Analysis and Recommendations of Sand Consolidation Methods to Limit Sand Production in Gas Wells

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Abstract. Nowadays more and more oil and gas fields are developed in unconsolidated sandstones. Sand production is becoming more common process and complicates the work of downhole equipment and also can lead to higher production prime cost and increase the frequency of repair works. The study of features of oil and gas fields’ development in unconsolidated terrigenous reservoirs showed that in rare cases, sand production can have a positive result, but only during the operation of low-permeability reservoir presented by sandstones, and in this case sand production increases the permeability of the pay zone. Sand production in slightly cemented formation is one of the most urgent problems in many regions of Russia. Wear of equipment and its failure are due to the removal of sand and mechanical impurities. Production of the existing well reserves is also greatly reduced. Huge amounts of money are spent annually to repair wells damaged as a result of sand removal, and the average downtime of one well is about 30 days.

1. Introduction
There are a lot of reservoirs which formations are composed of loose, unconsolidated formations in Russia. The most important technological issues in such hydrocarbon production from these fields are to implement sand control and prevention bridging [1].
Sand production from the reservoir is the result of unconsolidated or decaying grains of sand around the wellbore. Usually it is low or intermediate strength formation with small or no cementing material between granules. But in fact sand production is also possible from high-strength formations with good bonding of the grain. Sand production can begin immediately or it may lead to a later life cycle of the well.
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 [2].
Oluyemi and Oyeneeyin stated that the economic, operational and safety implications of sand failures require real time efficient sand management [3].
According to [4] 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 the cost of the deferred production must be considered.
Work [5] 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 [6] researchers both Russian and foreign 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 oil and gas fields development (particularly fields at the final stage of development) limits the possibility of their application. The solution in the oil and gas production [7] 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 wells. 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 bottomhole 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.

1.1. Sand control analysis of the Urengoy oil-gas-condensate field
At the Urengoy oil-gas-condensate field, the destruction of the bottom-hole zone occurs due to water occurrences that reduce the cement properties of clay rocks. Water enters the bottom-hole zone by raising the level of gas-water contact and condensing the moisture contained in the extracted gas and gas condensate [8].

The methods used in the field reduce the removal of sand, but do not solve the problem completely. To delay the overhaul, 80% of the existing wells at the Urengoy field reduce depression, but this decision is only temporary, and in the future it will be necessary to stop the wells for repairs (figure 1) [9]. For example, most of all gas wells annually exposed to sand and works with a limited yield, and 30% of the wells need to be repaired due to the formation of sand jams. In carrying out the repair mainly used solutions such as washing sand stoppers, installation of sand filter, gravel packing, cleaning bottom-hole formation zone [8].

Figure 1. The proportion of wells prone by the destruction of the bottomhole formation zone at the Urengoy field
1.2. Literature and patent analysis
The analysis of the literature shows that mechanical, chemical and physico-chemical methods are used to apply to limit destruction of bottom-hole formation zone and sand production. Figure 2 shows various sand control methods in wells.

| Procedures that lead to reduce sand production | Procedures that lead to exclusion sand production |
|-----------------------------------------------|-----------------------------------------------|
| **Technological methods**                      |                                               |
| Limitation of the depression during the well operation | Water cuttings reduction of well production |
| **Preventive methods**                         |                                               |
| Clean up of the bottom-hole zone               | Flushing sink hole                            |
| Supervise suspended particles in the technological fluids | Supervise suspended particles during the well operation |
| **Chemical methods** (chemical reagents) |                                               |
| **Physico-chemical methods** (coking)         |                                               |
| **Mechanical methods**                        |                                               |

**Figure 2.** Sand control methods for the production wells

Mechanical methods consist of the installation the downhole filters such as wire, slatted, suspended sand, metal-ceramic etc., Such methods are generally quite effective, but the well where the sand is a result of produced water, equip filters is impractical because the problem of sand production should be addressed by the use of technologies to reduce water production. Chemical methods based on artificial formation consolidation by astringent and cementing substances like resins cement with additives, silicates, etc. Their efficiency reveals at sufficient consolidation after treatment without significant deterioration of reservoir properties. Physico-chemical methods include consolidation of formations by oil coking in the bottomhole zone of the reservoir, treatment with chemical reagents using thermal effect. These methods are particularly effective in the production of heavy, high-viscosity oils. Technological methods include the constraint method of depression on the formation; water-shut-off bottom water.

2. Methodology
Laboratory experiments of the simulating of gas wells were carried out using a sand packed tube (Figure 3).

**Figure 3.** Scheme of the sand packed tube

1 - Collar of coreholder; 2 - O-ring; 3 - reticular membrane $D_{pore}=0.2\text{mm}$; 4 - reticular membrane $D_{pore}=0.01\text{mm}$; 5 - tube of coreholder; 6 - sand packed tube.
Disintegrated formations of Gatchina underground gas storage were used for preparing sand packed tube. Before each of the experiment formation was treated by mixture of benzene and isopropyl alcohol. Then it was dried at 100°C to stabilize of the formation mass. Depending on the desired permeability various fractions ratio from 0.1 to 0.5 mm were used.

