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Practical Possibilities to Prepare Low Density Cementing Slurries

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Abstract

By adding water, bentonite and different additives, it is possible to reduce the cementing slurries density. The paper presents some laboratory experiments carried out to obtain cementing compositions with low density.

Key words: *cementing slurries, density, additives, filtrate reducers.*

Introduction

A significant chapter in the successful drill of a well is represented by the techniques and technologies of opening and fitting the well when meeting productive strata. The special fluids for opening, crossing at or under equilibrium with light or unconventional fluids, using cementing slurries of low density, borehole enlargement and fitting for adequate exploitation of each well are only a few of the most common methods that are adopted and continuously improved.

Compared to the drilling, opening or completion fluids, the cementing slurry blocks the productive strata less with the solid particles, and more with filtrate.

The low density cementing slurries are of great practical interest because responds to frequent situations when there is a need to isolate porous, cracked or depleted strata. It is impossible to prepare cementing slurries of densities lower than 1700 kg/m^3 only by increasing the water amount with respect to the cement due to the instability of the system. There is a wide range of methods used to reduce the slurry density but, more or less, they modify the properties of the cementing rock, too [1].

One of the most accessible methods to decrease the cementing slurries density is to increase the water-cement factor simultaneously with adding stabilizers. These agents are macromolecular substances that, added in small amounts, fix a part of the preparation water, increase the slurry stability and reduce the filtration rate [2,3], so they make possible an increase of the water-cement factor in order to maintain the slurry fluid enough time (at a certain initial fluidity).
Among the high hydrophilic materials that can also be used to reduce the cementing slurry density under 1700 kg/m^3, the widest applicability belongs to the bentonite clays and the diatomite soils.

The paper presents a laboratory study in which, after preparing cementing slurries of different compositions, it has been observed the additives influence on the main properties of the cementing slurries [4].

Experimental

As a base binder for S2 cement and as hydrophilic additive, activated bentonite from Pleaşa (efficiency $10m^3/1t$ bentonite) and reactive ACIM-93 respectively were used.

The research aimed to investigate two practical possibilities of using activated bentonite to control the density and the filtration of the cementing slurry:

- dry bentonite (previously mixed with cement powder);
- pre-hydrated bentonite (previously mixed with water and kept for 24 hours).Regarding the way the additives act, certain aspects must be mentioned:
- the capacity to reduce the slurry density is based on their possibility to fix more water compared to the cement powder in compositions of known viscosity;
- regarding filtrate control, its reducing is due to bentonite capacity to disperse on colloidal level (less and slower when dry bentonite), and for ACIM-93, to its highly hydrophilic character.

The first experiments measured the specific water amounts fixed by the additives used in cementing compositions of different viscosities.

The specific amount of water (m_l), fixed by an additive, is defined as the water volume fixed per mass unit of additive in stable cementing slurries (separates water Sa < 5%) and of certain viscosity; it measures in cm^3 water/1g additive.

As well as the water-cement factor (m), the specific amount of water fixed by an additive can vary between m_{lmin}, corresponding to very viscous slurries, and m_{lmax}, corresponding to very fluid slurries, at the stability limit.

The equation that describes the influence of all factors involved in the preparation of cementing slurries using hydrophilic materials is:

$$\rho_{pc} = \frac{[(1 + m) + (1 + m_l)\, m_o\,]\, \rho_a\ \rho_c\ \rho_x}{(\rho_a + m\, \rho_c)\, \rho_x\ + (\rho_a + m_i\, \rho_x)\, m_o\ \rho_c} \quad , \qquad (1)$$

where:

ρ_a, ρ_c, ρ_x –densities of water, cement and hydrophilic additive, respectively;
m - water-cement factor (the ratio between water mass fixed by the cement and the cement mass);
m_l –the ratio between the mass of water fixed by the additive and the additive mass;
m_o –the ratio between the additive mass and the cement mass.

The specific amount of water fixed by the hydrophilic additive is:

$$m_l = \frac{m_s\,(1 + m_o) - m}{m_o} \quad , \qquad [cm^3 \text{ water / 1g additive}] \qquad (2)$$

where m_s is the mass ratio between water and the solid phase of the mixture.

