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TECHNICAL NOTE

Sedimentation Stability of Oil Well Cements in Directional Wells

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ABSTRACT

Unsuccessful cementing operation can jeopardize the whole well construction process, resulting in further costly and time consuming repair operations. The quality of cementing job is dependent on the cement composition and its properties. Design of cement composition is based on the available geological condition, materials and technical situation at well location. The cement properties like flow-ability and strength properties are tested by laboratory methods before application in field conditions. Study of the slurry sedimentation stability is of great importance especially for construction of directional or horizontal wells. There is no convenient direct method to investigate the sedimentation stability of the cements. In this paper, a laboratory method is presented to assess the stability of the slurry by measuring its free fluid content. Laboratory investigations are expanded to study the effect of different additives (weighting agent, silica sand, silica flour and magnesium oxide) and well inclination angle on the sedimentation stability of the slurries. Results show that additive specific surface area plays a significant role in the stability of the cements and therefore should be measured for every additive precisely.

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1. INTRODUCTION

Hydrocarbon resources play a historically crucial role in satisfying growing global energy demand. Utilization of these resources begins with the exploration of the oil and gas fields all over the world and developing them by drilling different kinds of wells into the formations, containing petroleum or natural gas [1, 2].

After drilling, the development plans include the cementing of the drilled wells. Cementing job is a complex, time consuming and costly operation. A successful cementing job can guarantee the achievement of the following goals [3, 4]:

- Filling the annular space between the casing pipe and surrounding formation.
- Providing the wellbore structural integrity.
- Supporting the casing.
- Protecting the casing from corrosion and induced stresses along the life of the well.
- Preventing unwanted migration of the fluids from one layer to another (zonal isolation).

A poor zonal isolation may lead to the fluid movement to the surface or nearby aquifers, which are considered as environmentally disadvantageous aspects of a low-quality cementing operation [5].

Cement compositions are designed based on the available geological conditions, materials and technical difficulties of the well location. Cements are usually composed of Portland cement and different additives, which are used to modify the final system properties.

Many researchers have developed the cement systems and investigated their properties in different circumstances. In literature [6], the authors studied the mechanical characteristics of the cement systems and concluded that the long term isolation is significantly related to the cement mechanical properties like Young's modulus, Poisson's ratio, tensile strength, impact strength and compressive strength. In reference [7], the authors presented a comprehensive assessment of the cement properties by combining the results of initial usual tests and advanced Nuclear Magnetic Resonance (NMR) test to predict the hydration

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properties of cement slurries containing various additives at room and elevated pressures and temperatures. In the work of Daou and Piot [8] the effect of microsilica densification on the slurry and set cement properties was investigated.

However, in these works and other similar studies less effort was made to investigate the sedimentation stability of the cement slurry, which has a significance influence on the effectiveness of the cementing job, especially during the construction of directional and horizontal wells. Sedimentation processes in the cement slurry may lead to the formation of the channels in the upper part of the directional boreholes. Presence of these channels, significantly lowers the set cement bond strength with the adjacent rock and casing pipe, resulting in further well integrity problems.

In this work, a practical laboratory method is presented to investigate the sedimentation stability of the cement slurries, considering the effects of different modifying additives, their specific surface areas and inclination angle.

2. EXPERIMENTAL METHODS

The sedimentation stability of the cement slurries is assessed by measuring the free fluid content (*FFC*) of the systems. By minimizing the free fluid content of the slurry, pathways channels for fluids can be eliminated.

In order to measure the *FFC*, the prepared slurries are stirred for 20 minutes in an atmospheric consistometer at a rotational speed of 150 rev/min and temperature of 25 °C. After 2 hours, the volume of developed free fluid is reported as the *FFC* of the slurry. Later, the volume of the free fluid is converted to a percentage of free fluid (*%FF*) by applying the following formula [9]:

$$\%FF = \frac{FFC \times \rho}{m} \times 100 \quad (1)$$

In the above equation, *FFC* is the reported value of the free fluid content in cm^3, ρ is the density of the slurry in g/cm^3 and m is the starting mass of the slurry before stirring in gram.

It should be noted that the volume of the free fluid is significantly dependent on the ability of the Portland cement and present additives in its composition to adsorb the excess fluid of the system. The specific surface area of a material is considered as an important property in adsorption processes. Therefore, the specific surface area of the Portland cement and used additives are also calculated from particle size distribution data, provided by laser diffraction method, in which the intensity of scattered light from the sample is measured.

