Hydraulically perfect modes of injection of grouting mixtures when isolating absorbing formations

A P Chizhov¹,², V E Andreev¹,², A V Chibisov¹,², V V Mukhametshin¹ and L S Kuleshova³

¹ Ufa State Petroleum Technological University, 1, Kosmonavtov st., Ufa, Republic of Bashkortostan, 450062, Russian Federation
² SASI “Institute of strategic research of the Republic of Bashkortostan”, 129/3, October avenue, Ufa, Republic of Bashkortostan, 450075, Russian Federation
³ Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54a, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation

E-mail: vv@of.ugntu.ru

Abstract. The article deals with a mechanism of isolation of absorbing intervals during the construction of oil and gas wells. Research is based on systemic approaches to complex scientific and technical problems. The results of laboratory and technological experiments aimed at improving the hydromechanical processes of cementation of absorbing rocks are presented. Various technological schemes for injecting hardening solutions into intervals of absorbing formations, the mechanism of interaction between solutions and permeable rocks, hydraulically perfect modes of injection of backfill mixtures and quality and efficiency of insulation works are analyzed.

1. Introduction

The main qualitative and technical and economic indicators of drilling and completing deep wells depend on the effectiveness of methods used to deal with complications (losses, gas and oil showings, hydraulic fracturing of rocks, rock falls, interstratal flows, etc.) [1–13]. However, the greatest amount of time (22–23%) and material and financial resources (4–8%) are spent on the fight against losses of drilling and grouting fluids [14–16].

To solve this complex technical problem, various technological methods are used: regulation of the parameters of drilling and grouting fluids, the supply of mud pumps, the concentration of clogging fillers, the injection of highly structured clay solutions of pastes and paste plugs, viscoelastic systems (VES), injection of cement, gel-cement and polymer-cement mixtures, etc. All these methods have the same significant drawbacks - low efficiency (efficiency rate - 20-50%) and quality of insulation works [2, 6, 14]. This situation is due to underdeveloped technologies and the lack of systemic approaches and solutions, methods for monitoring and regulating the hydromechanical processes of interaction between cement slurries and absorbing rocks during the implementation of various mechanisms of their isolation [15].

In practice, this leads to an arbitrary and unjustified choice of technological parameters of the mode of injection of plugging mixtures into the channels of absorbing formations (without taking into account the mechanisms for reducing the intensity of absorbing rocks), types, plugging-technical properties and volumes of waterproofing solutions and hardening mixtures, fillers and chemicals,
which are not adequate to the geological and physical conditions of insulation works [16]. As a result, the quality and technical and economic indicators of insulation works become worse, and the area of their effective application is reduced.

2. Materials and methods

Waterproofing of absorbing formations is an unsteady process of hydromechanical interaction of injected viscous-plastic fluids (HPL) and permeable rocks at the radius of penetration into filtration channels under the action of external factors: fluid flow rate and injection pressure. Despite the widespread use of this technology, the hydromechanical process of isolation of highly permeable absorbing rocks is understudied [1-14].

Therefore, the purpose of this article is to provide examples of implementation of system approaches and solutions in the drilling process.

3. Results and Discussion

Injection of cement slurries into the bottomhole zone of absorbing formations can occur under different injection modes - lateral transition and bottom ones [14]. Each mode has own mechanism of impact on permeable rocks, parameters and an area of effective application.

The mode of lateral injection of grouting mixtures into the lost circulation zone is implemented by creating repression on the formation top by regulating the initial structural and mechanical properties of the grouting mixtures and modes of their injection from the wellbore into the isolated interval (pump flow and injection pressure) (Figure 1).

Under hydrodynamic conditions, the movement of plugging mixtures in the bottomhole zone occurs simultaneously throughout the entire thickness of absorbing rocks. In terms of effectiveness of the influence of this injection scheme on the absorption intensity reduction, it is hydraulically perfect. It allows you to implement a number of important technological effects:

- "piston" displacement and replacement at the radius of penetration of formation fluid by cement slurries simultaneously throughout the entire thickness of the absorption interval, excluding negative changes in the initial properties of cement slurries and occurrence of intra-formation flows during and after the isolation operation;

- intensification of the dehydration process of hardening grout mixtures and their structural-mechanical and grout-technical properties (Figures 2, 3, Table 1). The mechanism of dehydration of hardening mixtures accelerates the process of structure formation in cement slurries, in which within 2–3 minutes the initial plastic viscosity of cement slurry increases 4–6 times (Figure 2), and the ultimate shear stress - 6.0–7.5 times (Figure 3). According to the results of laboratory studies, the time of the beginning of setting of the viscoplastic fluid and the water-cement ratio of 0.35–0.40 are reduced 1.5–1.9 times, and at the end of setting - 1.4–1.5 times.

