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FEATURES OF USING SURFACTANTS TO INTENSIFY THE OPERATION OF WATERED WELLS

At the late stage of field development, the reservoir pressure drops. For various reasons, liquid begins to rise into the bottomhole zone of the formation, which may entail a sharp drop in the gas well production rate and a reduction in the well life. There are many methods of flooded wells operating, among which the method of using foaming surfactants has recently become increasingly widespread. This paper examines the reasons for the influx of liquid into the wellbore, as well as the features of the use of foaming surfactants to intensify gas production from flooded wells. In addition, an overview was made of various types of foaming surfactants used to intensify gas production by removing liquid from flooded wells, their advantages and disadvantages, and the feasibility of using certain types of foaming surfactants was considered, depending on the mineralization of the liquid and the presence of gas condensate in its composition. An algorithm for selecting foaming surfactants to remove liquid from the bottomhole is presented. The requirements for foaming surfactant compositions are set forth. Processes occurring at application of foaming surfactants for liquid removal from wellbore are described. Parameters characterizing properties of foaming surfactants solutions and factors influencing foaming properties of surfactants are indicated. Methods of injecting aqueous solutions of surfactants into production wells are described. The technology of gas well bottomhole treatment with liquid surfactants, methods of process control, as well as problems that may arise when using surfactants are described.

Keywords: well flooding; surfactants; foaming surfactants; anionic surfactants; nonionic surfactants; foaming properties; intensification of gas production; bottomhole treatment; gas-liquid mixtures.

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ОСОБЛИВОСТІ ЗАСТОСУВАННЯ ПОВЕРХНЕВО-АКТИВНИХ РЕЧОВИН ДЛЯ ІНТЕНСИФІКАЦІЇ РОБОТИ ОБВОДНЕНИХ ГАЗОВИХ СВЕРДЛОВИН

На пізній стадії розробки родовищ відбувається падіння пластового тиску в покладі. За різноманітних причин починається підйом рідини в привибійну зону пласта, що може спричинити різке падіння дебіту свердловини по газу і скорочення терміну функціонування свердловини..Існують багато методів експлуатації обводнених свердловин, серед яких останнім часом все більше розповсюджується метод застосування пінотворних поверхнево-активних речовин. У даній роботі розглядаються причини надходження рідини у стовбур свердловини, а також особливості використання піноутворюючих поверхнево-активних речовин для інтенсифікації видобутку газу з обводнених свердловин. Крім цього зроблено огляд різноманітних типів пінотворних поверхнево-активних речовин, що застосовуються для інтенсифікації видобутку газу шляхом винесення рідини з обводнених свердловин, їх переваг та недоліків і розглянута доцільність використання тих чи інших типів пінотворних поверхнево-активних речовин в залежності від мінералізації рідини і наявності газоконденсату у її складі. Наведений алгоритм вибору пінотворних поверхнево-активних речовин для видалення рідини із вибою свердловин. Викладені вимоги до композицій пінотворних поверхнево-активних речовин. Описані процеси, які відбуваються під час застосування пінотворних поверхнево-активних речовин для виносу рідини зі стовбуру свердловини. Зазначені показники, що характеризують властивості розчинів пінотворних поверхнево-активних речовин, та чинники, що впливають на пінотворні властивості поверхнево-активних речовин. Описані методи закачування водних розчинів поверхнево-активних речовин в експлуатаційні свердловини. Описана технологія обробки вибоїв газових свердловин рідкими поверхнево-активними речовинами, методи контролю за веденням процесу а також проблеми, що можуть виникати під час використання поверхнево-активних речовин.

Ключові слова: обводнення свердловин; поверхнево-активні речовини; пінотворні ПАР; аніоногенні ПАР; неіоногенні ПАР; пінотворні властивості; інтенсифікація видобутку газу; обробка вибою свердловини; газо-рідинні суміші.

A significant number of gas reservoirs are associated with water drive formation systems and are developed under conditions of inflow of formation water into the gas-saturated zone and water flooding of wells [1].

The water flooding of a large number of fields under development is a serious and common problem in the oil and gas industry. Water flooding has increased rapidly in recent years. In this regard, the issue of reducing the amount of liquid accumulated in the well is becoming more acute in order to reduce operating costs and increase gas and condensate production.

