

INFLUENCE OF EXPANDING ADDITIVE ON PROPERTIES OF LIGHTENED CEMENTING SLURRY BASED ON MICROSPHERES AND MICROSILICA SUSPENSION

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ABSTRACT

Despite the successful implementation of the cementing process of oil and gas wells, the quality of cementing is significantly influenced by internal processes that occur during the strength development of the cement slurry, such as contraction and shrinkage. If these phenomena are not properly controlled, they may lead to various consequences, including gas migration, intercolumn pressures, and the formation of gas channels (grifons). To ensure the required quality, expanding additives have been widely used in recent years for all types of cement slurries, including lightweight slurries. However, when expanding additives are added to the cement slurry, many of them do not provide the required expansion, and even if expansion is achieved, the resulting strength is relatively low, which does not meet the necessary requirements. The aim of this study is to investigate the effect of an expanding additive on the technological properties of the cement slurry and the cement stone. The scientific novelty of the proposed work lies in the development and experimental validation of a lightweight cementing material synthesized predominantly from local mineral and/or industrial waste, which provides reduced density and improved rheological properties while maintaining the mechanical strength of the hardened cement stone. The obtained composition demonstrates compatibility with the expanding additive Wellfix +RD 50 in terms of key performance indicators (expansion, strength, and adhesion), which confirms its suitability for application in well cementing technologies. The investigations of the cement slurry were carried out in accordance with the requirements of GOST 26798.2-96 and GOST 1581-96, as well as using a special annular expansion mold according to the Schlumberger methodology. The developed formulation of the lightweight cement slurry containing locally produced microspheres and microsilica demonstrated effective compatibility with WellFix RD at a concentration of only 3%. An important aspect of the obtained result is that there is no need to add fiber to ensure the required strength of the cement stone, since the compressive strength of the cement stone increased by 6% without the use of CaCl₂. The expanding additive also demonstrated its effectiveness during the adhesion testing of the cement stone to the casing, increasing this parameter by 66.19% compared to the cement without additives. This formulation can be applied for cementing the upper section of the well, in particular the conductor or intermediate casing strings.

Keywords: oil well; cement slurry; lightweight cement slurry; microsilica; microsphere; expansive additive; adhesion; expansion.

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Introduction

In the context of well cementing, the cement slurry is meticulously positioned within the annular space that exists between the casing string and the rock formations, or alternatively, between the casing strings [1, 2].

It is imperative to acknowledge that a multitude of phenomena may arise during the process of cement hydration and hardening in the plugging slurry, with the potential to

exert a detrimental influence on the overall well cementing outcomes. The structural formation of cement slurry has been demonstrated to result in its «hanging» and the concomitant reduction of hydrostatic pressure on productive formations. This, in turn, has been shown to cause gas and oil spills during the waits on cement (WOC) [3-5].

As demonstrated by Malevansky V.D. [6], more than 50% of gas and oil spills that resulted in open fountains occurred precisely during the waits on cement (WOC), i.e. during the transition of liquid cement slurry into cement stone. This period typically extends from 3 to 8 hours, though it is

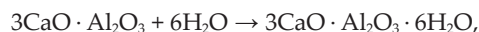
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important to note that the consequences of accidents are often grave. The formation of these channels leads to fluid migration behind the casing, which has a detrimental effect on well performance and productivity. In many cases, this migration results in the well's demise when fluids from upstream aquifers enter the bottom hole.

It has been demonstrated that a further unfavorable occurrence during the process of curing plugging solutions is that of shrinkage. The contraction of the cement stone is the primary cause of its shrinkage, manifesting as a decrease in the volume of cement stone following its insertion into the annular space. The curing process may also result in the formation of a channel between the cement stone and confining surfaces, such as casing and rock [3, 5]. Contraction is defined as the reduction in volume that occurs when water transitions from a free state in solution to a firmly bound state or to the crystal lattice of curing products.

For example, during the hydration of tricalcium aluminate (C3A) to form calcium hydroaluminate according to the equation



water enters into a chemical reaction, and, passing into the crystal lattice of curing products, reduces its volume by about 25%. As a result, the volume of the curing products becomes smaller.

A comparable volume loss effect is observed when other cement minerals interact with water. The extent of contraction porosity in cement stone can vary between 2 and 15 %, contingent on the composition of the binder. In the absence of water, for instance in the inter-column space of wells, cement stone may undergo a hardening process that can result in shrinkage and the formation of cracks [3].

The formation of micro channels is considered an unreliable indicator of cementing quality, as evidenced by cement-bond acoustic logging (CAL) results.

A variety of methods and additives are employed to mitigate the adverse effects occurring in the cement slurry during hydration and hardening in oil and gas wells cementing [7, 8]. These include the employment of gas-blocking additives [4], expanding cements [9, 12], sulfoaluminate additives [12], pozzolanic and microsilica additives [5, 13], self-healing cements [14] and reinforcing additives [15, 16], in addition to others [17-19].

This article considers the effects of expanding additives on the efficacy of plugging solutions. These additives have been used with increasing frequency by oil and gas-producing companies in Western Kazakhstan in recent years. The use of expansion additives in conjunction with microsilica mitigates adverse effects that occur during the transition of cement slurry to solid stone and its subsequent hardening.

In contemporary times, there has been an observable trend amongst oil companies to utilise expanding plugging materials with a view to enhancing the quality of oil and gas well support. This notion is not unprecedented, and it has been a subject of sustained promotion and development since the 1970s [4, 9]. In the context of well support, the utilisation of expanding cements was regarded as a methodology for enhancing the quality of support, thereby ensuring optimal tightness of contact zones between the cement stone (casing and well wall).

