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Liquid Additives Control Cement Slurry Properties

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Abstract

While liquid additives are used in offshore & international cementing operations, land-based operations use a bulk-dry-batch-mixed process. Additives control cement volumetric yield, thickening time, compressive strength, free water, rheology, and fluid loss control. Computerized closed-loop control of liquid additives 1) allow unused, uncontaminated cement to be hauled off location after an operation, 2) promote environmental responsibility by reducing the volume of waste cement hauled to a landfill, and 3) provide better quality control of slurries pumped "on-the-fly" due to better distribution of additives in the slurry and tighter computerized tolerances.

Surface slurries utilizing liquid sodium silicate in API Class C cement were designed to meet or exceed Texas Railroad Commission Rule 13 requirements for "zone of critical cement" "extended cement" systems. Slurries were tested for thickening time, free water, compressive strength, and rheology for various combinations of weight, water, yield, additive concentration, and adherence to TRRC (Texas Railroad Commission) Rule 13 specifications.

Introduction

Better quality control, cost savings, superior slurry performance, improved handling and logistics are some of the main factors why the uses of liquid-additives cement systems have been considered in the past. However, in recent years, environmental concerns and social responsibility considerations are perhaps the most compelling reasons why the use of liquid-additive cement systems should be employed.

In the industry today, liquid-additives cement systems are almost exclusively used for offshore and international cementing operations. This is due to two main reasons: space limitations and logistic/operational feasibility of dry-blending additives in cement systems. During this operation, bulk cement is stored on the rig, and liquid additives (such as sodium silicate, which is use as an extender in moderate concentrations and an accelerator in small concentrations) are precisely measured and added to mix water. This offers the convenience of having neat cement at a remote location with the ability to custom design cement slurries at the well site. However, cement ageing, additive shelf life, slow compressive strength development and end slurry sensitivity to density variation are some of the limitations associated with the use of slurries with liquid additives.

For most on-shore cementing operations, additives are dry blended with bulk cement, and fresh water is blended with the dry system and pumped on the fly or batch-mixed. Accurate and precise blending of dry additives is very difficult to achieve with this approach; contamination, inaccurate weighing, lack of thorough dispersion of the dry additive throughout the blend are some of the factors hindering the accuracy of this mixing process.

More than ever before, increasing environmental concerns are 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.

SLURRY DEVELOPMENT

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

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 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.

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**: Correlates to the pumpability of the cement slurry. 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. Extender concentration impacts slurry viscosity. Figure 2 shows the effect of liquid sodium silicate on the rheology of the cement slurry.

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. Thickening times less that 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.

III. **API Free Water**: This is both common to both the TRRC and operational constraints. Under the TRRC requirements, the API free water separation shall average no more than 6 ml/2hrs. However, due to the desire to prevent separation of cement and water in the wellbore and provide a margin of safety, a constraint of 5 ml/2hr was imposed.

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 cementing operations, and was a major consideration in the selection of the cement class used in this project. Most offshore systems utilize API Class H or G plus seawater; however our initial project objective was to investigate the use of API Class C + fresh water mixing systems for onshore operations.

Preliminary testing reveals that use of API Class C + fresh water yields unacceptable free water and thickening times. Figure 3 shows the relationship between free water and liquid-additive concentrations.

A decision was made to develop a system more similar to offshore 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 and $CaCl_2$ were developed. The mixture 5% NaCl (by weight of mix water) and liquid sodium silicate system resulted in a noticeable precipitation compared to the mixture of 5% $CaCl_2$ (by weight of mix water) and liquid Sodium Silicate. A system of API Class C + 2%$CaCl_2$ (by weight of mix water) + liquid sodium silicate was found give acceptable values for all imposed operating constraints.

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 liquid-additive 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.

TESTING EQUIPMENT

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

1. Consistometers
2. Rotor-bob type Rheometers
3. Free water testing apparatus
4. Compressive strength testing equipment

RESULTS

A basic cement slurry design specification for onshore surface pipe cementing operations was developed using a liquid-additive system. Table 2 shows the complete slurry design data.

Using the designed slurry specifications, comparative studies of different situations occurring during surface pipe cementing operations were conducted. Three major situations were considered, Figures 4a-4c. These comparisons contrasted liquid sodium silicate systems with dry blended sodium metasilicate systems mainly in terms of cost, and waste handling/disposal. Economic comparisons utilized typical pricing scenarios in place at the time of the study comparing the current dry batching process with the proposed liquid additive process. Prices presented represent the cost per cubic ft of wet slurry available for filling annular volume, and include costs of hauling cement and additives for a distance of 75 miles from the service point to the well location. See Table 3. Not considered were any extra costs associated with handling liquid additives on location and any labor savings resulting from not dry blending at the service contractor's bulk plant. Environmental-related cost savings could be significant, depending on job type and disposal issues.

