American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-12, pp-109-116
www.ajer.org
Research Paper Open Access

Effects of Seawater and Freshwater on Rheology of Cement Slurry with Varying Concentration of Sodium Silicate at Low Temperature

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ABSTRACT :(10 Bold) *Zonal isolation relies on cement slurries to seal the annular space between the casing and wellbore wall, preventing fluid migration and ensuring well integrity. The rheological behavior of the cement slurry, including viscosity, yield stress, and gel strength, is crucial for effective placement and hydraulic isolation. Mastering these rheological properties is essential for maintaining the structural integrity of the well. This study explores the effect of seawater and freshwater on the rheology of cement slurries containing varying concentrations of sodium silicate at low temperatures. The test temperatures were 80oF, 90oF, and 100oF. The experiments was conducted according to API RP 10B-2/ISO 10426-2 standards, using 12.5ppg cement slurry with 1%, 2%, and 3% sodium silicate, mixed with seawater and another recipe mixed with freshwater. Rheological properties were measured with a Fann model 35A viscometer across different shear rates and the free fluid, plastic viscosity and yield point were determined. The study reveals that cement slurry prepared with seawater (CSM), generally show low plastic viscosity and high yield point compared to cement slurry prepared with freshwater (CFM), due to seawater's ionic composition, which enhances flow resistance when combined with sodium silicate. For the same sodium silicate concentration and temperature, CFM demonstrated lower rheological values but higher free fluid than CSM. Increasing sodium silicate concentration reduces free fluid, increases the plastic viscosity and yield point both for CFM and CSM, signifying a more stable slurry. However, for the same sodium silicate concentration at the same temperature, the rheological reading for CSM is higher than CFM. Optimum concentration of sodium silicate needs to be used for cement formulation to obtain a stable slurry with good rheological properties. More so, seawater when combined with sodium silicate, can create cement slurries with better rheological properties, optimizing cementing operations in challenging offshore environments.*

KEYWORDS Offshore cementing , Rheology, sodium silicate, low temperature, plastic viscosity, free fluid.

Date of Submission: 06-12-2024 Date of acceptance: 18-12-2024

I. INTRODUCTION

In oil and gas drilling operations, achieving effective zonal isolation is crucial for ensuring well integrity and preventing fluid migration between different geological formations. Zonal isolation involves creating a reliable barrier using cement slurries to seal off the annular space between the casing and the wellbore wall. This barrier prevents the migration of fluids such as oil, gas, or water, thereby safeguarding the structural integrity of the well. Central to the success of zonal isolation is the rheological behavior of the cement slurry. Rheology, a fundamental concept in cementing and drilling operations, refers to the study of the flow and deformation of materials. In the context of cement slurries, rheology encompasses parameters such as viscosity, yield stress, and gel strength. Understanding and controlling the rheological properties of cement slurries are essential for achieving proper placement, ensuring hydraulic isolation, and ultimately, maintaining well integrity. The choice of mixing fluid significantly influences the rheological properties of cement slurries. Traditionally, freshwater sourced from surface or groundwater reservoirs has been the primary mixing fluid for preparing cement slurries. However, in offshore drilling operations or regions where freshwater availability is limited, seawater is often used as an alternative. Seawater differs from freshwater in its higher salinity and unique ion composition, which can impact cement hydration kinetics and, consequently, the rheological behavior of cement slurries. Moreover, chemical additives play a vital role in modifying the properties of cement slurries to meet specific performance requirements. One such additive is sodium silicate, commonly referred to as water glass. Sodium silicate is known for its ability to improve the rheological stability of cement slurries, particularly under challenging conditions such as low temperatures. By enhancing particle dispersion and controlling water loss, sodium silicate can optimize rheological parameters, ensuring the successful placement and consolidation of cement slurries.

However, the combined effects of seawater versus freshwater and varying concentrations of sodium silicate on cement slurry rheology at low temperatures (80, 90, 100°F) have not been extensively investigated. This gap in knowledge presents a significant challenge for optimizing cementing operations, particularly in offshore environments or cold climate regions where low-temperature conditions prevail. In this study, we aim to explore the effects of seawater against freshwater on the rheology of cement slurries containing varying concentrations of sodium silicate under low-temperature regimes (80, 90, 100°F). By examining these interactions, we seek to provide insights that will inform the development of tailored cementing solutions capable of withstanding the challenges posed by cold environments in oil and gas drilling operations, ultimately contributing to improved zonal isolation and well integrity.

