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Increasing of Wells Sealness Quality for Underground Reservoirs During Repair-and-Renewal Operations

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***Abstract*—In the world practice of hydrocarbon reservoirs design there is the steady tendency of rate increasing for underground reservoirs design in impermeable rocks. Design of underground reservoirs that are created in rock-salt sediments is intensively directed by the geotechnological method. It is determined by many economic and ecological advantages. One of the main tasks during renewal works of technological wells sealness for underground reservoirs in salt-rocks is the necessity to insulate the excavation-capacity of big geometrical volume filled by saturated sodium-chloride brine from technological well. The main point of offered technology is to develop stable with brine-contact flush fluid that is delivered on the brine surface with the aim to provide a possibility to install intermediate bridge for renewal works realization of borehole annulus sealness of main casing string and cementing of additional casing string using pakers and lightened drilling mud. The application of new scientific-technical developments allows providing a stable level of gas recovery from underground reservoirs wells due to the increasing of the overhaul period of its operation and the reducing of repair duration.**

Keywords*—underground reservoirs; well repair; support sealness

I. INTRODUCTION

One of the most important problems in the field of gas storage is to provide well sealness that guarantees the reliability of its operation and increases economic profitability. The top priority importance when solving these tasks is the necessity of maintenance for operating well stock of underground gas storages in operating status.

Changing of wells working conditions as a result of long operation: corrosive wear of casing pipes, non-sealness of the cement stone in hole annulus behind the main casing string and so on, - considerably widens the range of problems which demand solutions when repair-and-renewal operations are realized.

One of the main tasks during renewal works of technological wells sealness for underground reservoirs in salt-rocks is the necessity to insulate the excavation-capacity of big geometrical volume filled by saturated sodium-chloride solution (brine) from technological well. Technically, such division can be realized with the help of the intermediate bridge, installed below a shoe of production string in uncased well bore. To install the intermediate bridge, different mechanical devices or flushing fluids (the main purpose is to separate brine from cementing slurry) can be used.

The scheme of wellhead connections by specified equipment to install the intermediate bridge is shown in Fig. 1.

It is obviously that in the brine-filled well without application of some segregator of cement slurry, it is impossible to install the intermediate bridge

Nowadays, 100 recipes of flushing fluid are used in world practice; it is connected with its usage to decide big volume of tasks, appearing during cementing and wells repair. With the aim of optimal recipes choosing for every specific situation, there are developed different classifications of flushing fluid [1].

II. ANALYTICAL PART

The analysis of existed level of technique [2-4] shows the following:

We know that the flushing fluid, used when repair realization of underground reservoirs wells, is carried out in salt-rock; the recipe of it has the following ratio of components (weight percentage):

Hydrocarbon fluid – 20–25;

Aqueous solution of calcium chloride:

density – 1120 kg/m^3 74–78.5;

Cation emulsifier – 1.0–1.5;

with the filling agent content – polypropylene fiber 0.03-0.05 (weight percentage) of its volume [5].

The disadvantage of indicated flushing fluid is insufficient efficiency of sealness for brine-filled underground reservoirs wells. It is caused by low stability of its phase composition and low lift cuttings ability, not high ability to prevent contact of the cementing slurry (cement grout) used during well sealness with brine that filled underground reservoir and also increased material expenses when works are realized.

Moreover, low density of the cement slurry, which are regulated by physic-chemical rheological properties of emulsion as a non-solidifying (non-polymerized) system of the flushing fluid that must hold slurry on the surface, is caused by insufficient lift cuttings ability. It does not provide necessary strength characteristics of the cement stone for efficiency of works realization. According to the case study, with the aim to prevent mutual replacing in the process of injection of return emulsion with filling agent and the cement slurry (density 900–1000 kg/m^3), height of the liquid column for return emulsion with the filling agent is equal to 10 meters that leads to the growth of economic expenses when works are realized.

