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EXPERIMENTAL SIMULATIONS TO IMPROVE QUALITY CEMENT USED IN OIL AND GAS WELLS

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Abstract *In this paper, the results of the author's research about the rheologic properties of the well's cement slurry (normal and with additives) are presented.*
The paper concludes slurries analyzed are Bingham – plastic fluids and the values of the rheological parameters (η_{pl} and τ_0) are modifying versus time, strongly influenced by temperatures and the slurry type and quantity.

Keywords: *rocks, drill, cement, process, rheological model, dynamic shear tension.*

1. INTRODUCTION

By cementation is primarily aimed at isolating all layers carrying fluids (water, oil, gas) that could circulate behind the columns of pipes thus causing inconveniences. Thus, the water layers are isolated, the areas where the mud can be lost, the salt massifs, the clay rocks sensitive to water. The cement ring is enlarged so that the bearing capacity of the column avoids its buckling in case of dangerous compressive forced and corrosive action of mineralized waters.

The surface column is cemented over its entire height, thus the geological formations are consolidated, isolating the groundwater, and resistant support is formed for the eruption prevention installation and the following columns. The other columns are cemented up to at least 200 m above the last permeable payer. It is recommended for gas wells that all columns be cemented to the surface to reduce the possibility of gas migration through the annular space and possible leaks at the threaded joints.

The composition and properties of the cement paste are established depending on the nature of the rocks to be isolated, the pressure and nature of the fluids in the rock pores, the crack resistance of the formations, the geostatic and the circulation temperature.

From the statistical point of view (the cementations of wells of medium depth 2 – 3,5 km) the number of failed primary cement varies between 30 % and 70 % of the total operations performed, the higher percentages referring to wells drilled on structures that create complications during drilling [4]. In the case of deep wells (where 1 – 3 km are cemented in a single tranche), the heights of the annular space increase, encountering areas that give complications, which leads to unsuccessful cementations [1].

The main condition for achieving successful cementation is the complete displacement of the mud from the annular space "column – ground" by the cement paste so that, after setting and hardening, a compact and homogeneous, impermeable cement stone is formed in the annular space which adheres to the column and ground.

From a hydrodynamic point of view, the process of cementing the columns represents a successive movement of two visco-plastic fluids (mud and cement), whose rheological properties are different. The best displacement of the mud by the cement paste (up to 98 % in the case of the central placement of the column in the wellbore) is achieved by maintaining a turbulent flow regime in the mass of the cement paste.

In conducting experiments was used S-60 probe cement, diatomite, and NaCl.

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2. DESCRIBE THE METHOD

To establish the rheological model in which the cement pastes fall and to measure the rheological modules (during the first hours of hydration of cement minerals), a reo-viscometer with coaxial cylinders was used that eliminates the main shortcomings of similar classical viscometers. Both cylinders are inserted in the cement vessel, the outer cylinder is rotating and the annular space between the two cylinders is less than 1 mm, thus excluding the effect of centrifugal forces, and the measurement accuracy increases due to the elimination of the shear surface.

The measurement in time of the rheological modules modified as a result of the appearance of hydration products in the mass of the cement paste was made by points at an interval of 10-30 minutes. In the interval between the measurements, the cement paste is kept in the "Pan-American" sensitometer in a continuous state of agitation and at a thermal regime corresponding to the measurement moment, it was maintained (with the help of an ultratermometer) and in the bath where the paste was inserted measuring. It was stirring intensely according to the API [5] standards in the sensitometer so the previous stirring attempts of an electric stirrer with blades (having variable speeds) highlighted the strong and complex influence that the stirring intensity has on the value of the rheological modules (*figure 1*).

