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Sand control methods for the development of oil&gas fields with hard to recover reserves

Métodos de control de arena para el desarrollo de campos de petróleo y gas con difícil de recuperar reservas

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Content

ABSTRACT:

Preventing of the sand production during operation of gas wells that are drilled the semi-consolidated reservoirs is very acute challenge for gas fields. Such types of formation are often presented by sand and sandstone. It's impractical to equip bottom-hole zone of the wells where sand-related problems are the result of the formation water in flux, so it is preferable to apply chemical consolidation to strengthen reservoir. Both theoretical and experimental methods of standard and developed techniques were used in studies (rheological, filtration, determination of the effective diameter of the suspended particles, etc.). For the performing of the research determination a considerable amount of experimental laboratory studies using modern precision equipment was used. Paper shows results of the laboratory tests to consolidate semi-consolidated reservoirs that carried out on the sand packed tubes. Authors determined the mechanism of interaction developed by the chemical composition of liquid hydrocarbons based on the reaction of neutralization of alkali $NaHCO_3$ a weak acid and the process of saponification of oil - synthesis of surfactant in oil by neutralizing fatty acids with an alkali by conducting

RESUMEN:

La prevención de la producción de arena durante el funcionamiento de pozos de gas que se perforan en los embalses semi-consolidados es un reto muy agudo para los campos de gas. Tales tipos de formación se presentan a menudo por la arena y la piedra arenisca. No es práctico equipar la zona de fondo de los pozos donde los problemas relacionados con la arena son el resultado de la formación de agua en flujo, por lo que es preferible aplicar la consolidación química para fortalecer el depósito. Se utilizaron tanto métodos teóricos como experimentales de técnicas estándar y desarrolladas en estudios (reológicos, filtración, determinación del diámetro efectivo de las partículas en suspensión, etc.). Para la realización de la determinación de la investigación se utilizó una cantidad considerable de estudios experimentales de laboratorio utilizando equipos de precisión modernos. En este trabajo se presentan los resultados de las pruebas de laboratorio para la consolidación de depósitos semi-consolidados que se realizan en los tubos de arena. Los autores determinaron el mecanismo de interacción desarrollado por la composición química de los hidrocarburos líquidos basado en la reacción de

rheological studies.
Keywords: sand control; sand related problem; oil & gas fields; semi-consolidated reservoirs.

neutralización de $NaHCO_3$ alcalino un ácido débil y el proceso de saponificación de aceite - síntesis de surfactante en aceite neutralizando ácidos grasos con un álcali mediante la realización de estudios reológicos.
Palabras clave: control de la arena; problemas relacionados con la arena; campos de petróleo y gas; reservorios semi-consolidados.

1. Introduction

The majority of the developed gas fields all over the world are at the final stage of operation, in such a case semi-consolidated reservoirs or sandstones are destroyed during gas production, which leads to sand-related problems (Bliznyukov & Eganyants, 2008). Production from many wells that have penetrated these reserves, is already much longer than expected, and their further operation with a high degree of water cut can lead to the softening of the formation (Zotov, 1998; Adeyanju & Oyekunle, 2010; Tananykin, 2015).

Oluyemi and Oyeneyin (2010) stated that the economic, operational and safety implications of sand failures require real time efficient sand management.

According to (Ikporo & Sylvester, 2015) the sand production takes place if the sand grains around the cavity is disaggregated and as the volume of sand dislodged is deposited and accumulated on production equipment continuously, cleaning will be required to allow for efficient production of the well. To restore production, the well must be shut-in, the surface equipment opened, and the sand must be manually removed. In addition to the clean out cost, the cost of the deferred production must be considered.

Work (Kim, 2010) describes that many operators simply choose to install sand control or stimulate the formation if it is determined to be “weak” without necessarily evaluating or predicting the sand potential. Screens and gravel packs are widely used to prevent sand flowing into the wellbore and to the surface. Nevertheless, the initial costs are generally high and they are not free from problems. Screen systems come with a risk of failure by collapsing and bursting. Gravel packs can fail because of screen failure and plugging of the high permeability gravel. Frac and pack treatments bypass the damaged area of the wellbore and also stimulate the formation, yet sanding can still occur by the production of formation sand or proppant. In a different approach, sand consolidation treatments try to achieve small or no quantity of sand production from the formation, but the treatment often results in lower regained permeability and the longevity of the treatment is not guaranteed. In many cases, even with sand control completion in place, drawdown is carefully controlled throughout the life of the well to minimize the risk of sand production. However, this can bring about a disparity between the desired and feasible fluid production rate.

