Theoretical and practical aspects of absorbing layers insulation in the conditions of hydraulically perfect modes of grouting solutions injection

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Abstract. The article presents the results of theoretical and experimental studies of insulation of absorbing intervals during penetration of rocks. The proposed systematic approach makes it possible to effectively apply insulation methods in various mining conditions of well construction. The methods for controlling the absorption of drilling fluids in the conditions of abnormally low layer pressures are combined in a systematic technology.

1. Introduction

It is known that the main indicators of performance of field development management are largely determined by the efficiency of well drilling [1-5].

The main qualitative and technical-economic indicators of drilling and completion of deep wells largely depend on the effectiveness of the methods used to prevent complications (absorption, gas and oil ingress, hydraulic fracturing of rocks, caving formations, interlayer flows, etc.). However, the greatest time spent in the overall balance of drilling wells in the oil and gas industry (22-23 %) and material and financial resources (4-8%) are associated with the fight against the absorption of drilling and grouting solutions [6-8].

To solve this complex technical problem, various methods and technologies are used: regulation of the parameters of drilling and grouting solutions, the supply of drilling pumps, the concentration of clogging fillers, injection of highly structured clay solutions of pastes and paste plugs, viscoelastic systems, injection of cement, gel-cement and polymer-cement mixtures, etc. But all these methods, with an undeniable difference, have the same significant disadvantages – low efficiency (performance indicator – 20-50 %) and low quality of insulation works [6, 7]. The current situation is explained by the methodological underdevelopment of technologies and the lack of systematic approaches and solutions in the theory and practice of absorption prevention. First of all, this is due to the lack of...
techniques for controlling and regulating the hydro-mechanical processes of interaction between grouting solutions and absorbing rocks when implementing various mechanisms for their insulation [6, 7].

### 2. Methods and materials

In practice, specialists choose technological parameters of the modes of injection of grouting mixtures into the channels of absorbing layers, without taking into account the mechanisms for reducing the intensity of absorbing rocks, the type, grouting and technical properties and volumes of waterproofing solutions and hardening mixtures, fillers and chemicals, which, as a rule, are not always adequate to the geological and physical conditions of insulation works [6, 7]. As a result, there is a natural decrease in the quality and technical and economic indicators of insulation works and a reduction in the scope of their effective application.

Waterproofing of absorbing layers is a non-stationary process of hydro-mechanical interaction of injected visco-plastic liquids with permeable rocks at the radius of penetration into the filtration channels under the influence of external factors in time; fluid flow and injection pressure. Despite the wide application of technology in commercial practice, the mechanism of the hydro-mechanical process of insulation of highly permeable absorbing rocks is still insufficiently and fully covered in professional literature [6, 8]. The present article is intended to fill this gap and show how systematic approaches can be used to solve the set tasks in drilling technology.

From the methodological viewpoint, implementation of the systematic approach in the methods of insulation of absorbing intervals includes several interrelated stages of work, which can be represented as a diagram. Figure 1 shows the diagram for the system organization and execution of the insulation works under hydraulically perfect modes of injection of grouting mixtures into the bottom-hole zone of absorbing layers. However, the present article outlines the second stage and focuses on the mechanisms of insulation of absorbing intervals with grouting solutions.

![Diagram](image_url)

**Figure 1.** The block diagram of realization of the system organization and execution of the insulation works:

- **Stage I:** Estimation of the hydrodynamic state of the well and geological-physical parameters of the absorbing layer ($H_{w}, h_{m}, P_{pl}, h_{a}, \Delta h, T_{pl}, K$)
- **Stage II:** Substantiation of the mechanism of absorption insulation or their combination (coagulant structure formation, dehydration and crystallization hardening, effect of wedging pressure)
- **Stage III:** Choice of the type and properties of grouting mixtures, calculation of the required volume
- **Stage IV:** Calculation of the parameters of the insulation mode of the absorbing layer, choice of the technical scheme of works ($Q, P, T$ open barrel, filling pipes, disconnecting devices)
- **Stage V:** Control and regulation of the mode of grouting of the absorbing layer ($K_{dyn}, \delta, Q, P, T$)

### 3. Results and discussion

Restoration of impermeability under abnormal low pressure is carried out by injecting grouting solutions into the bottom-hole zone of the absorbing layers. This process can be implemented in different injection modes: lateral, transient and bottom [6, 7]. Each of the modes differs in the mechanism of influence on permeable rocks, the parameters of technological process and the scope of effective application.