Knowing the parameter, it is possible to calculate the formulations for a given viscosity, but at different additive contents. These compositions are needed to study the capacity of a certain additive to control specific characteristics of the cementing slurry and rock.

The proceedings consisted in the following steps:
1. The drawing of the variation curve of slurry viscosity (measured as the spreading, R, with the spreading cone) versus water-cement ratio, preparing several mixtures for different values of the m ratio (different water contents).
2. Imposing a ratio m_o = ct., a spreading curve was drawn, $R=f(m_s)$ for a mixture of three components, cement, additive, water.
3. For the viscosity values that interest, it is possible to read values for m and m_s and then to calculate the specific amount of water fixed by the additive (m_1).

Results

The following experiments and calculations were done:
- measuring the dependence of apparent viscosity (expressed as the spreading diameter, R in mm, with the spreading cone) versus the water-cement ratio (table 1);

Table 1. Variation of the physical-rheological properties for the water-cement mixture versus the m factor

Slurry composition		R mm	ρ_{pc} kg/m^3	S_a %	Rheological properties		
Cement	Water				η_{ap} cP	η_{pl} cP	τ_0 N/m^2
%, mass							
100	40	200	1 980	1.5	102.0	68	32.5
100	45	220	1 910	3.0	70.0	60	9.5
100	50	250	1 830	4.0	42.5	38	4.3
100	55	275	1 790	5.6	33.5	31	2.3

- measuring the dependence of apparent viscosity versus the water-solids ratio for the next compositions:

80g cement + 20g dry bentonite (m_o = 0.25), in table 2;
95g cement + 5g pre-hydrated bentonite (m_o = 0.0526), in table 3;
100g cement + 2g ACIM-93 (mo = 0.02), in table 4.

Table 2. Variation of the physical-rheological properties for a mixture water + (80g cement + 20g dry bentonite) versus the ratio m_s

Slurry composition			R mm	ρ_{pc} kg/m^3	S_a %	Rheological properties		
Cem.	Bent.	Water				η_{ap} cP	η_{pl} cP	τ_0 N/m^2
%, mass								
0	20	60	140	1 690	0.5	105.0	25	76.6
80	20	70	205	1 640	1.0	58.5	22	34.9
80	20	80	260	1 560	1.5	30.0	20	9.5
80	20	90	280	1 520	5.7	18.0	14	2.8

Table 3. Variation of the physical-rheological properties for a mixture water + (95g cement +5g pre-hydrated bentonite) versus the ratio m_s

Slurry composition			R mm	ρ_{pc} kg/m^3	S_a % Cem.	Rheological properties		
Cem.	Bent.	Water				Bent.	Water	τ_0 N/m^2
%, mass								
95	5	80	160	1 620	0.5	65.0	20	43.1
95	5	90	170	1 540	1.0	52.0	10	40.2
95	5	100	190	1 490	1.5	44.5	9	34.0
95	5	110	205	1 450	2.2	37.5	8	28.2
95	5	120	240	1 410	3.0	27.0	6	20.1
95	5	130	260	1 390	3.5	21.5	6	14.8

Table 4. Variation of the physical-rheological properties for a mixture water + (100g cement+ 2g ACIM93) versus the ratio m_s

Slurry composition			R mm	ρ_{pc} kg/m^3	S_a % Cem.	Rheological properties		
Cem.	ACIM93	Water				Bent.	Water	τ_0 N/m^2
%, mass								
100	2	50	180	1 840	0.6	66.0	31	32.6
100	2	60	220	1 780	1.0	60.0	27	31.6
100	2	70	260	1 680	4.0	37.5	25	11.9
100	2	75	280	1 610	9.0	25.0	24	0.5

The specific quantities of water fixed by the analyzed additives were calculated for the apparent viscosities of R=200, 220, 240, 260mm and they were presented in table 5.