Most (Urgens & Neviger, 2009; Khamehchi, Ameri & Alizadeh, 2015) both Russian and foreign researchers agree in opinion that the currently existing ways of dealing with the removal of the destroyed particles productive formations have a number of disadvantages, in the real economic conditions of development of oil and gas fields (particularly fields at the late stage of development) limits the possibility of their application.

The solution in the oil and gas production (Gharagheizi et al., 2017;Rawlins, 2013) is constrained due to the lack of inexpensive, highly effective means of protecting downhole equipment from mechanical particles that are brought together with the produced production wells.

Gas production from semi-consolidated reservoirs is always accompanied by sand entry. This can lead to a decrease in rate of gas withdrawal, damage of the surface and borehole equipment, as well as a significant increase in operating costs. Sand is formed by two-stage deformation process under the action of shear stresses that deplete the reservoir. For this reason, oil and gas operators are showing a growing interest in cost-effective methods for removing sand-related problems (Khamehchi, Kivi & Akbari, 2014; Wu et al., 2010; Rawlins, 2013).

The main goal of the laboratory researches is the increasing of consolidation efficiency of unconsolidated productive sandstones with chemical method.

Research tasks:

1. to perform the analysis of modern technologies and technical methods used in the operation of wells draining reservoirs those are presented by unconsolidated sandstone and siltstone.

2. explore the features of the destruction of bottom hole formation zone within the Gatchina underground gas storage (UGS).

3. to develop a chemical composition designed for consolidation terrigenous reservoirs of oil and gas and investigate its basic properties.

4. to justify technology of bottom-hole zone of producing wells with use of the developed composition.

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2. Methods

The mathematical description of the processes occurring during the exploitation of oil and gas wells in unconsolidated sandstones is almost impossible because of their complexity and size. Therefore, the effectiveness of measures to consolidate the unstable formations is established on the basis of laboratory studies.

Experimental studies were conducted in the laboratory of "Enhanced oil recovery" of the department «Development and exploitation of oil and gas fields» in the Mining University (Saint-Petersburg), at the modern equipment, allowing to perform tasks at a high technological level. The research was carried out according to GOST 8.563-96 "Methods of measurement", also we used to study the methodology of research work (Mardashov, 2008).

An overview of the foreign and domestic experience in solving this problem shows of the manifestation of the three types or mechanisms of reservoir’s destruction (VNIIGAZ, 2007):

- The excess of effective stress occurs in the reservoir above the limits of formation strength. The elimination of the instability of this type is possible by setting optimal values of the depression.

- The destruction of the filter surface, when the effective radial stress on the wall becomes tensile, i.e. the total radial gradient less than the gradient of the pore pressure. This leads to the collapse of the walls and to increase of the filtration surface, which in some cases introduces the cessation of the sand production (stabilization of the size of the “cavity pocket-cavity” until the effective stress are compensated by "arch effect").

- The destruction associated with the processes of suffusion and migration of fine particles together with the formation fluid in the pore space, which leads to the creation of zones with low permeability and cyclic removal of mechanical impurities (typical process for underground gas storage).

However, "despite of the identification of these formation destruction’s mechanisms, various laboratory tests and extensive parametric analyses, a clear understanding of the sand production process is still missing" (Tananykhin, 2014).

Increase of sand production accompanies with phase change of extracted fluid, particularly when the water breakthroughs occurs.

There were many attempts to explain in details the relationship between water breakthrough and destruction of the reservoir. One explanation is that, since most of the sandy productive layers moistened with water, the water breakthrough causes a decrease of the capillary pressure gradient due to the increased saturation by the wetting phase. Since capillary forces are able to hold the grain together by the surface tension, the water break through contributes the sand-related problems. In fact, the low water saturation of the reservoir corresponds to a high capillary pressure and high water saturation - to low capillary pressure (Khamehchi & Reisi, 2015; Ikporo & Sylvester, 2015).

Another theory suggests that the relative oil - and gas permeabilityis reducedduring a water breakthrough in the reservoir. Oil and gas operators respond by increasing depression in the reservoir to maintain the level of hydrocarbon production, using forced fluid withdrawal that triggers the movement of small particles in the reservoir. The creation of water-oil emulsions in progressive flooding also increases the viscosity of the produced fluid and increases the hydraulic resistance of the formation matrix. At the same time this occurs to the increase of the carrying capacity of the pore fluid and this contributes thus to the reservoir destruction and to push through it small particles. Finally, most specialists agree that the relationship between water breakthrough and sand is understudied and probably is caused by a number of factors (Urgens & Neviger, 2009; Zotov, 1998;Khamehchi, Ameri & Alizadeh, 2015).

With the beginning of the reservoir destruction and when the first signs of the sanding (or other solids) oil and gas operators have to perform a decision:

- to reduce the flow rate to a level at which removal of the particles will be minimal or acceptable for trouble-free operation of the equipment;
- to take measures for the timely removal of the produced sand;
- to create a barrier (filter) to prevent entry of formation sand into the wellbore.