- stable control and operational regulation of the technological process of isolation during the injection of solidifying solutions into the absorption channels.

![Figure 1](image-url). Isolation of absorption intensity up to 50 m³/h in the mode of lateral injection of grouting mixtures: 1-2 - clay paste; 2-4 - cement mortar
Figure 2. Dependence of plastic viscosity on the water-cement ratio: 1 - 20 minutes after mixing; 2 - 4 minutes after mixing:

Table 1. Dependence of the grouting properties of the cement mortar-stone on the water-cement ratio

| Water-cement ratio, units. | Spreadability, cm | Density, kg / m³ | Plastic viscosity, Pa s | Shear stress, Pa | Setting time, hour: min | Ultimate strength, MPa |
|---------------------------|-------------------|------------------|-------------------------|-----------------|------------------------|-----------------------|
|                           |                   |                  |                         |                 | start                  | end                   | When compressing      |
| 0.50                      | 22                | 1830             | 0.10                    | 300             | 6:19                   | 2:06                  | 2.22                   |
| 0.45                      | 20                | 1880             | 0.12                    | -               | 5:05                   | 2:05                  | 2.63                   |
| 0.40                      | 15                | 1950             | 0.26                    | 800             | 4:12                   | 1:45                  | 3.50                   |
| 0.35                      | 12                | 2030             | 0.60                    | 1750            | 3:20                   | 1:33                  | 4.60                   |

The practical implementation of the above-mentioned intrasystem effects in the side injection scheme allows the isolation of losses with an intensity of 10 to 70 m³/h and reduction of material and financial costs for combating losses by 1.5–1.85 times. The comparative technological efficiency of traditional and improved methods of absorption isolation is presented in Table 2.

The transient injection mode (Figure 4) is characterized by two sequential processes. At the beginning of the inflow of cement slurry into the bottomhole formation zone, this flow mode is formed during repression in the top of a formation close to or smaller than the formation (position 2 in Figure 4). At the second stage, as part of the filtration channels (cracks) is isolated and repression occurs in the top of absorbing strata, this flow mode switches to the mode of lateral injection of grouting mixture (positions 3-4 in Figure 4), where the indicator of hydraulic perfection of the injection mode $\delta$ is determined as:
\[ \delta = \frac{\Delta P_r}{\Delta P_b}, \]

where \( \Delta P_r \) – pressure drop on the roof of the block during injection of the cement slurry, MPa; \( \Delta P_b \) – pressure drop at the bottom of the absorbing formation during the injection of the cement slurry, MPa.

A characteristic feature of the technological process is the periodic supply of absorbing rocks from the top in the interval of isolation of formation fluids (water, gas). This leads to the dilution of grouting solutions and violation of their original functional properties. The indicator of the hydraulic perfection of the modes of injection is 0.4-0.6. The area of effective application of the transient HPF injection mode is associated with catastrophic losses of more than 80–100 m³/h.

The mode of bottom injection of HPF into an absorbing formation occurs when applied equipment (pumps, packers, etc.) and technological solutions (parameters of HPF injection, types and properties of backfill mixtures, plugging fillers, methods of regulating the setting and hardening of backfill mixtures etc.) do not create repressions on the top of the absorbing rocks (Figure 5). In such hydraulic conditions, the movement of grouting solutions is accompanied by a constant inflow of formation fluids from the roof part (intra-formation crossflow). The index of hydraulic perfection of the isolation mode does not exceed 0.4.

**Figure 4.** Isolation of absorption with an intensity of 50–80 m³/h in the transient injection mode of grouting mixtures: 1-3 - non-hardening and hardening FWP; 3-4 - hardening FWP

**Figure 5.** Hydraulic pressure in time.
4. Conclusion
The massive use of the improved technology of isolation of absorbing formations under hydraulically perfect modes of injection of backfill mixtures in Bashkortostan, Tatarstan, Eastern Siberia, and Orenburg region with the use of domestic non-scarce materials (clay powder, backfill cement, polymers and chemicals) contributed to the nonlinear improvement of quality and efficiency of insulation works (1.5-2.0 times higher than when using traditional methods) and reduction of financial costs and time to combat absorption with an intensity from 10 m³/h to 150 m³/h by 30-50%.