As is well-established within the relevant literature, the principle of production of any expanding cement is relatively

uncomplicated. It has been demonstrated that a substance (compound) with a greater volume than the initial one is formed inside the cement stone structure. The consequence of elevating the quantity of the expanding additive is the sliding of the crystals of hardening cement, which is characterised by an augmentation in its volume.

It is evident from the works of numerous researchers that oxide-type expansion is indicated in the majority of cases. This phenomenon is associated with the utilisation of calcium oxide (CaO) and magnesium oxide (MgO) [2, 3, 15, 20].

However, it should be noted that alternative methods of expansion can likewise be employed to achieve the aforementioned expanding effect. Of particular interest in the field of salt plugging cements is the expansion process, which commences after the material has gained a certain degree of strength. The expansion process reaches approximately 0.2%. This phenomenon is attributable to the formation of chlorosilicate crystals, which arise from the interaction of cement stone components with dissolved salts. The crystalline structures formed during this process occupy the pore space, resulting in a slight increase in the volume of hardened cement. When sodium sulfate (Na_2SO_4) is added to the plugging solution, this expansion can reach up to 0.3-0.4% [5].

Sulfoaluminate expansion is facilitated by the formation of $\text{Ca}_4\text{Al}_6\text{O}_{12}(\text{SO}_4)$ (ettringite), which undergoes an increase in volume of 4.5 times compared to the volume of the reacting substances [3, 4].

The use of calcium sulfoaluminate-based additives confers several advantages, including rapid and controlled expansion, enhanced early strength, and resistance to sulfate corrosion. The disadvantages of this approach include the limited period of action and the strict compliance requirement with the proportions. The constrained duration of action reflects the fact that sulfoaluminate additives are effective only during the initial phases of curing. The predominant reaction product, ettringite ($3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{CaSO}_4 \cdot 32\text{H}_2\text{O}$), is only formed in the presence of sulfate ions, calcium hydroxide and water. It has been demonstrated that when the system is depleted of sulfate ions (e.g., $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), the process of ettringite formation ceases. Furthermore, a transformation of some ettringite to monosulfate (AFm-phase) has been observed, which does not result in expansion [2].

Furthermore, the use of gas-extracting additives has been observed to cause cement stone expansion. This process, however, remains difficult to control and monitor [20], primarily due to the utilisation of active metal powders such as zinc, aluminum, iron and magnesium. For instance, the addition of aluminium to the grout mixture during its preparation stage has been observed to result in a reaction with alkali. It can thus be concluded that the process of stone expansion is rendered unfeasible once the mortar has been placed within the annular space. Moreover, as pressure increases, gas released from the reservoir dissolves in the mixing fluid.

The most common method of producing cements that undergo expansion when exposed to moisture is known as oxide expansion. In order to achieve this objective, the utilisation of calcium oxide (CaO) and magnesium oxide (MgO) additives, which are obtained through the process of firing at specific temperatures, is employed.

As demonstrated in studies [21], the incorporation of 3-6 % MgO into the cementing slurry can yield a volumetric expansion of up to 0.3%, thereby enhancing adhesion

properties and mitigating the risk of micro cracks. It has been demonstrated by other studies that the incorporation of calcium oxide, in quantities not exceeding five percent by weight, results in an augmentation of the initial strength of cement stone [22].

In the utilization of expanding cements, it is imperative to consider the distinct characteristics associated with their hydration and hardening processes.

It is imperative to coordinate the hydration kinetics of the base cement and the hydration (volume increase) kinetics of the expanding admixture.

It has been established that rapid hydration of the expanding agent (prior to the formation of a cement stone structure) will not result in cement stone expansion. This is due to the fact that the expansion energy will be used for the sliding of cement grains or unbound curing products that are still present in the cement-water suspension.

It is imperative to note that the processes of preparing, pumping and selling the plugging slurry collectively extend over several hours. Consequently, in order to accurately determine the expansion of the cement stone, it is necessary to simulate the aforementioned processes by measuring the expansion only after several hours of mixing the plugging slurry.

It has been demonstrated that the process of hydration of the expanding agent may be a contributing factor to the eventual failure of cement stone. This is due to the fact that, by the time hydration has occurred, a strong crystallisation structure has been formed in the cement stone. This structure may not be able to withstand the internal stresses that are generated when the volume of the expanding component increases.

Therefore, to achieve the optimum outcome when utilising expansion cements, it is considered optimal to allow for a period of 1-3 days, during which the structure of the base binder is still sufficiently elastic. It can be posited that, in accordance with the acceleration of cement hardening and the increase of cement stone strength, the active period of expansion should be reduced [23].

The optimum expansion value is 1.5-2.5 % [23]. The limitation of cement stone expansion is necessary to maintain the mechanical strength and integrity of the cement stone. A minor augmentation is required to counteract the effects of shrinkage and guarantee the integrity of the annular space. However, it is imperative to exercise caution against excessive expansion, as this may result in internal stresses and compromise the integrity of the cement structure [4, 22].

However, it is evident that the utilisation of expanding cements will not yield the anticipated favourable outcomes in intervals characterised by substantial clay crusts or cavernous interstices, i.e. where the available space for expansion exceeds the capacity of the expansion itself. It is imperative that wellbore preparation for starting and cementing casing should be mandatory. In addition, the implementation of efficacious buffer fluids and cementing regimes is imperative.

In the inter-column space or dense rock intervals, expanding cements will undoubtedly increase the contact stress with adjacent surfaces, since there will be no free space for expansion.