Changes in the mass of the coreholders before and after stuffing by formations estimate to determine the porosity of the sand packed tubes. Formula 3 were used for calculating the porosity:

\[
k_{\text{por}} = 1 - \frac{4 \cdot (m_2 - m_1)}{\rho_n \cdot \pi \cdot d_{\text{in}}^2},
\]

where: \(k_{\text{por}}\) – porosity of a sand packed tube, unit; \(m_2\) – coreholder mass after stuffing by formations, kg; \(m_1\) – coreholder and filters mass before stuffing by formations, kg; \(\rho_n\) – grain density, kg/m\(^3\) (in the calculation use \(\rho_n = 2700\) kg/m\(^3\)); \(\pi = 3,1415…\) – mathematical constant, \(d_{\text{in}}\) – inner diameter of the coreholder, m [10].

The investigation of reservoir properties of sand packed tube to gas was carried out according to the scheme shown in Figure 4, using the laboratory facility TKA-209.

![Figure 4. The scheme of the laboratory facility for simulating gas wells with using sand packed tube](image)

1 - air valve (input); 2 – facility for pressure creation; 3 - air regulator; 4 - air pressure gauge; 5 - the air inlet tube to the reservoir fluid; 6 - tubes connecting element; 7 - drive fluid; 8 - lower fluid storage capacity (changeable); 9 - filtered liquid; 10 - valve for liquid; 11 - liquid feed tube; 12 - valve at the inlet of the coreholder; 13 – coreholder; 14 – measuring capacity.

Filtration experiments with sand packed tubes were conducted to identify the following:
- To identify the most effective concentration of the chemical components. In the experiments the range of aqueous CaCl\(_2\) concentrations from 4 till 15% were observed. Concentration of NaHCO\(_3\) was calculated as the reaction of the neutralization;
- Residual resistance factor R (units) - the ratio of permeability to gas of the core sample before and after injection chemical composition during the stabilization of the pressure gradient.

### 3. The results of the gas simulation experiments

The results of the chemical treatment of the sand packed tubes are listed in the table 1.

| Models number | Chemical composition     | Permeability to air before treatment, mkm\(^2\) | Permeability to air after treatment, mkm\(^2\) | The maximum injection air pressure gradient , MPa/m |
|---------------|-------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| #1            | 4% CaCl\(_2\)+NaHCO\(_3\) | 1,14                                           | 1,01                                          | 1,32                                          |
| #2            | 7,5% CaCl\(_2\)+NaHCO\(_3\) | 1,19                                           | 1,10                                          | 1,57                                          |
| #3            | 10% CaCl\(_2\)+NaHCO\(_3\) | 1,1                                           | 1,05                                          | 1,44                                          |
| #4            | 15% CaCl\(_2\)+NaHCO\(_3\) | 1,1                                           | 0,99                                          | 1,45                                          |
Results of the filtration experiments indicate the possibility of application of the chemical composition for fixing unconsolidated productive sandstones with a slight decrease in the permeability of the bottom hole zone after chemical treatment with aqueous solutions. It is known, the main drawback of chemical consolidation methods is a significant reduction of reservoir properties. In the case of application of the developed composition minimum permeability reduction (residual resistance factor) is 1.04 times compared to the initial one. Coefficient of permeability recovery using a 7.5% aqueous solution of calcium chloride was 93%, as for concentration of CaCl₂ of 10% – coefficient was 96%, as for 15% CaCl₂ – 91%. Thus, the most effective concentration of the components for applications in gas wells is a chemical composition of 10% aqueous solution of calcium chloride and 7.5% aqueous sodium hydrogen carbonate solution.

3.1. Applications of the chemical technology on the Urengoy field

In order to improve the efficiency of chemical methods for preventing the removal of mechanical impurities and destruction of bottom-hole formation zone on the basis of St. Petersburg Mining University, a number of experiments were conducted to create a solution for fixing weakly cemented sandstones (Patent No. 2475622 “Method for fixing bottom-hole formation zone of gas wells”. Modern high-precision equipment of the research laboratory of the department "Development and operation of oil and gas fields" was used for research [11].

On the basis of a number of the carried-out experiments as preventive works on the prevention of sand manifestation it is recommended to use the method of hydrophobization which consists in curing, or gel formation of hydrophobizing structures at hit in watered intervals of layer. As a result, there is fastening of weakly cemented rocks of bottom-hole zone, as well as selective tamponding of water-saturated intervals of formation, thereby limiting the inflow of reservoir water into the well, which, as is known, also contributes to the destruction of weakly cemented rocks.

