

# A Formulated Silicate Preflush Combined with Specialized Mixing Equipment and Processes to Provide a Low Cost and Effective Solution for Improved Cement Bonds

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## Abstract

A few years ago, a formulated preflush was developed and introduced to the market as an easy to use, low cost option for improving wellbore cleaning and enhancing cement bond. The formulated preflush was based on a terpene and a combination of surfactants absorbed on the surface of a readily soluble sodium silicate powder. Parallel to the development of the formulated preflush, a fit for purpose mixing and pumping equipment was designed and built to reduce required location personnel, equipment footprint and lower cementing costs. The flush and specialized pumping equipment have been successfully utilized in Western Canada for both primary and remedial cementing. Since the introduction of these technologies, refinements have been made both to the flush chemistry and placement technique. The paper presents a review of preflush chemistry, pumping equipment and case histories showing improved cement bond logs.

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

Given the importance and challenges of removing oil-based residue and conditioning the wellbore, it is very common to run a sequence or “train” of different flush chemicals including sodium silicate. One commonly used train of chemicals is solvent, surfactant and then sodium silicate. This system is effective but does not capture the synergies that are known to exist between sodium silicate and surfactants. For over 175 years, sodium silicate has been a key component in soaps, detergents and degreasers. The detergent industry describes sodium silicate as a “builder”<sup>7</sup>. A builder is a chemical that creates an environment in which other components such as surfactants can function at their optimum performance. When 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. 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. 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 the oil-based residue is more easily removed. This also contributes to the wetting action. Greater surfactant efficiency is achieved while reducing surfactant consumption.

## Introduction

One of the most cost effective means for improving a cement bond is to run a properly sized and formulated spacer and preflush. By removing the mud and ensuring that the wellbore and casing are water-wet, the cement can achieve a better quality of bond. A few years ago a new spacer system was developed and introduced into Western Canada<sup>1</sup>. Innovation continues with the move towards a second generation product which would further enhance cement-to-casing and cement-to-formation bonding while further improving HS&E characteristics.

There are several excellent papers on the importance and function of a preflush<sup>2,3,4</sup>. The importance of flushes and the use of sodium silicate as a flush material is reflected in recent literature publications<sup>5,6</sup>. There are several different classes of chemicals used in flush and spacer systems. Families of chemicals include; sodium silicate, surfactants, solvents, mutual solvents, polymers, clays, phosphates and solids. As a generalization, most preflush chemicals perform one function very well. For example, solvents are effective at removing oil-based drilling fluids but leave the wellbore oil-wet. For sodium silicate-based flushes the commonly referenced performance attributes include;

Liquid and powder sodium silicate have both been used as a preflush (table 1). In formulating for Western Canada or the US Rockies it was felt that a powder sodium silicate would be the preferred form of silicate as it would allow for an ease in handling and remove the issue of freezing at subzero temperatures. The other advantage of powder silicates is they have a high carrying capacity for liquids. The sorption capacity of surfactants onto the surface of a silicate can be over 25% by weight. This allows for formulating with a wider range of with surfactants and solvent.

	Na <sub>2</sub> O (%)	SiO <sub>2</sub> (%)	SiO <sub>2</sub> :Na <sub>2</sub> O ratio	water	Solids (%)
Metso Pentabead® 20	29.3	28.4	1	42.3	57.7
N® Grade 3.2 ratio	8.9	28.7	3.2	62.4	37.6

Table 1. Properties of Typical Sodium Silicates

### Formulated Preflush & Optimization

The formulated preflush is based on sodium metasilicate as the silicate of choice. This form of silicate is readily soluble in cold water and is tolerant to some hardness and salinity. It is commonly used in the detergent industry for the formulation of “industrial strength” cleaners and degreasers. Adsorbed onto the surface of the sodium metasilicate was a package of surfactants. The formulation contained a package of surfactants. The choice of surfactants was based on current products in use as preflush. This was cross referenced with surfactants currently used with sodium silicate for applications such as degreasing. This list was further narrowed based on other factors such as cost and temperature stability. From this, a short list was developed for testing. Lab testing included API grid test, contact angle as well as field test methods such as “jar test”. Since introduction, the original surfactant package underwent minor adjustments to enhance cleaning and HS&E characteristics. The final component is a terpene to further boost cleaning. The terpene was shown to enhance displacement efficiency by reducing the viscosities of the oil-based residue and reduction of the oil /fluid interfacial tension. Given the distinctive smell, it is no secret the selected terpene is pine-based.