Research has demonstrated that expanding admixtures with a concentration of 5% are effective when used with reinforcing admixtures [15]. A decrease in the water-cement ratio from 0.7 to 0.44, an increase in the density of the cement

slurry, and an increase in the curing time of the cement stone resulted in a significant increase in the strength of the cement stone, both in flexure and compression.

In addition, the study conducted in [15] used lightweight cementing slurries. The research results demonstrated that the incorporation of fibres of any type into lightweight cements resulted in a 50-70 % augmentation of the effect of their expansion during the hardening process. This phenomenon can be attributed to the transfer of stresses from the expanding additive to the curing products.

The most significant benefit of expanding cements over traditional cements is their capacity to compensate for the volumetric shrinkage of cement stone that occurs due to contraction.

The incorporation of microsilica has been demonstrated to enhance the structural integrity of cement stone, thereby reducing microporosity. Microsilica's high specific surface area results in its amorphous nature, thereby enabling it to become hydraulically active at ambient temperatures [3, 4, 15]. Therefore, it is able to interact with calcium hydroxide, which is invariably located in the pores of cement stone, according to the following equation:

The reaction of silicon dioxide (SiO_2), calcium hydroxide (Ca(OH)_2) and water (H_2O) results in the formation of calcium hydrosilicate gel (C-S-H).

The resultant gel thickens the microstructure of cement stone, thereby reducing the effects of capillary shrinkage. The utilisation of microsilica confers several advantages, including enhanced density and strength of the resultant stone, diminished capillary shrinkage, and augmented resistance to aggressive media. The disadvantages of this approach are the lack of active expansion and the necessity for dispersion and uniform distribution in the solution.

Microsilica possesses a notably elevated specific surface area (ranging from 20000 to 25000 cm^2/g) and exhibits a propensity for particle aggregation, i.e. sticking. This phenomenon can be attributed to the presence of electrostatic forces between particles, the utilisation of nano and micro scale particles, and the hydrophobic surface properties that result from incomplete treatment.

In the absence of effective mixing and dispersion of the microsilica, the efficiency of the pozzolanic reaction is diminished, which may result in the heterogeneity of the cement stone. Furthermore, the mobility of the mortar will decrease, whilst its water consumption will increase.

A further method of mitigating the shrinkage of cement stone may be to reduce the water-cement ratio in the cement slurry. The utilisation of plasticisers has been demonstrated to be an effective measure in minimising the loss of mortar mobility.

The merits of this method are twofold: firstly, it is simple to implement, and secondly, it increases the density and strength of cement stone. The disadvantages of this method include the increase in density of plugging slurries, which is not always applicable in well consolidation, and the deterioration of pumpability without plasticisers.

The reduction of capillary shrinkage of stone by increasing the elasticity of the structure and moisture retention in the cement matrix can be achieved by the use of polymers (latexes). The latter method has been shown to create an elastic matrix that reduces cracking and capillary shrinkage [4, 27].

Furthermore, polymers have been shown to interact with

calcium hydroxide, thereby enhancing adhesion between phases (Smith et al., 2022). The utilisation of polymeric and elastic additives has been demonstrated to enhance the elasticity of cement stone, reduce water drainage, and mitigate micro cracks. The disadvantages of this approach are twofold: first, the high cost of the process; and secondly, the reduction in strength at excessive dosage [24, 25].

Materials and reagents used

Within the framework of conducted researches as the main binding material was used plugging portland cement of PCT-I-G-CC-1 grade, produced by «Company Gezhuba Shieli Cement» LLP (Kazakhstan).

When selecting additives, the main attention was paid to the possibility of their local production. In this regard, heat-insulating inorganic aluminosilicate microsphere (AMSP) supplied by FortunaTrade Company LLP (Republic of Kazakhstan) was introduced into the cement slurry. In addition, when selecting AMSP, its high strength was taken into account, which allows maintaining its integrity under the impact of loads arising under volumetric compression.

AMSP is a by-product formed during the combined hydroremoval of ash and bottom ash from the combustion of hard coal at thermal power plants.

Microsilica of MK-85 grade was used as a modifying component, produced by YDD CORPORATION in Karaganda, Republic of Kazakhstan. The specific surface area of MCR waste is 30000 m²/kg [20]. For hollow aluminosilicate microspheres, the specific surface area can reach approximately 2500 m²/kg.

WellFix RD (W+RD-50), developed by «Khimprom» (Russia), is an expanding additive for cementing slurries designed for use in the oil and gas industry during well construction and workover. It is designed to compensate for cement shrinkage and increase the tightness of the cement casing, particularly at low, medium and high temperatures.

Anhydrous sodium salt of silicic acid (SMA) was included as a technological additive in the composition of plugging materials, which performs the function of a chemical filler. Its use is intended to improve the technological characteristics of both the liquid mortar and the formed cement stone.

Methodology of conducting experiments

In the present article, the research methodology includes the study of various properties of cement slurries and the assessment of the influence of composition and testing time on their performance indicators. The methods involve laboratory tests and statistical analysis of the dependencies observed in the process. The experimental studies were carried out using the mathematical theory of experimental design. The primary data were initially processed. Data processing and analysis were performed using probabilistic and statistical methods.

Thus, the methodological basis of the study consisted of standard procedures for determining the physical and mechanical properties of cement slurries, the methodology of experimental design, as well as statistical methods for processing experimental data and analysing the obtained information. The need to identify regularities taking into account the composition of cement slurries and to predict their properties determines the importance of conducting experimental studies using design and statistical analysis methods. These

methods make it possible to analyse large data volumes, reveal hidden trends and dependencies, and test hypotheses, thereby increasing the reliability and validity of the results. In planning the experiments, methods in accordance with [28] were applied.