During the laboratory experiments the rock was previously prepared, purifying from hydrocarbons, cementing and polluting substances by extraction with an alcohol-benzene mixture. Initial collector properties of core samples were measured at Coretest systems TBP-804 (table 2). Permeability was measured by water, so after the measurements dried each sample at low gas consumption (1.91 psi).

| Core sample name | Permeability, μm² | Porosity |
|------------------|-------------------|----------|
| Sample #1        | 2.29              | 0.27     |
| Sample #2        | 2.1               | 0.25     |

Using sample No. 2 was pumped desiccant acetone to increase the filtration-capacitive properties of the reservoir and increase adhesion to the walls of pore channels to the hydrocarbons and treated with a water repellent, and then again dried. Made gradually purge gas of the two samples with the same exposure time and measured the loss of mass after each increase in pressure (figure 5).

Figure 5. The dependence of the weight loss of core samples versus the pressure before and after treatment by oil wetting agent.

Applications of the method of hydrophobization:
1. Consolidation of the loose formations and the prevention of sand;
2. The prevention and restriction of water influx to production wells by blocking areas of breakthrough of formation water.

If the bottom-hole zone of the well has been a violation of the structure of the reservoir rocks and, as a consequence, there is sand, we recommend the use of the chemical method of attachment weakly cemented rocks.

To achieve this goal, experiments were carried out on the injection of fastening agents into the formation. Through the sand packed tube, a consistent pumping of an aqueous solution of calcium chloride and, as a padding composition, an aqueous solution of sodium bicarbonate were carried out. As a result of the reaction, calcium ions form an insoluble compound in water, i.e., in a pore volume, a clogging precipitate is formed in the form of a fine suspension, and on the walls of pore channels in the form of solid microcrystals. Pumping of each of the specified solutions make equal portions. It is assumed that the resulting sediment in reservoir conditions will also prevent the breakthrough of formation waters by isolating the water-producing areas of the formation with a stable precipitation in water, thereby connecting to the development of stagnant and poorly drained zones of the formation.

The optimal ratio of dry matter in solutions was determined by stoichiometric calculations of the reaction with the calculation of mass fractions and laboratory studies. After each pumping, the permeability was determined initially by gas, and in the second part of the liquid experiment.

The results of the processing of the core samples of chemical solutions is given below. The initial permeability of the core sample for gas is $K_p = 3.9 \, \mu m^2$, the porosity is $m = 28\%$.

Sequential pumping of a 10% aqueous solution of $\text{CaCl}_2$ and 13.9% aqueous $\text{NaOH}$ solution:

$$\text{CaCl}_2 + 2\cdot \text{NaHCO}_3 = \text{CaCO}_3 + 2\cdot \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$$

**Table 3.** Results of sequential filtration of aqueous solutions of $\text{CaCl}_2$ and $\text{NaHCO}_3$ with successive post-increase of gas flow through the bulk model

| Pressure, psi (atm) | Processing time, sec | Liquid outlet | Removal of sand |
|---------------------|---------------------|--------------|-----------------|
| 5 (0.34)            | 90                  | no           | no              |
| 10 (0.68)           |                     | yes          | no              |
| 15 (1.02)           |                     | yes          | no              |
| 20 (1.36)           |                     | yes          | no              |
| 25 (1.7)            |                     | yes          | no              |
| 30 (2.04)           |                     | yes          | no              |
| 35 (2.38)           | 90                  | yes          | no              |
| 40 (2.72)           |                     | yes          | no              |
| 45 (3.06)           |                     | no           | no              |
| 50 (3.4)            |                     | no           | no              |
| 55 (3.74)           |                     | no           | no              |
| 60 (4.08)           |                     | no           | no              |
| 65 (4.42)           | 90                  | no           | no              |
| ---                 |                     | ---          | ---             |
| 95 (6.46)           |                     | no           | no              |

Strengthening bottomhole with these chemical solutions for gas wells can be recommended with the following parameters of the reservoir:

1) The perforation interval should not exceed 50 m;
2) The technical condition of the well should correspond to the conditions for setting liquids under pressure into the reservoir;
3) Consistency of the permeability of the reservoir in the section, including a sufficiently high vertical permeability.
The characteristics of the chemical reagents used to fix the bottomhole zone and the technology of its utilization must meet the requirements of GOST 12.1007-76 [11].

4. Conclusion
Application of the chemical technologies for sand control of the Urengoy oil-gas-condensate field could be one of the most effective methods due to the peculiarities of the geological structure of the reserves. Currently, similar chemical technologies are not actively used, and in this regard, still large wells are subject to constant removal of sand, resulting in the formation of sand jams on the bottom of the well and equipment wear.
In the near future, authors plan to justify that the deformation of the reservoirs is determined by the ratio of its elastic properties and the properties of the saturated formation, as well as by the geometric characteristics of the deposits. To do it we are going to apply numerical calculations of simulation process.

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