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Foam cement for super-hot geothermal wells

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ABSTRACT

In geothermal well applications, the integrity of the casing system is critically challenged by thermal stresses induced during operations. Portland cement-based systems have been widely employed for cementing geothermal wells. However, these solutions exhibit limitations in flexibility, leading to significant thermal stresses and potential casing failure, as observed in various geothermal projects.

In the context of the COMPASS project, innovative foam cement solutions have been designed to enhance flexibility within well systems. Foam cements consist of a gas-liquid dispersion that incorporates bubbles within a cement matrix, resulting in lower density and higher flexibility compared to conventional cements. This unique structure enables foam cements to accommodate casing expansion more effectively, significantly reducing the risk of high thermal stresses during heating cycles.

This work investigates the composition and design of these foam cements, comprising cement slurries, foaming agents, and inert gases, primarily nitrogen. The key objectives are to optimize foam quality, stability, and the mechanical properties of the set cement while ensuring effective cement placement under high-temperature conditions. Laboratory experiments focus on mechanical properties at elevated temperatures, simulating down-hole conditions.

The results indicate that the developed foam cement successfully retains its bubbles even at high curing temperatures and demonstrates improved flexibility and compressibility, contributing to enhanced performance in thermal loading cycles. To achieve reliable and representative results, an innovative high-temperature curing protocol has been developed to simulate real down-hole conditions. The development of foam cement designed for high-temperature geothermal wells, with static curing conditions up to 150°C, represents an innovation and advances the state-of-the-art of cementing materials. These findings highlight the potential of foam cements as a viable alternative to traditional cementing solutions in geothermal applications, promoting well integrity and operational efficiency in high-temperature environments.

1. INTRODUCTION

Geothermal energy represents a promising solution for the energy transition, yet the development of super-hot geothermal wells raises significant challenges regarding well integrity. In these environments, conventional cementing systems are subjected to extreme thermal and mechanical loads, which can lead to cement degradation, casing failure, and ultimately, loss of zonal isolation.

To overcome these limitations, the COMPASS project, funded by the European Union's Horizon programme, investigates new cementing strategies that combine improved stress tolerance with long-term thermal stability. Among the solutions explored, foam cement systems offer a unique advantage due to their intrinsic compressibility and low stiffness, which help accommodate casing expansion and reduce thermally induced stresses.

While foam cement has been applied in conventional oil and gas operations, its use in high-temperature geothermal wells remains limited and poorly documented. Existing literature mostly describes low-temperature or low-foam quality applications.

This paper presents the experimental evaluation of a novel foam cement system developed for geothermal wells operating at high temperature. A specific focus is placed on validating its behaviour under thermal loads and assessing its mechanical and structural performance after high-temperature curing. The objective is to contribute to the qualification of alternative cementing solutions that ensure long-term

well integrity under the demanding conditions of super-hot geothermal operations.

2. STATE OF THE ART

Foamed cements have been used for more than 40 years (Davies et al. 1981) to cement casings and liners in oil and gas wells. The low density, and relatively high compressive strength of foamed cement compared with other low density cement formulations were initially used to combat lost circulation problems, although Davies et al. (1981) also recognised the benefits of foamed cement for improved zonal isolation.

Benge et al. (1982) discussed the field application of foam cement at depths of up to 5000 m but the foam quality at bottom hole conditions was not disclosed. The bottom hole circulating temperatures were up to 93°C. These authors were also the first to provide data on the thermal conductivity of foamed cements at slurry densities between 840 and 1200 kg m^{-3}. The values, between 0.25 and 0.5 Wm^{-1} K^{-1}, were lower than those of conventional low density cement systems, although the conventional systems had a higher density. Later work (Nelson 1986) showed that the thermal conductivity of cement systems was approximately proportional to slurry density, irrespective of whether the systems were foamed.

An early application of foamed cement in geothermal wells was described by Rickard (1985). The base cement slurry comprised class G cement with 40% by weight of cement silica to prevent strength retrogression at the elevated production temperatures. Several subsequent papers (Bour and Rickard (2000), Spielman et al. (2006), Berard et al. (2009) and Niggemann et al. (2009) have presented field applications of foamed cement in geothermal wells. In all these applications, the placement temperatures were below 121°C and foam qualities were usually below 30%.