II. LITERATURE REVIEW:

The rheological behavior of cement slurries in oil well cementing operations is a critical aspect influenced by various factors, including water composition, temperature, and chemical additives (Alabduljabbar et al., 2018; Saad et al., 2020; Salehi et al., 2020). Studies investigating the rheological behavior of cement slurries under low-temperature conditions have emphasized the role of water composition and chemical additives in mitigating temperature-related challenges (Memon et al., 2021; Zhang et al., 2018). However, there is a gap in knowledge regarding the specific influence of sodium silicate concentration on the rheology of seawater versus freshwater-based cement slurries at low temperatures (Smith et al., 2016; Wang et al., 2021). Series of studies have demonstrated the significant impact of seawater versus freshwater as mixing fluids on the rheological properties of cement slurries (Al-Ansary et al., 2016; Bentz et al., 2018; Ghrici et al., 2020). Seawater, characterized by its higher salinity and unique ion concentrations, often leads to distinct rheological behavior compared to freshwater-based slurries (Hajimohammadi et al., 2021; Li et al., 2018; Rashad et al., 2017).

The inclusion of chemical additives such as sodium silicate can further modify the properties of cement slurries and impact rheological stability (Chen et al., 2018; Johnson & Brown, 2019; Rashid et al., 2020). As studies by Johnson and Brown (2019) explicitly showed that sodium silicate can improve the rheological stability of cement slurries, particularly at low temperatures, by enhancing particle dispersion and reducing water loss. Sodium silicate, known for its role in enhancing particle dispersion and reducing water loss, can influence key rheological parameters such as plastic viscosity and yield point (Smith et al., 2016; Wang et al., 2021). However, the combined effects of seawater, freshwater, and varying concentrations of sodium silicate on cement slurry rheology at low temperatures remain understudied. Buttressing the influence of rheological parameters by sodium silicate, Smith et al. (2016) demonstrated that seawater-based cement slurries generally exhibit higher viscosities and yield points compared to freshwater-based slurries due to the presence of dissolved ions. This difference in rheological properties can influence the pumping and placement of cement slurries in oil wells. Sodium silicate intricate role as an additive in cement slurries has also been investigated extensively. Sodium silicate, commonly known as water glass, is used to modify the properties of cement slurries, including setting time, strength development, and rheology. Studies by Johnson and Brown (2019) showed that sodium silicate can improve the rheological stability of cement slurries, particularly at low temperatures, by enhancing particle dispersion and reducing water loss.

Recent research has highlighted the importance of understanding these combined effects to optimize cementing operations in challenging environments (Ismail et al., 2019; Memon et al., 2021; Zhang et al., 2018). Studies investigating the rheological behavior of cement slurries under low-temperature conditions have emphasized the role of water composition and chemical additives in mitigating temperature-related challenges (Roshan et al., 2019; Sadeq et al., 2021). However, with limited availability of data, there is a need for comprehensive research to elucidate the specific influence of sodium silicate concentration on the rheology of seawater versus freshwater-based cement slurries at low temperatures (Xiao et al., 2017; Younes et al., 2020). The rheological behavior of cement slurries is intricately linked to water composition, temperature, and chemical additives such as sodium silicate. Studies exploring the effects of seawater versus freshwater and varying sodium silicate concentrations at low temperatures are essential for developing tailored cementing solutions that can withstand diverse downhole conditions. Further research such as the current study is required to address this gap in knowledge and provide insights into the combined effects of seawater, freshwater, and sodium silicate concentration on cement slurry rheology under low-temperature regimes. Understanding these interactions is crucial for developing tailored cementing solutions capable of withstanding diverse downhole conditions in oil and gas drilling operations (Zayed et al., 2019; Zhu et al., 2020).

