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STUDY OF THE INFLUENCE OF THERMOBARIC CONDITIONS ON THE RHEOLOGICAL CHARACTERISTICS OF PLUGGING SOLUTIONS FOR INSULATION WORKS

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Abstract

Since most of the fields in the Absheron peninsula of the Republic of Azerbaijan are at the final stage of development, an inevitable reduction in hydrocarbon production is expected. An increase in the proportion of formation water in well production, the presence of intra-reservoir, annulus and other cross-flows in this region, in most cases, is associated with inefficient isolation work.

The development of effective recipes for cement slurries with controlled rheological properties is relevant. Natural zeolite was used as an additive to control the rheological properties of cement slurries. A feature of zeolites is the presence of a system of regular channels and communicating cavities capable of holding ions, atoms and molecules of substances, whose size corresponds to the size of free space.

Zeolite (clinoptilolite) has the following properties: adsorption – the ability to absorb and release various substances; ion exchange – the ability to exchange cations; catalytic – the ability to speed up chemical reactions. In addition, clinoptilolite has a molecular sieve effect that transmits (filtration) and absorbs molecules of various substances selectively. In the course of experiments, the effects of zeolite dispersions on the physicochemical parameters of cement stone were studied. When regulating the rheological properties of cement slurries with zeolite additives, it is necessary to determine the effect of thermobaric factors on the values of these properties. In studies to assess the effect of temperature on the rheological properties of zeolite-cement mortars, they were carried out for the temperature range of 25÷75 °C.

Keywords: well cement, natural mineral zeolite, plastic viscosity, shear stress, bottomhole zone, thixotropy – the ability to reduce viscosity, dispersed systems, thermobaric factors.

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1. Introduction

Currently, hydrocarbon production in the Republic of Azerbaijan has almost reached its peak. In the near future, at most of the fields in the Absheron Peninsula, which are at the final stage of development, an inevitable reduction in hydrocarbon production is expected. An increase in the proportion of formation water in well production, the presence of in-situ, inter-casing and other cross-flows in this region, in most cases, is associated with ineffective isolation work.

The solution to this problem is the development of effective compositions for cement slurries with controlled rheological properties [1].

Traditionally used Portland cement-based grouting slurries in creating barriers against water usually do not provide high adhesion to rocks, and, as a result, contribute to effective isolation [2, 3].

The problem can be solved by creating cement slurries based on organic zeolite [4].

To regulate the rheological properties of cement slurries, natural zeolite from the Aydag deposit of the Republic of Azerbaijan was used as an additive. During the experiments, the influence of zeolite dispersions on the physicochemical parameters of cement stone was studied.

The physical and chemical regulation of the properties of cement slurries is based on the principle of the nature of the interaction of the binder with the aggregator, which is expressed in the inversion of the structures that arise in the process of hydration [5].

First of all, when regulating the rheological properties of cement slurries with zeolite additives, it is necessary to determine the effect of thermobaric factors on the values of these properties: pressure and temperature [6, 7]. Accounting for these factors is important when optimizing compositions for specific geological and operational conditions and choosing the optimal mode for preparing and placing the solution in the bottomhole zone of the well [8, 9].

2. Materials and methods

As a research methodology, it is proposed to use instruments to determine the compressive and bending strength, the time of the beginning and end of setting, as well as the adhesion of the cement slurry to the reservoir rock [10]. The device is used in research laboratories, as well as in field conditions during operational work – for testing cement slurry and cement stone, etc. [11]. The devices of the Italian company «Matest» were mainly used. For testing, special molds were made in the form of a cube, 40×40×40 in size, into which the studied cement slurry was poured. After that, the obtained cubes of cement stone were placed under a press and their compressive and bending strength was checked. As a criterion, the energy required for the formation of cracks in the molds was evaluated [12, 13].

The Atterberg, Pfefferkorn, stress/strain curves, indentation and rheological measurements were used to measure and characterize the plasticity of the cement solution. For rheometric measurements, indentation methods and methods that evaluate the relationship between the applied force and the resulting deformation were used, which were used to measure plasticity [14, 15].

3. Results and discussion

Studies to assess the effect of temperature on the rheological properties of zeolite-cement mortars were carried out for the temperature range of 25÷75 °C. The dry mix of oil well cement G-CC-1 (APİ Spec 10A Class G-HSR, Russia) and zeolite of the Aydag deposit of the Republic of Azerbaijan were used in the studies, the physical characteristics of which are given in **Table 1**. The given characteristics correspond to the standards required for isolation of in-situ flows in the bottomhole zone [16, 17].