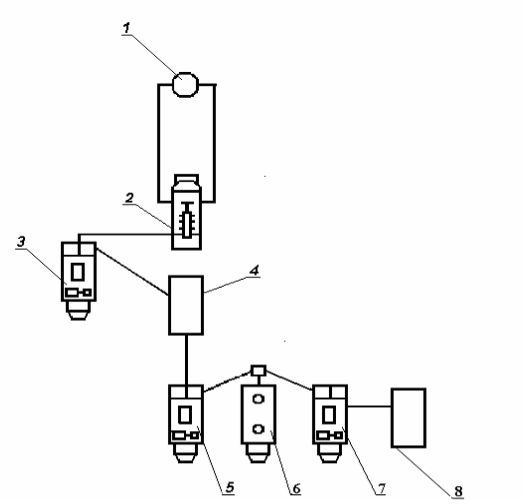


Fig. 1. Scheme of wellhead connections using specified equipment to install the intermediate bridge; 1 – well; 2 – manifold unit; 3, 5, 7 – cementing unit; 4 – mud surge tank; 6 – mixing unit -6/30, 8 – capacity with mixing water

As a prototype, we chose a flushing fluid, used during sealness of brine-filled underground reservoir well; the recipe has the following ratio of components (weight percentage) [6]:

Diesel fuel – 68;

Clay – 38;

Carboxymethyl cellulose – 4.

The disadvantage of indicated flushing fluid is insufficient efficiency of sealness for brine-filled underground reservoirs wells. It is caused by low stability of its phase content and low lift cuttings ability, not high ability to prevent contact of cementing slurry (cement grout) used during well sealness with brine that filled underground reservoir and also increased material expenses when works are realized.

Diesel fuel, as hydrocarbon liquid and a dispersing medium for the flushing fluid, has density of 720–830 kg/m^3; it is considerably lower than clay density (about 2000 kg/m^3). That is why, diesel fuel is not able to hold clay in suspension state due to clay's gravitational settling that makes the flushing fluid unstable.

The recipe of the flushing fluid in such qualitative and quantitative relations of ingredients does not provide necessary lift cuttings ability of the flushing fluid in the result of generation of clay-polymer layer on the base of carboxymethyl cellulose that is not sufficiently solid to endure stress created by cement slurry placed on its surface.

Obtained polymer-based viscoelastic compositions have viscoplastic properties, necessary to realize function of segregator for the cementing slurry from brine in underground reservoir well. However, at the same time, during 2-3 hours after viscoelastic compositions injection, on the brine there is a loosening of its surface that is adjacent to the sides of vessel with brine, it is indicated about insufficient stability of viscoelastic compositions in saturated solutions of calcium chloride.

Within this context, we may offer to apply organo-mineral flushing fluid to form a separating layer on the brine surface in underground reservoir in salt-rock, which must meet the requirements:

– be compatible with chloride-sodium solutions (NaCl) of different strength, with rock-salt and with other technological fluids (for example, cementing slurries), used when repair of technological wells is realized;

– have necessary density to provide possibility of separating layer generation and to get structural-mechanical properties on the brine surface;

– have sufficient time of gel forming for transportation on the brine surface in excavation-capacity;

– have adhesion to salt-rock and sufficient strength that provided possibility to inject the required volume of lightened cementing slurry on its surface with the aim to install the first (intermediate) bridge;

– be resistant and stable during the contact with working solutions (brine, cement slurry) in definite conditions of application;

– preserve its structural-mechanical properties during some time necessary for solidification of lightened cementing slurry in the process of installation for the first (intermediate) bridge;

– have ingredients composition providing environment safety of usage;

– be appropriate in preparation and application;

– do not to cause metal corrosion of casing pipes and elements of technological equipment;

– be fire-and- explosion proof.

III. EXPERIMENTAL PART

The most expedient thing is to provide a possibility of the intermediate bridge installation in salt reservoir containing the brine, is to apply polymer systems that allow one to eliminate negative influence of the brine on physic-mechanical properties of the cement slurry of installing intermediate bridge. In this case, the role of the flushing fluid as segregator of the cement slurry and brine can be provided under conditions of buffer layer forming on the brine surface; moreover, this buffer must have necessary strength properties and adhesion to salt-rock to endure the definite liquid column of the cement slurry and to prevent reliably its contact with the brine.

The technical result, which may be received in the process of the offered invention realization [7], results in: that efficiency of sealness of the underground reservoir brine-filled well is increased due to flushing fluid application with improved technological properties, caused by the high stability of its phase contact that is able to prevent a contact of the cement slurry used during well sealness and the brine (with the high lift cuttings ability) and also reducing material expenses when works are realized.