The effect of different modifying agents on the sedimentation stability of the slurries is investigated by adding them to the ordinary Portland cement, provided by local manufacturer (composition (wt. %): 61.34 C_3S, 14.61 C_2S, 5.49 C_3A and 16.62 C_4AF).

To evaluate the effect of inclination angle on the sedimentation stability, the prepared cement slurries are poured into the cylindrical tubes, which are placed at different angles (30°, 45° and 60°) with respect to the vertical plane (Figure 1). The *%FF* of the slurries are reported after 2 hours as an index of sedimentation stability. The following chemical agents, which are used to modify the slurry and set cement properties, are considered in this work:

- Hematite as weighting agent to adjust the density of the slurry and control the pressure balance inside the wellbore [10].
- Silica sand and silica flour to optimize the system compactness and increase the strength properties of the set cement [11].
- Magnesium oxide (MgO) to increase the expansion capability of the system and bond strength of the set cement with adjacent rock and casing pipe [12].

3. RESULTS AND DISCUSSION

Specific surface area of the used materials, i.e. Portland cement, silica sand, silica flour, hematite and MgO, are calculated from particle size distribution data which are presented in Table 1. Silica flour as the smallest particle among the considered materials has the largest value of the specific surface area, which increases its ability to adsorb excess free fluid. The mentioned additives are added in different concentrations to the slurries. The water to cement mass ratio for all systems is 0.5.

Figure 1. Cement slurry placement at different angles of 30º, 45º and 60º with respect to the vertical plane

TABLE 1. Specific surface area of the used materials

No.	**Material**	**Specific surface area ml/g**
1	Portland cement	3.66
2	Silica sand	0.0214
3	Silica flour	5.65
4	Hematite	0.155
5	MgO	0.43

The result of FFC analysis for the prepared slurries are presented in Figures 2-5.

Figures 2-5 clearly indicate that for all the additives, the free fluid content of the slurries increased at higher inclination angles. This is due to the fact that at these angles, the sedimentation velocity of the particles will increase [13].

Increasing the concentrations of the silica sand and MgO leads to the higher contents of free fluid (Figures 2 and 5), as they have much smaller specific surface areas in comparison to the Portland cement.

For systems, containing hematite, the *%FF* is less than the base Portland cement (with no additive).