References
[1] Clayton C and Power P 2002 Managing Geotechnical Risk in Deepwater Offshore Site Investigation and Geotechnics “Diversity and Sustainability” Proceedings of an International Conference (26–28 November, London, UK) 1–19
[2] Roberts T S, Schen A E, and Wise J L 2005 Optimization of PDC Drill Bit Performance Utilizing High-Speed, Real-Time Downhole Data Acquired under a Cooperative Research and Development Agreement SPE/IADC Drilling Conference (Amsterdam, The Netherlands, 23–25 February) 1–14 DOI: 10.2118/91782-MS
[3] Cayeux E and Daireaux B 2009 Early Detection of Drilling Conditions Deterioration Using Real-Time Calibration of Computer Models: Field Example from North Sea Drilling Operations SPE/IADC Drilling Conference and Exhibition (17-19 March, Amsterdam, The Netherlands) 1–13 DOI: 10.2118/119435-MS
[4] Dupriest F E, and Koederitz W L 2005 Maximizing Drill Rates with Real-Time Surveillance of Mechanical Specific Energy SPE/IADC Drilling Conference (23-25 February, Amsterdam, Netherlands) 1–10 DOI: 10.2118/92194-MS
[5] Mukhametshin V V and Andreev V E 2017 Search and argumentation of decisions aimed at increasing the efficiency of bottom-hole zone stimulation in oil accumulations with challenged reserves SPE Russian Petroleum Technology Conference (16-18 October 2017, Moscow) 1–23 DOI: 10.2118/187785-MS
[6] Pink A P, Harrell L L, Perez G D, Carrico J, and Mackinnon P 2011 Integrated Drilling Optimization and Downhole Drilling Dynamics Enables PDC Bits to Drill in the Colorado Region of the San Juan Unconventional Gas Basin SPE/IADC Drilling Conference and Exhibition (1-3 March, Amsterdam, The Netherlands) 1–12 DOI: 10.2118/139848-MS
[7] Logan W D 2015 Engineered Shale Completions Based on Common Drilling Data SPE Annual Technical Conference and Exhibition (Houston, Texas, USA, 28–30 September) 1–15 DOI: 10.2118/174839-MS
[8] Yakupov R F, Gimazov A A, Mukhametshin V Sh, and Makaev R I 2018 Analytical method for estimating efficiency of oil recovery technology in case of bottom water-drive reservoir, verified on the hydrodynamic model Oil Industry 6 66-69 DOI: 10.24887/0028-2448-2018-6-66-69
[9] Ejofodomi E, Baihly J, Malpani R, Altman R, Huchton T, Welch D and Zieche J 2011 Integrating All Available Data to Improve Production in the Marcellus Shale North American Unconventional Gas Conference and Exhibition (14-16 June, The Woodlands, Texas, USA) 1–37 DOI: 10.2118/144321-MS
[10] Khokhlov V I, Galimov Sh S, Devyatkova S G, Kotenev Yu A, Sultanov Sh Kh and Mukhametshin V Sh 2019 Justification of impact and planning of technology efficiency on the basis of lime-emulsion formulation in low-permeability highly-rugged reservoirs of Tyumen deposits IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012114 1–6 DOI: 10.1088/1755-1315/378/1/012114
[11] Bevilacqua M, Ciarapica F and Marchetti 2013 Bcquisition, Processing and Evaluation of Down Hole Data for Monitoring Efficiency of Drilling Processes Journal of Petroleum Science Research (JPSSR) 2(2) 49–56
[12] Malyarenko A M, Bogdan V A, Kotenev Yu A, Mukhametshin V Sh, Umetbaev V G 2019 Wettability and formation conditions of reservoirs IOP Conference Series: Earth and
Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012040 1–6 DOI: 10.1088/1755-1315/378/1/012040

[13] Dwars S 2015 Recent Advances in Soft Torque Rotary Systems SPE/IADC Drilling Conference and Exhibition (17-19 March, London, England, UK) 1-12 DOI: 10.2118/173037-MS

[14] Polyakov V N, Mavlyutov M R, Alekseev L A, and Kolodkin V A 1998 Technology and techniques for fighting absorption in the construction of wells Ufa: Kitap 192 p

[15] Polyakov V N, Chizhov A P, Kotenev Yu A and Mukhametshin V Sh 2019 Results of System Drilling Techniques and Completion of Oil and Gas Wells IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012119 1–7 DOI: 10.1088/1755-1315/378/1/012119

[16] Polyakov V N, Sayapin E D, and Valyamov R G 1977 Technological influence of the flow rate and pressure of injection of a tamponage mixture on the effectiveness of operations for isolation of absorbing layers Drilling: scientific and technical collection 9 20-22