Case A: Cement pumped down Casing with two slurries (Figure 4a)

This is the most common surface pipe cementing situation, accounting for ±65% (depending upon the current state of commodity prices and the ratio of oil rigs to gas rigs) of surface pipe cementing operations in the Permian Basin. Depths are usually between 450 ft and 3,200 ft; most common casing sizes are 13-3/8", 8-5/8", 9-5/8, and a few 11-3/4" or 10-3/4". The extended slurry may meet both the TRRC requirements for extended cements and critical cements. The advantage for this scenario is that the "20% or 300 ft" rule may be ignored. The critical (tail) slurry may minimally meet requirements for critical cement or radically exceed requirements for critical cement, depending upon the operator's desire for extensive protection against drillpipe-induced damage to the shoe area of the casing as deeper drilling progresses. Environmental advantages may be minimal, because there is most often no excess cement to dispose of by hauling to landfill. The cost of liquid additive slurries is higher than dry-blending processes, but is within reasonable tolerances. The liquid additive processes have substantial quality control advantages, however, over dry blending processes.

Case B: Cement pumped down casing with a single slurry (Figure 4b)

This category accounts for ±30% of the Permian Basin surface pipe cementing operations; and again may vary somewhat with time, commodity prices, oil/gas mix, and rig activity. Depths vary from 200 ft to 450 ft, and most common casing sizes are 8-5/8"and 9-5/8", with a few 7". The single slurry may minimally meet requirements for critical cement, or radically exceed requirements for critical cement, again depending upon the operator's need for additional protection during deeper drilling operations. There are occasional environmental advantages, because if proposed volumetric excesses are radically mis-estimated, pumping of cement slurry ceases upon cement circulation. In this case, if liquid additives are employed, only neat cement is hauled to location, and there is no excess dry contaminated cement to be disposed of. The "neat" dry cement is restocked, to be used in subsequent jobs. The cost of the liquid additive processes is relatively comparable to dry blending processes, except when elimination of waste occurs. When such is the case, then significant fiscal advantage is realized. Again, in this case, the liquid additive processes have quality control advantages over current dry blending processes.

Case C: Cement pumped down Drill Pipe inside large casing (Figure 4c)

This category is not common in the Permian Basin, and accounts for only ±5% of all surface pipes set. However, this scenario is one of the most critical, because volumes are generally large and expensive. Depths may vary from 1,000 ft to 5,500 ft, and most casing sizes are usually 20", 16", or 13-3/8"; and occasionally including 24". Cement mixing of the lead slurry may cease when lead cement is circulated to surface; and the designed tail is then pumped. Any excess dry lead cement is hauled to disposal, or simply pumped as waste to the pit. When liquid additives are employed, only neat cement is hauled to location, and there is no excess dry cement to be disposed of. The dry cement is restocked to be used in other jobs, resulting in a significant fiscal and environmental advantage over conventional dry blending. As in the previous two scenarios, the liquid additive processes have quality control advantages over dry blending processes. Table 3 shows the volumetric slurry cost comparison.

CONCLUSIONS

The following conclusions were arrived at:

a. Economics of using liquid additives are relatively comparable to current dry batch processes for most jobs.
b. Economics of using liquid additives when cementing large casing down drill pipe can be highly favorable.
c. Basic slurry design data are presented.
d. Additive concentration tolerances are improved when liquid additives are specified.
e. Less waste is possible (with certain job types) when liquid additives are utilized, resulting in a more environmentally responsible process.

RECOMMENDATIONS FOR FURTHER INVESTIGATION

a. The use of sodium silicate at very low concentrations for acceleration in critical zone cements rather than the addition of conventional salts such as calcium chloride or sodium chloride.
b. Substitution of NaCl for $CaCl_2$ – examination of multiple fresh waters with various salts.

c. The use of sodium silicate as an extender in casing strings subsequent to the surface pipe
d. 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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Tables:

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

	Extended Slurry	**Critical Zone Slurry**	**Tail Slurry**
Slurry Specification	API Class C,12.50 ppg + 0.7 gps LSS + 2% $CaCl_2$	API Class , 13.50 ppg + 0.65 gps LSS + 2% $CaCl_2$	API Class C, 14.50 ppg + 0.2 gps LSS + 2% $CaCl_2$
Rheology			
600 rpm	56	82	185
300 rpm	44	60	137
200 rpm	36	52	110
100 rpm	20	42	80
6 rpm	17	22	23
3 rpm	11	14	17
API Free Water	4.0ml/2hrs	2.0ml/2hr	0.9ml/2hrs
Thickening Time (74Bc)	5hrs, 39mins	4hrs, 36mins	2hrs, 45mins
Compressive Strengths			
8 hrs	108 psi	N/A	N/A
12 hrs	265 psi	500 psi	699 psi
24 hrs	388 psi	850 psi	N/A
72 hrs	N/A	1,469 psi	2,422 psi