In thermal recovery heavy oil wells, foam qualities as high as 40% have been used, but the slurry placement temperatures were low (Harms and Febus 1985).

In the applications reviewed above, the downhole hydrostatic pressures have been relatively low, allowing relatively high downhole foam qualities to be obtained. However, placement temperatures were low.

To achieve a high foam quality under high hydrostatic pressure downhole, very high foam qualities will be required at the lower surface pressures during mixing and placement. De Rozières and Ferrière (1991) concluded that foamed cement can be expanded without affecting its stability as long as the foam quality remains lower than 80%. In conventional oil and gas wells, high placement temperatures are typically associated with high hydrostatic pressures downhole and consequently lower downhole foam qualities. No examples of foamed cement prepared at 30% or higher quality and with placement temperatures >100°C have been found in the literature.

Kopp et al. (2000) used foamed cement to cement deep gas wells in Wyoming. The downhole foam quality was between 20 and 23% but the placement temperatures were not given. Harlan et al; (2000) used foamed cement in reservoir sections where the static temperature was 88°C. Griffith et al. (2004) described the application of foam cement in HPHT wells in the North Sea. The downhole foam quality was 20% and the placement temperature was 95°C. Heathman and Beck (2006) stated that "foamed cement is not conducive" to situations where the placement temperature may be higher than 200°C.

The objective of this paper is to extend the application of foamed cement to higher foam qualities at higher temperatures.

3. REQUIREMENT

Ensuring the long-term integrity of geothermal wells under super-hot conditions requires that foam cement systems meet precise performance requirements throughout their life cycle, from placement to long-term durability. These requirements can be grouped into three functional categories: placement, in-situ mechanical behaviour, and durability under thermal cycling.

3.1 Placement Requirements

Effective placement of foam cement in geothermal wells is critical to establishing a continuous and homogeneous barrier around the casing. The following parameters govern successful placement:

- **Rheological parameters:** The slurry must exhibit sufficient pumpability and stability during placement. Due to equipment limitations, viscosity measurements are typically performed on the unfoamed base slurry, including all additives, at temperatures up to 88°C.

- **Thickening time:** A thickening time of at least 5 hours at temperatures up to 150°C is required to allow safe operations. This is generally measured on the unfoamed slurry.

- **Foam stability:** The foam must remain stable throughout the placement process and during setting. This includes maintaining uniform bubble distribution and avoiding segregation. Stability is verified through visual and physical analyses of set samples, as recommended in ISO 10426-4.

3.2 In-situ Mechanical Behaviour

Once set, the cement must accommodate thermal and mechanical loads while preserving its sealing and structural function.

- **Foam quality:** A minimum foam quality of 20% ensures enhanced compressibility and flexibility, allowing the cement to absorb casing expansions without cracking. The

presence of foam bubbles also contributes to improved thermal insulation.

$$FQ = \frac{Gas\ volume}{Gas\ volume + liquid\ volume} \cdot 100 \qquad [1]$$

- **Density:** A target density below 1.5 g/cm³ helps prevent formation losses.

- **Compressive strength and Young's modulus:** A minimum unconfined compressive strength (UCS) of 3.5 MPa is generally recommended to ensure adequate mechanical support under geothermal conditions. For the Young's modulus, lower values (increased flexibility), typically below 5 GPa, helps reduce the risk of casing-cement interface failure. However, the optimal modulus should be determined based on the specific well architecture and in-situ stress conditions.

3.2 Durability and Long-Term Thermal Integrity

Under high-temperature geothermal conditions, long-term stability of the cement is influenced by internal water content and thermal cycles.

Pore fluid control: In foam systems, limiting the residual pore fluid density after hydration can help reduce internal pressure buildup during temperature increases. The foam structure should facilitate water redistribution during thermal expansion.

Due to the limitations of standard test equipment, not all parameters can be evaluated directly on the foam slurry, as emphasized in ISO 10426-4. For example, viscosity and thickening time are measured using the unfoamed base slurry containing all additives, while stability and compressive strength must be assessed on the foam system. This distinction is critical to ensuring that all requirements are adequately validated. Studies by McElfresh and Go Boncan (1982) have shown that the thickening time is not significantly affected by foaming, supporting the use of unfoamed slurries for this measurement. Similarly, De Rozières and Ferrière (1991) used sonic measurements and calorimetry to demonstrate that the setting time of foam cements remains comparable to that of the base slurry.

