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Study of Gas Wells Operation Regimes in Complicated Conditions

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Исследование режимов эксплуатации газовых скважин в осложненных условиях

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gas well, sand production, complicated conditions, bottomhole zone, forecasting complications, well operation, causes of sand production, sand production consequences, methods of sand control, production optimization, technological mode of well operation, final stage of field development, gas field, well bottom, well flow rate, abrasive wear.

The influence of reservoir rock properties on sand production in wells is considered. It was concluded that the rock should be considered rather not from the point of view of its strength, but from the point of view of the type of cementitious substance and its distribution. When predicting sand production, it is necessary to take into account the internal stresses of the rocks, as well as the change in these stresses during drilling, perforation and operation of the formation due to the violation of their initial state.
Within the framework of this work, an analysis of the main causes of sand production during the operation of gas wells is presented, as well as the negative consequences of sand production for gas production equipment. It has been established that water breakthrough, formation depletion, pressure drop at the bottom of the wells due to their frequent shutdown are the main prerequisites for the removal of sand from the bottomhole formation zone. Sand production is associated with such negative consequences as plugging in wells, erosion of underground and surface equipment, collapse of the top of the bottomhole formation zone and production strings.
The main technologies for the prevention and elimination of accidents associated with the removal of mechanical particles from the reservoir are considered. Based on the research results, an algorithm was proposed for selecting technological modes of well operation in conditions of water and sand. The parameters for choosing the optimal operating mode of a gas well are substantiated, in which sand is not extracted with the subsequent disabling of downhole and wellhead equipment, the integrity of the bottomhole zone is not violated, and the well is not self-contained.
The results obtained can be applied to improve the efficiency of gas wells operation and predict their trouble-free operation.

Ключевые слова:
газовая скважина, пескопроявления, осложненные условия, призабойная зона, прогнозирование осложнений, эксплуатация скважин, причины пескопроявлений, последствия пескопроявлений, методы борьбы с пескопроявлениями, оптимизация добычи, технологический режим эксплуатации скважин, завершающая стадия разработки месторождения, газовое месторождение, забой скважины, дебит скважины, абразивный износ.

Рассматривается влияние свойств пород-коллекторов на пескопроявления в скважинах. Сделан вывод о том, что горную породу нужно рассматривать скорее не с точки зрения ее прочности, а с точки зрения типа цементирующего вещества и его распределения. При прогнозировании пескопроявлений необходимо учитывать внутренние напряжения пород, а также изменение этих напряжений в процессе бурения, перфорации и эксплуатации пласта ввиду нарушения их первоначального состояния.
В рамках данной работы представлен анализ основных причин пескопроявлений при эксплуатации газовых скважин и негативные последствия добычи песка для газопромыслового оборудования. Установлено, что прорыв воды, истощение пласта, перепад давления на забое скважин из-за частой их остановки являются основными предпосылками для выноса песка из призабойной зоны пласта. Добыча песка связана с такими негативными последствиями, как пробкообразование в скважинах, эрозия подземного и наземного оборудования, обрушение кровли призабойной зоны пласта и эксплуатационных колонн.
Рассмотрены основные технологии предупреждения и ликвидации аварий, связанных с выносом механических частиц из пласта-коллектора. По результатам исследований предложен алгоритм подбора технологических режимов эксплуатации скважины в условиях водо- и пескопроявлений. Обоснованы параметры для выбора оптимального режима работы газовой скважины, при котором не осуществляется добыча песка с последующим выведением из строя скважинного и устьевого оборудования, не нарушается целостность призабойной зоны, не происходит самозадавливания скважины.
Полученные результаты могут быть применены для повышения эффективности эксплуатации газовых скважин и прогнозирования их безаварийной работы.

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Introduction

As of today, a significant number of gas fields have reached the final stage of their development, which is marked by a variety of complications: increase in the water cut of the extracted product, decrease in the formation pressure, damage of the integrity of the bottomhole zone, higher risk of well accidents due to the production of solids.

The enhancement of hydrocarbon extraction is most commonly accompanied by sand production in case of a reservoir with poorly-cemented rock or a water-flooded reservoir. The formation sand can settle in downhole and surface equipment and prevent it from operating normally, reducing the production rate, affecting the phase changes of hydrocarbons and increasing general operating costs.

Nowadays, the sand production control presents itself as a challenging and complex task which includes forecasting of sand production and searching for methods to minimize and prevent the negative impact caused by produced solids. A crucial task for today is to develop solutions that correctly describe the justification of gas well operation techniques under conditions of active sand production.

