\left(\frac{n\pi x}{L}\right)$$

Where

$$B_n = 2\int_0^L (\psi(x) - w(x)) \sin\left(\frac{n\pi x}{L}\right) dx$$

$$w(x) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L}$$

Table 1: TRRC Specifications, Rule13

Extender Slurry		
Duration (Hours)	12	24
Compressive Strength (Psi)	100	250
Tail Slurry		
Duration (Hours)	12	72
Compressive Strength (Psi)	500	1200
API Free Water (ml/2hrs)	6	

Table 2: Slurry Design Data

Class C Cement		
	50:50 2% Gel	**50:50: 0. 5% SMS**
Slurry Specification	**API Class C,14.2ppg + 14.2ppg + 2% NaCl**	**API Class C , 14.20ppg + 14.2ppg (SMS) + 2% NaCl**
600rpm	102	110
300rpm	72	87
200rpm	59	74
100rpm	45	61
6rpm	19	37
3rpm	16	28
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Thickening Time (74Bc)	3hrs, 36mins	3hrs, 19mins
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Fluid Loss, cc/30mins	I335	368
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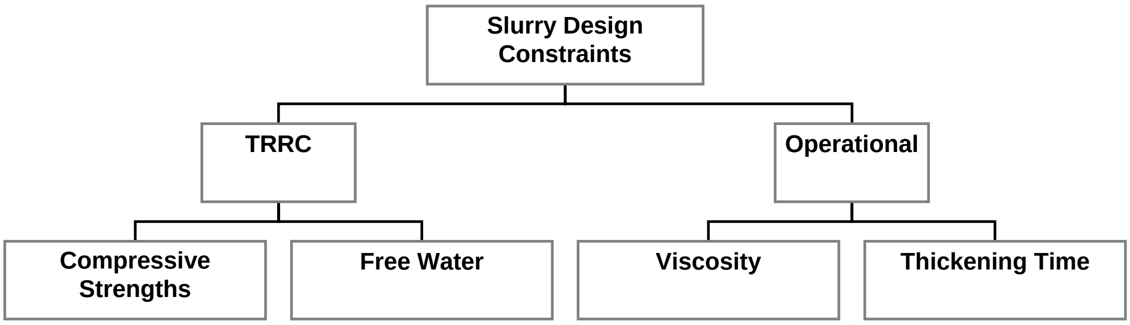
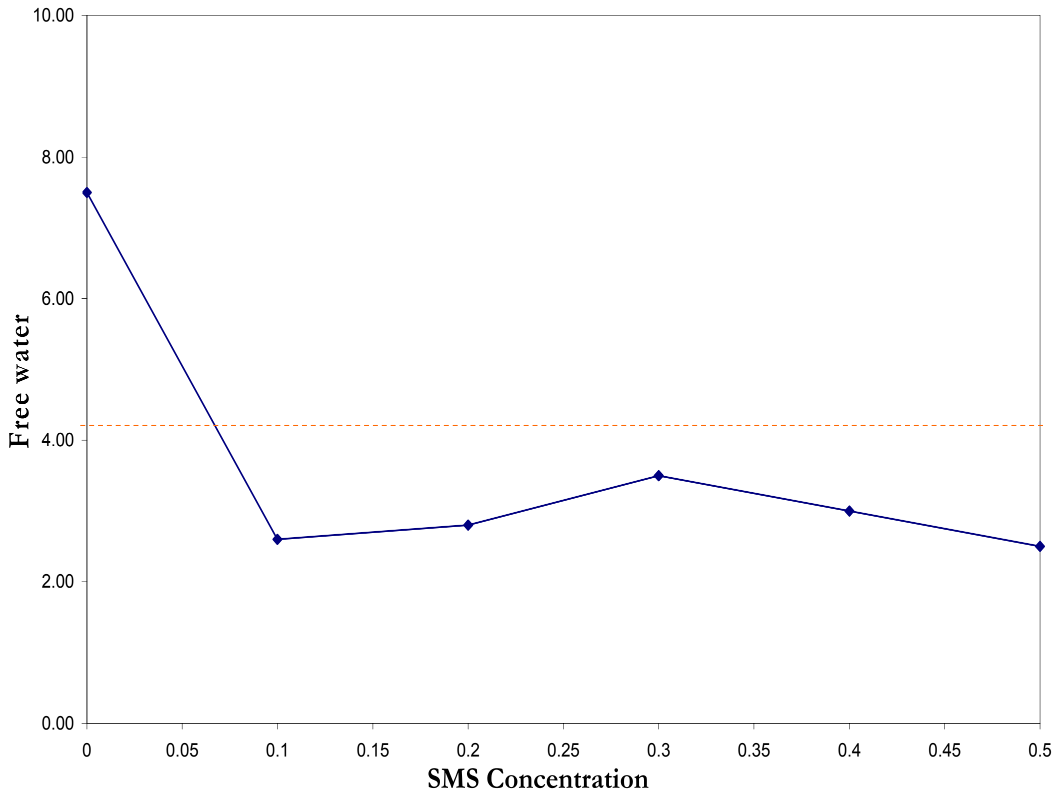