These performance requirements serve as the foundation for the formulation, testing, and qualification of foam cement systems in high-temperature geothermal wells.

4. TESTING PROTOCOL

To verify compliance with the defined requirements, a comprehensive testing campaign was implemented. The tests were structured around the two material states: the unfoamed base slurry and the foam cement system, each supporting specific performance targets.

4.1. Tests performed on the unfoamed base slurry

The base slurry was tested primarily to validate its pumpability, placement behaviour, and physical stability prior to foaming.

Mixing

The mixing procedure followed ISO 10426-2 using a high-speed mixer. Additives were first incorporated into the mixing water at 4000 rpm. The cement or blend was then added over a 15-second period while maintaining the same rotation speed. Finally, the full slurry was mixed at 12000 rpm for 35 seconds to ensure complete homogenization. This base slurry is used both as the initial material for foam generation and as a reference system to assess placement and stability properties that cannot be systematically evaluated on the foam cement.

Thickening time

Thickening time was measured using an HPHT consistometer following a temperature ramp of 3°C/min, which reflects a typical heating profile in geothermal wells. The test was carried out at a pressure of 35 MPa to simulate downhole conditions. These parameters, temperature ramp and pressure, were selected based on real field data from a geothermal well in the COMPASS project, where the well was cooled to 150°C before the cementing operation. As such, the temperature of 150°C was adopted as the reference for evaluating the thickening time. The test endpoint was defined at 100 Bearden Consistency (Bc), and a target of at least 4 hours was set to ensure sufficient pumpability and safe placement time under thermal constraints representative of actual field operations.

Rheology

Rheological properties were evaluated at ambient temperature using a standard API rheometer with a B1 bob and R1 rotor. Shear stress was recorded at various rotation speeds, and the data were interpreted using different rheological models: Newtonian, Bingham plastic, power law (Ostwald-de Waele), and Herschel–Bulkley. The Newtonian model assumes a constant viscosity with no yield stress. The Bingham model introduces a yield stress and a constant plastic viscosity. The power law model accounts for shear-thinning or thickening behaviour without yield stress, while the Herschel–Bulkley model combines yield stress with a shear-dependent viscosity. Fitting the data to these models helps identify the most accurate description of the slurry flow behaviour, which is essential to evaluate pumpability, risk of segregation, and shear response during placement.

Free fluid

The free fluid test was used to evaluate the tendency of the slurry to release water when left static, which is a key parameter for assessing its stability during placement. The test followed the ISO 10426-2 standard: a 250 ml volume of slurry was poured into a graduated cylinder, which was then sealed to prevent

evaporation, and left undisturbed for 2 hours at ambient temperature. The volume of clear liquid separating at the top was measured and reported as a percentage of the total slurry volume. A value below 1% was targeted to meet the requirement for adequate zonal isolation and avoid the formation of water channels that could compromise cement integrity.

Settling test

The settling test was conducted on hardened base slurry cast in a vertical cylinder, cured 24 hours at 120°C and 35 MPa. Once set, the specimen was sliced in four, and the density of each segment was determined using Archimedes' principle. Consistent density across segments indicated a homogeneous distribution of solids confirming that the formulation was stable during setting and did not exhibit significant segregation or phase separation.

These tests confirm that, prior to foaming, the slurry formulation meets key placement-related requirements and shows sufficient physical homogeneity. They provide essential information on properties such as pumpability, static stability, and the uniform distribution of solids, factors that are critical to ensuring a successful cementing operation. However, these tests are inherently limited to parameters that are not affected by the presence of gas. Because standard equipment, such as consistometers, cannot be used reliably on foam systems, the base slurry is only suitable for evaluating foam-independent properties. In contrast, characteristics that are intrinsically linked to the foam structure, such as the density or the mechanical properties, must be assessed directly on the foam cement. This distinction motivates the complementary testing campaign detailed in the next section.

4.2. Tests performed on the foam cement system

A dedicated series of tests was performed on the foam system to assess its properties in both the slurry and hardened states. These tests were designed to assess properties that are intrinsically linked to the presence of gas in the system, such as density, stability, and mechanical performance, and that cannot be reliably derived from measurements on the base slurry. This comprehensive approach ensured that all foam specific requirements were directly validated under conditions representative of geothermal well application

Mixing

The mixing of foam cement followed ISO 10426-4 and was conducted at atmospheric pressure, as prescribed by the standard. In the laboratory, foam is generated at atmospheric pressure, while in field operations, foam cement is typically mixed under pressure to provide the required foam quality under downhole hydrostatic pressure. In our case, the absence of pressure during laboratory mixing implies that excessive pressure during curing must be avoided, to prevent bubble compression and to maintain the integrity of the foam structure.