All cement slurries were prepared and tested in accordance with relevant standards. The physical and mechanical properties of plugging cement were determined in accordance with GOST 26798.2-96 (National State Standard), entitled «Plugging cements. Test methods». The technical conditions of these materials are regulated in GOST 1581-96 (National State Standard), which stipulates the requirements for «Portland plugging cements. Technical conditions».

The experimental studies were conducted at a temperature of 22 °C. Fresh water was also used as the displacement fluid. The dry additives were pre-mixed with the cement. The evaluation of cement slurry stability encompassed the determination of the absence of free liquid, channels, and solid phase precipitation. This was conducted within a 250 cm³ cylinder. The volume of separated water (water separation), according to GOST 34532-2019, must be measured in milliliters and should not exceed 7–10 mL. The slurry thickening time was determined in a consistometer.

The study on cement stone expansion was carried out using a special form of annular expansion according to Schlumberger methodology. The cement slurry sample is then subjected to grouting and subsequent pouring into a cylindrical mould or container, the inner diameter and height of which are known. In most cases, a temperature regime in close proximity to reservoir conditions is employed. The cement slurry is introduced into the annular expansion mould, where it is left to cure under specific conditions within the chamber. However, the expansion is measured at 24-hour intervals over a period of three days.

The linear expansion is determined by the following equation:

$$\text{Linear expansion} = \frac{(L_2 - L_1)}{\text{Length of circumference}} \times 100\%$$

where - L1, L2 are measurements of admittance, L1 is the distance between tendrils on the day of priming, L2 is the distance between tendrils after 24 hours.

The above considerations indicate that the application of experimental design theory does not eliminate the need to study and clearly understand the physical foundations of the processes occurring in the object of study, as well as the factors influencing the output parameters of the object. This information is necessary at the stage of developing the experimental plan, as well as for analysing and interpreting the results.

In recent years, experimental design has found practical application in various fields, including research on cementing slurries. For example, in [22], the results of preliminary experimental studies are presented, which made it possible to determine specific regularities in the variation of the water-cement ratio depending on the required slurry density and the concentration of aluminosilicate hollow microspheres. The work in [23] is devoted to the investigation of the composition and properties of cement slurries and to studying the influence of fiber reinforcement on their performance indicators, such as fluid loss, viscosity, sedimentation, and static shear stress.

The research presented in this article was also carried out experimentally using the methodology of experimental design. The experimental results were fully processed using probabilistic and statistical methods, and empirical dependencies were constructed to describe the variation of the measured properties as functions of the water–cement ratio and the concentration of fibrous material.

In this case, our objective was to obtain a model explicitly expressing the dependence of cement slurry consistency on the concentration of the expanding additive and on the thickening time.

The experimental data were processed using methods of mathematical statistics. To construct the required models, partial dependencies were first developed.

During the analysis, in accordance with the experimental design matrix, the values of the studied characteristic corresponding to constant values of one of the factors (input variables) – for example, the concentration of the expanding additive – were averaged, and then, successively for other values of this factor, a partial dependency was constructed. The dependencies of the same characteristic on the thickening time were constructed in a similar manner.

The partial dependencies were combined according to established approaches in mathematical statistics, resulting in the desired dependency. For the investigated properties of the cement slurry, the regression equation is represented as the product of individual functions:

$$Y = a_0 \cdot f_1(X_1) \cdot f_2(X_2) \quad (1)$$

The factors, as already noted, were the concentration of the expanding additive and the thickening time. Their influence on consistency was studied.

Experimental results

We have developed a lightweight plugging solution based on microspheres and locally produced microsilica [10]. The following lightweight plugging solution with formulations was obtained:

G cement + 10% microsphere (AMSP) + 10% microsilica suspension (MSS) + 1% CaCl_2

G cement + 10% microsphere (AMSP) + 10% microsilica suspension (MSS) + 2% CaCl_2

G cement + 10% microsphere (AMSP) + 10% microsilica suspension (MSS) + 3% CaCl_2

From the formulations presented, formulation No.3 (G cement + 10% microsphere + 10% microsilica + 3% CaCl_2) was chosen. The basis for the choice was the results obtained during the research of calcium chloride influence on lightweight cementing slurry. Tables 1 and 2 show the influence of calcium chloride on the strength of the obtained stone and technological properties of the tested composition at B/C=0.7.

Table 1 shows that as the concentration of CaCl_2 setting accelerator increases from 1 to 3 %, the strength of the cement stone and compressive strength increase. Addition of setting accelerator as a rule decreases setting time.

Table 2 also shows the feasibility of choosing formulation No.3, as water yield decreases from 116.6 to 94.4 $\text{cm}^3/30\text{min}$. Spreadability decreases slightly, from 24 to 22 cm. In terms of pumpability, a decrease in thickening time from 4 hours 15 minutes to 3 hours 45 minutes was also observed.

Further studies were continued to investigate the effect of Welfix + RD-50 expanding additive on the basic properties of cement slurry and grout. The expanding additive W + RD-50 was added with different concentrations from 1 to 5 %. The results of the studies are summarized in table 3.