Water flows through a cement plug at the bottom of the well, through the filter holes along with the well product, defects in the tubing (cracks, shells in the metal, leaky threaded connections). These defects occur during poor-quality cementing, corrosion of the tubing under the influence of mineralized waters of the formations washing it.

In addition, it is possible that water flows from one formation to another, which occurs as a result of their opening during well drilling and the absence of insulation from each other with cement stone. Although in this case the formation water does not enter the tubing, its contact with the outer surface of the pipes can lead to corrosion and subsequently damage the tightness of the tubing.

Cross-flows are always unacceptable as the following undesirable effects occur:

- well production rate is disturbed, as well as the nature of saturation of the productive formation, which leads to a decrease in both the production capabilities of the well and the coefficient of extraction of well product from the formation;

- the natural salinity of formation waters along the well section is disturbed, which distorts the assessment of the nature of formation saturation during geophysical studies;
- reduced reliability of gas-oil ratio value during oil production, which disturbs the design reservoir development technology;
- secondary oil and gas deposits are formed, which may make it difficult to drill further wells at the field;
- in the presence of hydrogen sulfide and carbon dioxide in the incoming water, intense corrosion of underground and ground-based equipment and cement stone occurs. During insulation work, it is necessary to isolate the upper and lower waters flowing through the cement plug and through the annulus, as well as the bottom waters of individual beds and waters flowing through an adjacent well.

Accumulation of liquid in a gas well occurs when the produced gas is unable to carry it out of the wellbore, which leads to a decrease in production and a reduction in the life of the well.

The main reason for the accumulation of liquid at the bottomhole of gas wells is the low difference between the operating pressure and the pressure in the flow line within one well cluster, which leads to the accumulation of liquid at the bottomhole of the wells.

When gas moves to the ground surface at a sufficiently high speed, it carries liquid too. The high gas velocity provides a flow regime in which the liquid is in a finely dispersed state. This results in a low volume fraction of liquid in the flow in the tubing or production string and low pressure losses caused by the gravitational component of the flow.

The main reasons for the flooding of production wells in gas fields are a drop in reservoir pressure in productive formations, active movement of bottom water, which leads to flooding of perforated intervals of the productive formation.

The presence of annular pressures during well operation is also one of the contretemps. One of the reasons for the presence of annular pressures is the poor quality of cementing and the insufficient supply of cement slurry behind the casing string to the wellhead when the well exits the drilling. Poor quality of well cementing also promotes to the formation of interbed flows and their premature flooding.

For low-rate gas wells operating on the verge of profitability, the continuation or termination of operation may depend on the optimization and reduction of the volume of accumulated liquid. Fluid accumulation is shown not only in low-rate wells, in gas wells with a large tubing diameter and/or high wellhead pressure, fluid accumulation can also occur, even at high production rates.

Few gas wells produce completely dry gas. Under certain conditions (with a decrease in temperature and pressure of the gas stream rising to the ground surface), liquid can be formed in the wellbore of a gas well. Both hydrocarbons (condensate) and water can condense from the gas. In some cases, fluid may enter the wellbore as a result of an influx of water from an underlying aquifer or other sources.

If the formation pressure drops lower the dew point, the condensate is produced together with the gas in liquid form; if the formation pressure is above the dew point, the condensate enters the wellbore as a vapor phase together with the gas and becomes liquid in the tubing or separator.

There may be several sources of water entering the well:
- water may come from the aquifer zone above or lower the pay bed;
- if the formation is operated in water drive mode, the water moving through the formation will eventually reach the wellbore;
- water may enter the wellbore from another productive zone which is some distance from this gas formation;
- unbound formation water can be removed from the formation together with gas;
- water and/or hydrocarbons may enter the wellbore as a vapor phase along with the gas and condense in the production tubing.

If the gas production rate is high enough, the gas may entrain water from the bottom aquifer, even if it is not perforated in the well.

Liquid hydrocarbons may also enter the gas well as a vapor phase. If the formation temperature exceeds the critical condensation temperature (the maximum temperature at which the formation of a liquid phase is possible with a decrease in temperature), there is no liquid in the formation, but it can fall out in the form of droplets in the wellbore in the same way as it happens with condensation of water vapor.