The preparation involved two distinct mixing stages. First, the base slurry was mixed in a standard blender equipped with a single-blade assembly. After this, the mixture was transferred to a specialized five-blade blender specifically designed for foam generation, and the foaming agent (surfactant) was added. Although the standard protocol prescribes high-speed mixing, it was adapted in our case to improve the homogeneity and reproducibility of the foam. Mixing was carried out at atmospheric pressure until the foam visibly expanded and filled the blender. Based on repeated trials, a rotation speed of 7000 rpm was found optimal. This setup ensured effective gas dispersion while minimizing variability and ensuring repeatable foam quality in the laboratory environment.

Fluid density

Foam density was measured immediately after mixing using a calibrated open-top container of known volume. The filled container was weighed, and density was calculated from the mass-to-volume ratio. This measurement is critical, as foam density directly reflects the foam quality, i.e. the gas volume fraction in the slurry, and is a key parameter of the system. While it must be measured on the foam slurry to determine foam quality and gas content at placement, it is equally important to assess the density of the set cement to evaluate final structural performance. These two measurements provide complementary insights and are both necessary to fully characterize the system.

Free fluid

The free fluid test on the foam cement followed a similar approach to that used for the base slurry. A 250 ml graduated cylinder was filled with the foam slurry, sealed, and left undisturbed for 2 hours at ambient temperature. The volume of separated fluid was measured to assess slurry stability. Acceptable performance was defined by minimal or no free water at the top.

Settling test

Settling was evaluated on cylindrical foam samples cured for 24 hours at 150°C and 0.5 MPa (just above the vapour pressure of water at 150°C). The set samples were cut into four segments along their height. Density of each segment was determined by Archimedes' principle. A uniform density profile confirmed the stability of the foam during setting and the absence of gas migration or phase segregation.

Mechanical testing

Mechanical testing was performed on two foam specimens, each cured in a different setup under different conditions using a test cell designed to support thermal curing under pressure and to isolate the specimen from direct contact with water, enabling more representative simulation of downhole conditions. This is particularly important for foam systems, as pressure and moisture management during curing significantly

affect bubble preservation and the representativeness of the final material.

The first specimen was cured at 150°C and 0.5 MPa. After curing, the density of the hardened foam was measured, and a uniaxial compression test was conducted to determine the compressive strength (UCS). Strain was not monitored during this test.

The second specimen was cured at 70°C and atmospheric pressure. After curing, the density was also measured. This sample was then subjected to a uniaxial compression test with displacement tracking, allowing for the determination of both UCS and Young's modulus from the loading-unloading cycle.

These two protocols provided complementary insights: the first focused on the mechanical behaviour of the material under elevated temperature and mild confinement, while the second enabled the quantification of its elastic response. Together, they contribute to a more complete evaluation of the foam cement's ability to withstand mechanical loads and accommodate thermal stresses in geothermal wells.

Together, these tests constitute a complete experimental protocol designed to evaluate the foam cement system both in its slurry and set cement states. They establish a robust methodological foundation for characterizing foam-specific parameters that cannot be captured through base slurry testing alone. This testing protocol provides the methodological basis for evaluating the cement systems developed in this study. The following section describes the materials and formulations used to design and produce the base slurries and foam systems tested.

5. MATERIALS

The cement systems developed for this study are based on a Class G Portland cement, selected for its well-known behaviour and compatibility with geothermal well environments. Class G cement is a type of oil well cement standardized by the API (American Petroleum Institute), and is the most commonly used cement in well construction due to its versatility and adaptability to a wide range of downhole conditions. This type of cement provides a robust and stable base that supports further formulation adjustments tailored to extreme temperature applications.

To enhance thermal stability and prevent strength retrogression, silica flour was incorporated into the blend. The inclusion of silica is a common practice in high-temperature cement systems, as it promotes the formation of stable calcium silicate hydrates at elevated temperatures.