In development is a next generation product to further improve cement adhesion to casing and wellbore. In looking at a new generation product, a hydrous potassium silicate powder was evaluated as the base silicate (table 2). Potassium silicate powder retains quick dissolution characteristics but the move from sodium to potassium allows for a high ratio of silica to alkali. At a molecular level, the large silica species are more reactive to polymerization and precipitation. This allows for more effective sealing of microfractures and a higher level of inhibition and fluid loss control<sup>8,9,10</sup>. The more reactive form of silicate anions would further augment cement adhesions well as prevention of lost circulation and cement fallback. The hydrous potassium silicate powder also has the advantage of a lower pH which improves the handling characteristics. The base cost of a formulated potassium silicate-based preflush would be higher than the sodium version.

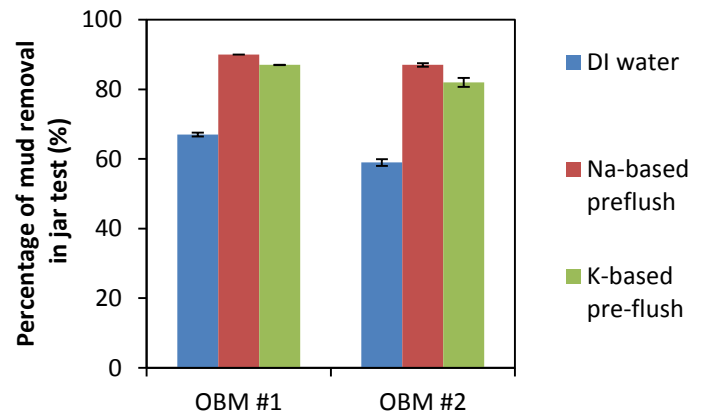
The cleaning efficacy of existing surfactant package with pine oil was compared on the sodium silicate and potassium silicate. “Jar test” was also used to evaluate cleaning efficacy under field conditions (graph 1, figure 1). Duplicate samples were prepared for each test. Flush was formulated to 1 bag of formulated preflush per barrel of water (i.e. 50 pounds per barrel, or ~14% w/w). Testing was also done using API grid

test for guidance. A mesh rotor was coated with oil-based mud and weighed. The mud laden rotor is placed on a rheometer and then rotated in a flush system for 5 minutes. The rotor is then removed and re-weighed (graph 2, figure 2). Oil-based drilling fluids were supplied by different drilling fluid companies. These samples were taken from the field but details were not provided as it was not important to the study of cleaning efficacy of the preflush. Most of the supplied oil-based drilling fluids were based on Distallate 822 with calcium chloride used as the salt in the internal phase. Solids levels varied from system to system.

There was minimal difference in cleaning efficacy going from sodium silicate to potassium silicate. This is supported by observations from the detergent industry. Typically, higher pH silicates provide better cleaning but potassium silicates are more effective than sodium silicate at the same alkalinity.

	K <sub>2</sub> O (%)	SiO <sub>2</sub> (%)	SiO <sub>2</sub> : K <sub>2</sub> O ratio	water	Solids (%)
Kasolv®16	32.4	52.8	1.6	14.5	85.5