Figure 1: Chart of Slurry Design Constraints



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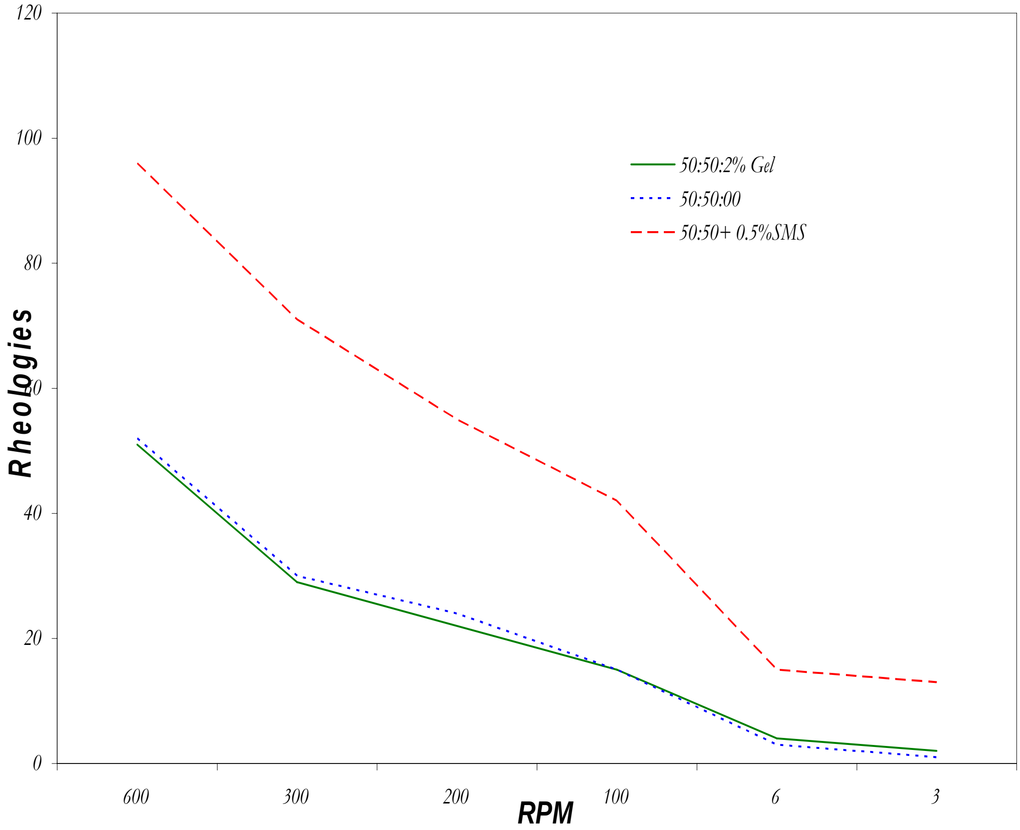
API Class H 14.2ppg) fresh water mixing