Several additives were also introduced to adjust the slurry behaviour and address the specific challenges posed by foam systems.

A dispersant was used to reduce slurry viscosity and improve the rheological properties, thereby facilitating the mixing phase, placement, and foamability.

An anti-settling agent was added to limit particle segregation and maintain uniformity in both base and foam slurries during and after placement.

A high-temperature retarder was selected to ensure sufficient thickening time under geothermal conditions. This additive was critical in this project due to the elevated placement temperatures (up to 150°C). Among the retarder concentrations considered during preliminary screenings, one was retained for its ability to provide sufficient delay in setting time without compromising pumpability. The selected retarder ensured extended pumpability despite the acceleration of the hydration process at elevated temperatures.

Finally, a specific foaming agent (surfactant) was used to generate and stabilize the gas phase within the slurry. The selection of this product was key, as most commercial surfactants do not retain their efficiency under high-temperature conditions. The agent used in this study was chosen for its thermal tolerance and compatibility with the cement matrix. Its behaviour was carefully characterized throughout the testing protocol to ensure stable bubble formation and prevent bubble collapse during curing.

All materials were selected to meet the performance requirements defined in Section 3, with particular attention given to compatibility, thermal stability, and the ability to maintain homogeneity in the foam system.

6. RESULTS

6.1 Base

Mix

The initial stage in the development of the foam cement base focused on improving slurry mixability by adjusting the dispersant concentration. This adjustment aimed to facilitate the incorporation of solid phases into the liquid. This parameter was monitored through the time required to add the blend during mixing. Once a satisfactory composition was obtained, the formulation was optimized to meet thickening time requirements.

Thickening time.

Four formulations with different concentrations of high-temperature retardant were tested at a temperature of 140 °C and a pressure of 35 MPa (Figure 1a). The data show that the thickening time can be controlled by varying the retarder concentration. System FB04, with the highest retarder concentration, had a thickening time longer than 6 hours. This was too long for the current project so the test was stopped. System FB04, with a thickening time of 5h35min, meeting the project requirements, was selected as the optimised formulation.

To evaluate the robustness of this optimized formulation, FB04 was retested at 150 °C (Figure 1b), corresponding to the expected placement temperature in the target geothermal well. Interestingly, the thickening time increased to approximately 6h30, contrary to the typical acceleration of hydration

observed with higher temperatures. This unusual behaviour needs to be investigated further.

All the tests in Figure 1a used the same temperature ramp. Measured temperatures for all tests were within ±3°C of the programmed temperature during the ramp and were within ±1°C of the required final temperature, 10 minutes after the end of the ramp as specified in ISO 10426-2. For visual clarity only one measured temperature curve is shown. This simplification was not necessary for Figure 1b, as it represents a single test at 150 °C.
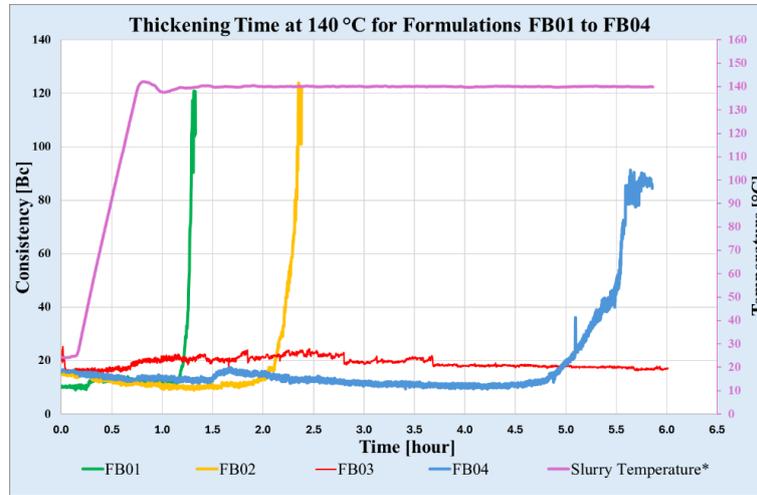
Figure 1a: Thickening Time at 140 °C for Formulations FB01 to FB04
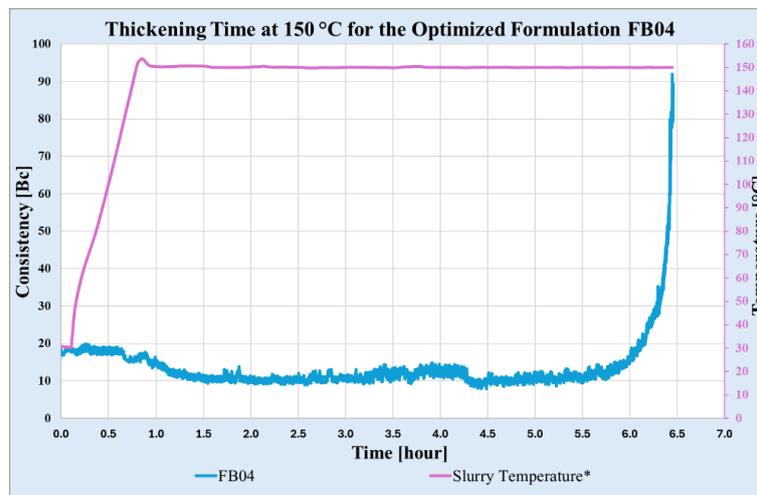*Evolution of consistency for five cement slurry formulations tested at 140 °C and 35 MPa.*

