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Lightweight oil well cement slurry modified with vermiculite and colloidal silicon

Romero Gomes da Silva Araujo Filho [a,*], Julio Cesar de Oliveira Freitas [b], Marcus Antônio de Freitas Melo [a], Renata Martins Braga [c]

[a] Chemical Engineering Department, Federal University of Rio Grande do Norte, Brazil
[b] Chemistry Institute, Federal University of Rio Grande do Norte, Brazil
[c] Escola Agrícola de Jundiaí, Federal University of Rio Grande do Norte, Brazil

HIGHLIGHTS

- Cements with vermiculite can be used in oil wells in zones with low pressures.
- With vermiculite, cements with high water/cement factors can be obtained.
- Lightweight cements with vermiculite retain most of it mechanical strength.
- Colloidal silica was used as a thickener in the cement paste.
- Due to the thickener, the cohesion between vermiculite and cement was improved.

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ABSTRACT

This paper present a study on the influence of both vermiculite and colloidal silicon on the physical, mechanical and microstructural properties of a lightweight oil well cement slurry. Vermiculite was incorporated with Class G Portland Cement at a rate of 5, 7 and 9% and colloidal silicon at a rate of 0.5, 1.0 and 1.5%. The density, settling test and compressive strength of the blended slurries were determined in accordance with API standards. The microstructure characteristics of the hardened samples were investigated by scanning electron microscope (SEM). The experimental results were analyzed using a statistical method based on Analysis of Variance (ANOVA) to identify the influence of the vermiculite, colloidal silicon and calcium chloride. The results revealed that the compressive strength is strongly related to both the concentrations of vermiculite and colloidal silicon, with values up to 10 MPa and that the use of vermiculite as an extender for oil well cement slurries allowed for very stable slurries, with high water/cement ratio and low densities (12.5 lb/Gal).

1. Introduction

Oil well cementing operations in geological zones with low fracture gradients require cement slurries with low densities, aiming to reduce hydrostatic pressure at the bottom of the well. If the pressure exerted by the cement column is greater than the fracture pressure of the geological formation, it may fracture and allow the fluid to flow into any geological formations adjacent to the well, contaminating those areas and possibly leading to operational problems lack of operation and/or accidents. In the oil industry, this process is known as flow loss.

When it is necessary to apply lightweight slurries in oil wells, cements with a higher water/cement factor are used. However, we have the reduction of the mechanical strength of the pastes as a negative effect. Another way to achieve the same result is to include lighter materials in order to reduce the average density of the cement paste without compromising its mechanical strength. Materials such as hollow microspheres and micro air bubbles are commonly used in lightweight slurry systems [10]. NURIYEV [13], SAVARI [15] and FIDAN [5] studied the behavior of these materials, demonstrating their high cost and high chance of failure and/or inefficiency during cementation operations, mainly caused either by microspheres breaking down, which increases the slurry density, as well as the rupture of the air bubbles generated by the incorporating agents. Considering the ease of obtaining and the low cost of acquisition and handling of the

* Corresponding author at: Petroleo Brasileiro S.A., Av. Eusébio Rocha, 1000, CEP 59064-100 Natal, RN, Brazil.
E-mail address: romeroaraujof@gmail.com (R.G. da Silva Araujo Filho).

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vermiculite, it is presented as a response of very low cost and high efficiency for the creation of low density cement pastes. KAN [6] has studied that the production of light cements can occur in three ways, mainly using gaseous agents, addition of low density aggregates and aggregate plastic polymers. KOKSAL et al. [8] showed that the incorporation of vermiculite to the cement presented satisfactory results in the increase of its thermal and mechanical resistance, considering that vermiculite is a fire resistant material with low values of thermal conductivity (0.065–0.062 W/m K). Due to these characteristics, when the slurry is heated to high temperatures the vermiculite acts as an insulating element, preventing the innermost layers of the cement paste from suffering the deleterious effects of high temperatures. According to KOKSAL et al. [8], the vermiculite assists the cement slurry, helping it to maintain its mechanical resistance values unchanged even when heated up to 900 °C.

The vermiculite is a hydrated silicate of magnesium, aluminum and iron that has a micaceous-lamellar structure with basal cleavage. The term vermiculite is also used to commercially designate a group of micaceous minerals consisting of about nineteen varieties of hydrated silicates of magnesium and aluminum with iron and other elements. Expanded vermiculite has many applications, especially in acoustic and thermal insulation, aggregates for lightweight concrete. In the hydrophobicized form it can be used in the removal of polluting layers of oil on the surface of ocean waters and adsorbents for water purification [14].

When heated between 650 and 1000 °C, the vermiculite flakes expand 8–30 times their size, due to the conversion of the interstitial water into steam. After cooling, vermiculite maintains its new condition, with very thin layers of air between its lamellae. The expanded particles can be seen as thin plates separated by spaces with air, and as a result have several desirable characteristics, such as low thermal conductivity, high resistance to high temperatures for long periods of time, is non-combustible, bio stable, neutral to action of acids and resistant to plastic deformation. The world's largest reserves of vermiculite are in South Africa (42%), the United States (33%) and Brazil (11%) [8].