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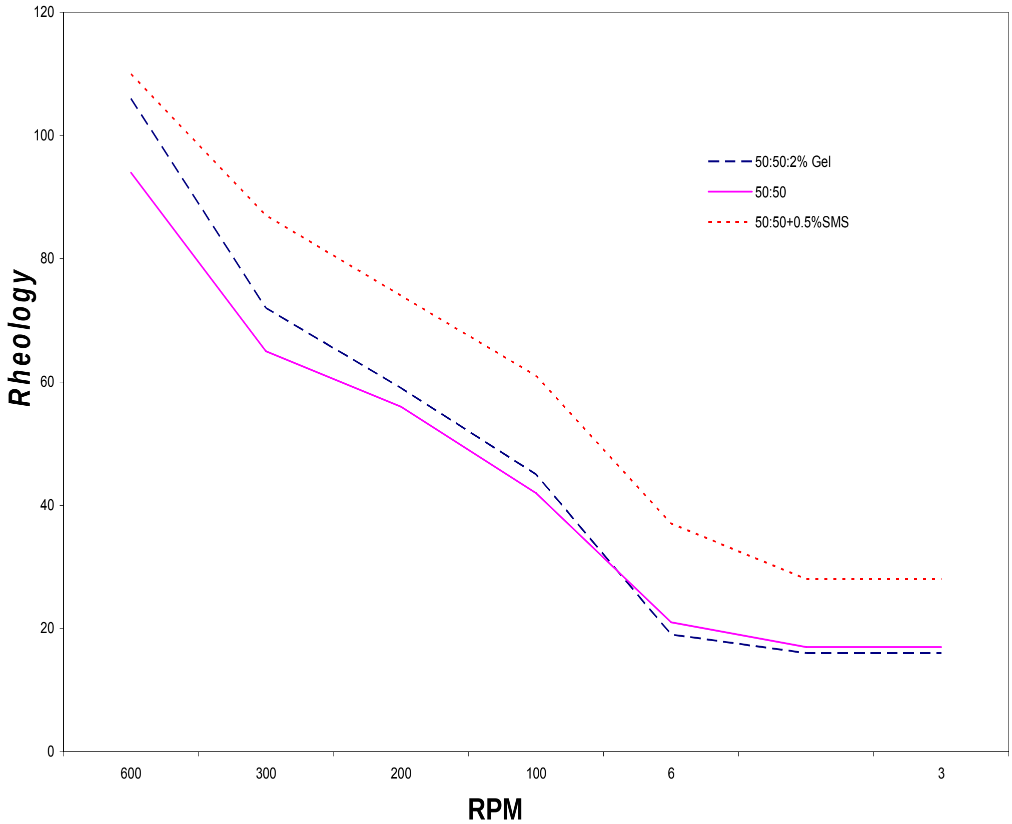

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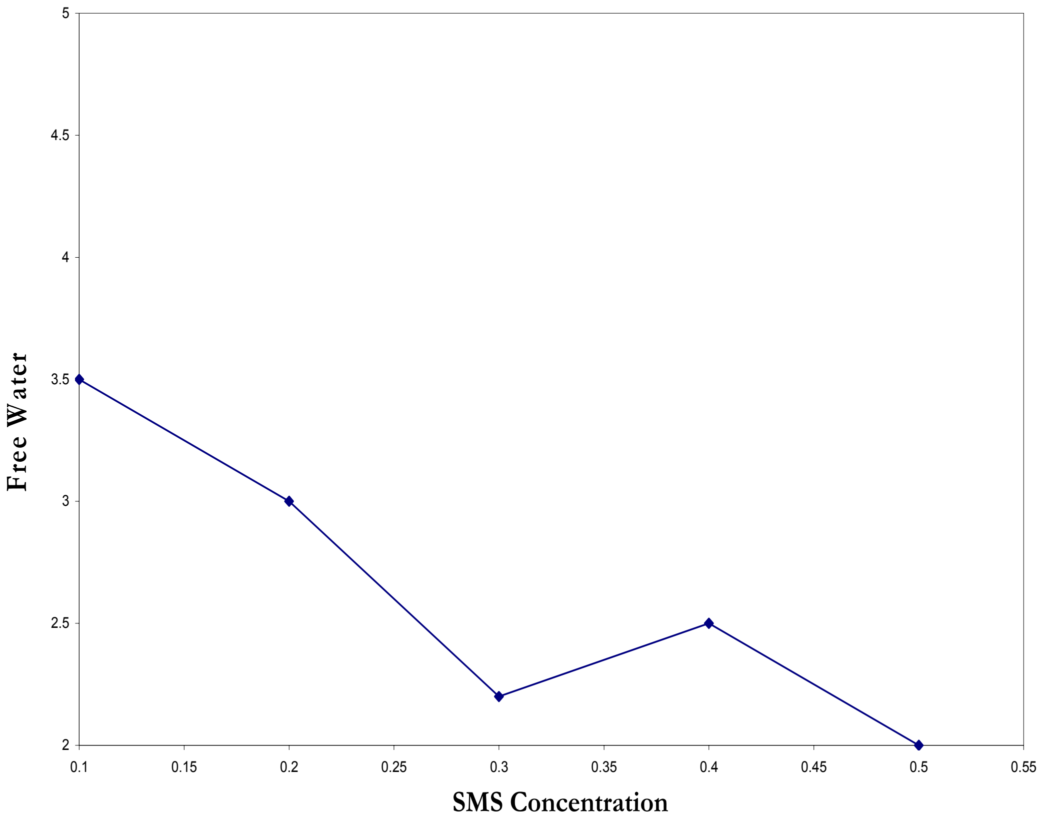