The flushing fluid includes dispersion medium, clay and anion polymer. Dispersion medium of claimed flushing fluid is an aqueous dispersion of polyurethane with mass fraction of dry substance 28-32%, i.e. it contains sufficient quantity of water (68-72%) to activate processes of gelling as a result of hydrolysis of polymer components and mud powder swelling. The produced clay-polymer system during mixing of added dry substances in aqueous polyurethane dispersion trademark “Akvapol 10” after1.5-2 hours is a gel-like liquid with plastic viscosity within the limits of 120-144 mPa·s, sufficient to hold the dispersion phase (mud powder particles, “Monasila” and polymers-acrylamides) in a suspension state all over the volume and to inject on the brine surface in the well of underground reservoir without complication.

The high ability of the flushing fluid to prevent a contact of cement slurry used during well sealness with the brine filled underground reservoir is provided by the joint interaction of used mud powder Bentokon “Super 200”, aqueous polyurethane dispersion “Akvapol 10” using the brine with the participation of Monasila in flushing fluid recipe to create an equal distributed layer on the brine surface.

Terminal groups of alkylamides of polyurethane dispersion (amine and carboxylic) are able to create metals salts. After delivery of the flushing fluid on the brine surface along the boundary of its contact with the brine, a solidified part is practically immediately formed, containing clay particles. This part consists of alkylamides (polyurethane-link of “Akvapol 10”), which are rapidly interacting with sodium chloride. Above this solidified part, the flushing fluid has a non-solidified paste-like state. At the same time, an insulating layer of paste-like flushing fluid, situated on the surface of its solidified part, joins tightly to the side surface of reservoir sides having created a solid polymer-clay screen to inject cement slurry on it, used during well sealness.

Equal distribution of the layer on the brine contributes to the contact density of paste-like flushing fluid with reservoir sides of salt-rock due to its homogeneous stabilized composition. Moreover, when interaction of Monasila hydrolysis products and mineral-constituent of mud powder, cementing film of silicates of polyvalent metals of clay fraction is formed on the surface of reservoir sides in salt-rock. That is an additional factor of tight joint for flushing fluid layer to the reservoir sides. In total, the described-above processes provide the high insulating ability of flushing fluid.

The insulating ability of the flushing fluid is defined as a ratio of differences for cement slurry volume, which are placed on the insulating layer of the flushing fluid and passed through it, to the volume of cement slurry, which was primary poured on the layer of the flushing fluid. The calculation of this ratio is realized according to the formula (1):

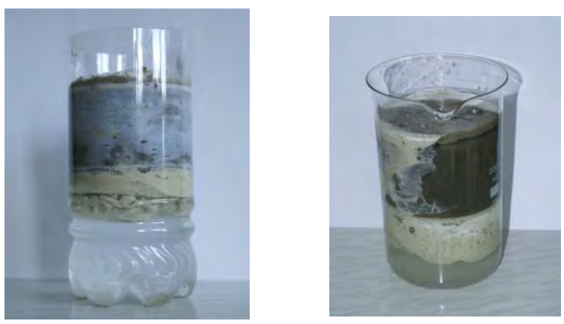
$$IA_{FF} = \frac{V_1 - V_2}{V_1} \cdot 100(\%) \quad (1)$$

where, IA_{FF} – insulating ability of flushing fluid (percentage);

V_1 – primary volume of cement slurry (millilitre);

V_2 – volume of cement slurry passed through the insulating layer of the flushing fluid (millilitre).

The lift cuttings ability of the flushing fluid characterizes its ability after polymerization to endure the stress without relocation on the contact with reservoir sides; this stress is created by the cement slurry with density of 1320 kg/m^3 during its placing on the surface of flushing fluid. It is determined by calculation as unit load (kPa/m) based on the conditions of forming on the brine of flushing fluid liquid column, its height equal to 1.5 diameter of the placing vessel on the surface of it, after polymerization abovementioned cement slurry is delivered in the volume that exceeds the liquid column of the flushing fluid no less than 2.5 times (Fig. 2).



a *b*

Fig. 2. Forming of the flushing fluid layer and the liquid column of cement slurry on the surface of saturated brine NaCl in polyethylene (*a*) and glass (*b*) vessels according to results of laboratory research

The flushing fluid has the following technological properties: density ρ=1055 kg/m^3, plastic viscosity η=120 mPa·s, stability of phase composition 97 %, insulating ability 98 %, lift cuttings ability 35.1 kPa/m.