Table 1
Effect of CaCl_2 on strength characteristics of cement stone in lightweight cement slurry

Formulation	Density, kg/m^3	Bending strength, MPa	Compressive strength, MPa	Beginning of setting, h-min	End of setting, h-min
G cement+10% AMSP+10% MSS+1% CaCl_2	1.560	2.14	4.91	6:15	8:20
G cement+10% AMSP+10% MSS+2% CaCl_2	1.552	2.21	5.8	5:35	7:25
G cement+10% AMSP+10% MSS+3% CaCl_2	1.545	2.86	6.27	4:50	6:45

Table 2
Effect of CaCl_2 on technological properties of lightened cementing slurry

Formulation	Density, g/cm^3	Filtration rate $\text{cm}^3/30\text{min}$	Flowability, cm	Thickening time, hrs-min
G cement+10% AMSP+10% MSS+1% CaCl_2	1.560	116.6	24	4:15
G cement+10% AMSP+10% MSS+2% CaCl_2	1.552	100.4	23	4:00
G cement+10% AMSP+10% MSS+3% CaCl_2	1.545	94.4	22	3:45

Table 3
Effect of expanding additive on the properties of cement slurry and grout

Formulation	W/C	Density, g/cm^3	Bending strength, MPa	Compressive strength, MPa
			2 days	2 days
G cement+10% AMSP+10% MSS+1% CaCl_2	0.7	1.586	2.46	5.43
G cement+10% AMSP+10% MSS+2% CaCl_2	0.7	1.567	2.47	6.75
G cement+10% AMSP+10% MSS+3% CaCl_2	0.7	1.567	2.75	6.41

The results of physical and mechanical properties of the cement stone showed (table 3) that the density of the cementing slurry does not change significantly. The strength of cement stone increases. And formulation No.2 containing 3% of expanding additive is considered to be more optimal.

Graphical interpretation of the obtained results is shown in figure 1.

Further it was necessary to investigate the influence of Wellfix+RD-50 on the technological properties of lightened cementing slurries and to determine the setting time, thickening time, water release and mobility of different cement slurry formulations (table 4).

Table 4 shows that the expanding additive W+RD-50 at concentrations from 1 to 5 % does not affect the water release and flowability of lightweight cementing slurry, which contains microsilica and microsphere. To solve this problem, it was decided to add SMA from 0.5 to 1.5 %.

From table 5 and 6, the effect of SMA on the lightened cementing slurry which contains expanding agent and microsilica can be seen. Experiments were conducted with the formulation of PCT+1% W+RD-50+10% MSS+10% AMSP+ +3% CaCl₂ (table 5) and PCT+5% W+RD-50+10% MSS+ +10% AMSP (table 6).

It was not possible to achieve the required result of reducing the water release of the plugging slurry by SMA. If a more effective type of water-reducing agent is found, the flow ability will also decrease. Therefore, formulation No. 2 is more optimal.

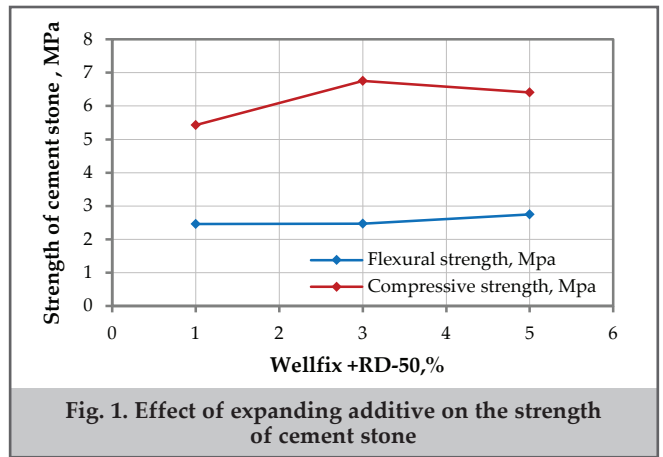


Fig. 1. Effect of expanding additive on the strength of cement stone

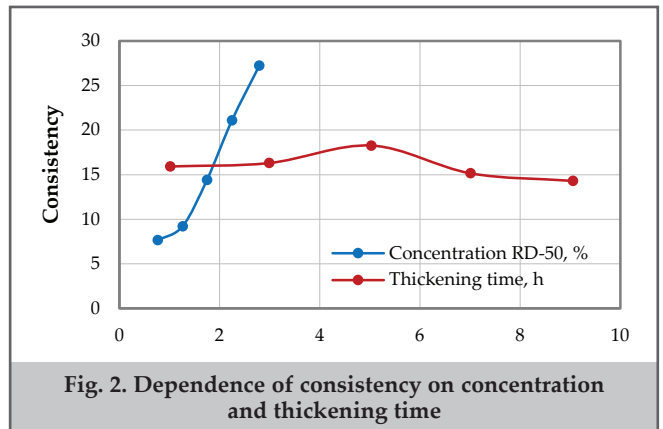


Fig. 2. Dependence of consistency on concentration and thickening time

Formulation	Density	Filtration rate cm ³	Spreadability, cm	Beginning of setting, h-min	End of setting, h-min
Formulation No.1 PCT+1% W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	1.586	105.2	25	3:10	4:55
Formulation No.2 PCT+3 % W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	1.567	108.8	25	2:45	3:50
Formulation No.3 PCT+5 % W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	1.567	106.0	25	2:55	4:15

Formulation	Density, kg/m ³	Filtration rate, cm ³	Spreadability, cm
Formulation No.1 PCT+1% W+RD-50+10% MSS+10% AMSP+3% CaCl ₂ +0.5% SMA	1.575	94	24.5
Formulation No.2 PCT+3% W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	1.569	82.8	25
Formulation No.3 PCT+5% W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	1.571	86.8	23.5

Formulation	Density, g/cm ³	Filtration rate cm ³	Spreadability, cm
Formulation No.1 PCT+1% Wellfix RD-50+10% MSS+10% AMSP+3%+0.5% SMA	1.568	90.42	25
Formulation No.2 PCT+3% W+RD-50+10% MSS+10% AMSP+1% SMA	1.591	88.27	23.5
Formulation No.3 PCT+5% W+RD-50+10% MSS+10% AMSP+1.5% SMA	1.594	87.7	20.5