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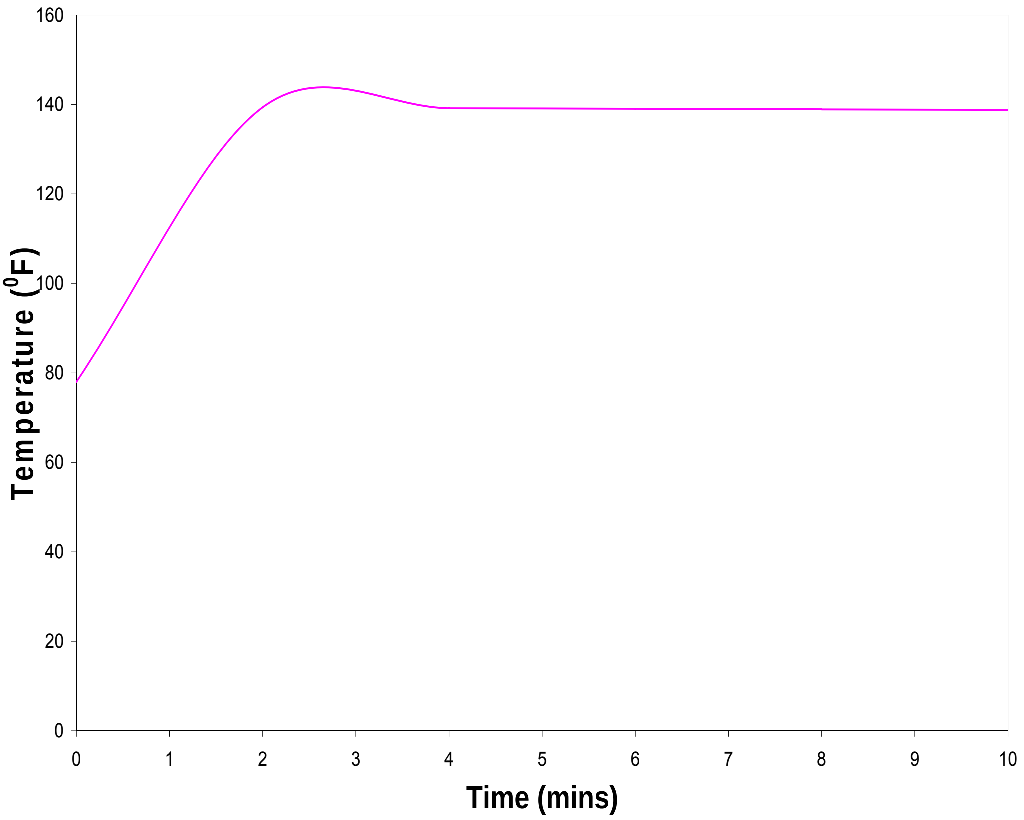

Figure 6 Variation of Temperature with Time

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*PAPER 2005-***201**

CANADIAN INTERNATIONAL
PETROLEUM CONFERENCE

Enhanced Properties & Cost-effective Application with incremental Improvements in 50:50 Poz Cementing

FASESAN, O.A, HEINZE, L.R
Texas Tech University

DOUG.W WALSER
B.J. Services USA

This paper is to be presented at the Petroleum Society's 6th Canadian International Petroleum Conference (56th Annual Technical Meeting), Calgary, Alberta, Canada, June 7 – 9, 2005. Discussion of this paper is invited and may be presented at the meeting if filed in writing with the technical program chairman prior to the conclusion of the meeting. This paper and any discussion filed will be considered for publication in Petroleum Society journals. Publication rights are reserved. This is a pre-print and subject to correction.

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Appendices

The consistometer is made up of Homogenous material with a
laterally insulated (1-D flow in the x-direction) medium and thin rod (Temperature $U(x,t)$)at all pints of the cross-section is constant and using the Parabolic Heat Equation. With Conditions at the boundary being:

$$U_t = \alpha^2 U_{xx}$$

$$\alpha^2 = \kappa / c\rho$$

$$U(0,t) = \kappa_1 \qquad 0 < t < \infty$$

$$U(L,t) = \kappa_2$$

Initial Condition

$$U(x,0) = \psi(x) \qquad 0 \le x \le L$$

The given system is a composite heat flow and consisting of the general solution which can be expressed as the sum of the steady state system and the transient state system.

$$U(x,t) = w(x) + u(x,t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where

$U(x,t)$ = The general solution to the given composite system
$w(x)$ = The steady state component of the general solution
$u(x,t)$ = The transient state component of the general solution

$$w(x) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$U(x,t) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L} + u(x,t)$$