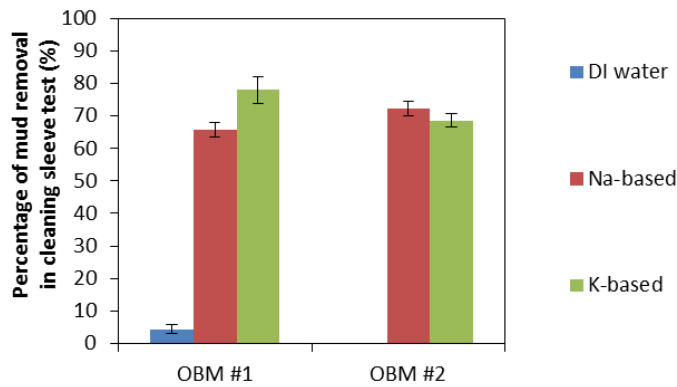
Table 2. Properties of Hydrous Potassium Silicate



Graph 1: flush efficiency -1 jar test



Figure 1: flush efficiency jar test



Graph 2, Mud removal grid test

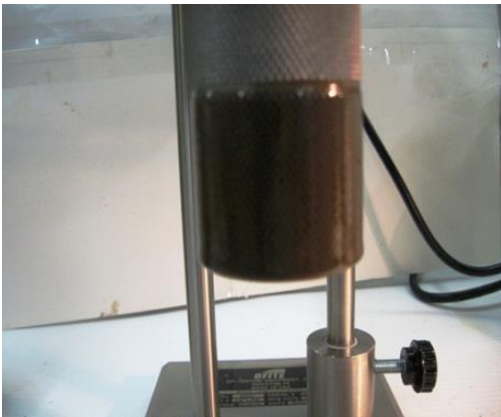


Figure 2a: Rotor covered with OBM #1



Figure 2b: Rotor after 5 minute flush in K silicate solution

### Fit for Purpose

The predominant truck mounted oilfield cement pumping unit in field operations today uses a high energy mixer to produce high quality slurry. The mixer recirculates cement slurry through a centrifugal pump and proportioning head. This is where fresh cement powder is added with the required amount of water through a shearing mix nozzle and then transferred to a slurry averaging tank of 1 to 3 m<sup>3</sup>. The slurry is mechanically agitated to remove the air entrained during the mixing process and sheared and transferred with a second centrifugal pump to one or two high pressure triplex pumps and pumped into the well. The limitations of the system are the slurry residence time and mixing energy are proportional to the desired injection rate. Density variance from optimal is directly affected by the size of the slurry averaging tank.

Batch mixing cement is recognized as the best method of ensuring slurry quality in well cementing operations. The higher levels of mixing energy and extended surface residence time permits the cement and additives to fully hydrate. This ensures optimum distribution of additives throughout the slurry and minimizes density variations. Batch mixers have traditionally been designed to mix slurry volumes of 16 m<sup>3</sup> or less to facilitate transport on a tractor trailer unit. This volume has restricted batch mixing use to critical well applications such as liners and small volumes of tail or remedial cements.

The large volume batch mix process virtually negates the slurry density deviation from optimum values, improving the quality of the slurry with an average deviation of less than 1% between compartments. Prepared slurry is held, mechanically agitated under low shear conditions and recirculated as required to increase the available shear and total mixing energy. Separation of the mixing process from well injection and displacement operations requires fewer personnel on location, allows equipment operators to task focus and eliminates the job uncertainty associated with conventional job mixing interruptions. Non-productive rig time due to the

overall cementing operation is reduced because the slurry mixing operations are executed during wellbore and drill fluid conditioning operations. When mixing the slurry on-the-fly (without using a large volume batch mixer) at high pump rates, factors like changing pump rate during mixing or dry product (cement blend) delivery can cause variations in density. Variation in pump rates can also create challenges in maintaining slurry density. Figure 3 of an actual job pumped at a rate of 2.4m<sup>3</sup>/min (15.0 bpm) demonstrates that even with variations in pump rates, the density of the slurry does not fluctuate.