Figure 1b: Thickening Time at 150 °C for the Optimized Formulation FB04
Evolution of consistency for the selected formulation FB04 tested at 150 °C and 35 MPa.

Free Fluid

The free fluid test was performed on the base slurry at ambient temperature. No free fluid was observed, confirming the stability of the system (0 mL).

Settling Test

A static settling test was conducted on the cement after curing at 120 °C and 35 MPa. The density profile across the sample height showed very limited variation, indicating minimal sedimentation:

Table 1: Settling Test - Base density profile after curing 24h at 120 °C & 35MPa

Position	Density (SG)
Top	1.913
Layer 2	1.916
Layer 3	1.915
Bottom	1.922

These results confirm the homogeneity of the cured material.

Rheological Properties

Rheological measurements were performed at 25 °C.: The flow curve obtained from the test is presented in Figure 2, with model fits using Newtonian, Bingham, Power Law, and Herschel–Bulkley equations.

Clearly, the Herschel–Bulkley model provides the best fit to the experimental data. The consistency with the 10-second gel strength further supports the validity of this model, as both yield stress values are nearly identical.
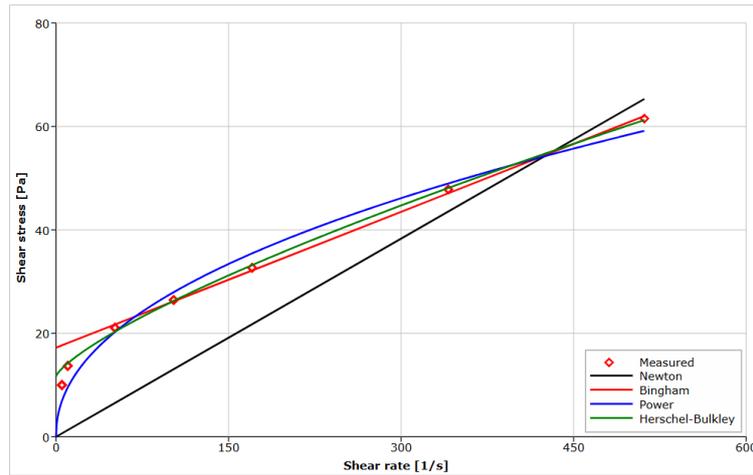
Herschel–Bulkley model parameters:
- $n = 0.760$
- $k = 0.433$ Pa.s^n
- *Yield stress* = 11.69 Pa
- *COV* = 1.000

Gel Strengths:
- 10 sec = 23.8 lbf/100 ft²
- 10 min = 42.5 lbf/100 ft²

Figure 2: Rheological model comparison for the base formulation at 25 °C
Measured shear stress vs. shear rate, with model fits using Newtonian, Bingham, Power Law, and Herschel–Bulkley.

These values indicate a non-Newtonian shear-thinning behaviour with moderate yield strength and good gel development, suitable for maintaining particle suspension and ease of pumping. This shear-thinning behaviour means that the apparent viscosity of the fluid decreases with increasing shear rate, which facilitates pumping while maintaining sufficient structure to prevent particle settling during static conditions.