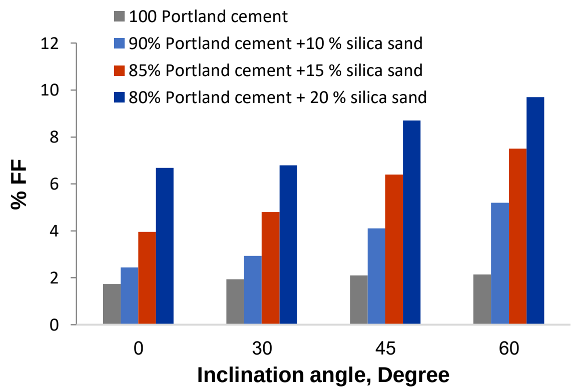

Figure 2. Effect of silica sand on the *%FF* of the slurry

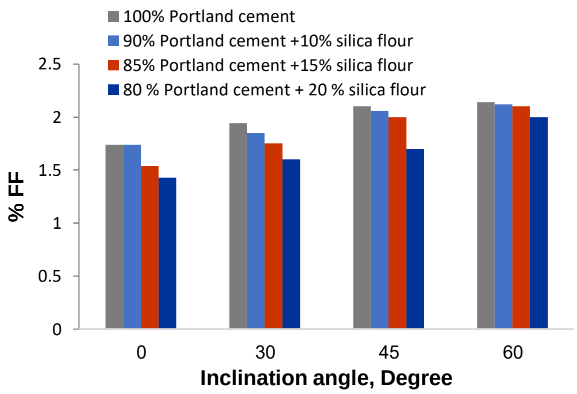

Figure 3. Effect of silica flour on the *%FF* of the slurry

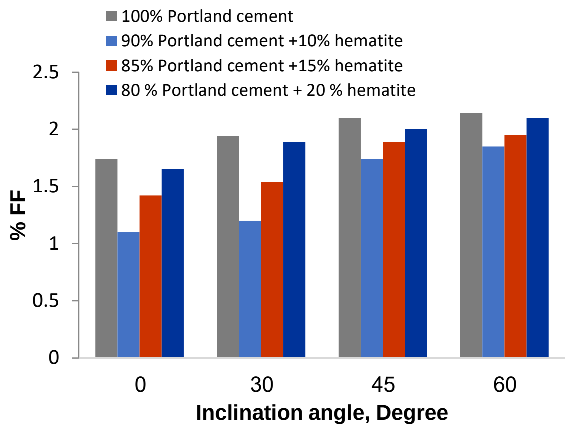

Figure 4. Effect of hematite on the *%FF* of the slurry

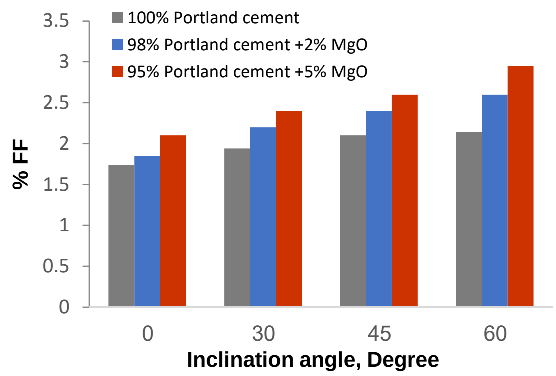

Figure 5. Effect of MgO on the *%FF* of the slurry

This is due to the fact that hematite is known to increase the slurry viscosity [14], as a result these systems are characterized by a lower free fluid content. However, by increasing the hematite concentration in the slurry the *%FF* is also increased.

In the case of silica flour with a specific surface area larger than Portland cement, increasing its concentration in the slurry composition leads to the less content of free fluid and therefore more stable systems (Figure 3).

The sedimentation process in the cement slurries is controlled by the following equation, which represents the velocity of particle sedimentation [15]:

$$v = \frac{2gr^2(\rho_d - \rho_p)}{9\,\mu} \qquad (2)$$

where v is the particle sedimentation velocity, cm/s^2; g is gravity of the earth, cm/s^2; ρ_d – density of the disperse medium, g/cm^3; ρ_p – density of the dispersed phase, g/cm^3; r – radius of the particles, cm and μ – viscosity of the disperse medium, 10^{-2} m^2/s.

Therefore the sedimentation stability can be provided by decreasing the particle sedimentation velocity, which is achieved by decreasing the density of the system or increasing its viscosity.

To provide the sedimentation stability of the cement systems two types of additives can be used: polymers and structure-forming agent. Polymers can provide the stability of the system by increasing its viscosity and therefore lowering the sedimentation velocity of the particles. Polymers also adsorb on the particle surfaces, as a result of which the density and sedimentation velocity of the particles will decrease.

Structure-forming agents like clay minerals and salts provide the structure of the cement slurry at early stage of hydrations and prevent the particles from sedimentation.

4. CONCLUSION

Different laboratory experiments are carried out during designing the cement composition. The sedimentation stability of the cement slurry is considered as an important factor to achieve a successful cementing job without formation of channels that may serve as pathways for formation fluids. In this work, free fluid content of the slurry is taken as the sedimentation stability index of the slurries and is measured at different angles with respect to the horizontal plane with the presence of different modifying additives.

Results of the experimental investigations show that at higher inclination angles the systems are instable due to the increase in the particle sedimentation velocity.

It can be also concluded that the specific surface area of the used materials in the compositions of the slurry plays a crucial role in analyzing the stability of the system. Higher values of additive specific surface area in comparison with the Portland cement facilitate the adsorption of the excess free fluid, which leads to more stable systems.