III. EXPERIMENTAL PROCEDURE

The experimental work is illustrated in the following paragraphs and the flow chart of the research methodology as shown below:

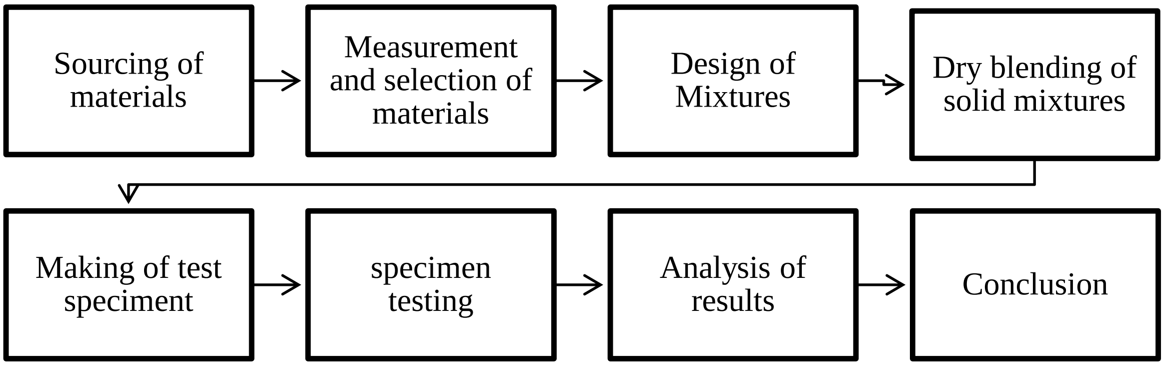

Figure 1: Research Methodology Flowchart

Table 1: Slurry mixtures for rheology test

S/N	SLURRY MIXTURE	Defoamer (ml)	NaSio3 (%)	NaSio3 % BWO	Cement (g)	Water (ml)	Yield (ft3/sk)	Mix Fluid (gal/sk)
1	CFM-1	0.77	1	4.34	434.07	459.47	2.08	11.94
2	CFM-2	0.76	2	8.61	430.42	458.85	2.1	12.02
3	CFM-3	0.77	3	12.8	426.83	458.25	2.12	12.11
4	CSM-1	0.74	1	4.18	418.5	464.51	2.16	12.52
5	CSM-2	0.74	2	8.3	434.07	463.91	2.18	12.61
6	CSM-3	0.73	3	12.35	411.56	463.33	2.2	12.7

IV. METHODS

The rheological measurement was conducted based on API Rp 10B-2/ISO 10426-2. After the cement slurry was prepared, it was transferred into the viscometer cup maintaining its temperature at given temperatures and subjected to shear in Fann direct- indicating viscometer. The torque response for each rotational speed provided by the equipment 300, 200, 100, 6 and 3 rpm which is also 511, 340, 171 and 10s-1 respectively were recorded. At each rotation speed, the revolution per minutes (rpm) was taken when the speed of rotation was stabilized. At each temperature, cement slurry was subjected to rheological test and at each rotation speed, the dial reading was taken when the speed of rotation was stabilized. Rheological values obtained from the viscometer and various calculation obtained from test results are shown below. Thus, the reference for measuring viscosity and performing calculations was by American Petroleum Institute specifications (API RP 13B-1/ISO 10414-1, 2016).

V. RESULTS AND DISCUSSIONS

The results of rheology conducted shows the combined effects of seawater, freshwater, and sodium silicate concentration on different cement slurry rheology under low-temperature regimes. For lead slurry (12.5ppg) formulation, it can be observed as the temperature increases from 70^{0}F to 100^{o}F, the level of consistency of the shear stress relative to the shear rate was consistently and gradually increase relative to the water mixture utilized. The Cement Freshwater Mixture (CFM) shows higher rheology values and this increases in correspondence to the increase in temperature.