Overall, the base formulation exhibited favourable behaviour in terms of stability and pumpability, confirming its suitability as a foundation for the development of foam cement systems. The following section presents the design and evaluation of these foam-based formulations.

6.1 Foam cement system

Fluid density and Free Fluid

The fluid density of the foam cement slurry, measured after mixing according to API 10B-4 (ISO 10426-4), was 1.38 SG. A free fluid test was also conducted at ambient temperature following the same standard. No free fluid was observed (0 mL), indicating good phase stability immediately after mixing.

Density of the set foam cement

After curing at 150 °C, the set foam cement exhibited a density of 1.39 SG, confirming that the material retained its lightweight character even after exposure to elevated temperature.

Settling Test

Two static settling tests were performed on cured foam samples to evaluate the homogeneity of the set foam cement:

Table 2: Settling Test – Foam density profiles after curing 24 h at 25 °C & atmospheric pressure and 150 °C & 0.5 MPa

Position	24 h Curing @25 °C Density (SG)	24 h Curing @150°C Density (SG)
Top	1.33	1.65
Layer 2	1.33	1.45
Layer 3	1.34	1.44
Bottom	1.34	1.62

At ambient temperature, the foam showed good homogeneity with minimal variation in density. The system cured at 25 °C did not contain the high-temperature retarder, as this additive prevents setting at

low temperatures. After curing at elevated temperature (150°C), no sedimentation-related gradient was observed. Higher densities were measured at the top and bottom of the sample. This effect is due to the pressure applied during the test (0.5 MPa), which was required to prevent water boiling at high temperature. Since the foam was mixed at atmospheric pressure, the applied overpressure might have led to local compaction of the structure at the extremities. This artefact is linked to the specific curing cell used during the test, which can induce slight compression effects under pressure. The curing protocol has since been improved, and updated results will be available shortly.

Compressive strength and elastic response

The unconfined compressive strength (UCS) of the foam cement was evaluated after curing for 48 h at 70 °C and atmospheric pressure using the C36 cell, specifically designed to cure the cement without water access, in order to better replicate downhole conditions. This test was performed on a formulation without the high-temperature retarder, as the additive prevents setting at low temperatures. This variation in formulation does not impact the validity of the results presented, as the mechanical performance trends remain consistent and comparable.

The stress–strain curve showed a linear elastic response followed by a peak stress of 5.7 MPa, after which the material exhibited a gradual post-peak softening.

The Young's modulus was estimated at approximately 2.09 GPa from the linear portion of the loading cycle of the curve (Figure 3), confirming the material's flexibility in the elastic regime.
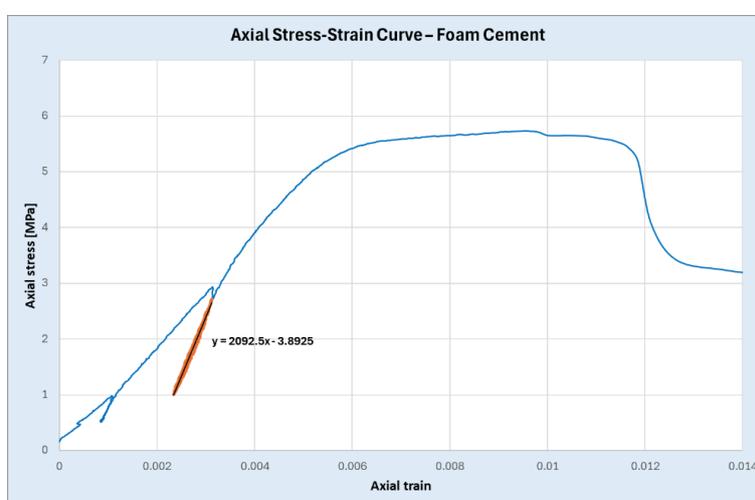

Figure 3: Stress-strain response of foam cement after 48 h curing at 70 °C
Axial stress versus strain curve, with linear regression used to determine the Young's modulus.

Overall, the foam cement system exhibited good fluid stability, limited segregation at low temperature, and a mechanical response consistent with the requirements for geothermal well applications. The results validate the potential of this formulation for further testing under representative downhole conditions.

7. CONCLUSION

This study presents the development and laboratory validation of a novel foam cement system tailored for high-temperature geothermal wells. Designed within the COMPASS project, this formulation addresses key challenges related to thermal stress, casing expansion, and long-term well integrity.

