

## A formulated silicate-based preflush & spacer for improved wellbore cleaning and wetting

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### Abstract

It is well understood that a good cement bond improves the environmental and economic performance of a well. By improving the quality of the cement bond the net result is better zonal isolation as well as the prevention of gas migration, gas entrapment and excessive water production. One of the most cost effective means for improving a cement bond is to run a properly sized and formulated spacer and preflush. Beyond separating the drilling fluid from the cement the spacer/preflush should also provide, fluid loss control, improve water wetting of surfaces and prevent cement fallback. This is particularly challenging for the displacement of oil-based drilling fluids. To properly prepare the wellbore, it is common practice to run a sequence or a train of different chemicals with each chemical performing a specific function.

Overlooked has been the possible synergies and reduction in cost by combining different flush additives. In particular, the cleaning and wetting properties of solvents and surfactants can be significantly enhanced in the presence of alkali and soluble silica. This paper describes the chemistry, development and field results of an environmentally friendly, variable density, single-component product built on a quick dissolving powder sodium silicate.

### Introduction

There are several excellent papers describing the importance and attributes of preflush & spacers for achieving a good cement bond<sup>1,2,3,4,5</sup>. These papers have several points worth re-stating as a refresher and provide a background on the development of a formulated silicate-based preflush. A successful preflush can contribute to improved cement bonding and mitigate the chance of out of zone gas and water migration. A spacer system is required to perform several functions with the goal of the casing and formation being clean and water wet prior to cementing. Beyond functionality, spacer design also needs to take into consideration; cost, ease of use and HS&E characteristics of the various spacer components. The spacer is also required to be compatible at the interface of the drilling fluid as well as the cement.

To achieve all the required performance characteristics it is common to run a train of different chemicals. Classes of chemicals include; solvents, mutual solvents, surfactants, polymers, clays, phosphates, weighting material and sodium silicate. Sodium silicate has a long history as a flush material and appears in the product literature of many cementing service companies. The recognized performance attributes of sodium silicate include;

- controls downhole fluid loss
- prevents lost circulation and slurry migration
- prevents slurry fallback
- improves cement bonding

In the case of oil-based mud (OBM), it has been common to run a solution of sodium silicate behind a flush of solvent and/or surfactant<sup>6</sup>. Recognizing this sequence of treatment, it was felt there was an opportunity to retain the functions of a silicate flush while enhancing the performance of the surfactant at a lower surfactant concentration.

The concept of combining surfactants with sodium silicate was felt to be on safe ground given the extensive use of sodium silicate in soaps, detergents and degreasers. The role of sodium silicate in these applications is described as a “builder”<sup>7</sup>. The detergent industry describes a builder as a chemical that creates an environment in which other components such as surfactants, enzymes and oxidizing agents can function at their optimum performance. A major benefit associated with sodium silicate is greater surfactant efficiency while reducing surfactant consumption.

Applying detergent technology to preflush technology, the role of sodium silicate would be the removal of hardness ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ) which can complex with anionic surfactants making them less reactive or unstable. The silica anions minimize these unwanted charges by sequestering the metals via a precipitation reaction. The silica anion also competes for active, positively-charged sites on the casing and wellbore thereby reversing their surface charge and repelling surfactants.

Surfactant efficiency is increased by the sodium silicate acting as pH buffer and keeping the pH at a high and constant

level during the flush process (i.e. similar to the pH of the cement used). The combination of soluble silica and alkali reduces the interfacial tension between oil and water. Silicate ions are very hydrophilic and help promote partition between the oil and water phases. This translates into higher performance from the surfactants and oil-based residue is more easily removed. This also contributes to the wetting action.

In the case of powder alkali silicates, another role it plays as a builder is that of a carrier of liquid additives. The sorption capacity of surfactants onto the surface of a silicate can be over 25% by weight<sup>7</sup>. Recognizing the high liquid carrying capacity of a powder sodium silicate, the decision was made to develop a formulated product based on a powder silicate with liquid surfactants sorbed onto the surface. Historically liquids have been the product of choice for silicate flushes but it felt that a powder would provide a concentrated product that was easy to handle and not prone to separation. A further advantage is it removes the issue of freezing at subzero temperatures.

### Design & Selection of Chemical Components

Invariably in the development of a formulated product, the selection and concentration of additives leads to balancing one performance feature against another. Also entering the equation is cost and the HS&E characteristics of additives. Given that sodium silicate is an environmentally friendly product, a premium was placed on additives with similar positive HS&E characteristics. The need for an environmentally friendly product was thought to be of particular importance where the flush would not be circulated out of the well. A less toxic product left behind the pipe should help reduce long term liability from contamination of adjacent, non-hydraulically isolated annular sections. The presence of sodium silicate would also serve to reduce pipe corrosion<sup>8</sup>. For flush/spacers circulated out of the well, toxicity is an important factor for determining method of disposal (i.e. surface method vs. deep well vs. land fill).