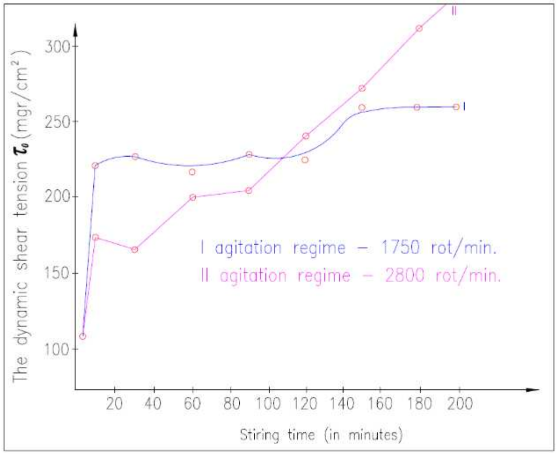

Figure 1 – The simulation of the influence of agitation intensity on the dynamic shear tension of the cement paste (A: C=0,5; t=26,7 ^{o}C)

To avoid damaging the appliance, the determinations were extended to 3 hours and stopped when approaching the measuring limit of the appliance. The results obtained show a deviation in time from the reality in the borehole due to the failure to take into account the pressure that accelerates the hydration processes of cement minerals.

3. RESULTS AND DISCUSSIONS

3.1 Experimental results

The measurements performed on normal cement pastes (with factor A: C = 0,5) and additive cement (with bentonite or diatomite with different factors A: C), determined that these suspensions fall within the Bingham Flow Model, both in the initial phase (after preparation) and in the next period (period of rapid hydration of cement minerals), the flow phenomenon of this suspension being acceptably described by the plastic viscosity (η_{pl} in cP) and the dynamic shear tension (τ_0 in mgr/cm^2) [6]. This is clear from (*figure 2*), where the simulations of the programs of a normal cement paste are presented, considered immediately after preparation at intervals of 30 and 90 minutes with a working temperature of 26,7 ºC [2].

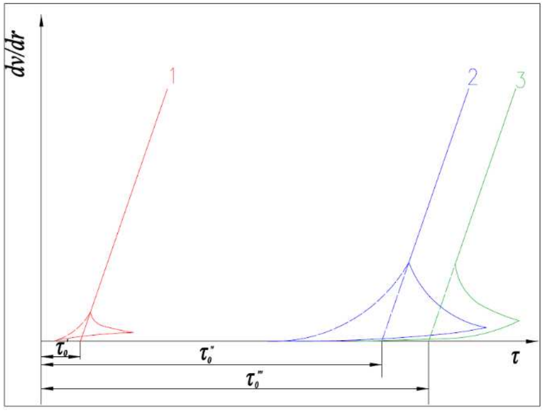

Figure 2 – The simulation of characteristic programs for cement paste (A: C=0,5) initially measured (1), 30 minutes (2) and 90 minutes (3)

There is a substantial increase in the dynamic shear tension of the cement paste (compared to the change in plastic viscosity), as a result of the appearance of hydration products (colloidal and crystalline) in the mass of the cement paste.

In (*figure 3*) is shows the simulation of the time variation as a function of the temperature of the two rheological modules of the cement paste. In this simulation the ambient temperature (27,6 ºC) the plastic viscosity (η_{pl}) remains almost constant around 32 cP, instead, the dynamic shear tension (τ_0) increases rapidly in the first half-hour (from 20 to 200 mgr/cm^2 – the period of hydration of the aluminum phase) remaining around 200 mgr/cm^2 until minute 120, after which a slight decrease is observed (destruction due to agitation of the aluminate structures).

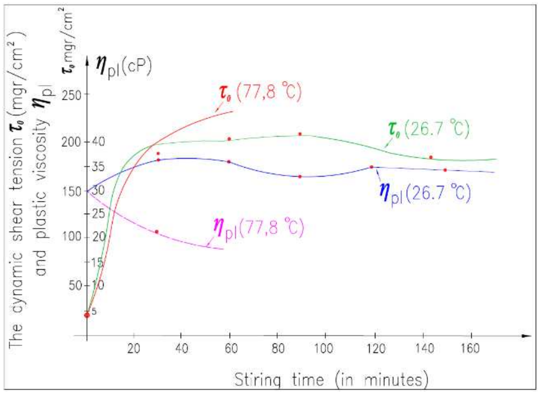

Figure 3 – The simulation of the variation in time depending on the temperature of the rheological modules of the cement paste (A: C=0,5). The agitation intensity and temperature rise according to A.P.I.