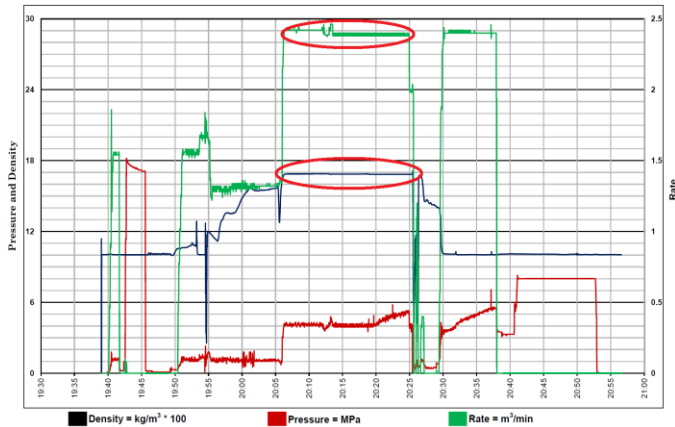


Figure 3: Job Chart – Pressure, Density and Rate chart

A high volume quintuplex pump is mounted on a high power tri-axle truck chassis and the suction and discharge piping was optimized for high rate fluid transfer from the hybrid batch mixing unit. Stand-alone mixing and pumping capabilities have not been compromised. Units are paired on location to provide the programmed power and pump rates. The tri-axle design offers greater flexibility when spotting equipment than conventional larger tractor trailer units.

### Case History: SAGD wells

The first trials of the formulated flush and fit-for-purpose pumping equipment were on Steam Assisted Gravity Drainage (SAGD) wells<sup>11</sup>. These wells can be particularly challenging to achieve complete annular zonal isolation from the intermediate casing shoe to surface. The large diameter drilled hole and casing are set horizontally at relatively shallow and cool true vertical depths. These wellbores penetrate through formations of variable competency and then are subjected to steam injection pressures and temperatures exceeding 200°C (390°F). These challenging parameters require detailed consideration of all aspects of the drilling and casing cementing operations. Flushes and spacers are utilized in cementing operations to seal off porous formations, reduce cement fallback and provide a reactive film on the borehole and casing to improve the quality of the cement bond. The placement of cementing fluids into wells at high annular velocities has a 30+ year history in Western Canada of

improving drilling fluid/solids removal from casing annuli and enhancing cement to formation/pipe bond, thereby reducing/eliminating well problems associated with incomplete zonal isolation.

A typical SAGD well consists of a 444.5 mm (17.5 in) surface hole drilled down to competent sandstone at + 200 m (650 ft) and 339.7 mm (13 3/8 in) casing is cemented to surface to hydraulically isolate all potential ground water resources. The cement of choice is typically Oilwell ‘G’ based slurry containing 40% of 325 mesh silica flour (by weight) to provide thermal stability to the set cement at SAGD steam operating temperatures. The intermediate casing string of 244.5 mm ( 5/8 in) in 311 mm (12.25 in) hole is run and the drill fluid and borehole conditioning are typically accomplished during a three hour well circulation interval before the intermediate casing is then cemented full length. Casing reciprocation is maintained throughout wellbore conditioning, cement injection and for a portion of the displacement before securing to ensure the desired landing depth is maintained. One of the benefits of batch drilled wells is that the cement used for casing interval has an opportunity to fully develop its strength and bond components without being subjected to the shock loads of subsequent drilling operations.

In combination with the use of the batch mixer, the formulated silicate preflush was used to help strip and emulsify any downhole hydrocarbon and provide stronger wetting and bonding capabilities. SAGD cementing operations typically use sodium silicate as part of the spacer design. This provided for comparison to the formulated powdered silicate. The manufactured approach to SAGD well development was conducive to making comparative

analysis and step-changes if/when required to optimize spacer and pumping equipment. The formulated preflush followed typical SAGD spacer design and was made as a thin, lightweight fluid that could be pumped in turbulent flow. Average program volumes for preflush design targeted annular velocities of a min of 80 m/min (260 ft/min) to provide a high displacement efficiency. This typically resulted in an average annular height of 300 m (984 ft) and a contact time of 7 minutes at designed cement injection and displacement rates. Figures 3 & 4 demonstrate the advantages of cementing SAGD wells using batch mixing technology vs. on-the-fly mixing. Both figures show that improved bonds were seen when batch mixing over on-the-fly mixing. The well pairs were 5m (16.4 ft) apart and were cemented using the same slurry and formulated preflush systems. Rates achieved for the batch mixed wellbore was 2.6 m<sup>3</sup>/min (16.4 bpm) vs. 2.2 m<sup>3</sup>/min (13.8 bpm) for the on-the-fly.