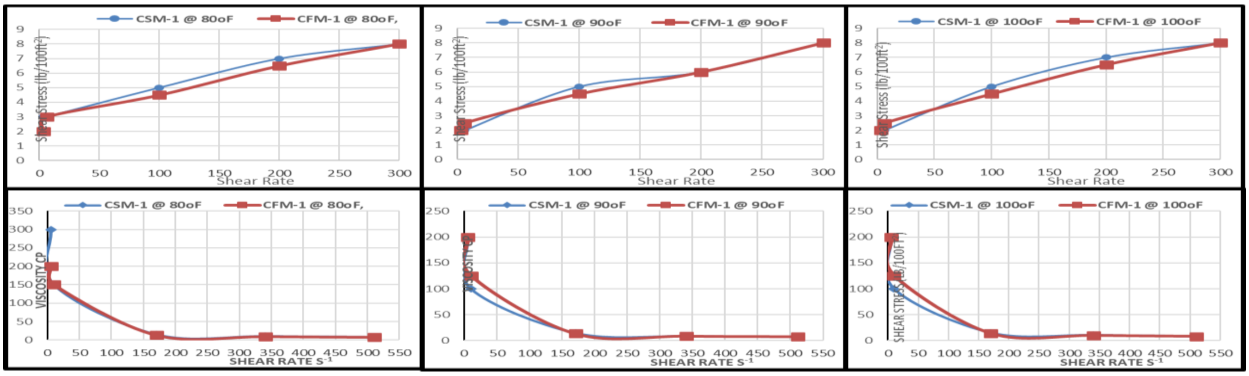

Figure 2: Results of Rheological Properties of Cement Fresh & Sea water Mixture of 12.5ppg at 1% $NaSio_3$

The effect of 1% sodium silicate concentration on CFM (cement freshwater mixture) and CSM (cement seawater mixture) demonstrated distinctive changes in rheological properties were observed. At 80%, cement freshwater mixture (CFM) exhibited higher plastic viscosity (PV) and lower yield point (YP) compared to cement seawater mixture (CSM), indicating increased resistance to flow and easier initiation of flow, respectively (SPE-198664-MS). This was attributed to the thickening effect of sodium silicate, enhancing CFM's resistance to flow, and its lubricating effect, reducing internal friction and facilitating flow. The significant drop in viscosity of CFM at higher shear rates compared to CSM could be attributed to shear-thinning behavior (SPE-166380-MS), where the viscosity of the slurry decreases with increasing shear rate. At 90°F, based on the test rheological data. CFM showcases a higher plastic viscosity (PV) of 5.25 and a lower yield point (YP) of 2.75 compared to CSM with PV of 4.5 and YP of 3.5. Across various shear rates, CFM generally exhibits higher viscosity values, reflecting a more pronounced thickening effect of sodium silicate. Although CFM's plastic viscosity is marginally higher than CSM, this difference minimally influences viscosity at tested shear rates. CFM's lower yield point indicates it flows more readily under lower shear stresses, possibly advantageous for pumping and placement. These distinctions in rheological behavior are attributed to interactions between sodium silicate and freshwater/seawater components, alongside factors like particle size distribution and hydration kinetics. At 100°F, notable differences emerge. CFM exhibits a slightly higher shear stress than CSM across various shear rates, indicating a potentially enhanced resistance to flow. Despite this, both mixtures show comparable shear stress values at higher shear rates, suggesting sodium silicate's influence on flow resistance may diminish under higher stress conditions. Additionally, CFM demonstrates a marginally higher plastic viscosity and a slightly lower yield point compared to CSM, implying subtle distinctions in flow behavior between the two mixtures. These findings underscore the complex interplay between sodium silicate concentration and fluid composition in cement slurries, necessitating a nuanced understanding of their rheological properties for optimal well cementing practices (SPE-180381-MS). Moreover, while sodium silicate is known to affect cement slurry rheology, its precise impact can vary based on factors such as temperature, shear rate, and fluid composition (API RP 10B-2).

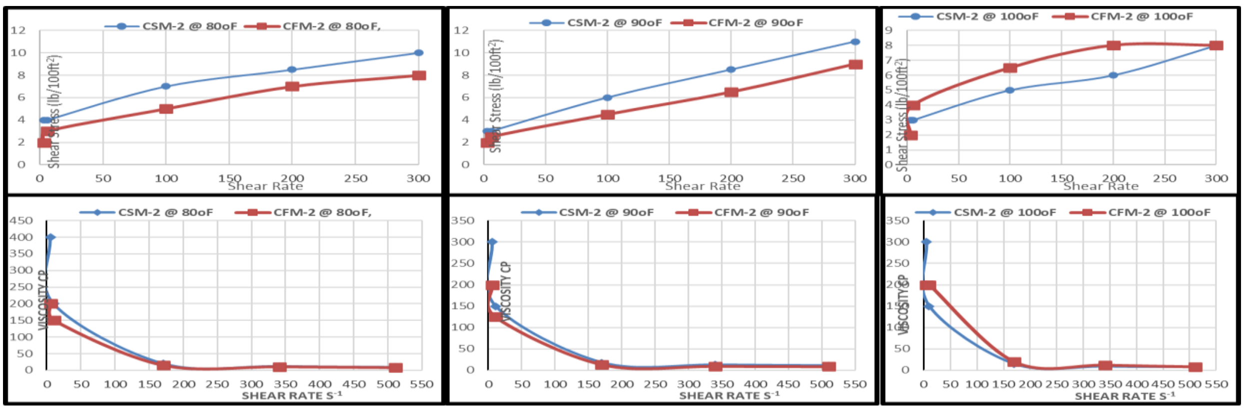

Figure 3:Results of Rheological Properties of Cement Fresh & Sea water Mixture of 12.5ppg at 2% NaSio3