Concentration RD-50 C, %	Thickening time <i>t</i> , min	Consistency K, Bc (actual values)	Consistency K, Bc (calculated values)
1	45	7	1.71
3	45	7	1.73
5	45	8	1.6
7	45	9	1.39
9	45	8	1.17
1	75	9	2.38
3	75	9	2.41
5	75	10	2.23
7	75	9	1.93
9	75	9	1.62
1	105	15	3.31
3	105	15	3.35
5	105	16	3.15
7	105	13	2.69
9	105	13	2.26
1	135	21	4.61
3	135	22	4.66
5	135	25	4.31
7	135	19	3.74
9	135	18	3.14
1	165	27	6.41
3	165	28	6.48
5	165	32	6
7	165	25	5.2
9	165	23	4.37

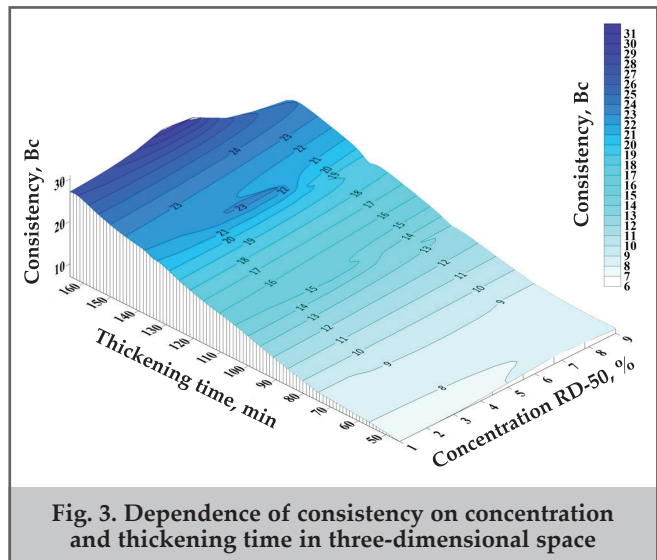


Fig. 3. Dependence of consistency on concentration and thickening time in three-dimensional space

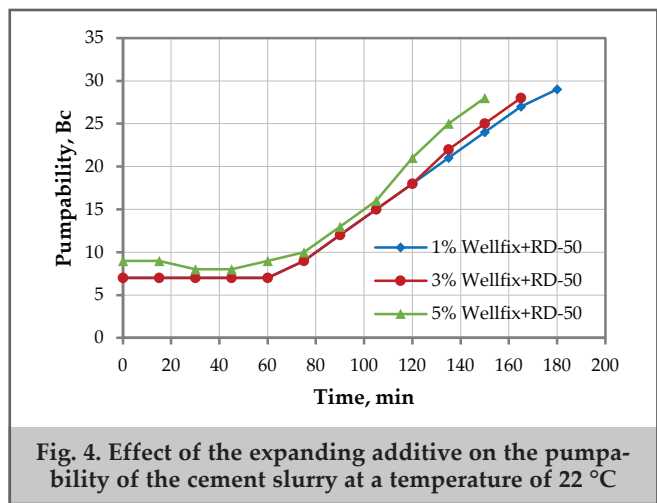


Fig. 4. Effect of the expanding additive on the pumpability of the cement slurry at a temperature of 22 °C

As noted above, after all the partial experimental studies, a planned experiment was conducted to study the effect of expanding additive concentration and setting time on consistency. The design matrix is shown in table 7.

The results of experimental studies are presented in the form of graphs in figure 2.

Figure 3 shows the noted dependence in three-dimensional space.

From this data, partial dependences were constructed and analytically approximated, resulting in the following analytical expression:

$$K = \frac{5.25e^{0.015C+0.01t}}{0.012C^2 - 0.037C + 1}$$

where *K* – consistency, Bc; *C* – concentration, %; *t* – thickening time, min.

After conducting experiments to determine the effect of the W+RD-50 additive on the technological properties of the cement slurry and the hardened cement stone, it was essential to evaluate its influence on pumpability. The results of the experimental studies are presented in figure 4.

Following the experimental investigation of the influence of the expanding additive on the primary technological properties of the cement slurry and cement stone, the principal results concerning the expansion characteristics of the cement stone were obtained (table 8).

The findings demonstrated that the expansion additive, contingent on the concentration, can yield an expansion of

No.	Formulation	Coefficient of linear expansion, % after, hour		
		24 hours	48 hours	72 hours
1	Formulation No.1 PCT+1% W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	0.32%	0.32%	0.32%
2	Formulation No.2 PCT+3% W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	0.97%	1.62%	2.59%
3	Formulation No.3 PCT+5% W+RD-50+10% MSS+10% AMSP+3% CaCl ₂	2.92%	4.87%	7.14%

Table 9 Influence of expansion additive on adhesion of cement stone with casing string		
No.	Formulation	Bond strength, MPa
1	Additive-free PCT	13.4
2	Formulation No.1 PCT+1% W+RD-50+10% MSS+10% AMSP+ 3%+0.5% SMA	18.87
3	Formulation No.2 PCT+3% W+RD-50+10% MSS+10% AMSP+1% SMA	22.27
4	Formulation No.3 PCT+5% W+RD-50+10% MSS+10% AMSP+1.5% SMA	22.54

up to 7.14%.

Some additives have been found to expand well, but they do not provide the necessary adhesion of the grout with the casing. It was necessary to test the adhesion of the formulations that had been obtained (see table 9).