5. REFERENCES

1. Ghoble, V.T., "Global energy consumption paradigm: Future trends and trajectory", in International Conference on Applied Life Sciences, InTech., (2012).
2. Lior, N., "Energy resources and use: The present situation and possible paths to the future", ***Energy***, Vol. 33, No. 6, (2008), 842-857.
3. Tabatabaee Moradi, S.S. and Ivanovich Nikolaev, N., "Considerations of well cementing materials in high-pressure, high-temperature conditions", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 29, No. 9, (2016), 1214-1218.
4. Moradi, S.T. and Nikolaev, N., "Optimization of cement spacer rheology model using genetic algorithm (research note)", ***International Journal of Engineering-Transactions A: Basics***, Vol. 29, No. 1, (2016), 127.
5. Bellabarba, M., Bulte-Loyer, H., Froelich, B., Le Roy-Delage, S., van Kuijk, R., Zeroug, S., Guillot, D., Moroni, N., Pastor, S. and Zanchi, A., "Ensuring zonal isolation beyond the life of the well", ***Oilfield Review***, Vol. 20, No. 1, (2008), 18-31.
6. McDaniel, J., Combs, N.K. and Watters, L., "Zonal isolation assurance: Relating cement mechanical properties to mechanical durability", in Unconventional Resources Technology Conference, Denver, Colorado, Society of Exploration Geophysicists, American Association of Petroleum Geologists, Society of Petroleum Engineers., (2014), 2639-2648.
7. Kelessidis, V., Fraim, M., Fardis, M., Karakosta, E., Arkoudeas, P., Diamantopoulos, G., Elhardalo, S., Lagkaditi, L. and Papavassiliou, G., "Comprehensive assessment of additive and class g cement properties affecting rheology, fluid loss, setting time and long term characteristics of elastic cements", in SPE/EAGE European Unconventional Resources Conference and Exhibition., (2014).
8. Daou, F. and Piot, B.M., "Cement-slurry performance and set-cement properties vs. Microsilica densification", ***SPE Drilling & Completion***, Vol. 24, No. 04, (2009), 590-598.
9. Choolaei, M., Rashidi, A.M., Ardjmand, M., Yadegari, A. and Soltanian, H., "The effect of nanosilica on the physical properties of oil well cement", ***Materials Science and Engineering: A***, Vol. 538, (2012), 288-294.
10. Wilson, A., "Tests detail effects of weighting materials on performance of thermal cements", ***Journal of Petroleum Technology***, Vol. 65, No. 05, (2013), 147-152.
11. Murtaza, M., Rahman, M., Al-Majed, A. and Samad, A., "Mechanical, rheological and microstructural properties of saudi type g cement slurry with silica flour used in saudi oil field under hthp conditions", in SPE Saudi Arabia Section Technical Symposium and Exhibition, Society of Petroleum Engineers., (2013).
12. Appah, D. and Reichetseder, P., "Practical improvements in cao-swelling cements", ***Journal of Petroleum Science and Engineering***, Vol. 36, No. 1, (2002), 61-70.
13. Moradi, S.T. and Nikolaev, N., "Considerations of cementing directional wells in high-pressure, high-temperature conditions", in 7th EAGE Saint Petersburg International Conference and Exhibition., (2016).
14. Salim, P. and Amani, M., "Special considerations in cementing high pressure high temperature wells", ***International Journal of Engineering***, Vol. 1, No. 4, (2013), 2305-8269.
15. Smith, S.J. and Friedrichs, C.T., "Size and settling velocities of cohesive flocs and suspended sediment aggregates in a trailing suction hopper dredge plume", ***Continental Shelf Research***, Vol. 31, No. 10, (2011), S50-S63.

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چکیده

عملیات ناموفق سیمانکاری می تواند کل فرآیند ساخت چاه را به خطر بیاندازد که به عملیات تکمیلی گران قیمت و زمان بر تعمیر چاه منجر می گردد. کیفیت عملیات سیمان کاری بستگی به ترکیب سیمان و ویژگی های آن دارد. طراحی ترکیب سیمان بر اساس شرایط زمین شناسی، مواد شیمیایی موجود و شرایط تکنیکی موجود در محل چاه می باشد. ویژگی های سیمان نظیر قابلیت جریان پذیری و خواص مقاومتی به وسیله روش های آزمایشگاهی، قبل از کاربرد سیمان در شرایط میدانی، تست می شوند. مطالعه پایداری رسوبی دوغاب سیمان، به ویژه در عملیات ساخت چاه های جهت دار و افقی از اهمیت بسیاری برخوردار است. هیچ راه مناسب و مستقیمی برای ارزیابی پایداری رسوبی سیستم های رسوبی وجود ندارد. در این مقاله یک روش آزمایشگاهی جهت ارزیابی پایداری رسوبی دوغاب سیمان به وسیله اندازه گبری محتوای سیال آزاد آن، ارائه شده است. بررسی های آزمایشگاهی به مطالعه اثر افزودنی های مختلف (عامل وزنی، ماسه سیلیکایی، آرد سیلیکایی و اکسید منیزیم) و اثر زاویه شیب چاه بر پایداری رسوبی دوغاب سیمان بسط داده شده اند. نتایج نشان می دهند که سطح ویژه افزودنی ها نقش مهمی در پایداری سیستم های سیمانی ایفا می کنند و در نتیجه باید برای هر یک از افزودنی ها به صورت دقیق اندازه گیری شود.

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