Table 5. Measured and calculated data to establish the specific amounts of water fixed by S2 (m) cement and the additives: dry bentonite, pre-hydrated bentonite and ACIM 93 (m_1)

R mm	m cm^3 water/ g cem.	m_s			m_1 (cm^3 water / g additive)		
		Dry bentonite	Pre-hydrated bentonite	ACIM 93	Dry bentonite	Pre-hydrated bentonite	ACIM 93
		m_0 = 0.25	m_0 = 0.0526	m_0 =0.02			
200	0.400	0.71	1.04	0.55	1.95	13.2	8.05
220	0.450	0.76	1.13	0.60	2.00	14.05	8.10
240	0.490	0.80	1.22	0.65	2.04	15.09	8.65
260	0.525	0.84	1.28	0.70	2.10	15.63	9.45

For the chosen range of apparent viscosity of the cementing slurry, as seen in table 5, the following values were obtained:

- for the cement powder, m = 0.4-0.525cm^3 water/ 1g cement;
- for the dry bentonite, m_1 = 1.95-2.1cm^3 water/ 1g bentonite;
- for pre-hydrated bentonite, m_1 = 13.2-15.63cm^3 water/ 1g bentonite;
- for ACIM-93, m_1 = 8.05-9.45cm^3 water/ 1g additive.

It is noticeable that the dry bentonite fixes a specific amount of water significantly smaller than the pre-hydrated one. This behavior is due to the fact that the hydration of dry bentonite occurs in the conditions of increased amount of sodium hydroxide in the cementing slurry. Its presence severely limits the bentonite hydration degree.

The viscosities of the cementing slurries prepared were measured with the viscosimeter FANN-35A and written in tables.

Another set of experiments was performed to research the practical possibilities to obtain low densities and, in addition, to control the filtration of cementing slurries.
The compositions prepared had an apparent viscosity of R=220mm, value frequently seen in practice. The results are presented in tables 6, 7, 8.

Table 6. Possibilities to control the density of cementing slurries with dry bentonite

Slurry composition			**ρ_{pc} kg/m^3**	**Filtrate cm^3**
Cement- q_c	**Bentonite- q_x**	**Water (q_c m + q_x m_1)**		
% mass	**% mass**	**% mass**		
100	-	100 x 0.45 + 0 x 2 = 45.0	1 880	789
90	10	90 x 0.45 + 10 x 2 = 60.5	1 730	547
80	20	80 x 0.45 + 20 x 2 = 76.0	1 610	252
80*	20	80 x 0.4 + 20 x 1.95 = 71.0	1 620	134

*) -Composition of apparent viscosity R=200 mm

Table 7. Possibilities to control the density of cementing slurries with pre-hydrated bentonite

Slurry composition			**ρ_{pc} kg/m^3**	**Filtrate cm^3**
Cement- q_c	**Bentonite- q_x**	**Water (q_c m + q_x m_1)**		
% mass	**% mass**	**% mass**		
100	-	100 x 0.45 + 0 x 14.05 = 45.00	1 880	789
98	2	98 x 0.45 + 2 x 14.05 = 71.10	1 650	727
96	4	96 x 0.45 + 4 x 14.05 = 99.44	1 530	576
94	6	94 x 0.45 + 6 x 14.05 = 126.80	1 430	450

Table 8. Possibilities to control the density of cementing slurries with pre-hydrated bentonite ACIM-93

Slurry composition			ρ_{pc} kg/m^3	Filtrate cm^3
Cement- q_c	ACIM-93- q_x	Water (q_c m + q_x m_1)		
% mass	% mass	% mass		
100	-	100 x 0.45 = 45.00	1 880	789
99	1	99 x 0.45 + 1 x 8.1 = 52.60	1 800	560
98.5	1.5	98,5 x 0.45 + 1.5 x 8.1 = 56.50	1 770	230
98	2	98 x 0.45 + 2 x 8.1 = 60.30	1 730	26
97	3	97 x 0.45 + 3 x 8.1 = 67.95	1 680	6

The last set of analysis studied several aspects as:

- the binding capacity of the limit compositions, measured as the initial mechanical strength to compression in the first three days of the cementing rock, at 60°C;
- the possibility to prepare low density and small filtrate slurry by using the synergetic effect of the two hydrophilic additives, by reducing the water-solids ratio (to R=200mm) and by using accelerators to improve the initial mechanical resistance of the cement rock.