Among the many effective ways of preventing sand production from the bottom hole formation zone in our country and abroad, the largest application received - installation of filters and injection into the reservoir chemical materials to hold grains together (Gharagheizi et al., 2017).

Filter’s application are efficient in gas wellsin the absence of water influx. When water is produced the efficiency of filters is greatly reduced, since the gas-liquid flow does not allow to form on their surface a protective "bridge" - the consistent layering of different fractions of sand, preventing the removal of the small particles. Fine abrasive particles quickly cut a "window" in the filter and it loses its protective properties (Santarelli, Dethan & Sundell, 1994).

It is impractical to equip the wells in which the sand production is a result of the produced water in flux with sand filters (Tananykhin, 2016).

The bottom hole of such wells, it is preferable to strengthen by the chemical methods, if there are conditions for processing without carrying out round-trip operations.

3. Results and Discussions

There are series of experiments to create a solution for chemical consolidation of the sandstones in the Saint-Petersburg mining university. The work was carried out using sand pack tubes, made from loose Devonian sandstones, which were selected from outcrops of bedrock in the Leningrad region.

Successive pumping of aqueous solution of sodium hydroxide (sodium bicarbonate) and as a plugging composition, an aqueous solution of calcium chloride was implemented through the sand pack tubes. The reaction of the calcium ions forms a water-insoluble compound, i.e. there is a plugging precipitate in the pore volume in the form of fine mist, and on the walls of the pore channels in the form of solid microcrystals. Injection of each of these solutions produces by equal portions. It is expected that the obtained in situ sediment will also prevent the breakthrough of formation waters, by isolating water saturated areas of the reservoir by sustainable water sediment, due to this there will be a connection to the development of stagnant and poorly drained parts of the formation zones (Tananykhin, 2015).

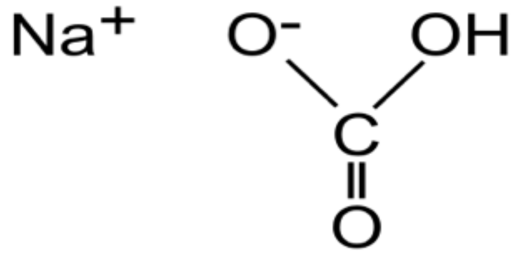
To implement this method we used the available reagents and substances of domestic production:

Technical Acetone (GOST 2768-84)– density not exceeding 807,5 kg/m3, the water content should not exceed 5 %.

Calcium chloride (GOST 450-77) – colorless crystals with a density of 2,51 g/cm^3, melting point=772 °C. It has high hygroscopic properties. solubility (g per 100g H2O): 74 (20 °C) and 159 (100 °C).

A valid application is processed corresponding to the formula CaCl2×2H2O with a dry matter content of 66 – 70 % and calcium chloride anhydrous, powder.

Sodium bicarbonate $NaHCO_3$ (GOST 2156-76) (other names: baking soda, bicarbonate of soda, sodium bicarbonate) is a crystalline salt, but most often it occurs in the form of a fine grinding powder of white color. Chemical formula:



Sodium bicarbonate is not toxic, fire - and explosion-proof.

Molecular mass (according to international atomic mass) — 84,00.

Sodium hydroxide (sodium hydroxide) (GOST 2263-79) is a white opaque solid mass with a fibrous fracture. Solubility in water of the following (in percent at a certain temperature): 29,6 (0°C), 52,2 (20°C), 59,2 (50°C), 75,8 (80°C), 83,9 (192°C). Trigidrata point is 28°C (19 % NaOH).

The density of sodium hydroxide is 2,13 g/cm^3, melting point is 320°C, the boiling point is 1378°C.

The optimal ratio of dry matter in the solution was determined by stoichiometric calculations of the reaction by taking into account the mass fraction and laboratory tests, for example:

To prepare 100 ml of a 21,8 % aqueous solution of $CaCl_2$ need 20 g dry powder of $CaCl_2$ and 92 ml of H2O, since ρ ($CaCl_2$) = of 2,51 g/cm^3.

The reaction between calcium chloride and sodium bicarbonate:

$$CaCl_2 + 2\cdot NaHCO_3 = Ca(HCO_3)2 + 2\cdot NaCI$$

Molar mass (M): $CaCl_2$– 111 g/mol; M($NaHCO_3$)= 84 g/mol, therefore

To neutralize the calcium chloride is necessary m($NaHCO_3$)= 111/168·m($CaCl_2$), hence m($NaHCO_3$)=13,26 g and 93,86 ml of H_2O, since ρ ($NaHCO_3$) = 2,16 g/cm^3.