Measurements performed under normal API conditions for the sensitometer at 77,8 ºC (corresponding to wells at a depth of 3600 m) showed a pronounced decrease in plastic viscosity (from 30 to 18 cP) due to the reduction of the viscosity of the continuous phase (water) and a sudden increase in the dynamic shear tension, which forced the interruption of measurements after one hour from the preparation of the cement paste to avoid its capture in the real viscometer.

It is important that for normal cement paste both the plastic viscosity and the dynamic shear tension have much higher values than natural and special drilling fluids, even if they are burdened with barite. Thus, the most influential rheological modulus in the case of cement paste flow is τ_0.

In (*figure 4*) is presented the simulation of the variation in time of the dynamic shear tension for five mixtures of "*gel – cement*" (cement with the addition of active bentonite), the measurements being made at the chosen ambient temperature of 26,7 ºC.

It is found that mixtures 1 and 2 significantly increase their dynamic shear tension, this parameter gaining dangerous values (600 – 800 mgr/cm^2).

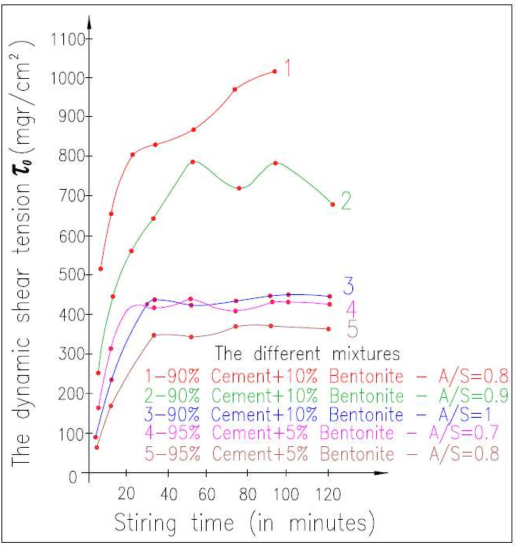

Figure 4 – The simulation of the time change of the dynamic shear tension of the "gel cement"

To have a clearer picture of these binder mixtures' fluidity, the simulation of the result of the standard spreading sample is shown in (*figure 5*).

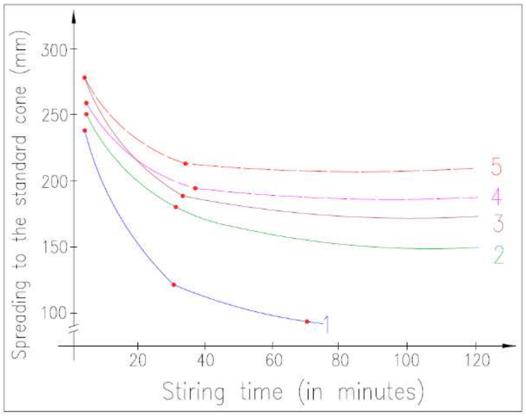

Figure 5 – The simulation of the time change of the spread to the standard cones for different "gels cement" (the same composition as in figure 4)

The five gel–cement mixtures from this simulation satisfy the standard spreading sample (D > 180 mm), and in time mixtures 3, 4, and 5 maintain their fluidity above the standard norm.

Given that mixtures 3, 4, and 5 (according to the spreading sample) are recommended as having acceptable fluidity, it shows a significant increase in τ (from 20 – 80 mgr/cm^2 to 300 – 400 mgr/cm^2 after only 30 minutes, which remain high throughout the determination up to 120 minutes). The effect of sodium chloride (NaCl) on the most fluid gel - cement is presented in the simulation from (figure 6), (cement 90 %, Bentonite 10 % and A: S=1).