The rheological assessment of 12.5ppg cement slurries with 2% sodium silicate concentration in freshwater (CFM) and seawater (CSM) at 80°F reveals notable distinctions in flow behavior. CFM exhibits lower shear stress values compared to CSM across all shear rates tested, indicating a reduced resistance to flow in the presence of sodium silicate. This difference is particularly evident at higher shear rates, suggesting that the interaction between sodium silicate and freshwater components may enhance the flowability of CFM. Furthermore, CFM demonstrates a lower plastic viscosity and yield point compared to CSM, indicating a propensity for easier flow initiation and higher fluidity. At 90°F reveals distinct flow behavior patterns. CFM consistently exhibits lower shear stress values than CSM across all tested shear rates, indicating a tendency towards easier flow initiation and higher fluidity. This difference is particularly pronounced at higher shear rates, suggesting that the interaction between sodium silicate and freshwater components enhances the flow properties of CFM. Furthermore, CFM demonstrates a lower plastic viscosity compared to CSM, signifying a thinner consistency and potentially improved pumpability. At 100°F the rheological analysis of 2% sodium silicate-enhanced cement slurries in freshwater (CFM) and seawater (CSM) reveals intriguing differences in flow behavior though with a high level of consistency with respect to the previous test done. CFM consistently demonstrates higher shear stress values compared to CSM across all tested shear rates. This suggests that sodium silicate interacts differently with freshwater and seawater constituents, resulting in varied rheological properties. Additionally, CFM exhibits a lower plastic viscosity, but a higher yield point compared to CSM. The lower plastic viscosity of CFM implies a thinner consistency, possibly enhancing pumpability, while the higher yield point suggests increased resistance to flow initiation. These findings align with established principles of rheology in cement slurries, highlighting the complex interplay between additives and fluid composition (API RP 10B-2).

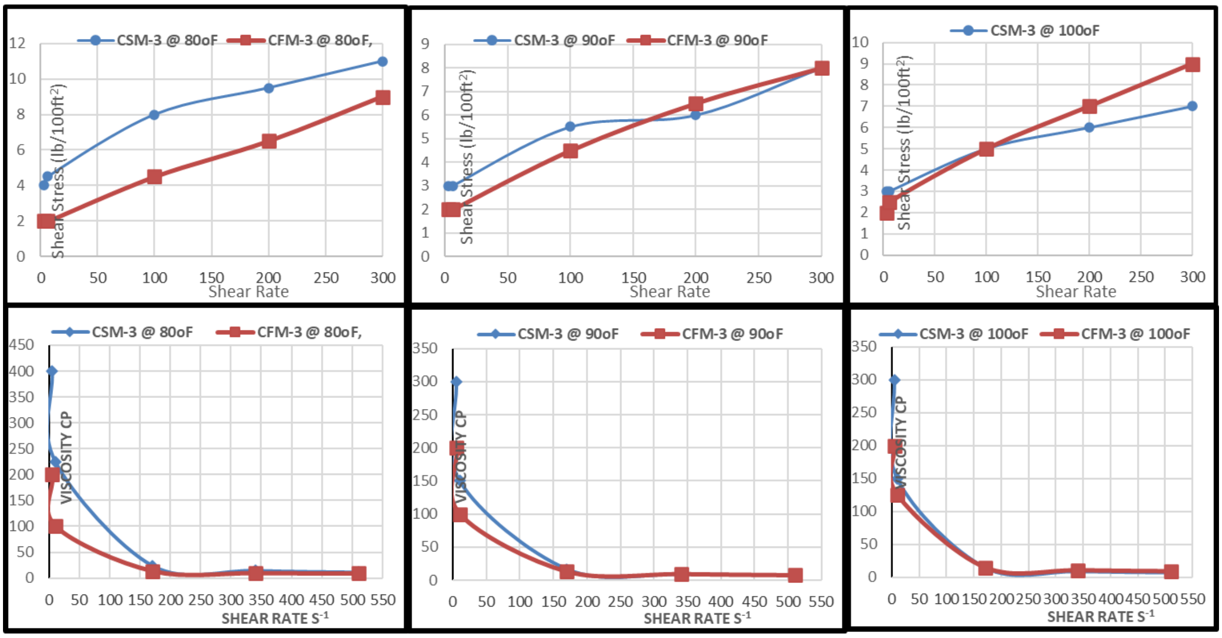

Figure 4:Results of Rheological Properties of Cement Fresh & Sea water Mixture of 12.5ppg at 3% NaSio3

