Stoke’s theory in problem solution of cementing slurry sedimentation in horizontal sections

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Abstract
The paper studies the application of Stokes theory in problem solution of cement slurry sedimentation in horizontal sections. As a rule, during the horizontal cementing of wells, due attention is paid to the composition of cement slurry. The final composition should ensure stable casing of the horizontal column - cement slurry - rock. A slight deviation in the fluid loss index can lead to a loss of contact between the cement stone and the rock. The study of the process of sedimentation of solution particles in horizontal sections is relevant. This paper assesses the application of Stokes theory in the solution of the above mentioned problem. The material described in this article will be useful during the study of this topic by students of Mining and Petroleum Faculty, the direction of drilling oil and gas wells, in order to improve the level of knowledge gained during the course of “Well casing” discipline.

1. Introduction
During the drilling of unstable rocks, various kinds of geological complications and related accidents occur, which cause significant costs of physical and intellectual labor, time, money and material resources. The stability of rocks in wells is mainly reasoned by the geological features of the rock massifs and drilling technology. The violation of the stability of the downhole walls is observed mainly in rocks with weak bonds of particles grains and individual elements: swelling clays, sands, crushed rocks.

In case of violation of the natural mode of occurrence, exposure of rocks, saturation of rocks with water, exposure to vibrations and impacts of the drill string, these rocks lose their stability. As a result they collapse, crumble and swell. Cracks and voids lead to losses of drilling fluid, core blocking in the core pipe and deterioration in the quality of well testing. For the possibility of further drilling of wells in these rocks, special work is required to fix their walls, their clogging - cementing of wells. Well casing is an integral part of the well construction process. It is carried out by casing in a certain interval, followed by cementing. Well cementing is performed using cementing mixtures.

The main purpose of cementing during the construction of oil and gas wells is to obtain high-quality and reliable isolation between the rock, cement stone and casing in specific geological and technical conditions, including the action of technological loads, temperature and aggressive formation fluids.

In addition, the composition of the cementing slurry must ensure complete sealing of the column with the rock. The sealing during the construction of vertical wells does not decrease. However during
the construction of horizontal wells with a small water loss of the cement slurry it can lead to the appearance of behind-the-casing flows [1]. For the further successful operation of the well, the strengthening of the walls by cementing and, in particular, the quality of the resulting cement stone, plays a primary role. The composition of cementing flushing solutions should provide [2–7]:

- Void-free, continuous filling of the zone between the casing and the wellbore walls;
- The estimated value of adhesion both with the walls of the casing pipes and with the wellbore surface;
- The isolation of productive and permeable formations;
- The protection of the annular space from the penetration of oil and (or) gas-oil mixture under the influence of excessive reservoir pressure;
- The strengthening of casing in the strata of the developed rock;
- The anti-corrosion protection of metal parts of the casing from oxidative destruction by interstratal waters;
- The partial unloading of the drill string from external pressure.

The experience of cementing wells with horizontal and inclined sections shows that stratification of cement slurry at the upper boundary of the wellbore leads to the occurrence of behind-the-casing flows during its operation. This significantly reduces the efficiency of the development of the reservoir as a whole. One of the main reasons of the emergence of behind-the-casing flows is the use of cementing compounds that do not meet the well conditions. Due to the fact that the cement stone can not be replaced and must ensure the reliable functioning of the well during the entire operation period, the cementing of the casing must be performed in strict accordance with the developed technical regulations, providing the availability and use of high-quality cementing agents.

It is obvious that the main way to improve the quality of well cementing is to change the properties of the cement slurry adjusting its composition. The introduction of various additives makes it possible to change the basic characteristics of the cement slurry to a certain extent. Some of them change in the diametrically opposite direction and the improvement of some properties inevitably leads to the deterioration of others. High sedimentation stability and pumpability of cementing slurry are one of these properties. During the cementation of a sidetrack, a high degree of pumpability of cementing slurry is the main requirement for its composition. In a small annular space, the bottom hole pressure during cement slurry injection can reach values exceeding the absorption and hydraulic fracturing pressures, which affects the success of the sidetrack casing operation and further well productivity. Due to the small size of the resulting cement ring, the plugging stone should also have increased strength characteristics.

Cementing of a casing includes a cycle of works on preparation of flushing cement slurry and injecting it into the well, into the annular space. During the work, the parameters of the flushing cement slurry and its compliance with the technological characteristics are constantly controlled. After cementing the well and the time required for the solution to harden, the quality assessment is performed. If the cement stone corresponds to the calculated technological parameters, the cementing process of the object is considered complete.

The indicator of the sedimentation stability of cementing slurry is its fluid loss. In the initial period after mixing, there is an intensive downward movement of the solid phase and the rise of water. Over time, as the binder is hydrated, the structure of the solution changes, the cement particles form aggregates, as a result of which the intensity of water rise decreases and occurs along the already formed channels (the formation of suffusion channels). The separation of water from the solution is reasoned by the setting of hydrophobic cement particles in accordance with Stokes' law under its own weight, as a result of which the solution becomes transparent without cement.

One of the urgent tasks is to study the processes associated with the setting of cement particles during the cementing of horizontal sections. In this paper, the authors tried to explain the setting stability of cementing slurry using Stokes' theory and his equation based on the experiments.
2. Materials and methods
During the research the authors used the method of literary analysis of publications devoted to the research topic.