This paper considers the main causes of sand production and analyzes measures of sand control and conditions of practical application of methods for preventing sand production and/or eliminating accidents.

The purpose of this paper is to increase the efficiency of gas well operation in conditions complicated by water and sand production.

Effect of Reservoir Rock Properties on Sand Production

Even though nearly 60 % of the global oil and gas production comes from carbonate rocks, 90 % of the production wells are in sandstone reservoirs. About 30 % of these sandstones may be weak enough for a well to start producing sand [1]. In some carbonate reservoirs, the production of solid particles may also occur [2, 3]. The produced sand can lead to erosion of underground and surface equipment, thus damaging its integrity, which can eventually cause potential fatal injuries among operating personnel. However, using sand control methods and techniques for all wells intentionally is not economically viable and can be detrimental to hydrocarbon extraction.

The ability to predict when a well will start producing sand is crucial to deciding whether to use methods of sand control and what methods to use when needed.

The probability of sand production depends on three main factors:

1) strength of the rock and its other geomechanical properties;

2) regional stresses;

3) local loads imposed on the formation due to drilling, perforation and operation of wells.

Sandstone is a sedimentary rock composed of sand grains and cementing materials that hold them together (clays, carbonates, silica and other materials) [4]. The main rock-forming minerals are quartz, feldspar, mica and glauconite. One of the strongest and most common cementing materials is quartz (Fig. 1). The pore channels are shown in blue in the figure above. The figure also shows angular quartz grains (quartz overgrowths) and the cementation between individual grains.

Other minerals that act as a cementing material are calcite (calcium carbonate), dolomite (calcium magnesium carbonate) and various clays. Clays may be part of the original sediments or form where the dissociation of feldspars

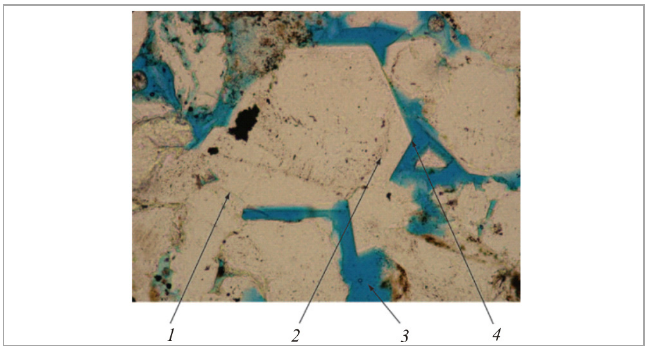

Fig. 1. Quartz overgrowths in sandstone: *1* – grains cemented together; *2* – original grain outline; *3* – pore channels; *4* – quartz overgrowths on original grains

Fig. 2. Clay and quartz grains

and other minerals initially occurs. Clays may form individual grains, plates or fibers. The distribution of clay in the rock is more important than its volume fraction. For example, a low volume of clays distributed around pore channels as fibers or plates can adversely affect the rock permeability to a much higher extent than a higher volume of clays distributed as clay layers or debris in the cementing material (Fig. 2).

Older rocks are generally stronger than younger ones in geological terms. However, older rocks can still be relatively weak if they are insufficiently compacted or cemented, such as the Sinai sandstone deposited on the Arabian shield [5]. Some overpressured reservoirs were protected from the groundwater in the course of geological development, which allowed them to maintain both high permeability and low strength. Even though sandstones are the main source of solids during well operation, carbonate rocks can also produce solids. These include oolites – spherical carbonate deposits.

Normally, the structures that bind the grains together also restrict the pore channels and thus reduce both permeability and porosity. Therefore rocks ought to be considered not in terms of their strength but in terms of the type of cementing material and its distribution. It is also important to take into account the internal stresses imposed on the rocks, as well as changes in these stresses in the course of drilling, perforation and operation of the formation due to the loss of their initial state [6, 7].

Causes of Sand Production

It is important to take into account the state of the well bore zone when developing gas fields, especially at the last stage of the development [8, 9]. For example, an increased level of reservoir drawdown causes damage to the reservoir integrity and therefore solids production is likely to occur [10]. It has been established that water accumulated in the bottomhole zone, soaking of the rock, formation depletion, bottomhole pressure drop due to frequent shutdown of the wells act as the main factors responsible for the destruction of producing horizons [11–14].

