УДК 622.245.422

ТЕХНОЛОГИЯ НАУЧНО ОБОСНОВАННЫХ ПРОГНОЗИРОВАНИЯ И ПРЕДУПРЕЖДЕНИЯ ПЕРЕТОКОВ ПЛАСТОВЫХ ФЛЮИДОВ В ЗАЦЕМЕНТИРОВАННОМ ЗАКОЛОННОМ ПРОСТРАНСТВЕ СКВАЖИНЫ

THE TECHNOLOGY OF SCIENTIFIC BASED PREDICTION AND PREVENTION OF FLUID MIGRATION IN CEMENTED WELL ANNULUS

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Аннотация. В статье приведена информация о том, как математическое моделирование процессов в скважине позволяет успешно предупреждать перетоки пластовых флюидов в зацементированном заколонном пространстве скважины.

Ключевые слова: скважина, тампонажный раствор, горные породы, перетоки по заколонному пространству скважины, пластовые флюиды, миграция газа по зацементированному заколонному пространству скважины.

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Annotation. The article gives information on how mathematical modeling of the processes occurring in the well allows successfully to prevent flows of formation fluids in the cemented annulus.

Keywords: well, cement slurry, formation, annulus flows, formation fluids, gas migration in annular space of the well.

In memory of Dr. Chernenko Alexander Vasilievich

The problem of gas, water or oil migration in cemented well annular space has always been and remains relevant and very significant, causing great damage not only economic, but also to the subsoil and the environment (not everytime manifast).

Many techiques to prevent migration of formation fluids, mostly gas, over 50 years have been used. There are some of them: using «high quality» oil well cements; increacing replacement ratio; two-stage cementing, setting muds; limitation of fluid loss of cement; different types of cements: tixotropic, latex, shot transition time, low free water and low permeable (with colmatants of pores), expending, «right angle» and others; additives in cement: dispersed gaz, gaz generated, surfactants, «gazblocks», adhesion enhancers...; packers; holding backpressure from serfase at last. Many tecnques – no universal success (here we call only one source-1, in fact there are hundreds of them, if not thousands).

But it seems there can not be a universal solution of the problem. There are so many different technical and downhole combinations of the conditions in each specific well that we have only way – to know the conditions and select and apply that techique what «guarantees» success.

In the 80–90s in VNIIKRneft-NPO «Burenie», Krasnodar, Russian Federation, Dr. Chernenko A.V. with the colleagues after study of literary sources, thear own deep experimental and theoretical investigations confirmed and found follow.

Migration of formation fluids starts either in the initial period of time after stop of well cementing (transition period) through the matrix of the cement slurry or, after hardening of the cement – in the contact zones of the cement stone, primarily with mud, clay cake or formation.

Most of the flows start during first 10–40 minutes of transision period. At this time formation of fluid-conducting channels in cement is possible. The riasons of the channeling are: sedimentation of the solid phase and local suffusion destructions of the coagulation cement particles structure by ascending flows of water displaced by settling solid phase and later – in addition – by formation fluid. The channels sharply reduce ability of cement to resist to fluids filtration. The abbility may be evaluated by so called *initial gradient of the fluid filtration through slurry* – it is least gradient at which fluid movement begins.

At the same time due to the drop in the hydrostatic pressure of the column of the cement (cement pore pressure) pressure gradient directed from the formation into the well appears and arises. (The reasons of the pressure drop are: solid phase suspension on bounding surfaces and water phase loss). The gradient can become a driving force for formation fluid movement into the annular. If the time-increasing pressure gradient exceeds the current (also time-varying) initial gradient of the fluid filtration through the cement slurry, the movement of a formation fluid from the formation into the well and further along the annular starts. The migration will evolve or, much less likely, die down. If structure of cement slurry and than – stone is not broken, i.e. the chanels are absent, initial gradient usually is above than gradients that take place in cemented annular-flow throught cement matrix is unpossible.