During the late phase of gas field development, specific issues must be addressed to increase well production rates and reduce water cut.

When gas-liquid mixtures move along the wellbore, the following gas-liquid structures may exist: dispersed, dispersed-annular, projectile-annular, projectile, etc. In the gas-liquid flow, when it moves along the wellbore, the processes of film formation and fluid dispersion occur.

To change the structure of the gas-liquid flow, foaming compositions of surfactants are injected into wells, when they are dissolved in the well fluid and gas passes through it, a foam structure, consisting of gas bubbles separated by a film of water, is formed, but the density of the foam structure is significantly less than the density of the liquid in the wellbore and a significantly lower gas velocity is required for its removal than for water removal.

The accumulated experience in the development of gas and gas condensate fields evidences that the injecting of surfactant based foaming agents at the bottomhole, which lead to foaming of the liquid or gas-liquid mixture in the wellbore and its removal to the ground surface, is the most effective way to remove the accumulated liquid from the well.

Water surfactant injection is also effective for oil wells. Aqueous surfactant solutions injected into the formation have a multifaceted effect on the physical and chemical properties of formation systems. Even with a small concentration, they promote a significant decrease in the surface tension of water at the border with oil and solid surface, as a result of which oil is more completely displaced from the porous medium. Surfactants promote the crushing of oil globules covered by water, reduce the necessary pressure drop for liquids filtration in a pore medium, and improve the washing properties of water. Surfactants affect the wettability of the pore surface with formation fluids: a decrease in the wettability angle, the intensity of capillary absorption of water into oil-saturated rock. As a result, oil droplets that stick to the rock are washed away.

The essence of this method is that when foaming surfactants are injected at the bottomhole, they dissolve in the liquid accumulated at the bottomhole, and when gas passes through a column of liquid with dissolved surfactants, a foam, consisting of gas bubbles separated by a liquid film, is formed.

When the reagent is at the bottomhole, it dissolves in the well fluid. The rate of dissolution of the reagent in the well fluid depends on the rate and volume of gas that passes. When the gas is filtered through the liquid remaining at the bottomhole, the solution foams. Having a density 3 or 4 times lower than the density of water, the foam system with a gas flow rises along the tubing to the wellhead, which ensures the removal of well fluid. The developed surfactant compositions make it possible to remove condensation liquid with an admixture of formation water from the bottomhole without negative impact on the gas gathering network, booster complex and gas dehydration units.

The list of surfactants used to remove bottomhole fluid is quite large, but anionic (ASA) and non-ionic surfactants (NSA) are most used. ASA belong to the class of surfactants that, when dissolved in water, dissociate into a positively charged cation and a negatively charged anion. The most typical representatives of these surfactants are water-soluble soaps of higher carboxylic acids, which are the products of the interaction of these acids with alkali metal hydroxides. The foaming capacity of these surfactants depends on the length of the hydrocarbon radical: it is maximum with a length of 13 to 14 carbon atoms, and then it decreases. Depending on the length of the alkyl chain of the original organic substances, methods for the synthesis of sulfates and sulfonates, various brands of surfactants of this class are produced: sodium decyl sulfate, sulfanol NP-1, sulfanol NP-3, DS-PAC, etc. The main disadvantages of these surfactants are the significant effect of the salt composition of water on the solubility, dissociation and surface tension of the formed systems, and the change in the characteristics of surfactants in the presence of organic solvents. Anionic surfactants have a high foaming capacity, but their using is limited by the salinity of the liquid and the presence of gas condensate in the liquid.