Table 1

Physical and chemical parameters of well cement and zeolite [18]

Well cement (mineral and chemical composition)								
Al_2O_3	CaO	SO_3	SiO_2	Alkalinity, Na_2O	MgO	C_4AF+2C_3A	Tribasic Calcium Silicate	Tribasic Calcium Aluminate
5.2	62.4	≤2.6	20.7	0.56	≤1.23	18.41	≥59.2	2.21
Zeolite (mineral and chemical composition)								
Chemical composition (wt %)								
SiO_2	Al_2O_3	CaO	Na_2O	K_2O	MgO	Fe_2O_3	MnO	H_2O
66.3	12	4.2	2.7	1.1	0.6	1.2	–	10.9
Physical characteristic								
Pore diameter, A°	Bulk density, kg/m^3	Specific surface area, m^2/gr	Pore volume, %	Thermal stability, °C	Vibroware, %	Mechanical strength, MPa	Alkali resistance, pH	Acid resistance, pH
4.0	760–1283	40	15	650	0.3–0.53	14–18	7–10	3–7

Note: Tetra Calcium Aluminoferrite +2 tricalcium aluminum silicate.
M – average molecular weight

Organic zeolites are aqueous aluminosilicates of framework structure with uniform pores of molecular size. The simplified formula of zeolites in the oxide form can be written as follows: $Me_{2}/nO\cdot Al_2O_3\cdot xSiO_2\cdot yH_2O$, where M are exchange cations. A feature of zeolites is the presence of a system of regular channels and communicating cavities capable of holding ions, atoms and molecules of substances, whose size corresponds to the size of free space. The maximum dimensions of channels and cavities in zeolites can reach 1–1.5 nm. It should be noted that organic zeolites exhibit high stability over time, and, unlike synthetic ones, do not have an induction period [19]. Zeolite has the following properties: adsorption – the ability to absorb and release various substances; ion exchange – the ability to exchange cations; catalytic – the ability to speed up chemical reactions [20]. In addition, zeolite has a molecular sieve effect that transmits (filtration) and absorbs molecules of various substances selectively [21].

Cement mixtures were prepared in the following proportions: cement and organic zeolite 1, 3 and 5 % by weight of dry cement. The research results are displayed in **Fig. 1, 2**:

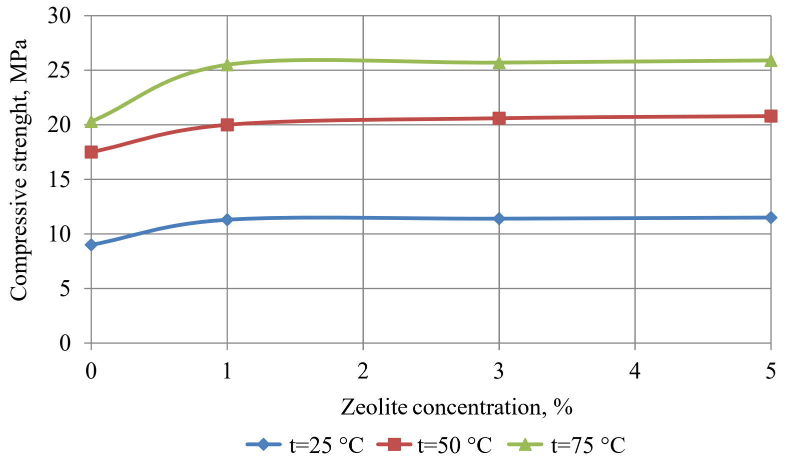

Fig. 1. Effect of organic zeolite concentration on compressive strength

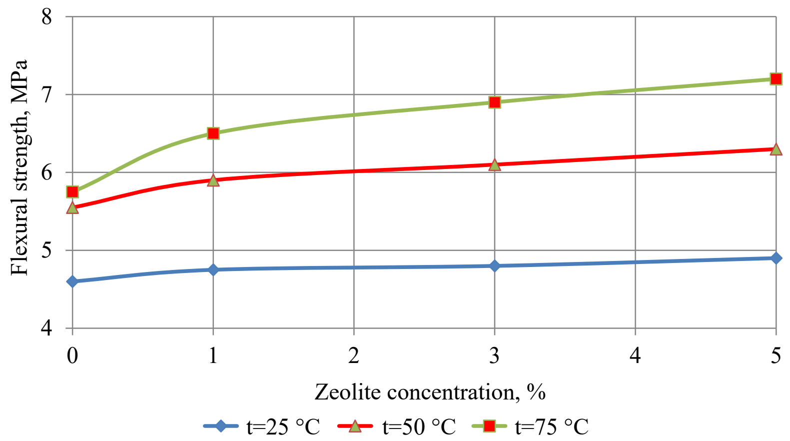

Fig. 2. Effect of organic zeolite concentration on flexural strength

If $t = 25$ °C, then it could be described by the following equation:

$$y = -0.042x^4 + 0.55x^3 - 2.31x^2 + 4.3x + 9.$$

If $t = 50$ °C then it could be described by the following equation:

$$y = 0.1045x^3 - 1.02x^2 + 3.2x + 17.6.$$

If $t = 75$ °C then it could be described by the following equation:

$$y = -0.11x^4 + 1.3x^3 - 5.5x^2 + 9.4x + 20.32.$$

Of considerable interest from the point of view of cementing technology is the effect of zeolite concentration on the rheological parameters of cement slurries. As is known, rheological characteristics determine the magnitude of hydrodynamic pressure losses during injection and displacement of cement slurries into the bottomhole zone of wells.

If $t = 25$ °C then it could be described by the following equation:

$$y = -0.0054x^2 + 0.08x + 4.63.$$

If $t = 50$ °C then it could be described by the following equation:

$$y = -0.024x^2 + 0.25x + 5.6.$$

If $t = 75$ °C then it could be described by the following equation:

$$y = -0.02x^3 - 0.18x^2 + 0.76x + 5.8.$$

Studies of plastic viscosity and shear stress of cement slurry were carried out. During measurements, the concentration of zeolite was 0, 1, 3, and 5 % by weight of the mixture. The research results are shown in **Fig. 3, 4**.

Based on the conducted laboratory studies, the following conclusions can be drawn:

1) zeolite-containing solutions are extremely sensitive to temperature changes – an increase in temperature leads to a reduction in thickening time by an average of 2 times (for Portland cement, this value is on average 1.3). In this case, the duration of the induction period varies in direct proportion;

2) temperature change in this range has little effect on the dynamic shear stress. This is explained by the fact that the measurements were carried out during the induction period, when there was still practically no change in the size of the solvate shells of the particles;

3) the value of shear stress increases with increasing test temperature, and at 75 °C, strong thixotropic structures of solutions are formed [22].

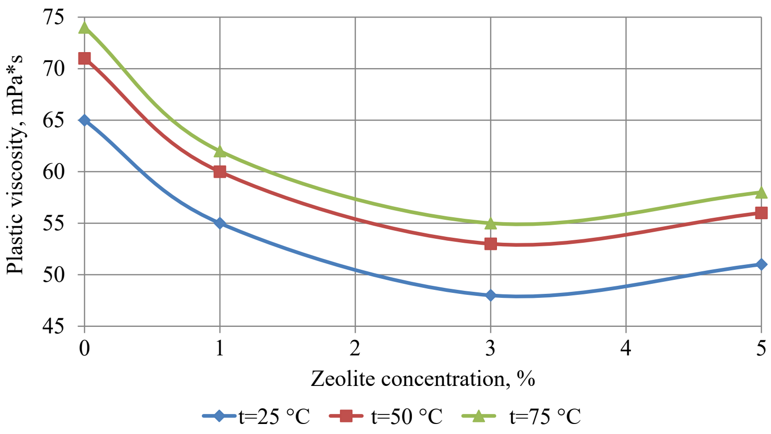

Fig. 3. Dependence of the plastic viscosity of the cement slurry based on cement G-CC-1 (Class G API) on the concentration of zeolite at a water-cement ratio of 0.5

If $t = 25$ °C then it could be described by the following equation:

$$y = -0.15x^3 - 2.54x^2 - 11.8x + 64.9.$$

If $t = 50$ °C then it could be described by the following equation:

$$y = -0.23x^3 + 3.334x^2 - 13.8x + 70.9.$$

If $t = 75$ °C then it could be described by the following equation:

$$y = -0.32x^3 - 4.1x^2 - 15.4x + 73.94.$$

For Portland cement materials, with an increase in pressure acting on the cement slurry, the processes of dispersion of solid phase particles are accelerated. In this case, the activity of the disperse system increases: the number of particles per unit volume of the solution increases and, consequently, the number of coagulation contacts. Due to the decrease in the size of the solvate films, the strength of the formed contacts increases. With increasing pressure, the probability of formation of a crystallization structure increases. This leads to an increase in the values of the rheological properties of solutions and their accelerated thickening.