All of above described processes depend on a lot of factors.

Figure illustrates the idea of the occurrence of a driving force of fluid flow from the formation into the well and of the moment of flow start.

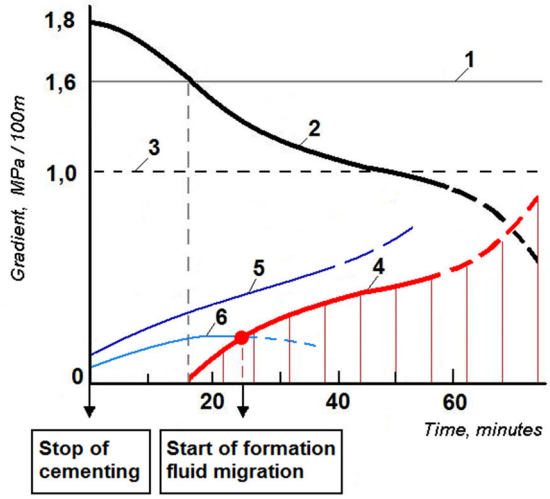

Figure. Scheme of pressure gradients changes in cemented annular space of a well in time

Designations: 1 – gradient of reservoir pressure. 2 – gradient of cement pore pressure. 3 – nominal gradient of hydrostatic pressure of cement water phase. 4 – gradient of differential pressure in the reservoir and in the well (driving force of formation fluid migration). 5 – initial gradient of the fluid filtration through the cement slurry (flow resistance), cement A. 6 – initial gradient of the fluid filtration through the cement slurry (flow resistance), cement B.

The two situations are shown:

a) cement A has sufficient insulating ability. The cement ring remains tight.

b) cement B does not have sufficient insulating ability. Movement of formation fluid from formation to well occurs.

The parameters values are approximate.

An analytical criterion for the tightness of cemented annular space was proposed, which has the following form:

$$1 \geq \Theta_{cr} = \frac{P_1 + \Delta P - P_2}{P_3 + \Delta P - P_2} \geq 0 \quad ,$$

where: Θ_{cr} – tightness criterion for cemented annular space, non-dementional; P_1 – pressure in annulus during WOC (function of time); ΔP – pressure required to overcome resistance to formation fluid injection into annulus (function of time), MPa; P_2 – formation pressure, MPa; P_3 – formation fracturing pressure, MPa.

If $\Theta_{cr} \geq 0$, then fluid manifestations and inter-reservoir flows will not occur, i.e. tightness of the cemented annular space will be ensured. If $\Theta_{cr} \leq 1$ – hydraulic fracturing is excluded when additional pressure (backpressure) is created during the period WOC (during cement setting).

The special laboratory stand was constructed. The similarity criterias of geometric, temperature, and what is most important, pressure gradients in the model and in nature – well borehole-were met. The scientists have tested different varieties of oil well cements and studied kinetics of changes in pore pressure and initial gradient.

The obtained data, unknown before, and the analytical constructions allowed to develop the mathematical models of processes occurring not only during cementing, but also in the already cemented annulus space of well. Mathematical quantitative simulation with a high degree of similarity has made it possible to know the growth kinetics of both the driving force and the resistance to the movement of fluids through cement slurry in a particular(!) well. Thus, it has become possible to predict level of probability of formation fluids flows in the initial period of hardening of the cement slurry. As far as we know, other similar functional dependencies are not known.

On the base of the mathemetical models the new computer programs and technology of well cementing have been developed (further-the Technology, it was registrated in 2002). The Technology is unique in terms of a scientific highly reasonable prediction of the probability of achieving tightness in the annular space.

If first forcast is negative, known technological methods of preventing leakages are chosen, corrected, adopted and applied. There are some of the most preferred of them: optimization of the properties of the cement slurry, imparting it with the required insulating ability (optimization of coagulation structure (gel) bulding-up and thikenning time, increasing the viscosity of the liquid phase, pore space colmatation), if the specified measures are not enough, creation according the calculated, emphasize calculated, timing of backpressure is used. Selection is made until a positive forecast is obtained.