A targeted laboratory testing campaign was carried out on both the base slurry and the foam cement system. The results confirmed that the slurry meets placement requirements and that the foam structure remains stable during curing at static temperatures up to 150 °C. Initial mechanical tests on specimens cured under controlled conditions confirmed satisfactory compressive strength and elastic behaviour, aligned with geothermal application needs.

While these results are encouraging, further evaluation is necessary to confirm the long-term mechanical performance of the system under actual geothermal conditions. To this end, a dedicated exposure test will be conducted this year, placing foam cement samples in a geothermal well at 300 °C for three weeks. This in-situ evaluation will provide critical insights into the material's resistance to extreme temperature and geothermal fluids, and its suitability for future deployment in super-hot geothermal environments.

These findings contribute to the development and qualification of foam cement solutions for geothermal wells exposed to severe thermal conditions.

REFERENCES

Benge, O.G., Spangle, L.B. and Sauer, C.W.: Foamed cement – solving old problems with a new technique, *presented at the 57th annual fall technical conference and exhibition of the Society of Petroleum Engineers of AIME*, New Orleans, USA, (1982), paper SPE-11204-MS.

Berard, B., Hernández, R. and Nguyen, H.: Foamed calcium aluminate phosphate cement enables drilling and cementation of California geothermal wells, *presented at the Society of Petroleum Engineers Western regional meeting*, San Jose, USA, (2009) paper SPE-120845-MS.

Bour, D. and Rickard, B.: Application of foamed cement on Hawaiian geothermal well, *Geothermal Research Council Transactions,* **24**, (2000), 55-60.

Davies, D.R., Hartog, J.J. and Cobbett, J.S.: Foamed cement - a cement with many applications, *presented at the Middle East Oil Technical Conference of the Society of Petroleum Engineers*, Manama, Bahrain, (1981), paper SPE-9598-MS.

De Rozières, J. and Ferrière, R.: Foamed-cement characterisation under downhole conditions and its impact on job design, *SPE Production Engineering*, August (1991), 297-304.

Griffith, J.E., Lende, G. Ravi, K., Saasen, A., Nødland, N.E. and Jordal, O.H.: Foam cement engineering and implementation for cement sheath integrity at high temperature and high pressure, *presented at the IADC/SPE Drilling Conference*, Dallas, USA (2004) paper SPE-87194-MS.

Harlan, T.D., Foreman, J.M., Reed, S.D. and Griffith, J.E.: Foamed cement selection for horizontal liners proves effective for zonal isolation – case history, *presented at the Rocky Mountain Petroleum Technology Conference*, Keystone, USA (2000) paper SPE-71055-MS.

Harms, W.S. and Febus, J.S.: Cementing of fragile-formation wells with foamed cement slurries, *Journal of Petroleum Technology*, June (1985), 1049-1057, paper SPE-12755-PA.

Heathman, J. and Beck, F.E.: Finite element analysis couples casing and cement designs for HPHT wells in East Texas, presented at the IADC/SPE Drilling conference, Miami, USA (2006), paper SPE-98869-MS.

Kopp, K., Reed, S., Foreman, J., Carty, B. and Griffith, J.: Foamed cement vs. conventional cement for zonal isolation – case histories, *presented at the SPE Annual Technical Conference and Exhibition*, Dallas, USA, (2000) paper SPE-62895-MS.

McElfresh, P.M. and Go Boncan, V.C.: Applications of foam cement, *presented at the 57th annual fall technical conference and exhibition of the Society of Petroleum Engineers of AIME*, New Orleans, USA, (1982), paper SPE-11203-MS.

Nelson, E.B.: Improved cement slurry designed for thermal EOR wells, *Oil&Gas Journal*, 84(48), (1986), 39-44.

Niggemann, K., Samuel, A., Morriss, A. and Hernández, R.: Foamed cementing geothermal 13 3/8-in. intermediate casing: NGP #61-22, *Geothermal Research Council Transactions,* **33**, (2009), 217-222.

Rickard, Wm. M.: Foam cement for geothermal wells, *Geothermal Research Council Transactions,* **9(1)**, (1985), 147-152.

Spielman, P., Rickard, W. and Teplow, W.: Puna geothermal venture, Hawaii – 2005 drilling program, *Geothermal Research Council Transactions,* **30**, (2006), 309-313.