Determination of permeability to liquidwas performed after each pumping:

$$K\pi p=(Q\cdot \mu\cdot L)/(F\cdot dP) ,$$

where Q is the volume of fluid pumped through the model;

μ - dynamic viscosity of the liquid;

L – length of the model;

F - cross-sectional area of the model;

dP – pressuredifference.

Sequential pumping $CaCl_2$ and *NaOH*

Sample No. 1

Sequential pumping of a 10 % aqueous solution of $CaCl_2$ and a 13,9 % aqueous solution of NaOH:

$$CaCl_2+2\cdot NaOH=Ca(OH)_2+2\cdot NaCI$$

Table 1. The results of sequential filtration of aqueous solutions of $CaCl_2$ and NaOH

Samplenumber	Permeability before treatment, mkm^2	Treatment pressure, psi/atm	Permeability after treatment, mkm^2	Pressure gradient, atm/m	Notes
Sample №1	1,69	5/0,34	-	2,29	There is a pure water at the output from a sample
		10/0,68	-	4,59	There is a pure water at the output from a sample
		15/1,02	-	6,89	There is a pure water at the output from a sample
		20/1,36	0,82	9,19	There is a pure water at the output from a sample
		25/1,7	0,92	11,48	There is a muddy water at the output from a sample
		30/2,04	1,33	13,78	There is a muddy water at the output from a sample
		40/2,72	1,7	18,38	There is a muddy water and the low content of sand particles at the output from a sample
		43/2,92	-	19,73	Completedestruction

Sample No. 2

Sequential pumping of 14 % aqueous solution of $CaCl_2$ and 18,7 % aqueous solution of NaOH:

$$CaCl_2+2\cdot NaOH=Ca(OH)_2+2\cdot NaCI$$

Table 2. The results of sequential filtration of aqueous solutions of $CaCl_2$ and NaOH

Samplenumber	Permeability before treatment, mkm^2	Treatment pressure, psi/atm	Permeability after treatment, mkm^2	Pressure gradient, atm/m	Notes
Sample №2	1,1	5/0,34	0,95	2,29	There is a pure water at the output from a sample
		10/0,68	0,89	4,59	There is a pure water at the output from a sample
		15/1,02	0,96	6,89	There is a pure water at the output from a sample
		20/1,36	1,2	9,19	There is a muddy water at the output from a sample
		25/1,7	1,3	11,48	There is a muddy water and the low content of sand particles at the output from a sample
		27/1,84	-	12,43	Completedestruction

Sequential pumping of acetone, $NaHCO_3$and $CaCl_2$.

Sample No. 3

Sequential pumping 20 % aqueous solution of $CaCl_2$ and a 13,2 % aqueous solution of $NaHCO_3$:

$$CaCl_2+2\cdot NaHCO_3=Ca(HCO_3)_2+2\cdot NaCI$$

Table 3. The results of sequential filtration of aqueous solutions of $NaHCO_3$ and $CaCl_2$

Samplenumber	Permeability before treatment, mkm^2	Treatment pressure, psi/atm	Permeability after treatment, mkm^2	Pressure gradient, atm/m	Notes
		5/0,34	0,97	2,29	There is a pure water at the output from a sample
		10/0,68	1,02	4,59	There is a pure water at the output from a

					sample
Sample №3	1,1	15/1,02	1,07	6,89	There is a muddy water at the output from a sample
		20/1,36	1,15	9,19	There is a muddy water and the low content of sand particles at the output from a sample
		23/1,56	-	10,54	Completedestruction

4. Conclusion

Chemical consolidation of the semi-consolidated reservoircan be recommended for the following parameters of the productive formation:

1. Objects have to presented by semi or unconsolidated formations within which the well operates with the minimum allowable flow rates for sand free production with a low level of water content;

2. The perforation interval should not exceed 50 m;

3. The technical condition of wells must comply with the conditions for pumping into a formation of liquids under pressure;

4. A tendency to a slight sand production from the reservoir;

5. The consistency of permeability of the productive reservoir section, including a sufficiently high vertical permeability.

Characteristics of chemicals used for chemical consolidation of the bottom hole formation zone and the technology of its disposal must meet the requirements of GOST 12.1007-76.

During the research discussed in this paper, the authors set the scientific novelty that is selective destruction unconsolidated sandstones due to the formation of high permeability channels along the cracks developed in the reservoir vertically and along layer stratification plane.

The author provides guidance on the application of aqueous solutions of calcium chloride and sodium bicarbonate with the purpose of consolidation of the bottom hole formation zone.

One of the upcoming trend of the current research work of the developed chemical method is the increasing the depth of penetration of the reagent, making it possible to operate the reagent with abnormally low reservoir temperatures.

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