As shown in table 9, the bond strength of cement stone increases as the amount of expanding additive increases. The highest index was obtained with formulation 3.

Expansion additives are an effective means of improving cementing quality. They compensate for shrinkage, improve the adhesion of cement stone to rocks, and increase the durability of the support. The choice of additive type should be based on the cementing conditions and the required grout characteristics, with the most suitable additive being selected for each specific job.

During the curing process, the addition of expansion additives (such as CaO oxides, MgO oxides and aluminates) leads to an increase in the volume of the cement. In the presence of microsilica, this effect is stabilised. Microsilica enhances the distribution of the expanding agent and mitigates the risk of voids or fissures arising from over-expansion.

Discussion

The results for the physical and mechanical properties of the cement (see table 3) showed that the addition of Wellfix+RD-50 increased the flexural and compressive strengths. For example, increasing the concentration of the expanding admixture from 3 to 5% increased the flexural strength from 2.46 to 2.75 MPa and the compressive strength from 5.43 to 6.41 MPa. To make a comparative evaluation, the data can be compared with that in table 1, which presents data without Wellfix+RD-50. Analysis shows that the maximum bending strength value of the cement stone in the absence of RD-50 in the composition is 2.86MPa (recipe 3, table 1). However, when RD-50 is added, this value decreases slightly to 2.75 MPa (table 3, recipe 3). A comparative analysis of compressive strength showed positive results. For example, the same formulations show a difference of 0.14 MPa when RD-50 is added and 0.16 MPa when it is not. According to the technological conditions adopted at LLC «Cement Technologies», the strength of the cement stone is 1.5 MPa in bending and 8 MPa in compression after 48 hours of exposure at $T=22^{\circ}\text{C}$.

The setting accelerator is used to control both the beginning and the end of setting, and a time frame of 2 to 10 hours is generally considered to be more optimal. Adding calcium chloride (CaCl_2) at a concentration of 3% or less to a cementing slurry without an expanding agent decreases setting times (see table 1). For instance, increasing the concentration from 1 to 3% changed the onset of setting from 6.15 to 4.50,

and the end of setting from 8.20 to 6.45. However, adding an expanding admixture to formulation No.3 (G cement + 10% microspheres + 10% microsilica + 3% CaCl_2) showed that RD-50 acts as a setting time accelerator (table 4). Formulation 3 (G cement + 10% AMSP + 10% MSS + 3% CaCl_2) had setting times of 4.50 and 6.45 (table 1). However, after adding an expanding additive at a concentration of 5%, the setting times decreased to 2.55 and 4.15. Comparing the obtained results with those of similar cementing slurries from advanced companies such as 'Cement Technologies' LLC (Ufa, Bashkortostan, Russian Federation) reveals a similar outcome when CaCl_2 is not included in the formulation.

The water yield of the plugging solution should be no more than 50 ml/30 min. This is at standard conditions. As can be seen in Table 4, the expanding additive does not affect the water release of the plugging solution. In previous work, we solved this problem by adding SMA reagent [12]. This reagent is an anhydrous sodium salt of silicic acid. Sodium silicate interacts with the calcium hydroxide ($\text{Ca}(\text{OH})_2$) that is formed during cement hydration. This results in the formation of an additional C-S-H gel, which thickens the cement stone structure. However, more effective methods are needed to achieve complete reduction to the required standard.

There is not much difference in the bond strength between formulations 2 and 3. Therefore, formulation 2 is considered more optimal, as it reduces the consumption of the expanding agent and the SMA reagent (see table 8).

The results of the study investigating the effect of the expanding agent on the coefficient of linear expansion showed that Wellfix+RD-50 is highly effective with light-weight plugging solutions containing microspheres and microsilica.

Comparing the developed formulation with the light-weight mortar formulation presented in [10] showed that adding the expanding additive does not reduce the bending or compressive strength. In this case, the technological characteristics of the mortar remain within the established regulatory requirements.

Adhesion tests also produced positive results, even when only 3% Wellfix + RD-50 was added.

The key feature of the developed composition is the presence of expanding additives that have a positive effect on the physical and mechanical properties of the cementing slurry. This cementing slurry exhibits superior adhesion properties compared to the additive-free version.

One limitation of this study is the absence of microstructural analysis using a scanning electron microscope (SEM) to examine the interaction between the additives and the hydration products, and X-ray phase analysis to reveal changes in the quantitative and qualitative composition data.

Conclusions

1. The expansion additive Wellfix + RD-50 does not affect the density or water-holding capacity of lightweight cementing slurry containing microsilica and microspheres.
2. The expansion additive Wellfix + RD-50 has a positive effect on the physical and mechanical properties of lightweight cement stone.
3. The Wellfix + RD-50 Expansion Additive acts like a gas pedal.
4. The addition of microsilica to lightweight grouts containing expanding additives improves strength, reduces permeability, and increases the durability of cement stone.
5. The addition of SMA reagent to lightweight grout containing microspheres and microsilica reduces water release.
6. Compared to additive-free and other lightweight cementing slurries, Wellfix + RD-50 showed efficiency with only a 3% addition.
7. As a result of the conducted experiments, an analytical expression was obtained for the dependence of cement slurry consistency on the concentration of the expanding additive and the thickening time.