The experimental data is presented in table 9.

Table 9. Measurements to establish the optimum cementing composition (low densities and filtration)

Nr. crt.	Slurry composition (% mass)						Slurry properties			Rez. compres σ_c 60°C, daN/cm^2		
	Ce-ment	Bentonite dry	Bentonite prehyd	ACIM 93	Accelerator	Water	R mm	ρ_{pc} kg/m^3	F cm^3	24h	48h	72h
1	80	20	-	-	-	76	220	1610	252	44	63	82
2	80	20	-	-	-	71.5	200	1620	134	48	72	96
3	80	20	-	-	2.5% $CaCl_2$	71.5	200	1620	336	70	88,5	121
4	80	20	-	-	2.5% $CaCl_2$	71.5	200	1620	114	49	76.5	98.5
5	94	-	6	-	-	126.6	220	1430	450	15	26	37
6	98	-	-	2	-	60.3	220	1730	26	-	-	-
7	98	-	-	2	-	55.3	200	1800	31	-	-	-
8	98	-	-	2	2.5% $CaCl_2$	55,3	200	1800	342	50	-	-
9	98	-	-	2	3% Na_2SiO_3	55.3	200	1800	33	-	-	-
10	98.25	-	-	1.75	-	53.4	200	1780	91	-	-	-
11	98.25	-	-	1.75	3% Na_2SiO_3	53.4	200	1780	93	-	-	-
12	93	-	6	1	-	90	230	1540	168	20	29	36
13	93	-	6	1	3% Na_2SiO_3	90	220	1570	133	57	68	78.5
14	84	15	-	1	-	70.6	200	1600	152	37	78	115

Conclusions

In table 6 is shown that the dry bentonite allows, added in 20% and with a quantity of water corresponding to an apparent viscosity of R=220mm, to reduce the slurry density to 1610kg/m^3 and to a filtrate volume of F=252cm^3.
Reducing the water amount (for R=200mm) does not modify the density, but improves the filtrate volume, F=134cm^3.

The pre-hydrated bentonite (table7), in percentage of 6% in the cementing slurry allows a major decrease of density, to 1430kg/m^3, but the filtrate is maintained at high values, F=450cm^3. The high content of preparation water contributes to this filtrate and, probably, will affect the mechanical resistance and cementing rock permeability.

The organic additive, macromolecular, ACIM-93 (table 8) allows, at a concentration of 2%, to rapidly reduce the filtrate (F=26cm^3) and, to a small extend, the density to 1730kg/m^3. The possibility to use this composition must be confirmed by the binding capacity in the initial phase (at 60^{o}C), considering that the additive has a secondary effect of retarding the set.

From the data presented in table 9, the conclusions are as follows:

- the composition with 20% dry bentonite (nr.2) insures reasonable values of the density and the filtrate, together with maintaining the rheological properties and the mechanical resistance of the cement rock;
- the addition of the accelerator $CaCl_2$ (nr.3) increases the mechanical resistance of the rock, but increases the filtration volume, too;
- the use of sodium silicate as accelerator (nr.4) improves in a certain degree the filtrate and the mechanical resistance of the rock;
- the composition with 6% pre-hydrated bentonite (nr.5), though insures the lowest density, has a high filtrate and a low mechanical resistance;
- the compositions based only on the ACIM-93 filtrate reducer (nr.6, 7, 8, 9), even with supplementary treatment adding accelerators, can not be used because the cement rock does not harden in the first three days;
- the compositions based on the combined effect of bentonite and ACIM-93 (nr.13, 14), lead to slurries of low density and relatively reduced filtrates, together with an acceptable initial mechanical strength.

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Posibilități practice de preparare a pastelor cu densitate redusă

Rezumat

Adăugând apă, bentonită şi diferiți aditivi este posibil să se reducă densitatea pastelor de ciment. Lucrarea prezintă câteva experimente de laborator efectuate pentru a obține compoziții de cimentare cu densitate redusă.