Having opted to use a powder silicate, field requirements would require the product be readily soluble in cold water. Sodium silicate and potassium silicate chemistry is largely governed by the weight ratio of  $\text{SiO}_2$ :  $\text{Na}_2\text{O}$  or  $\text{SiO}_2$ :  $\text{K}_2\text{O}$ . Given these criteria, a low ratio sodium silicate or a lower to mid ratio potassium silicate would have the requisite cold water solubility. In the case of potassium silicate, a higher ratio product could be chosen and still maintain solubility. For reasons of cost, sodium silicate was selected over potassium silicate.

Beyond quick dissolution rates, low ratio silicates are typically the product of choice for detergents. The other reason to support the selection of lower ratio silicates is the greater tolerance to additives and/or contaminants. This also helps improve compatibility at the cement and/or drilling fluid

interface. The lower ratio product would allow for the use of hard water or sea water.

To be fair to the higher ratio silicates, the larger silica species are more reactive to polymerization and precipitation and thus would be more effective at sealing microfractures and providing a slightly higher level of inhibition and fluid loss control.

With the selection of form and ratio of sodium silicate, the next step was to look for suitable surfactants and co-surfactants. Of the numerous available products, the list of candidate surfactants was narrowed based on the following criteria;

- chemically stable under alkaline condition
- compatible with other additives
- effective over a wide range of conditions
- temperature stable
- current types of surfactants used in flush
- surfactants used in the past with silicates
- cost
- HS&E characteristics

A short list of potential surfactants was developed and screened using a simple field procedure of measuring mud removal.

In developing a formulated product, the decision was made to include a solvent as part of the package. It is known that displacement efficiency is enhanced by reducing the ratio of the viscosities of the oil-based residue and the flush. The solvent further reduces the oil /fluid interfacial tension. Aromatic solvents such as xylene are highly effective at "cutting" oil-based drilling fluids but have the disadvantages flammability and toxicity. Terpene-based solvent represent a safer and less toxic alternative but have the disadvantage of higher cost. A small amount of a terpene-based solvent was blended into the granular silicate to further enhance the removal of oil-mud residue. Given the distinctive smell of the formulated product, it is no secret the selected terpene is pine-based.

### Cleaning & wetting

Most testing was conducted at room temperature. Interfacial testing decreases with increasing temperature and therefore room temperature was considered a worst case scenario for measuring cleaning efficacy. Testing was typically conducted at a dosage of 50 lbs per bbl (i.e. 1 bag of product per barrel) and a slightly lower concentration of approximately 2 bags per 3bbls. These dosages were selected for ease of use and once dissolved the silicate concentration would be in-line with a concentrations typically used for a liquid sodium silicate flushes. Viscosity of the dissolved system was less than 5 centipoises at room temperature. This low viscosity would allow the flush to go into turbulent flow

at low pump rates. As discussed in the field trials, the option exists to add a viscosifier and weighting material to the silicate-based flush in cases where the flush also needs to act a spacer.

Testing involved a broad section of oil-based drilling fluids that were generously supplied by several different drilling fluid companies. For reasons of confidentiality, oil-based muds were supplied with no mention of location or operator and only a basic description of drilling fluid properties. OBM properties were typically limited to; type of base oil, oil:water ratio and density. The predominant base oil was Distillate 822 but also included some synthetics. Testing also included OBM formulated in the lab.

Initial testing used field methods to screen the efficacy of surfactant combinations and loadings. The efficiency of a single component product was compared against surfactant(s) and neat sodium silicate. Cleaning efficiency was determined by coating the surface of a beaker with oil-based mud. A fixed volume of flush material was stirred under moderate agitation for 5 minutes. (graph 1). For certain oil-based drilling fluids, the difference in percent of mud removal was minimal between the single component flush and the surfactant flush (figure 1). However, the glass surface washed with the surfactant flush would often have a thin film of oil and show signs of water beading.

Volume Efficiency was measured using a simple field procedure used to gauge the volume, chemical compatibility and concentration of additives to add to a flush. The procedure measures the volume of flush material required to clean a glass jar coated with oil mud. For most of the tested oil-based drilling fluids, the surfactants required 3 flushes while the single component product required 2 flushes (figure 2).

Flush efficiency was further measured using a Fann® 35 rheometer fitted with a metal screen on the rotating surface. The screen was weighed at the start of testing, after 5 minutes of rotation at 100 rpm then again after 5 minutes of rotation in the flush solution. The cleaning efficiency was calculated as the % oil-based mud removed. In most cases good mud removal could be achieved after 5 minutes of rotation in the sodium silicate-surfactant-solvent solution. It was also observed that any residue appeared to be “looser”.