The given PDE, boundary conditions, and initial conditions have been transformed into the following PDE and boundary conditions:

$$u(0,t) = 0 \qquad 0 < t < \infty$$

$$u(L,t) = 0$$

And the initial Condition becomes

$$u(x,0) = \psi(x) - w(x) \qquad 0 \le x \le L$$

Solving for the transient part gives:

$$u(x,t) = \kappa_1 \exp\left(-\frac{\alpha^2 \lambda^2 t}{L^2}\right) * \left(B_1 \sin\left(\frac{\lambda x}{L}\right) + B_2 \cos\left(\frac{\lambda x}{L}\right)\right)$$

$$u(x,t) = \exp\left(-\frac{\alpha^2 \lambda^2 t}{L^2}\right) * \left(B \sin\left(\frac{\lambda x}{L}\right) + C \cos\left(\frac{\lambda x}{L}\right)\right)$$

Applying the Boundary conditions gives:

$$u(x,t) = \sum_{n=1}^{\infty} \exp\left(-\frac{\alpha^2 n^2 \pi^2 t}{L^2}\right) * B_n \sin\left(\frac{n\pi x}{L}\right)$$

And applying initial conditions gives

$$u(x,t) = \sum_{n=1}^{\infty} B_n \sin\left(\frac{n\pi x}{L}\right) = \phi(x) - w(x)$$

Using Fourier Orthogonality properties

$$B_n = 2\int_0^L (\psi(x) - w(x)) \sin\left(\frac{n\pi x}{L}\right) dx$$

From Equation 1

$$U(x,t) = w(x) + u(x,t)$$

$$U(x,t) = w(x) + \sum_{n=1}^{\infty} \exp\left(\frac{\alpha^2 n^2 \pi^2 t}{L^2}\right) * B_n \sin\left(\frac{n\pi x}{L}\right)$$

Where

$$B_n = 2\int_0^L (\psi(x) - w(x)) \sin\left(\frac{n\pi x}{L}\right) dx$$

$$w(x) = \kappa_1 + \frac{x(\kappa_2 - \kappa_1)}{L}$$

Table 1: TRRC Specifications, Rule13

Extender Slurry		
Duration (Hours)	12	24
Compressive Strength (Psi)	100	250
Tail Slurry		
Duration (Hours)	12	72
Compressive Strength (Psi)	500	1200

API Free Water (ml/2hrs)	6

Table 2: Slurry Design Data

Class C Cement		
	50:50 2% Gel	**50:50: 0. 5% SMS**
Slurry Specification	**API Class C,14.2ppg + 14.2ppg + 2% NaCl**	**API Class C , 14.20ppg + 14.2ppg (SMS) + 2% NaCl**
600rpm	102	110
300rpm	72	87
200rpm	59	74
100rpm	45	61
6rpm	19	37
3rpm	16	28
API Free Water, ml/2hrs	2.1	2.0
Thickening Time (74Bc)	3hrs, 36mins	3hrs, 19mins
8hrs	N/A	N/A
12hrs	60psi	0psi
24hrs	750psi	1938psi
Fluid Loss, cc/30mins	I335	368
Class H Cement		
	50:50 2% Gel	**50:50: 0. 5% SMS**
Slurry Specification	**API Class H,14.2ppg + 14.2ppg + 2% NaCl**	**API Class H , 14.20ppg + 14.2ppg (SMS) + 2% NaCl**
600rpm	51	96
300rpm	29	71
200rpm	22	55
100rpm	15	42
6rpm	4	15
3rpm	2	13
API Free Water, ml/2hrs	6.5	2.5
Thickening Time (74Bc)	5hrs, 53mins	4hrs, 11mins
8hrs	N/A	N/A
12hrs	0psi	263psi
24hrs	737psi	921psi
Fluid Loss cc/30mins	1697.14	1009.09