NSAs do not dissociate into ions in aqueous solutions. Their typical representatives are oxyethylated chemical compounds: alkyl phenols, alcohols, fatty acids, amides, etc. These NSAs also include imidazolines, high molecular weight oil-soluble amines, oxazolines, carboxylic acids and their esters, metal soaps of these acids with polyvalent metals. NSAs include neonol AF 9-12, oxyethylated fatty alcohols and alkyl phenols, oxyethylated fatty acids, block copolymers based on diamine, block copolymers of ethylene oxide and propylene oxide, oxyethylated alkyl phenols OP-7, OP-10, etc. Due to the high molecular weight and low solubility of these surfactants, they cannot form a large amount of foam, therefore, it becomes necessary to combine ASA with them. NSAs are more cost effective because they are easier to produce than surfactants from other groups. The greatest development was the production of oxyethylated fatty acids, alkylphenols, alcohols, amines, mercaptans, etc. The disadvantages of NSAs include their high cost, especially block copolymers, low solubility in aqueous solutions, and the need to clean the well from the remnants of NSAs. The advantages of using NSAs are the formation of foams with hydrocarbon fluids (gas condensate). The main indicators characterizing the properties of foams are their stability, rheological characteristics, density and elasticity. The duration of the existence of foam depends on the concentration and type of surfactant, the multiplicity of the foam, its temperature, dispersion and the presence of stabilizers. Non-ionic surfactants are mainly used to remove highly mineralized liquids from gas wells.

Two reagents for foaming at well bottomhole have been developed by JSC "UKRGASVYDOBUVANNYA" and PE "RPE ALEXSS-A".

The first one is "Reagent for foam RF-1," designed for foaming highly mineralized (up to 300 g/dm^3) water-gas-condensate mixtures (with a condensate content of up to 50 %) in a wide temperature range (up to 170 °C); the second one - "Reagent for foam RF-1K," designed for foaming hydrocarbon mixtures in a wide temperature range and removing them from oil and gas production wells.

The task of the foaming agent RF-1 is to increase the efficiency of removing highly mineralized water-condensate mixtures and formation water from the bottomhole of gas, gas-condensate, oil-gas-condensate wells at high temperatures. The task is solved by the fact that foaming reagent, which includes alkyl sulfates, alpha olefin sulfonates and water, contains triethanolamine salts of alkyl sulfates.

Due to addition of alkyl sulphates to triethanolamine salts as foaming component, efficiency of removal of water-condensate mixture with gas condensate content of up to 30 vol % and dissolved calcium and magnesium salts of more than 1.5 wt % of liquid from well increases. The efficiency of using the reagent does not decrease at temperatures of 90-150 °C. The foaming agent RF-1, together with the liquid, is easily removed from the well, which ensures the flow of gas, and, as a result, increases production by 3-5 times. Sludge is removed from the well together with water, which ensures effective cleaning of the wellbore from pollutions. The technology for preparing the reagent does not differ from the known one, therefore, there are no additional costs.

The RF-1K foaming agent was designed to improve the efficiency of removing hydrocarbon condensate at its significant content and insignificant water content. The problem is solved by the fact that polymethylsiloxane and hydrocarbon solvent are introduced into polymethylvinylsiloxane.

As the hydrocarbon solvent, for example, diesel fuel, kerosene, condensate, etc. can be used. The RF-1K reagent is not aggressive to the well equipment, therefore it can be used as a corrosion inhibitor. The reagent is RF-1K easy to use, does not require complex preparatory work and additional equipment.

When selecting surfactants to remove water from the bottomhole, geophysical surveys (GPS) should be carried out and information about the state of the well should be refined. During GPS, the following parameters are determined:

- well depth;
- sump;
- perforation interval height;
- casing string and tubing diameters;
- packer availability and setting depth;
- bottomhole temperature;
- salt content in water (PPM);
- bottomhole pressure;
- wellhead pressure;
- wellhead pressure drop;
- type of produced fluid (oil, gas, gas condensate);
- current well production (oil, gas, gas condensate);
- the height of the water column in the tubing or casing string (it is necessary to calculate the volume of liquid that will be removed by foam).

Before surfactant is injected into the well, a hydrochemical analysis of the removed fluid is performed, and based on the results of the analysis, the surfactant composition is selected for treatment of the bottomhole in laboratory conditions. Laboratory studies evaluate the ability of surfactants to foam well fluids (condensation, formation water, process fluids), foam system stability. Based on the stability of the foam obtained from the surfactant, the surfactant concentration in the well fluid is selected, at which foaming begins.

Developed surfactant compositions should provide foaming of liquid with mineralization from 1 to 30 g/dm^3 and more. The life cycle of the foam must ensure that liquid can be removed from the well and breaking before entering the complex gas treatment unit. Surfactant solutions shall not affect DEG drying properties, well operation and corrosion of field equipment.