The addition of NaCl significantly reduced the value of the dynamic shear tension (for additions of 10 and 20 % NaCl, the value of the dynamic shear tension (τ_0) fell below 200 mgr/cm^2 (lower values than normal cement paste) to the samples analyzed at ambient temperature.

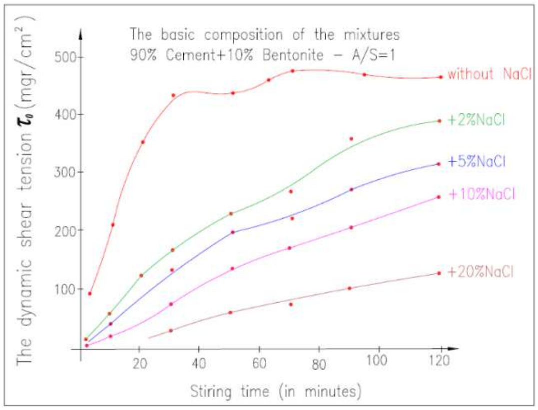

Figure 6 – The simulation of the change dynamic shear tension of the gel cement depending on the addition of NaCl

The influence of temperature on the same binder mixture is simulated in (*figure 7*).

At low percentages of NaCl (5%) this addition has an accelerating effect both at 45 ºC (curve 1) and at 77,8 ºC (curve 1'). The addition of 20 % NaCl has a strong delay effect that is maintained at 45 ºC (curve 2) to be much reduced to 77,8 ºC (curve 2').

The cement paste must remain fluid until the start of the setting ($\tau_0 \approx 30$ *mgr/cm*^{2}).

The results of the measurements made on light cement with diatomite (according to two recipes used in the practice of drilling hydrocarbon wells) are simulated in (*figure 8*). The addition of diatomite and especially a large amount of water for the preparation of the cement paste it requires attracts a significant reduction in plastic viscosity (compared to normal cement without addition), instead, the dynamic shear tension (τ_0) is maintained at values comparable to those of normal cement, but the rate of increase of this stress is much slower.

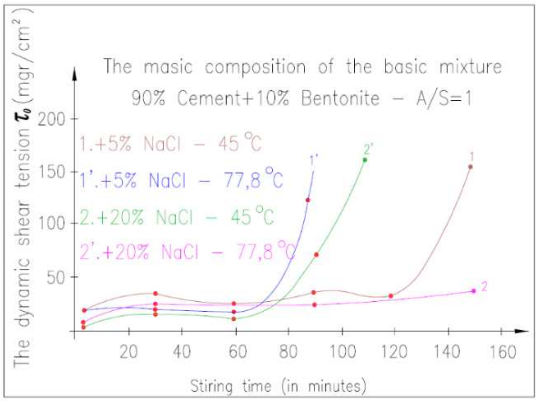

Figure 7 – The simulation of the influence of NaCl addition and temperature on the dynamic shear tension of gel cement

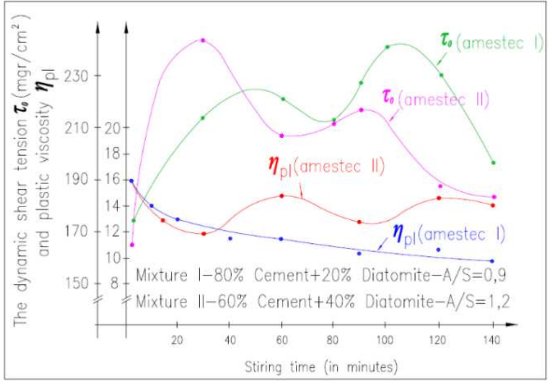

Figure 8 – The simulation of rheological modules of light cements with diatomite (t = 26,7 ºC)

The maxima and minima of the dynamic shear tension (τ_0) variation curves may indicate the situations in which the hydration process of the various components of the Portland well cement is in continuous development.