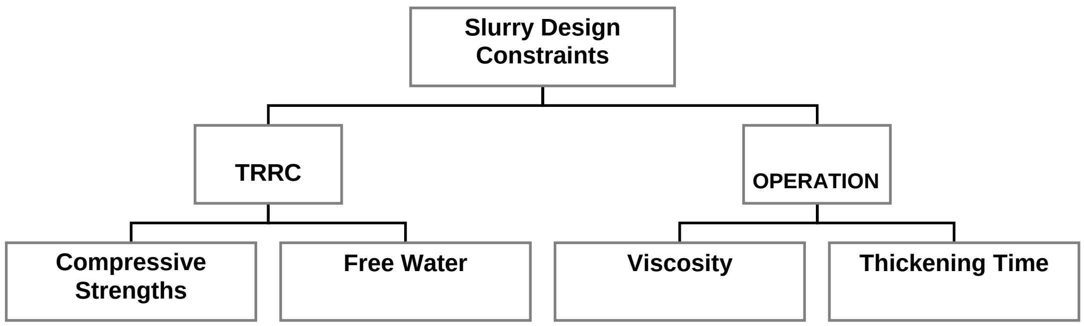

Figure 1: Chart of Slurry Design Constraints

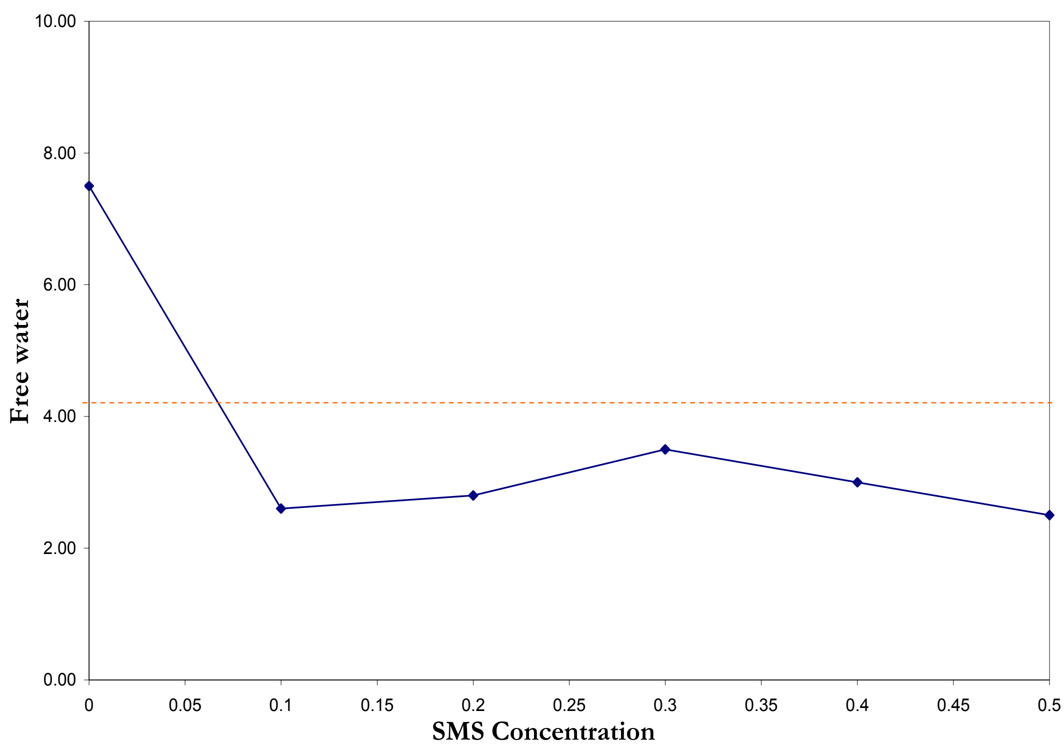

Figure 2 : Curve of Free Water vs SMS Concentration
API Class H 14.2ppg) fresh water mixing