The mode of lateral injection of grouting mixtures into the absorption zone is achieved by pressing the layer roof by regulating the initial structural and mechanical properties of grouting mixtures and their injection modes from the borehole to the insulated interval (pump supply and injection pressure).
(Figures 2, a; 3). Under these hydraulic conditions, the movement of grouting solutions injected into the bottom-hole zone occurs simultaneously along the entire thickness of the absorbing rocks. This injection mode is considered to be hydraulically perfect and allows implementing a number of important technological effects (internal factors) that provide a non-linear increase in the quality and technical and economic indicators of insulation operations [8, 10]. These factors include:

The first effect (internal factor) consists in "piston" displacement and replacement of layer fluid at the radius of penetration of grouting solution simultaneously throughout the thickness of the interval of absorption, which eliminates adverse change in original properties of the grouting solution and the occurrence of intra-layer flows during and after the insulating operation.

The second internal factor is the intensification of the dehydration process of hardening grouting mixtures and the growth of their structural-mechanical and grouting-technical properties (Figures 4, 5, Table 1). The mechanism of dehydration of hardening mixtures accelerates the process of structure formation of grouting solutions, in which for 2–3 minutes the initial plastic viscosity of the cement solution increases by 4–6 times (Figure 3), and the maximum shear stress — by 6.0–7.5 times (Figure 4). It should be mentioned that according to laboratory research, the start time of setting of viscous-plastic liquid at water-cement ratio (W/C) of 0.35–0.40 reduces by 1.5–1.9 times, and the end time — by 1.4–1.5 times.

Figure 2. Diagrams of hydraulic modes of grouting absorbing layers: a – lateral injection mode, b – transient injection mode; c – bottom injection mode. Numbers indicate: 1 – technical column; 2 – drill pipe column; 3 – well; 4 – dynamic liquid level; 5 – static liquid level; 6 – drilling solution; 7 – displacement liquid; 8 – grouting solution; 9 – low pressure zone; 10 – absorbing layer; 11 – preventer; 12 – rock mass; 13 – packer
Figure 3. Insulation of absorption with intensity up to 70 m$^3$/h in the mode of lateral injection of grouting mixtures: 1–2 – clay paste; 2–4 – cement solution η

Figure 4. Dependence of plastic viscosity on water-cement ratio:
1– in 20 minutes after closing;
2 – in 4 minutes after closing

Figure 5. Dependence of the shear stress on the velocity gradient for different water-cement ratios:
- - - - - - – in 4 minutes after closing;
- - - - - - – in 20 minutes after closing
Table 1. Dependence of grouting and technical properties of cement mortar-stone on the water-cement ratio

| Water-cement ratio, (W/C) | Spreadability, cm | Density, kg/m³ | Plastic viscosity, Pa·s | Shear stress, Pa | Setting time, hour-min | Ultimate strength, MPa |
|-------------------------|------------------|---------------|-----------------------|-----------------|-----------------------|-----------------------|
|                         |                  |               |                       |                 | start end at bending | at compression        |
| 0.50                    | 22               | 1830          | 0.10                  | 300             | 6-19 2-06            | 2.22 4.5              |
| 0.45                    | 20               | 1880          | 0.12                  | –               | 5-05 2-05            | 2.63 7.5              |
| 0.40                    | 15               | 1950          | 0.26                  | 800             | 4-12 1-45            | 3.50 11.0             |
| 0.35                    | 12               | 2030          | 0.60                  | 1750            | 3-20 1-33            | 4.60 18.3             |

Table 2. Indicators of improved methods of insulation of absorbing layers

| Insulation technology | Analyzed volume | Efficiency coefficient | Time spent per absorption, h | Expenditure of grouting materials and reagents per absorption |
|-----------------------|-----------------|------------------------|-----------------------------|---------------------------------------------------------------|
|                       | wells | insulation | cement, t | clay solution, m³ | fillers, t | calcium chloride, t |
| Serial                | 74    | 156        | 0.474     | 28.53            | 24.4       | 11.6 | 6.5 | 0.3 |
| Improved              | 87    | 104        | 0.836     | 15.42            | 16.4       | 10.3 | 1.0 | 0.1 |

The third factor is continuous monitoring and operational regulation of the insulation process when injecting solidifying solutions into the absorption channels.