Graph 2 demonstrates the synergetic effect of sodium silicate with surfactant. Testing was done with using fresh and simulated sea water. In cases where OBM removal was low, it was noticed the OBM had the physical properties of higher densities and viscosity. Lack of complete mud removal was thought to be a function of low shear and thus insufficiently low interfacial tension. Best practices suggest pumping the spacer fluid at the highest rate possible without

breaking down the formation. Where viable, it is recommended the flush be in turbulent flow and the casing be rotated and reciprocated.

Reformulating the surfactant package to achieve a lower interfacial tension was considered as a possible approach to achieving higher oil mud removal under low shear conditions. This approach had merit and the development of a “2.0” version incorporating microemulsion technology is a possibility in the future. However, it was felt that a simpler and more economical option would be to run a solvent spacer ahead of the formulated silicate where field testing indicates insufficient OBM removal. Solvent spacers are commonly used to thin OBM and filtercake. Rotor testing showed that 100% mud removal and water wetting could be achieved if a solvent was used to pretreat the OBM.

### Cement Adhesion

While the objective of any flush is the complete removal of all OBM, the reality is that factors such as poorly centralized casing, zones of high viscosity fluid, inadequate flush size, etc. will lead to pockets of mud & filtercake. It was felt important to look at the impact of flush material on cement adhesion. A simple experiment was developed that measured cement-cement adhesion where one surface has been exposed to OBM and then lightly flushed so as to retain OBM on the surface. As shown in figures 3, cement forms were made using ordinary type S mortar. The interior surface was coated with OBM and hot rolled for 2 hours @ 50C. The surface was flushed under moderate agitation and then filled  $\frac{3}{4}$  with type G cement. The partially filled interior was sealed and aged for a minimum of 24hours @ 50C. An Instrom® was used to measure the force of extrusion of cement plug.

Data suggests the formulated silicate and to a slightly lesser extent, unmodified sodium silicate providing an improvement cement adhesion (graph 3). At the time of the paper, research was being conducted on the possible mechanisms for the improved cement bond adhesion. A better understanding of mechanisms should lead to further improvements in cement adhesion. Mechanisms under consideration include the silicate reacting with calcium in the brine phase. This would be supported by the literature where the wellbore is pretreated with a calcium chloride solution subsequent to a sodium silicate flush<sup>9</sup>. Other possible mechanisms include some degree of penetration into the OBM surface with a deposition of silica on solids. A silica matrix would then be available to react with cement.

### Field Testing

Several field trials have taken place in Western Canada. Trials have taken place primarily with wells drilled using oil-based mud. The increasingly complex subsurface well designs associated with conventional & unconventional resource

development has resulted in a growth in wells drilled using oil based drilling fluid systems. Maintaining drill hole stability and geometry are critical in today's extended reach conventional and monobore horizontal well designs. Removing and recovering the oil based fluids for re-use while properly preparing the wellbore for cementing operations requires preflush/spacer fluids that can accommodate a wide range of service and operating company preferences. These have included: rheological, density, volume and concentration optimization based on the individual well requirements. The formulated silicate allowed for fluid property modifications with locally available materials and a minimum of resources consuming lab & field testing. Flushes were designed to have a contact time between 5-10 minutes. Flushes were viscosified so as to be weighted 25 to 50 kg/m<sup>3</sup> above drilling fluid density. From a cost perspective an easily customizable one bag powder minimized storage & transportation costs which are accentuated in cold climates. Trials showed the technology easily transitioning from the lab to the field.

While several factors go into achieving a good cement bond, wells flushed with the formulated product have consistently had excellent cement bond logs. While there are a number of critical bonding areas in any wellbore, the interval above the intermediate casing shoe is shown in Figure #4 as a region of interest. As comparison the cement bond logs of offset wells varied from poor to excellent.

The formulated silicate has also found application as a preflush/spacer in remedial cementing operations whenever there is potential for cement contact with hydrocarbons, oil wet/stained surfaces or a requirement for superior cement bonding potential to downhole surfaces. The need may not be as quantifiable as with drilling fluids but can be regarded as "cheap insurance" by most energy companies

## Conclusion

This paper has highlighted many of the factors that affect design of a single component chemical flush. The results of the oil mud displacement studies show the synergistic effect between surfactants with sodium silicate. Such a single component system reduces surfactant loading and promotes a higher level of water wetting. These results are not surprising considering the extensive use of sodium silicate as a detergent builder, particularly low ratio sodium silicates used in this application. Retained in this single component system are the traditional benefits associated with sodium silicate