The cement slurry to install the intermediate bridge in uncased wellbore must meet the following requirements, having possessed:

- the high level of compressing and shear strength for the cement stone to hold liquid column of the cement slurry during insulation of borehole annulus of the main casing string and cementing of the additional casing string;

- good adhesion to well sides of salt-rock and casing pipes;

- low gaspermeability of the cement stone;

- the high strength of the cement stone from fissuring and cracking under the influence of impact loads;

- be appropriate in preparation and application.

With the aim to increase strength and better adhesion, we can offer to add an inert fiber-filling agent – NBV-6 [8] in the composition of the cement slurry.

To decrease gaspermeability of the cement stone, gas migration prevention additive is added to the cement slurry. The recipe of reinforced cement slurry contains the following components (weight fraction):

Portland cement - PCT I-50 100;

Filling agent - (NBV-6) 0.5;

Gas migration prevention additive – 5;

Water - 50.

Comparative characteristics of pure slurry of PCT I-50 and reinforced cement slurry are shown in Table I. Obtained cement stone differs by the low permeability and the high adhesion to metal unlike the cement stone of pure portland cement. When strength test is realized, reinforced stone has elastic-plastic fracture mode, while stone of pure cement – brittle with particle cracking of different size [9,10].

To avoid fissuring of the cement stone during impact loads, insulating works and cementing of the additional casing string are also realized by reinforced cementing slurry with the same composition as during the installation of the second cementing bridge.

Volume of lightened cementing slurry to install the intermediate bridge is determined by lift cuttings ability of flushing fluid liquid column on the brine surface and strength properties of the cement stone that is formed from it. This stone perceives stress of liquid column of reinforced cementing slurry poured on its surface, i.e. if layer thickness of the flushing fluid is less than 3 meters, but maximal height of bridge of lightened cementing slurry will be equal to 9 meters.

TABLE I. TEST RESULTS OF PURE AND REINFORCED CEMENTING SLURRY WITH THE GAS MIGRATION PREVENTION ADDITIVE

Composition (weight fraction)				WATER/CEMENT	Density (kg/m^3)	Spreadability (cm)	Strength of cement stone (MPa)		Permeability (10^{-3} μm^2)	Setting period, (h-min.), start/end	Thickening start (h min.)	Adhesion of stone with metal (kPa)
Cement PCT I-50	Water	Gas migration prevention additive	Filling agent NBV-6				bending	compressing				
100	50	-	-	0.5	1800	17	3.25	6.67	17.8	7-00 / 8-30	6-20	33.3
100	50	5	0,5	0.5	1790	19	2.95	7.30	9.1	9-00 / 10-30	8-30	241.5

IV. CONCLUSIONS AND RECOMMENDATIONS

Works of composition selection and properties research of the flushing fluid based on polyurethane dispersion – chemical agent "Akvapol 10" - were carried out. The order of preparation and injection for the flushing fluid on the brine surface in dehydrated well was developed. Polymerization character of the flushing fluid on the brine provides the forming of the high-qualitative insulating layer with high lift cuttings ability, loss preventing of cementing slurry injected on it (because of leaky joint to the reservoir sides and partial leaking on the reservoir bottom). It reduces material expenses and contributes to the increasing of efficiency for works realization.

New technological fluids with described properties allow one to install two-layer cementing bridge on solidified organo-mineral mixture on the brine surface; it consists in lightened and reinforced cementing slurry with the aim of well sealness renewal to realize insulating works in the main casing string, to run in and cement the additional casing string.

To provide sealness of the cement sheath at alternating-sign loads of operation for underground gas storage wells and to prevent intercasing pressures, the cementing of the additional casing string is provided to realize by basalt fiber reinforced cementing slurry and containing the gas migration prevention additive.

Thus, application of actions by organization of repair works and technologies realization introduced in this research allow increasing efficiency of repair-and-renewal operations carried out in the underground reservoirs wells in salt-rock.

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