The phenomenon of sand production in oil wells is caused mainly by water breakthrough which reduces the strength of sand reservoirs and capillary interaction between sand grains [8, 15–20]. For gas wells, water inflow is not a prerequisite for sand production. For example, 73 % of wells of the Urengoyskoye oil and gas condensate field that are complicated by sand production show no signs of water breakthrough. Besides, this negative phenomenon comes to light only 10–12 years after bringing the well into production [21, 22].

A.A. Akhmetov [23] who studied the performance of the super-reservoirs of the Urengoyskoye oil and gas condensate field came to the conclusion that gas wells produce sand due to the following reasons:

- formation pressure decline;
- accumulated volume of produced gas per unit of super-reservoir thickness;
- location of perforated zones relative to the bottom and top of the Cenomanian horizon;
- breakthrough of bottom water to the bottom hole.

A. A. Akhmetov states that well completion methods play an essential role in the sand production process. In case of an open hole well, the stability of the bottomhole formation depends mainly on stresses which include ground pressure and filtration stresses. In case of a cased well, the stresses of the "tube – cement – rock" system act in addition to those mentioned above.

G.A. Zotov [24] studied the influence of the bottomhole design on the stability of sandstone reservoirs. It has been established that a cased perforated well causes destruction of the bottomhole formation zone more often than an open hole well. In order for a reservoir to maintain stability, the well bottomhole must be open if the rock loading conditions on the surface of the open hole do not exceed the strength limit of the rock within the entire formation pressure range or be equipped with a filter if the loading conditions exceed the strength limit [25].

R. Armentor and M. Wise [26] make an attempt to establish the relationship between water breakthrough and a dramatic increase in sand production. The authors suggest two theories in this regard:

1. Due to the fact that the major part of the sand production horizon is saturated with water, water breakthrough causes a dramatic reduction in capillary pressure between sand grains. This pressure reduction makes the force holding sand grains together weaker which causes sand production and its carry-over with water.

2. The water influx causes reduction in relative permeability to gas and oil. The operating personnel shall take actions to maintain the fluids withdrawal rate by increasing the reservoir drawdown. This, in its turn, initiates movement of the sand particles in the formation. Due to the increased viscosity of the extracted hydrocarbons, water increases flow resistance of the formation, which enhances the ability of fluids to carry sand particles.

Complications Due to Sand Production

The operation of wells in the conditions complicated by sand production is accompanied by a variety of adverse effects on underground and surface equipment, which may affect the recovery rate of production wells (Fig. 3) [27].

The main issues that can be caused by sand production are:

- plugging of wells and downhole equipment (Fig. 4);
- erosion of equipment and buildup of sand inside it;
- malfunction and permanent damage of pipelines, pumps, fittings, shutoff and control valves;
- collapse of the top of the bottomhole zone (BHZ) and production strings.

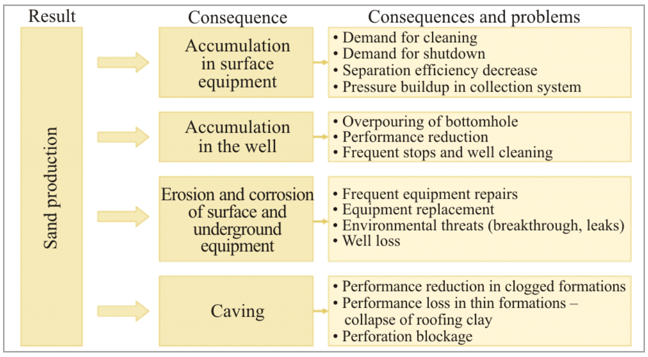

Fig. 3. Consequences of solids production

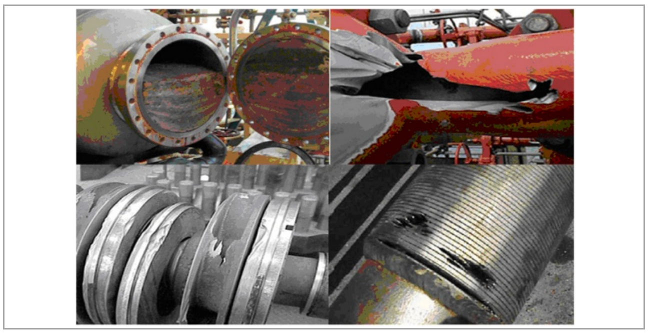

Fig. 4. Equipment out of service due to sand production

Review of Sand Control Methods and Techniques

For our purpose, all operation methods for wells complicated by sand production can be divided into two categories [28, 29]:

1) well operation with sand production from the formation;

2) preventing sand production from the formation.