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References

1. Ovchinnikov, V. P. (Ed.). (2017). *Tekhnologiya bureniya neftyanykh i gazovykh skvazhin*. 2nd Ed. Vol. 3. *Tyumen Industrial University*.
2. Murtaza, M., Tariq, Z., Rahman, M. K., et al. (2021). Novel expandable cement system for prevention of sustained casing pressure and minimization of lost circulation. *ACS Omega*, 6(7), 4950–4957.
3. Agzamov, F. A., Izmukhambetov, B. S., Tokunova, E. F. (2011). *Chemistry of plugging and drilling fluids*. Saint Petersburg: Nedra.
4. Agzamov, F. A., Babkov, V. V., Karimov, I. N. (2011). On the necessary value of expansion of plugging materials. *Territoriya Neftegaz*, 8, 14-15.
5. Suleimanov, B. A., Abbasov, H. F., Aliyev, R. Y., et al. (2025). Selection of proxy modelling methods for streamline simulation to waterflooding management process in oil reservoirs. *SOCAR Proceedings*, 2, 55-60.
6. Alyami, A. (2015). An overview of different chemicals used in designing cement slurries for oil and gas wells. SPE-175259-MS. In: *SPE Kuwait Oil and Gas Show and Conference, Mishref, Kuwait, October*. Society of Petroleum Engineers.
7. Aslanzade, F. B., Mirzaliyev, S. R., Alimuradova, L. Ch. (2026). Assessing carbonate impact on reservoir properties in the Oligocene–Miocene South Caspian Basin. *SOCAR Proceedings*, 1, 30-38.
8. Efendiyev, G. M., Moldabayeva, G. Z., Buktukov, N. S., Kuliyeu, M. Y. (2024). Comprehensive cementing quality assessment and risk management system. *SOCAR Proceedings*, 4, 42-47.
9. Malevansky, V. D. (1963). Open gas fountains and their control. *Moscow: Gostoptekhizdat*.
10. Karimov, N. H., Danyushevskiy, V. S., Rakhimbaev, Sh. M. (1980). Development of formulations and application of expanding plugging cements. *Moscow: VNIIOENG*.
11. Chernyshov, S. E., Kunitskikh, A. A., Votinov, M. V. (2015). Investigation of hydration dynamics and development of compositions of expanding additives to plugging mortars. *Petroleum Engineering*, 8, 42–44.
12. Cao, L., Cao, P., Wang, Z., et al. (2025). Hydration characteristics and mechanism analysis of calcium sulphoaluminate cement mixed with calcareous sand powder in different water environments. *Construction and Building Materials*, 482, 141595.
13. Kابدushev, A. A., Kembayev, A. R., Bimbetova, G. Zh., et al. (2025). Development of the composition of lightweight cement slurry using microspheres and microsilica. *SOCAR Proceedings*, 2, 40–47.
14. Agzamov, F. A., Ismagilova, E. R. (2019). Self-healing cements – the key to maintaining the integrity of cement sheath. Part 2. *Nanotechnologies in Construction*, 11(6), 577–589.
15. Agzamov, F. A., Bekbaev, A. A. (2016). Investigation of the influence of reinforcing additives on expansion in lightweight cements. *Oil and Gas Business*, 1, 11–19.
16. Efendiyev, G. M., Moldabayeva, G. Zh., Tuzelbayeva, Sh. R., et al. (2025). Enhancing cement mortar performance for construction and oil well applications using fiber reinforcement. *ES Materials & Manufacturing*, 30, 1771.
17. Suleymanov, E. M., Kuznetsov, V. A. (2026). Studying and improving additives for regulating the density and stability of cement mortars. *SOCAR Proceedings*, SI2, 36-42.
18. Hasanov, S. H., Mammadov, V. A., Bayramov, F. H. (2026). Improvement of the rheological properties of cement used in the drilling process of oil and gas wells. *SOCAR Proceedings*, SI2, 28-35.
19. Stavychnyi, Ye. M., Femiak, Ya. M., Vytyaz, O. Yu., et al. (2025). Improving the reliability of oil and gas well cementing with the applying of composite plugging systems. *SOCAR Proceedings*, 3, 59-69.

20. Rubiandini, R., Siregar, S., Suhascaryo, N., Efrial, D. (2005). The effect of CaO and MgO as expanding additives to improve cement isolation strength under HPHT exposure. *Journal of Engineering and Technological Sciences*, 37(1), 29–48.
21. Tanoto, E., Kusumawatie, R., Inayah, F., et al. (2016). Enhancing zonal isolation with expandable cement system for gas field. SPE-180527-MS. In: *IADC/SPE Asia Pacific Drilling Technology Conference, Singapore, August. Society of Petroleum Engineers*.
22. Zhang, Y., Liu, X., Chen, M. (2018). Expansion characteristics of MgO expansive agent in oil well cement. *Journal of Petroleum Science and Engineering*, 166, 165–172.
23. Qin, H., Wang, Y., Li, Z. (2020). Study on the expansion performance of CaO expansive agent in cement slurries. *Construction and Building Materials*, 247, 118527.
24. Patel, H., Salehi, S., Teodoriu, C. (2019). Assessing mechanical integrity of expanding cement. SPE-195225-MS. In: *SPE Oklahoma City Oil and Gas Symposium, Oklahoma City, Oklahoma, USA, April. Society of Petroleum Engineers*.
25. Tripathi, B. (2024). Effects of polymers on cement hydration and properties of concrete: A review. *ACS Omega*, 9(2), 2014–2021.
26. Wang, R., Zhang, S. (2025). Interaction between polymer and cement: A review. In: L. Czarnecki et al. (Eds.). *Concrete-polymer composites in circular economy*. Vol. 61. *Springer*.
27. Protodyakonov, M. M., Teder, R. I. (1970). *Methodology of Rational Experimental Design*. Moscow: Nauka.
28. Mamuna, V. N., Gromova, A. A., Namiot, A. Yu., et al. (1956). Mutual solubility of carbon dioxide in Romashkinskaya oil. *Trudy VNI*, 8, 392–399.