The experiments show that the rheological modules of cement pastes (normal and additive) are variable over time both at ambient working temperature and at high temperatures encountered in the wellbore.

To control the process of dislocation of the mud in the annular space by the cement paste, it is necessary to know the values of the rheological modules of the paste from the moment it passes from the column into the annular space and in conditions of temperature and pressure existing during the annular space.

3.2 Applications

Using the measured rheological modules and admitting that the cement paste passes into the annular space after 30 minutes, can be calculated the critical velocities required to be achieved in the annular space of a 214 mm borehole in which a column of $6^{5/8}$ in was tubed (168 mm) to obtain laminar and turbulent flow regime [3]. It was admitted in the calculations (according to t othe literature) that:

- Re < 2000 – laminar flow regime;
- 2000 < Re < 8000 – transition flow regime;
- Re > 8000 – turbulent flow regime.

**Re* – Reynolds number generalized for plastic fluids – viscous which has the expression:

$$Re = \frac{V_m(D_s - D_e)\gamma_{lc}}{g\eta_{pl}\left[1 + \frac{\tau_0(D_s - D_e)}{6V_m\eta_{pl}}\right]} \tag{1}$$

where:

I'm – average fluid flow rate in the annular space;

D_s – diameter of the borehole (equal to the diameter of the screed);

D_e – the exterior diameter of the column;

γ_{lc} – the specific weight of the milk of cement;

g – gravitational acceleration;

η_{pl} – the plastic viscosity of the milk of cement;

τ_0 – the dynamic shear tension of milk of cement.

From relation (1) can be obtained the expression that gives the average speed necessary to be achieved in the annular space, for the desired flow regime thus:

$$V_m = \frac{g\eta_{pl}Re*}{2\gamma_{lc}(D_s - D_e)} \pm \sqrt{\left[\frac{g\eta_{pl}Re*}{2\gamma_{lc}(D_s - D_e)}\right]^2 + \frac{g\tau_0 Re*}{6\gamma_{lc}}} \tag{2}$$

a) The calculation of average speeds for normal cement (A: C=0,5):

τ_0 = 184 mg/cm^2; η_{pl} = 31 cP; γ_{lc} = 1,79 gr/m^3

For the laminar regime we will have:

$$V_m = \frac{2000 \cdot 981 \cdot 21 \cdot 10^{-5}}{2 \cdot 1{,}79(21{,}4 - 16{,}8)} + \sqrt{\left[\frac{2000 \cdot 981 \cdot 21 \cdot 10^{-5}}{2 \cdot 1{,}79(21{,}4 - 16{,}8)}\right]^2 + \frac{2000 \cdot 981 \cdot 10^{-3}}{6 \cdot 1{,}79}} \tag{3}$$

For the turbulent regime (Re* = 8000), V_m = 6,50 m/s.

For the cement paste will be made:

- *laminar regime* la V_m < 2,25 m/s;
- *transition regime* – 2,25 < V_m < 6,50 m/s;
- *turbulent regime* at V_m > 6,50 m/s.

b) The calculation of critical velocities for cement with diatomite (80 % cement and 20 % diatomite, A: S=0,9) at temperature 45 °C:

This mixture has the following characteristics after 30 minutes:

τ_0 = 208 mg/cm^2; η_{pl} = 19 cP; γ_{lc} = 1,50 gr/m^3

Based on the calculations you will get:

- *transition regime* – 2,35 < V_m < 5,20 m/s;
- *laminar regime* at V_m < 2,35 m/s;
- *turbulent regime* at V_m > 5,20 m/s.

c)The calculation of critical velocities for prescription gel – cement (90 % cement and 10 % bentonite, A:S = 1) at temperature 26,7 °C:

This mixture has the following characteristics after 30 minutes:

τ_0 = 426 mg/cm^2; η_{pl} = 17 cP; γ_{lc} = 1,48 gr/m^3

Based on the calculations you will get:

- *laminar regime* at V_m < 3,35 m/s;
- *transition regime* – 3,35 < V_m < 7,30 m/s;
- *turbulent regime* at V_m > 7,30 m/s.

d)The calculation of the critical velocities for the gel – cement from point "c" treated with 50 % NaCl at a temperature of 26,7 °C:

τ_0 = 116 mg/cm^2; η_{pl} = 8 cP; γ_{lc} = 1,5 gr/m^3

Based on the calculations you will get:

- *laminar regime* at V_m < 1,73 m/s;
- *transition regime* – 1,79 < V_m < 3,73 m/s;
- *turbulent regime* at V_m > 3,73 m/s.

e) The calculation of the critical velocities for the gel – cement from point "d" at a temperature of 45 °C, the binder mixture possesses the characteristics:

τ_0 = 34 mg/cm^2; η_{pl} = 4 cP; γ_{lc} = 1,5 gr/m^3

Based on the calculations you will get:

- *laminar regime* V_m < 0,93 m/s;
- *transition regime* – 0,73 < V_m < 2 m/s;
- *turbulent regime* at V_m > 2 m/s.

For comparison, the critical velocities of the mud in the annular space with the following characteristics were also calculated:

γ_n = 1,20 gr/m^3; η_{pl} = 10 cP; τ_0 = 48 gr/m^3

Where obtained:

- *laminar regime* at V_m < 1,38 m/s;
- *transition regime* – 1,35 < V_m < 3,13 m/s;

- *turbulent regime* at $V_m > 3{,}13$ m/s.

It is necessary to check the number of Reynolds that delimits the flow domains because there are different proposals on it in the literature.

4. CONCLUSIONS AND PROPOSALS

The following conclusions are obtained from this research:

1. The analyzed cement pastes (normal S-60 well cement and cement added with bentonite, diatomite, and NaCl) fit into the Bingham model. Their flow phenomena are satisfactorily described by the value of the plastic viscosity (η_{pi}) and the dynamic shear tension (τ_0). Specific for cement pastes is the change over time in the values of these parameters as a result of hydration of cement minerals and the appearance in the mass of cement paste of hydration products (colloidal or crystalline). The rate of change of rheological parameters is influenced by the same factors that influence the rate of hydration.
2. Of the rheological modules (τ_0) it changes the most during the hydration of Portland cement minerals (in the first 30 minutes it increases about 10 times, far exceeding the values (τ_0) for ordinary drilling mud), so it substantially changes the regime of flow in the annular space. To be able to recommend the best displacement regime (the best cementing technology), it is necessary to measure the values of the rheological parameters of the cement paste corresponding to the temperature, pressure, and time after which the cement paste passed from the pipes into the annular space.
3. The mineral additives used (diatomite and bentonite), influence differently the rheological modulus, thus the diatomite (introduced according to the usual recipes) improves the modules of the normal cement, requiring lower speeds to obtain the turbulent flow regime, instead, the bentonite significantly increased the parameter (τ_0) requiring speeds large flow rates (V_m>7 m/s) to obtain the turbulent regime.
4. Additions of NaCl on „gel – cement” have led to a substantial improvement in rheological properties, turbulent regimes can be achieved at speeds appropriate to current well-cement technology.
5. A good displacement of the mud is obtained by the cement pastes which can also be achieved in a transient flow regime (at speeds slightly higher than the speed delimiting the laminar regime) as the additional equipment with which the column is equipped is an obstacle that creates and maintains the turbulences apar.
6. The method of measuring the rheological properties of cement pastes and the method of calculating critical speeds can be used to recommend the best cementing technology.

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Simulari experimentale pentru îmbunatatirea calității cimenturilor utilizate la sondele de țiței si gaze

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