Colloidal silica was used as a thickener (spreading agent) in the cement paste, in order to improve the cohesion between vermiculite and cement. CHOOLAEI [4] evaluated the effects of colloidal silica on the cement paste, identifying that its presence positively aids in compressive strength, free water reduction and rheological properties of the pulp. Colloidal silica particles improve the microstructure and mechanical strength of the cement by decreasing the permeability of the slurry by filling its void pores.

This work aims at the development of light pastes using vermiculite and colloidal silica, for application in oil wells. A Box-Behnken 3^3 statistical design was performed using Analysis of Variance (ANOVA) and response surface methodology.

2. Materials and methods

2.1. Materials used

The materials used in this study were Portland cement grade G (Lafarge/Holcim S/A), colloidal silica (PRODCON), expanded vermiculite (MPL) and calcium chloride (VETEC). The chemical composition of expanded vermiculite and Portland cement was performed using X-ray fluorescence (XRF) by dispersive energy using a Shimadzu EDX-820. Thermogravimetric analysis was performed using a TGA 60H balance from Shimadzu, from 25 to 900 °C at 10 °C·min^{-1}, using 50 mL·min^{-1} of N2 (99.999%) and 15 mg of each sample. The crystallinity of the vermiculite and cement were determined by X-ray diffraction using a XRD-7000 from Shimadzu, using a Cu-Kα radiation source with a voltage of 30 kV, current of 30 mA at 2Θ (Cu-Kα) step of 0.02° and scan speed of 1°/s. The morphological characterization of the materials was done by scanning electron microscopy. Microscopic examinations of the samples were performed on a Philips scanning electron microscope model XL30 ESEM. The preparation procedure of the materials for the analysis consisted of the deposition of a portion of the solid onto a carbon adhesive tape attached to the sample port.

The vermiculite used had a mean diameter between 0.32 and 1.19 mm, commercially named "Fine Grain Vermiculite". His density was measured at 0.73 g/cm^3. The colloidal silica used was 99.9% composed of SiO_2, with a density of 2.33 g/cm^3.

2.2. Slurries development

The formulation of the slurries was done according to a Box-Behnken 3^3 statistical design, where three parameters were varied in three different levels: concentration of vermiculite in cement slurry (5, 7 and 9% in weight), concentration of colloidal silicon (0.5, 1.0 and 1.5% in weight) and calcium chloride concentration (0.5, 1 and 1.5% in weight). Table 1 shows the composition of each of the cement slurries developed for this work.

After weighed, the water, the cement and the expanded vermiculite were blended in a Chandler 80–60 mixer at 4000 ± 200 rpm for 15 s. Then, uninterruptedly, the stirring speed of the slurry was increased to 12,000 ± 500 rpm, where it remained constant for 35 s according to standard NBR 9831: 2006 [3]. All materials were incorporated by addition. Fig. 1 below shows the equipment used to mix the slurries.

2.3. Slurries' characterization

The compressive strength, stability, X-ray diffraction (XRD) and scanning electron microscopy (SEM) tests were performed to characterize the cement paste obtained. In the first two, the recommendations of API SPEC 10A and RP 10B were followed, which regulates and standardizes the parameters of cementing slurries for use in oil

Table 1
Formulations of studied slurries.

Formulation	Cement (g)	Vermiculite (g)	Water (ml)	$CaCl_2$ (g)	Coll. Silicon (g)	Density (g/cm^3)
1	441.94	30.94	373.76	4.42	47.64	1.4978
2	440.54	30.84	373.22	6.61	47.49	1.4978
3	443.34	31.01	374.31	2.22	47.80	1.4978
4	435.81	30.51	357.55	4.36	70.47	1.4978
5	434.45	30.41	357.06	6.52	70.26	1.4978
6	437.17	30.60	358.04	2.19	70.70	1.4978
7	448.24	31.38	390.44	4.48	24.16	1.4978
8	446.80	31.28	389.83	6.70	24.08	1.4978
9	449.68	31.48	391.05	2.25	24.24	1.4978
10	447.35	40.26	358.39	4.47	48.23	1.4978
11	445.92	40.13	357.89	6.69	48.07	1.4978
12	448.79	40.39	358.90	2.24	48.38	1.4978
13	441.07	39.70	342.20	4.41	71.33	1.4978
14	439.68	39.57	341.75	6.60	71.10	1.4978
15	442.47	39.82	342.65	2.21	71.55	1.4978
16	453.80	40.84	375.05	4.54	24.46	1.4978
17	452.33	40.71	374.49	6.78	24.38	1.4978
18	455.29	40.98	375.62	2.28	24.54	1.4978
19	436.65	21.83	388.77	4.37	47.07	1.4978
20	435.29	21.76	388.19	6.53	46.93	1.4978
21	438.03	21.90	389.36	2.19	47.22	1.4978
22	430.67	21.53	372.54	4.31	69.64	1.4978
23	429.35	21.47	372.02	6.44	69.43	1.4978
24	432.01	21.60	373.07	2.16	69.86	1.4978
25	442.81	22.14	405.45	4.43	23.87	1.4978
26	441.41	22.07	404.81	6.62	23.79	1.4978
27	444.22	22.21	406.10	2.22	23.94	1.4978