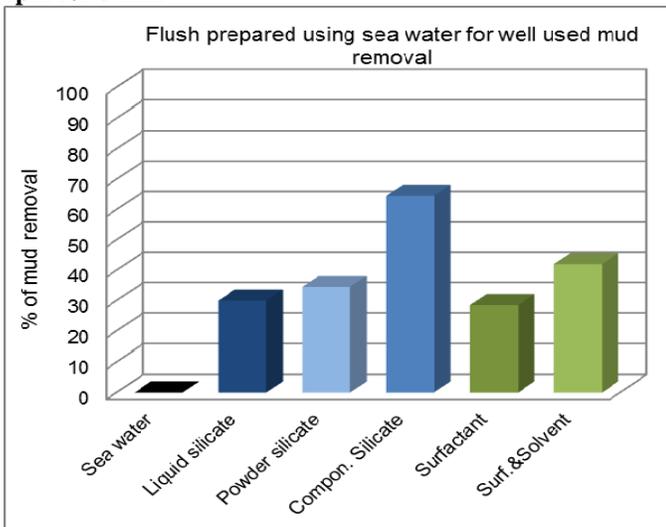
## Acknowledgments

PQ Corporation and Magnum Cementing Services would like to acknowledge Jim Kelly for his forward thinking and assistance for bringing this technology to the field. Thanks to PQ Corporation and Magnum Cementing Services for permission to publish this paper.

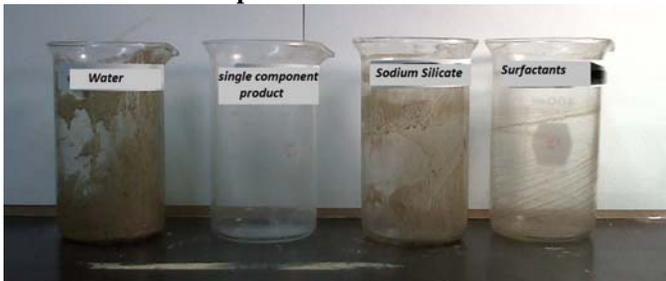
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**Graph #1: Cleaning efficiency was tested by coating the surface of a beaker with oil-based mud, flushing at 600 rpm for 5 min**



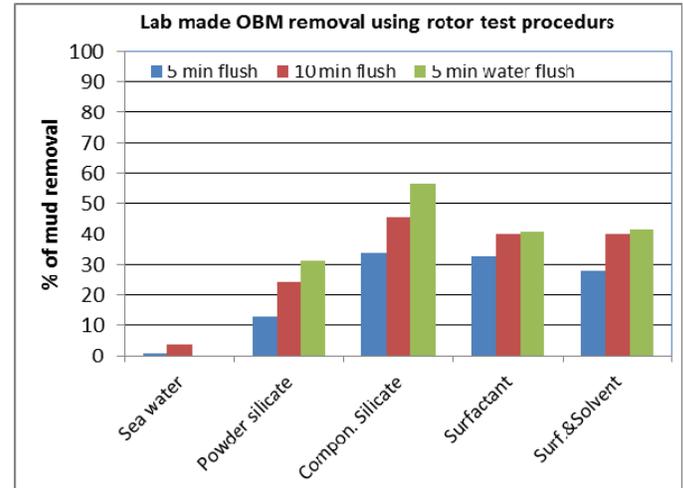
**Figure #1: Cleaning efficiency using fresh water and OBM from the field. 600 rpm for 5 min.**



**Figure #2: Flush Volume Efficiency using OBM from field**



**Graph 2: Rotor Test**



**Figure #3a: Cement Forms**



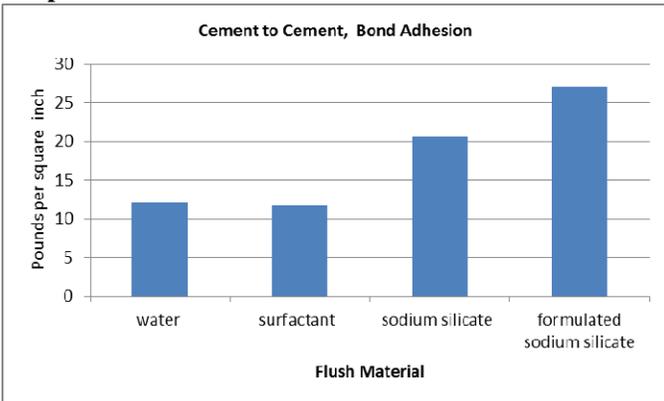
**Figure 3b: After Coating and flushing**



**Figure 3c: Glass G Cement Plug & extrusion test**



**Graph 3: Cement Adhesion**



**Figure4 : Cement Bond Log taken above the intermediate casing shoe**