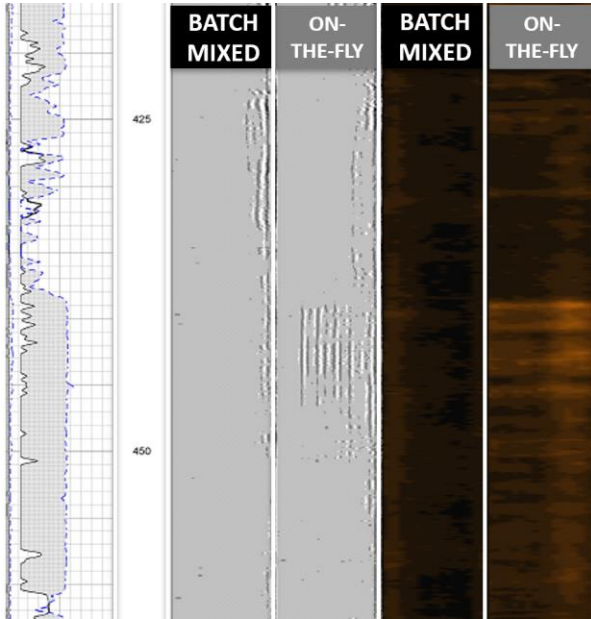


Figure 4: Bond log interval of 416 m (1365 ft) to 463 m (1519 ft). Batch Mixed Slurry vs. On-The-Fly mixed

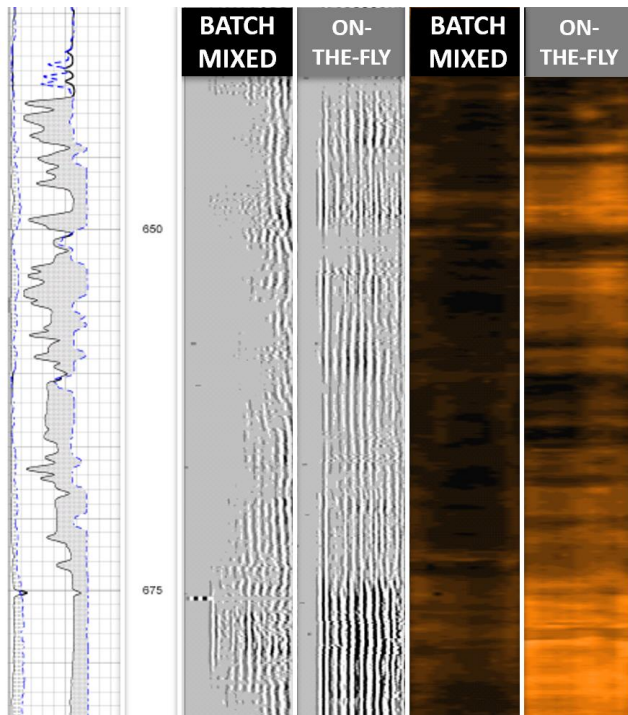


Figure 5: Bond log interval of 635 m (2083 ft) to 684 m (2244 ft). Batch Mixed Slurry vs. On-The-Fly mixed

## Conclusion

Several factors are involved in achieving a good cement bond that provides long term zonal isolation.

- A formulated preflush based on alkali powder silicate has demonstrated
- there is a synergistic effect between surfactants and silicate
- retained are the traditional benefits associated with silicate flushes
- a single component reduces volume requirements for flushes while improving wetting
- pumping the flush with higher velocity improves oil mud removal
- batch mixing mitigates risk to achieving desired density at required higher rates of over 1.5 m<sup>3</sup>/min (9.4 bpm)
- bond logs demonstrate a quantifiable improvement when batch mixing vs. on-the-fly
- fit for purpose formulated preflushes combined with fit for purpose mixing/pumping equipment improve mud removal and cement placement
- increasing annular velocities improve mud removal efficiencies

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