The rheological assessment of 12.5ppg cement slurries with 3% sodium silicate concentration in freshwater (CFM) and seawater (CSM) at 3%, for 80oF CFM consistently displays lower shear stress values compared to CSM across all examined shear rates, indicating a potentially smoother flow behavior. This discrepancy may stem from the varying interactions between sodium silicate and the distinct components of freshwater and seawater. Furthermore, at both 80oF and 90oF CFM demonstrates a higher plastic viscosity but a lower yield point than CSM. The higher plastic viscosity of CFM implies a thicker consistency, while the lower yield point suggests easier flow initiation. Across all measured shear rates, CFM consistently shows lower shear stress values than CSM at 3% sodium silicate-enhanced cement slurries, suggesting a potentially smoother flow behavior. The observed disparity could potentially be explained by the distinct ways in which sodium silicate interacts with the various constituents found in freshwater and seawater. In addition, CFM has a lower yield point than CSM but a higher plastic viscosity. A thicker consistency is suggested by CFM's higher plastic viscosity, and simpler flow initiation is shown by its lower yield point. These results highlight the significance of fluid composition and additive concentration in cementing operations and are consistent with accepted rheological principles in cement slurries.

VI. FREE FLUID ANALYSIS

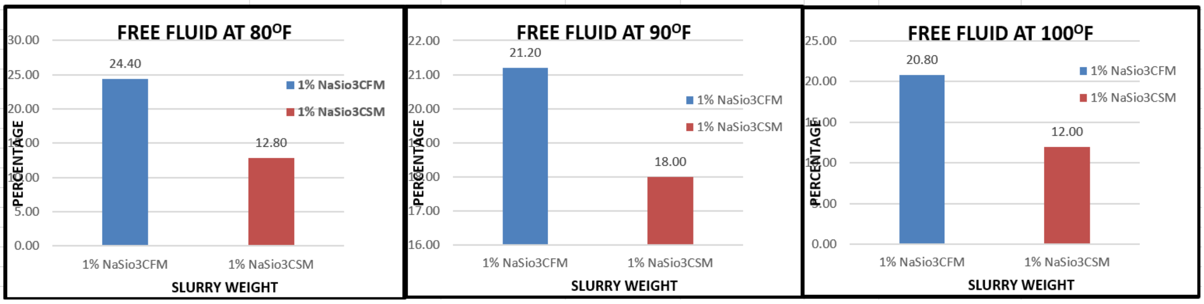

Figure 5: 24hrs free fluid test analysis at 1% Na_2SiO_3

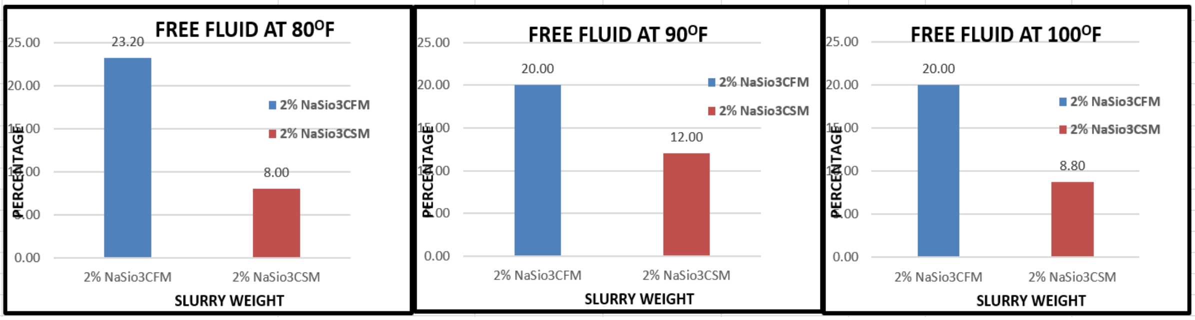

Figure 6: 24hrs free fluid test analysis at 2% Na_2SiO_3

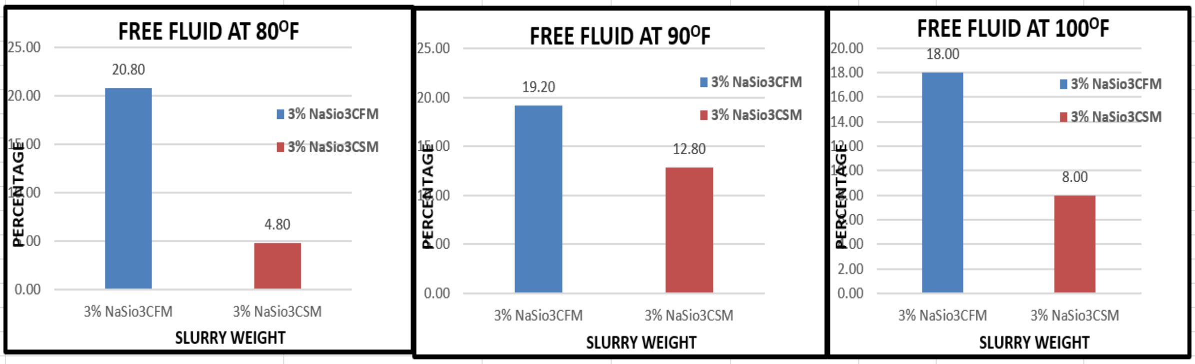

Figure 7: 24hrs free fluid test analysis at 3% Na_2SiO_3

For all concentrations of Na_2SiO_3, CFM consistently shows higher free fluid content compared to CSM at all temperatures. As the concentration of Na_2SiO_3 increases, the difference in free fluid content between CFM and CSM becomes more pronounced. Higher temperatures generally lead to a decrease in free fluid content for both CFM and CSM, but CFM still maintains a higher free fluid content compared to CSM across all temperature ranges and concentrations of Na_2SiO_3.

VII. CONCLUSION

This study explores the rheological effects of seawater and freshwater on cement slurries with varying sodium silicate concentrations at low temperatures. Effective zonal isolation in oil and gas well cementing relies on precise rheological control of cement slurries, with parameters like viscosity and yield stress crucial for achieving structural integrity and preventing fluid migration. While freshwater has traditionally been used in slurry preparation, seawater is increasingly utilized in offshore regions. Seawater's higher salinity and unique ion composition, combined with chemical additives like sodium silicate, can influence the rheology of cement slurries, especially at low temperatures.