The Technology also includes the application of the already usual soft for calculating case running, its centralization, hydraulic, dynamic pressure on the different depths, barothermal regime of the cement slurry head and others intended both for designing a trouble-free cementing process itself, and for obtaining the principal, final result – sealing tightness (2, 3).

Table 1 shows the main source data used for analysis.

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Well profile
Depths of reservoir layer, pore and hydraulic fracturing pressures, type of formation fluid, cavernous coefficients
Diameter of drill pipes and bit at the last runing
Depth of descent of the previous and cemented casing strings, their sizes
Placement of the «stop ring»
Geostatic temperature at the bottom
Surface temperature
Mud outlet temperature
Pump performance, wellhead pressure when flushing after the descent of the column
Volumes, density, rheological properties of : drilling mud, buffers, cement, its water phase and squeezing fluid
Water-cement ratio, preparing and activating time, spreadability (a cement parameter used in Russia, conditionally characterizing its fluidity), the start time of cement setting (other not API parameter of cement) after the moment of «stop»
Cementing plan

Table 2 shows the output obtained using the set of computer programs.

Table 2 – The output obtained using the set of computer programs

1. The forecast of the tightness of the cemented annulus in the period of WOC 1.1 The probability of fluid manifestations from the formation at the wellhead
1.2 The probability of inter-reservoir flows indicating which layer to which cross-flow is possible
1.3 Intervals of formation of fluid-conducting channels in annulus
2. Optimal arrangement of centralizers, indicating the number of centralizers and their installation locations
3. The calculation of the maximum allowable values of the speed of the descent of the column and the flow rate of the liquid during intermediate flushings
4. Cementing plan
5. Simulation of the cementing process
5.1 Process visualization
5.2 Pressure on the roof and sole of each layer during cementing
5.3 Thermobaric regime of the «head» of each portion of cement (necessary for the correct informative laboratory testing of cement)
5.4 Upflow speed
5.5 Column emptying depth during cementing
5.6 Cement head design pressures
5.7 Upflow mode according to Reynolds Theory

The Technology has been applied many times in some parts of the world. Its high performance of achieving tightness in the annular space has been proven beyond doubt (look table 3).

Table 3 – The results of using the Technology for the selection and implementation of technological methods for preventing serface casing vent leaks and inter-reservoir flows of formation fluids

Year	Region	Number of wells cemented by the Technology	Tightness	
			Befor use the Technology not reached	After use the Technology reached
1987	Langepas, Russia	10	Product flooding up to 95 %	Anhydrous oil production for 3 years of observation
1989	Radugnyi, Russia	10	Product flooding up to 95 %	Anhydrous oil production for 3 years of observation
1987	Groznyi, Russia	3	Serface casing vent leaks during WOC	Absent
1989–1995	Astrahan, Russia	7	Serface casing vent leaks during WOC	Absent
1992–2000	Ukraine	10	Serface casing vent leaks during WOC	Absent
1996–1997	Vietnam	More 30	In 85 % of the wells serface casing vent leaks	In 10 % of the wells annular pressures due to leakage of the wellhead
1994–2001	Krasnodar, Russia	7	Serface casing vent leaks during operation	Absent
2002	Igevsk, Russia	5	Product flooding	Anhydrous Oil Production
2002	Nefteugansk, Russia	17	Product flooding	Anhydrous Oil Production
2008	Urengoy, Russia	26	Serface casing vent leaks during WOC	Absent
2013–2017	Iraq	More 100	Serface casing vent leaks during WOC	Positive reviews

All data in the tables have been presented by Dr. Chernenko A.V.

Unfortunately, for some objective reasons that are completely irrelevant to the quality of the Technology itself, it, the Technology, was not published to the necessary degree and turned out to be practically unknown to a wide circle of specialists and potential users. This article is aimed at correcting this situation.

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