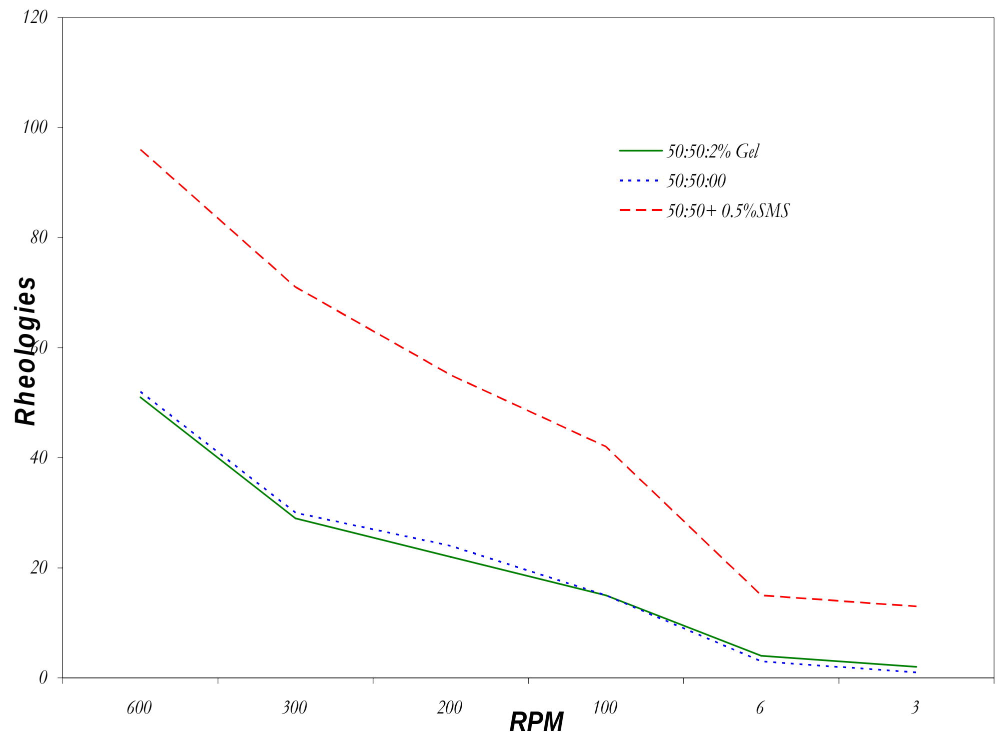

Figure 3 : Correlations between Slurry Rheology and RPM
API Class H 14.2ppg fresh water mixing

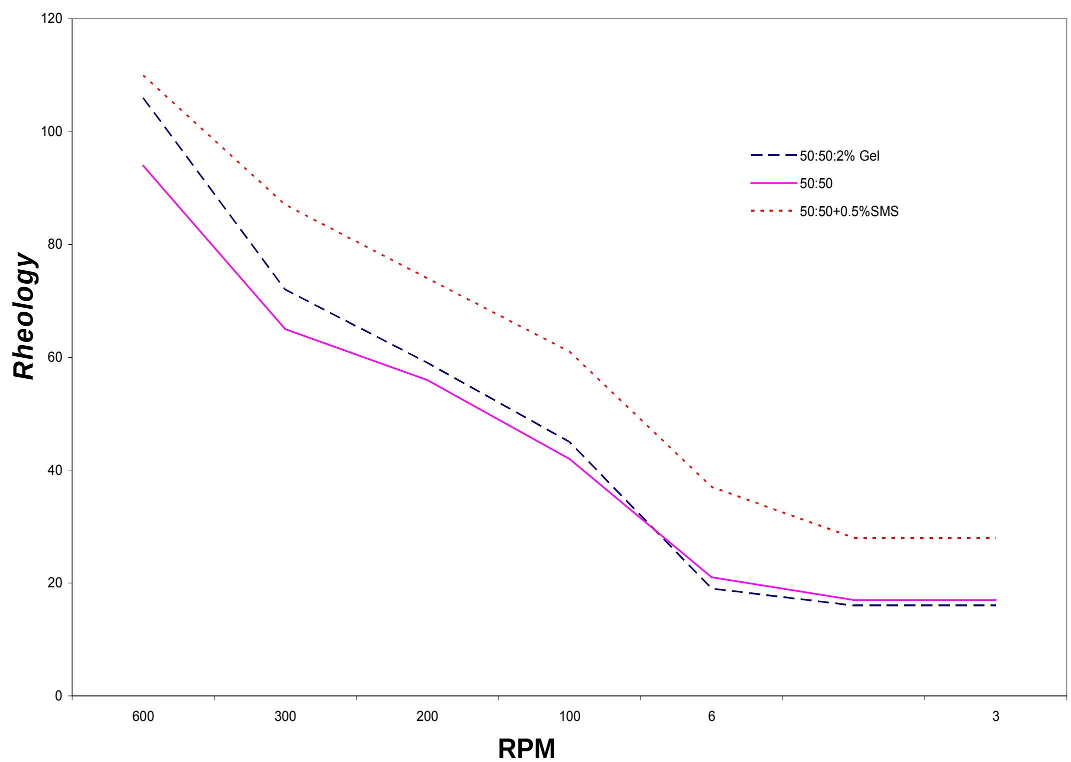

Figure 4 : Correlations between Slurry Rheology and RPM
API Class C 14.2ppg fresh water mixing