The practical implementation of the above-mentioned intra-system effects in the lateral injection scheme allows insulating absorption with intensity from 40 to 80 m³/h by performing a single operation (in most cases) and reducing material and financial costs for preventing absorption by 1.5–1.85 times [6, 8]. The comparative technological efficiency of traditional and advanced absorption insulation methods is presented in Table 2.

Transient mode of injection (Figures 2, b; 6) is characterized by two consecutive processes. At the beginning of the flow of the grouting solution into the bottom-hole zone of the layer, the bottom flow mode is formed at pressures in the roof of the layer close to the values of the layer or less (item 2 in Figure 6). At the second stage, in the process of insulation of some filter channels (cracks) and occurrence of repression in the roof of absorbing layers, bottom flow mode switches to a lateral mode of grouting mixture injection, where the indicator of hydraulic perfection of the mode δ is determined as:

$$\delta = \frac{\Delta P_{rf}}{\Delta P_{sl}},$$

where $\Delta P_{rf}$ – pressure drop on the roof of the absorbing layer during injection of the grouting solution, MPa; $\Delta P_{sl}$ – pressure drop on the sole of the absorbing layer during injection of the grouting solution, MPa.

A characteristic feature of the technological process in this scheme is represented with the periodic intake of absorbing rocks from the roof in the insulation interval of layer fluids (water, gas). This leads to dilution of grouting solutions and violation of their initial functional properties. The indicator of hydraulic perfection of injection modes for grouting mixtures is 0.4–0.6 (Figure 7). The area of effective application of the transient mode of the viscous-plastic liquid injection is associated with catastrophic absorption intensity of more than 80-100 m³/h.
Figure 6. Insulation of absorption with intensity up to 80 m$^3$/h or more in the mode of lateral injection of grouting mixtures: 1–2 – clay paste; 2–4 – cement solution

Figure 7. Dependence of the coefficient of hydraulic perfection of the solution injection mode on the thickness of the absorbing rocks (h) and the pressure drop (ΔP): δ$_1$ = 0.1–0.4 – bottom injection mode; δ$_2$ = 0.4–0.6 – transient injection mode

The mode of bottom injection of the viscous-plastic liquid into the absorbing layer occurs in cases when the applied technical means (pumps, packers, etc.) and technological solutions (parameters of injection, types and properties of grouting mixtures, clogging fillers, the methods for regulating the setting and hardening of grouting mixtures, etc.) do not lead to reprisals on the roof of absorbing rocks (Figure 8). In such hydraulic conditions of insulation works, the movement of grouting solutions in the
absorption intervals is accompanied by a constant influx of layer fluids from the roof part (intra-layer flow) and all the negative consequences that follow from this process. The indicator of hydraulic perfection of the insulation mode does not exceed 0.4.

![Graph](image)

**Figure 8.** Insulation of absorption with intensity of 100 m³/h or more in the bottom mode of injection of grouting mixtures: 1–9 – preparation of insulation works; 10 – clay paste; 11–12 – cement solution; 12, 13 – movement of mixtures during the setting period for cement solidification

4. Conclusion

It should be pointed out in the conclusion that the mass application of advanced technology for insulation of absorbing layers under hydraulically perfect injection modes of grouting solutions in the fields of Bashkortostan, Tatarstan, Eastern Siberia, Orenburg region with the use of non-deficit materials (clay powder, grouting cement, polymers and chemicals) has led to a non-linear increase in the quality and efficiency of insulation works (1.5-2.0 times higher than the indicators of traditional methods) and to the 30-50% reduction in the cost and time spent for solving the problem of absorptions with intensity ranging from 40 m³/h to 150 m³/h.

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