3. Results
It is known that the decisive factor affecting the quality of cementing of wells with inclined and horizontal sections is the sedimentation stability of cementing slurry. The presence of water separation causes behind-the-casing flows due to the formation of channels in the cement stone under the hanging wall of the well. In order to achieve high sedimentation stability, cementing slurries are stabilized through the introduction of various agents.

According to the nature of the action of additives, the following mechanisms of stabilization of cement slurries are distinguished:
- electrostatic stabilization;
- stabilization by reducing the particle size of dry cement;
- steric stabilization;
- displacement stabilization.

High-quality cementing of directional wells is an important and difficult task.

The failures in high-quality cementing can lead to the complications during the operation of wells and cause water break from adjacent layer, indrawal of the bottom water to the perforations, gas breakthrough from adjacent reservoirs and gas cap to perforations, oil and gas losses due to their overflow into reservoirs with low reservoir pressures, behind-the-casing water flows in the unproductive part of the section, griffin formations and pollution of subsoil and environment.

For cementing directional wells, sedimentation-resistant cementing slurries are used. The sedimentation stability of a dispersed system is determined by the difference between the densities of the dispersed phase and the dispersion medium. Stoke’s formula can be used to find the rate of solid phase deposition.

The deposition rate of the solid phase is directly proportional to the difference in phase densities and the square of the radius of the solid phase, and inversely proportional to the viscosity of the dispersion medium. It is obvious that the radius of the solid phase has a much stronger influence than other factors. In order to ensure the sedimentation stability of cement slurries, steric, displacement and electrostatic stabilization mechanisms are used. During the steric and displacement stabilization methods, the polymers which promote the formation of adsorption shells on the surface of solid phases are used, as a result of their activity the overall density of the system decreases. The introduction of polymers also leads to the increase in the viscosity of the system and, consequently, a decrease in the setting rate of the solid phases.

Stoke’s equation, mathematical description of Stoke’s theory is as follows:

\[ \nu_r = \frac{2r^2 \cdot g \cdot (\rho_n - \rho_{\infty})}{9n} \]

where \( \nu_r \) – particle setting rate; \( r \) – particle radius; \( g \) – gravity acceleration; \( \rho_n \) – rock density; \( \rho_{\infty} \) – fluid density; \( n \) – dynamic viscosity of fluid.

The above mentioned equation is typical for particles that do not interact with each other and the sedimentation of a finely dispersed system in which there is no interaction between the particles can be represented as matrices moving to each other in the opposite direction (Figure 1, a, b).

In unlimited volume with density \( \rho_0 \), the solid phase matrix in the form of a rectangle with sides \( dx \) and \( dy \) in \( dt \) time travels the distance \( dh \) equal to the product of the particle velocity \( \nu_r \) by the time interval \( \Delta t \) [8]. In this case, the density of the dispersed medium remains constant at all heights of the matrix and is equal to the initial \( \rho_0 \). In the case when the downward movement of solid particles is limited (Figure 1, c, d, e), after some period of the beginning of the movement of particles in the lower part (the 5th layer, Figure 1, d), the increase in the density of the solution occurs. It is explained by the accumulation of solid phase and displacement of liquid from this layer. There is a gradual crushing and
compaction of the matrix. The squeezed liquid from the bottom, rising to the overlying middle layers (the 2nd, 3rd, 4th layers, Figure 1, d), maintains the density of the medium at the initial level.

The density of the top layer becomes lower than the initial. With complete setting of particles (Figure 1, e), the lower layers occupied by the deposited material (the 3rd, the 4th and the 5th layers) have the same density greater than the initial \( \rho_0 \), the overlying layers (the 1st, 2nd) have the density of the initial dispersion medium [9].

\[ \text{Figure 1. Sedimentation model} \]

Until the cementing slurry thickens, complex physical and chemical processes take place in it. According to many scientists (A.A. Baykov, P.A. Budnikov, A.V. Volzhensky, K. Green, S. Greenberg, R. Kondo, O.P. Mchedlov, Petrosyan, A.F. Pollak, P. A. Rebinder, S. Ugda, etc.), who studied the nature of cement thickening, initially when cement is mixed with water, a small part of it dissolves in the mixing liquid, forming a supersaturated solution, the rest remains in a solid state, and its hydration is carried out through the surface layers of cement particles. As the binder is hydrated, the reaction products set in the form of crystals on the surfaces of cement particles [10]. Over time, the growth of crystals provides the coalescence of the initial particles, forming a coagulation structure (Figure 2). Further hydration of the cement and the formation of an increasing number of crystals and their intergrowth provide the thickening of the cement mixture and strengthening of the cement stone.
Figure 2. Changes in the structure of cementing slurry over time: on the left - in the initial period of time after mixing; on the right - at the time of the thickening of solution

4. Conclusion

According to the research the following conclusions can be drawn:

- Sedimentation stability of cementing material is the main indicator that provides high-quality casing of horizontal sections of wells;
- Today the process of sedimentation of cementing slurry and its effect on the properties of the resulting cement stone remain not fully understood, there is no method to determine the sedimentation stability of cementing slurries, and therefore the study of the processes caused by the setting of cement particles which occur during hardening is a relevant issue.

All of the above mentioned statements and theoretical justifications were empirically proved and reflected in scientific publications devoted to the research topic. The links are given below in the list of references.

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