Based on the analysis of the development object operation, the surfactant component composition and its volume are selected to remove fluid from the bottomhole.

The developed surfactant compositions create a stable foam system, which in static mode has a degree of destruction from 10 to 35 % per 10 minutes. In the process of being the surfactants at the bottomhole, their dissolution in the liquid occurs during 14 - 16 hours in static mode. In dynamic mode, the dissolution of the surfactant is much faster and depends on the speed and amount of gas passing through the liquid. When gas passes through the liquid accumulated on the bottomhole, the process of its foaming occurs, and the amount of foam constantly increases throughout the process. Foam system is lifted by gas flow to wellhead. In the process of lifting the foam system along the tubing, its destruction occurs in the amount of 10 to 15 %, depending on the roughness of the tubing walls. As a result of destruction of the foam system, it turns into a liquid, which, depending on the velocity of the upward gas flow, flows to the bottomhole at a flow speed of less than 5 m/s or rises to the wellhead at a gas flow speed of more than 5 m/s. At the wellhead, foam from the tubing enters the trail and moves here faster than through the tubing, where it loses its properties and collapses.

However, few surfactants and stabilizers can be effectively used in gas production. The main parameters characterizing the properties of surfactant solutions are their stability, rheological characteristics, density and elasticity. The lifetime of foam formed from surfactants in a well depends on the type and concentration of surfactants in the fluid. Injection of foaming surfactants into the well can be carried out in the form of aqueous solutions or solid rods and balls. The most common bottomhole treatment technology is the injection of aqueous surfactant solutions with hydrate inhibitor into the well.

The technology of the bottomhole treatment with liquid surfactants is the most technologically advanced and simple method.

A prerequisite for effective removal of liquid with surfactants is the formation of a stable foam at the bottomhole, which is a dispersed system consisting of gas bubbles. The foaming properties of surfactants are influenced by a number of factors such as the salinity of the formation water, the temperature of the formation, the presence of condensate in the liquid, etc.

These processes become more difficult significantly due to the presence of water of various mineralization in the formation. High mineralization sharply reduces the foaming ability of surfactants. The foaming process is mainly influenced by calcium and magnesium salts. The composition of the foaming agent and its concentration are selected depending on the composition of the liquid, its mineralization and the presence of hydrocarbons.

The following methods of introducing foaming surfactants into the gas-liquid flow are possible: centralized injection into the hole annulus from CGTP by inhibitor pipelines; dosed surfactant injection into the hole annulus from wellhead tanks; periodic injection of diluted and viscous surfactant solutions into the hole annulus using mobile pumping units; surfactant dosing by using tubing as a container for surfactant storage and well operation through the hole annulus; surfactant injection through capillary tubes mounted inside tubing; introduction to the bottomhole of solid surfactants in the form of cylindrical rods, balls, cones and other shapes by tubing and other methods.

Pumping of liquid surfactants to the bottomhole is performed through the well pipeline, which is lowered into the well to the bottomhole.

The technology for treatment the bottomhole of gas wells with liquid surfactants is carried out in the following order: the well is worked out at the flare device and stopped; surfactant is then pumped and pushed to the bottomhole using a compressor; at the next stage, the well is worked out at the flare device and put into operation.

Control over the process is carried out both for production and injection wells. The concentration of the solution is measured both during injection into injection wells and during sampling from production wells, and the surface tension is measured in laboratory conditions. Input profile for injection wells and output profiles for production wells are taken. Water content, gas and liquid production rates, etc. are measured.

But problems can arise with surfactants. This is the formation of stable foam systems (emulsions), which causes difficulties in the operation of field equipment, a decrease in the quality of industrial gas treatment, and an additional load on the BCS equipment.

In wells with sand plug growth in the perforation interval, surfactants will increase sand production due to high foam bearing capacity. The use of surfactants is not recommended in these wells, it is most reasonable to carry out work to fix the bottomhole zone of the formation in them.

One of the important factors influencing the efficiency of liquid removal from well bottomholes is the design of production wells, therefore, when productive formations are penetrated by wells with horizontal end, the efficiency of treatment of well bottomholes with liquid surfactants becomes very low.

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