Table 3: Volumetric Slurry Cost Comparison

Systems for lead and tail slurries	**Normal or proposed utilization**	**Weight (lb/gal)**	**Cost/ft3 (dollars)**
Dry Blended C + 2% $CaCl_2$	Case B	14.8	7.54
Dry Blended Class C + 4% Bentonite + 2% $CaCl_2$	Shallow Case A lead	13.5	6.15
Dry blended Class C + 3% sodium metasilicate + 2% $CaCl_2$	Case A and C lead	11.9	5.18
Class C + 0.7 gps LSS + 2% $CaCl_2$	Case A and C lead	12.5	5.92
Class C + 0.65 gps LSS + 2% $CaCl_2$	Shallow Case A or Case B	13.5	7.25

Figures

Figure 1: Chart of Slurry Design Constraints

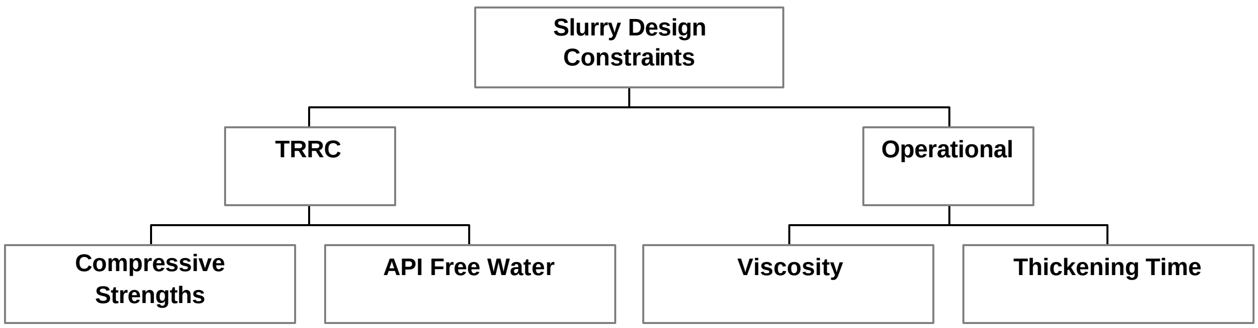

Figure 2: Correlation between LSS concentration and Slurry Rheology
(API Class C, 12.0ppg Slurry, Fresh Water Mixing)

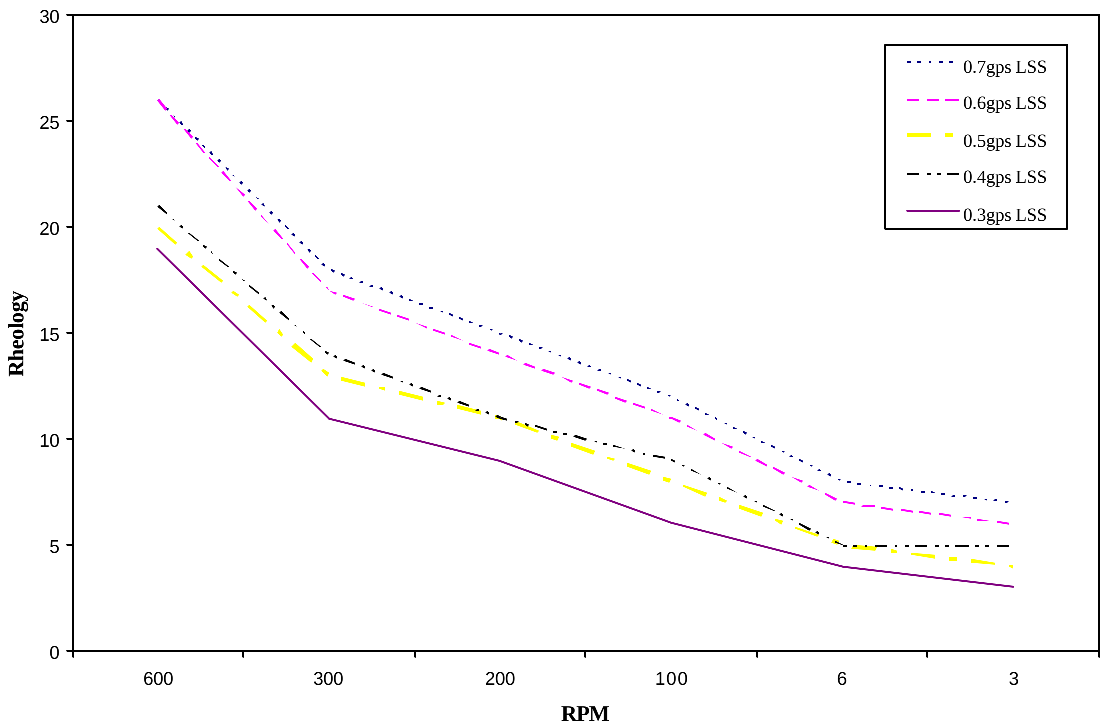

Figure 3: Correlation Between LSS Concentration and API Free Water
(API Class C, 12.0ppg Slurry, Fresh Water Mixing)