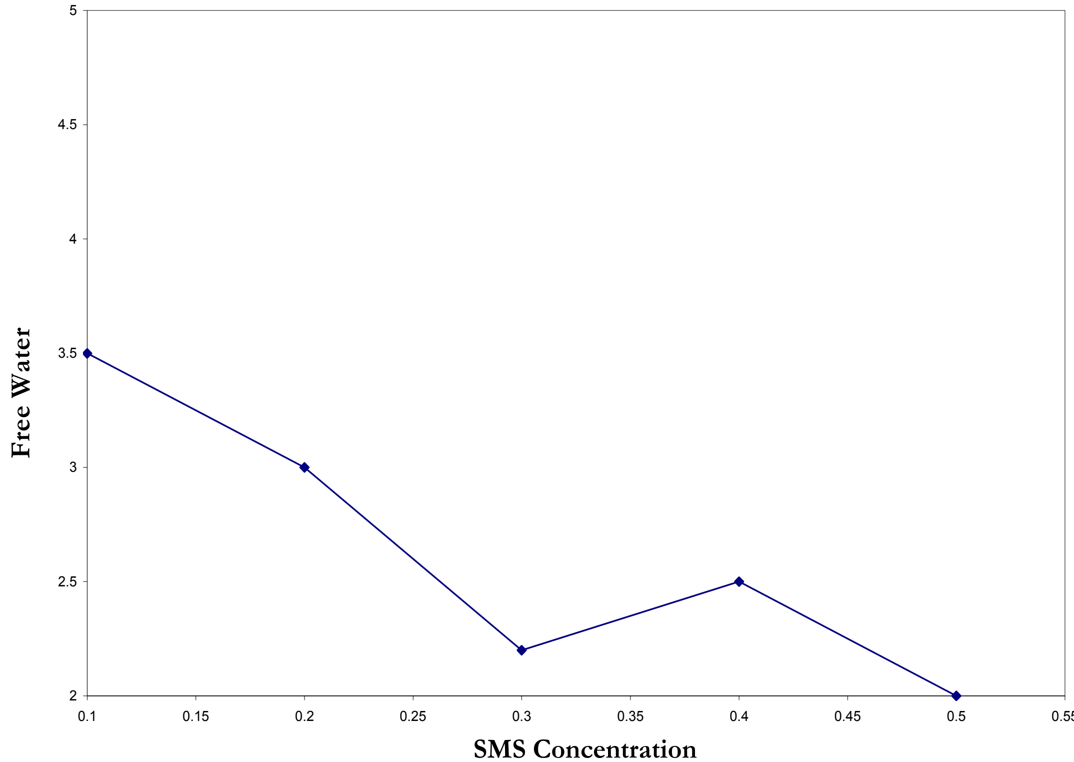

Figure 5 : Curve of Free Water vs SMS Concentration
API Class C 14.2ppg fresh water mixing

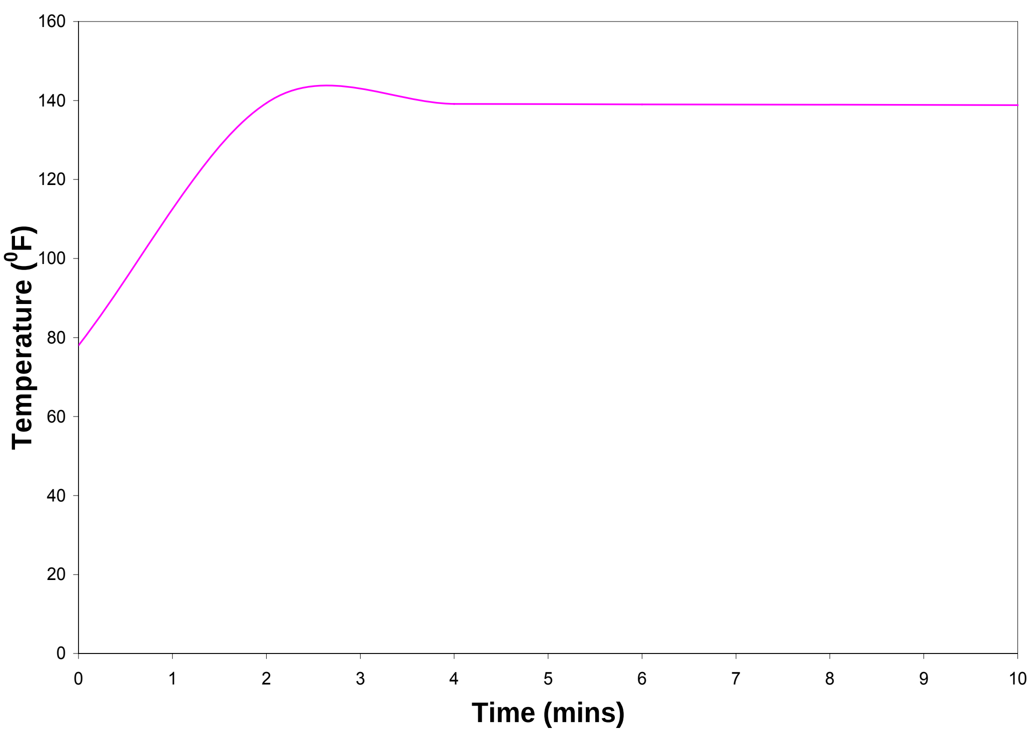

Figure 6: Variation of Temperature with Time

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