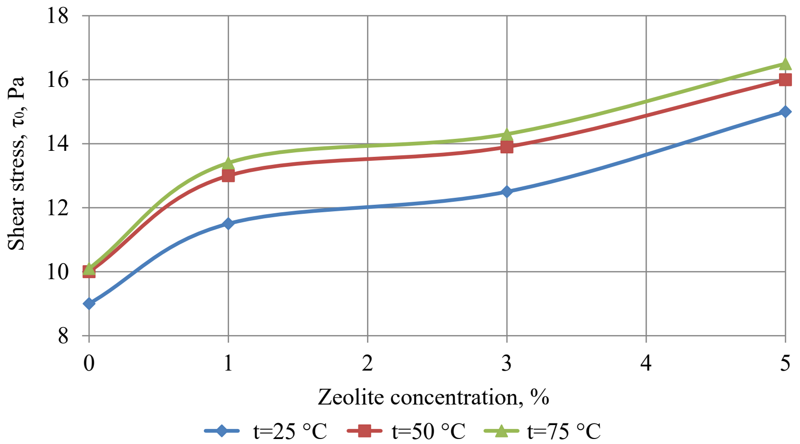

Fig. 4. Dependence of the shear stress of cement slurry based on cement G-CC-1 (Class G API) on the concentration of zeolite at a water-cement ratio of 0.5

If $t = 25$ °C then it could be described by the following equation:

$$y = -0.042x^4 + 0.55x^3 - 2.31x^2 - 4.3x + 9.$$

If $t = 50$ °C then it could be described by the following equation:

$$y = -0.13x^3 - 1.14x^2 + 3.55x + 10.1.$$

If $t = 75$ °C then it could be described by the following equation:

$$y = 0.192x^3 - 1.554x^2 + 4.2x + 10.2.$$

A rotational viscometer was used to determine the rheological properties of zeolite-containing cement slurries under pressure. After conditioning in an atmospheric consistometer, the solution was placed in a viscometer beaker, pressurized, and the solution was stirred for three minutes, after which a rheological curve was obtained. The results of the performed studies are shown in **Fig. 5**.

Plastic viscosity equation:

$$y = -0.001x^2 + 0.041x + 65.$$

Shear stress equation:

$$y = 0.001x^2 + 0.067x + 9.02.$$

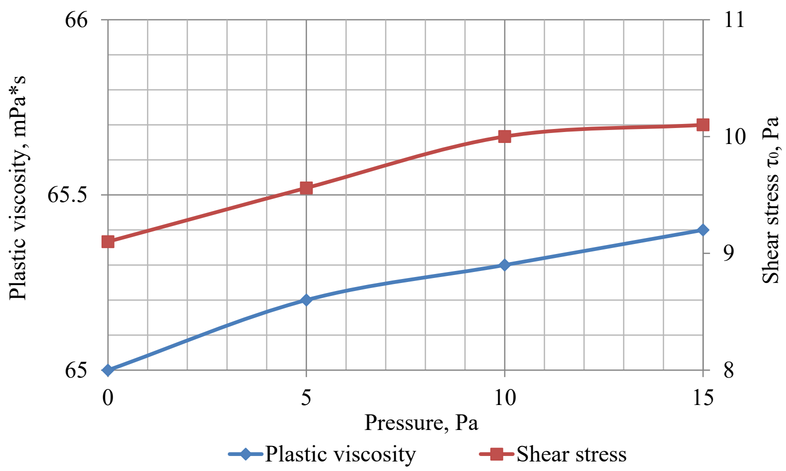

Fig. 5. Rheological properties of solutions of zeolite cement slurries at different pressures

The studies were carried out in certain intervals, since the geological and operational characteristics of the onshore deposits of Azerbaijan, limited by the indicated thermobaric conditions, were taken into account. Further research should be developed towards temperatures above 75 °C and pressures above 15 MPa. It is more preferable for fields developed at depths of more than 3000 m, which is typical for offshore conditions.

4. Conclusions

Based on the conducted laboratory studies, the following conclusions can be drawn:

1. The setting time of the cement slurry with an increase in pressure from 0.1 to 14 MPa is reduced by 20 %, which is associated with the intensification of the processes of coagulation structure formation.

2. With an increase in pressure up to 15 MPa, an increase in plastic viscosity is observed – by 7 %, dynamic shear stress – by 20 %. With a further increase in pressure over 15 MPa, further compaction of cement particles in the system is noted, but the increase in the values of rheological characteristics becomes less significant and amounts to no more than 5 % for plastic viscosity and no more than 7 % for dynamic shear stress.

3. Studies on the influence of thermobaric conditions have established a significant effect of temperature (in the range of 25–75 °C) on the rheological properties of the studied zeolite-containing cement slurries; pressure in the range of studied values (0.1–14 MPa) also has a noticeable effect, but to a lesser extent.

4. The addition of zeolite up to 3 % leads to a decrease in the viscosity of cement solutions. At a dosage of more than 3 %, the viscosity increases. With an increase in the percentage of zeolite in the mixture, an increase in the thixotropy of cement slurries is observed.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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The study was performed without financial support.

Data availability

Manuscript has data included as electronic supplementary material.

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