The experimental approach involved testing cement slurries with 1%, 2%, and 3% sodium silicate in both freshwater and seawater. Rheological measurements were conducted per API and ISO standards using a Fann VG viscometer. Results indicated distinct rheological behaviors between seawater-based and freshwater-based slurries with sodium silicate, including variations in plastic viscosity and yield point, which influence flow resistance and pumpability. Generally, cement seawater mixtures (CSM) exhibited higher rheological values than cement freshwater mixtures (CFM), likely due to sodium silicate's differential interaction with water types and varying ion compositions.

Notably, increasing sodium silicate concentration led to higher plastic viscosity and lower yield point in freshwater-based slurries, indicating enhanced resistance to flow and easier initiation of flow, respectively. For seawater mixtures, the effect was more complex, with variability in flow resistance influenced by sodium silicate concentration and temperature.

Free fluid analysis suggests that the choice of mixing water, whether freshwater or seawater, significantly influences the free fluid content of concrete, particularly at low temperatures and varying concentrations of sodium silicate. It also showed higher free fluid content in freshwater-based slurries, suggesting that seawater mixtures may offer better fluid retention under low-temperature conditions. CFM consistently retains more free fluid compared to CSM, minimizing free fluid content in cement slurries is essential for achieving optimal cementing outcomes in oil and gas wells. Slurries with lower free fluid exhibit superior strength, durability, fluid loss control, rheological properties, setting characteristics, and overall cement quality, making them preferable choices for effective zonal isolation and wellbore integrity.

These findings underscore the complex interactions between water type, sodium silicate concentration, and temperature, highlighting the need for tailored cementing solutions in cold environments. The study contributes valuable insights into the optimization of cement slurry formulations for offshore and low-temperature applications, ultimately supporting improved well integrity and zonal isolation.

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