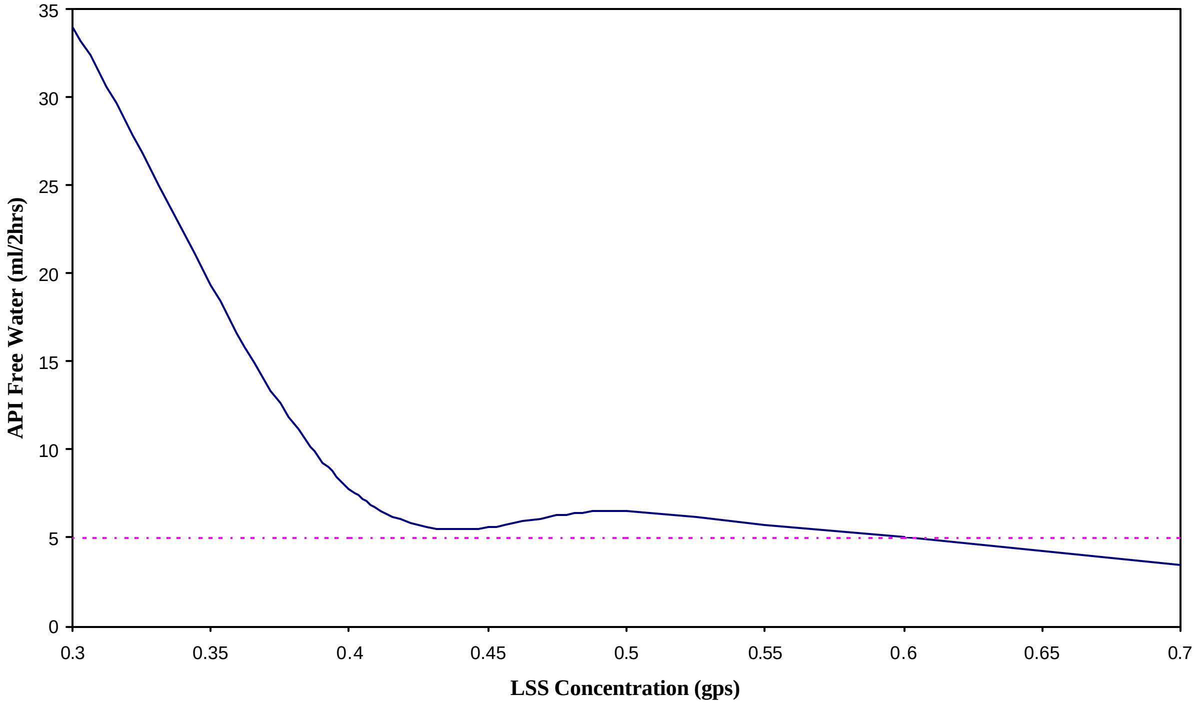

Figure 4a

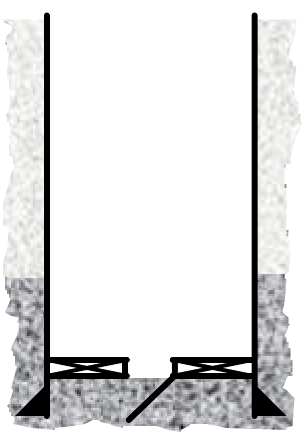

Figure 4b

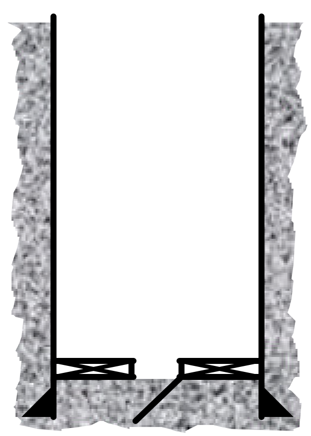

Figure 4c

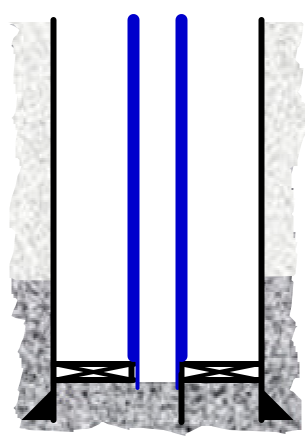

Figure 5: Distribution of Surface Pipe Cementing Scenerios In the Permian Basin