In the first case, actions are taken to prevent sand plugging and ensure the eruption of sand to the surface (adding liquid, running the liner into the production zone, using hollow rods) [3, 30]. In order to prevent erosion, this method involves the use of protective equipment of various designs, as well as separators, anchors, etc. However, the main drawback of the first method (destruction of the bottomhole zone) makes it preferable to use methods aimed at preventing the sand particles from entering the well. In particular, these include various chemical, physicochemicall and mechanical methods of sand control.

A number of measures are used to reduce sand production [31]. Such measures include: a number of preventive impact methods (bottomhole zone treatment, flushing the well sump, control over suspended particles during well operation, etc.), reducing the water cut of well production, as well as limiting the production rate by optimizing well operating parameters.

D.S. Tananykhin [32] comes to the conclusion that the most effective sand control method is the stabilization of producing formation of sandy rocks. Various chemical, physicochemical and mechanical methods, as well as their combinations, are used for this purpose.

Chemical impact methods involve the use of bonding and cementing materials to stabilize the rock matrix. This ensures adequate stability of the BHZ without greatly decreasing its permeability.

Physicochemical methods are based on the stabilization of producing formation by oil coking through polymerization, which works best for high-viscosity oil fields.

Mechanical methods have gained the most popularity, primarily due to their simplicity. These methods include the use of filters applicable in a wide variety of conditions [33, 34].

All mechanical methods can be divided into three categories:

1. Using insert filters for cased wells. They are usually placed in the perforated zone under the packer. The filtration process is done by means of layouts with different types of holes.
2. Installation of gravel-packed filters. The injection of coarse-grained quartz sand allows to prevent solids from entering open hole wells [35, 36, 37–40].
3. Sand control in steam-injection wells. Filter designs differ depending on the operational aspects of cyclic steam wells.

Review of Gas Well Operation Modes

The operation mode represents operating parameters that ensure the maximum possible production rate under conditions of limiting factors and observance of safety requirements and environmental standards. The selection is based on the gas reservoir type, gas composition, initial formation pressure and temperature, reservoir properties and other factors.

There are six main operation modes that reflect different factor groups:

- constant gas filtration rate $V(t)$ = const (used to prevent equipment corrosion if reservoir gas contains corrosive compounds);
- constant gas production rate $Q(t)$ = const (used for substantial reservoirs when there is no risk of breakthrough of bottom and edge waters and no risk of formation destruction);
- constant bottomhole pressure $P_b(t)$ = const (used at gas condensate fields when a decrease in bottomhole pressure is undesirable due to condensate dropout);
- constant well head pressure $P_w(t)$ = const (used if there are no boosting compressor stations or if their installation is delayed);
- constant drawdown pressure $dP = p_f(t) - p_b(t)$ = const (used to prevent the penetration of bottom and edge waters into the well, casing collapse or reservoir deformation);
- constant pressure gradient dP/dR = const (used under the conditions of soft rocks when a high production rate can cause rock failure).

The best operation regime for unstable reservoirs is to gradually increase the load on the formation and operate at minimum filtration rates. This is usually achieved by reducing the production rate to the maximum allowable values based on the state of geological exploration of the rock.

The operating parameters for a single well are calculated in combination with the parameters for the entire gas field based on geological properties of the rock, physical properties of fluids, technical data of the field and well equipment.

Four parameters of the gas production rate have to be considered in order to calculate optimal well operating parameters [41]:

- Q_{MR} – the minimum required production rate which ensures lifting of liquid up to the wellhead;
- $Q_{MA}(\Delta P)$ – the maximum allowable production rate with respect to the maximum allowable reservoir drawdown;
- $Q_{MR.sand}$ – the minimum required production rate which ensures solids production from the bottom hole;
- $Q_{MA.sand}$ – the maximum production rate in terms of "allowable" abrasive wear of the equipment.

The Q_{MR} parameter that needs to be calculated in order to prevent fluid accumulation in the well can be determined theoretically. The calculations are based on such parameters as surface tension, gas head, gravity force, fluid viscosity.

There are various methods presented for calculating critical gas velocities. The best known authors are A.A. Tochigin, B.G. Akhmedov, S.N. Buzinov, R.J. Turner, V.N. Gordeev.

Based on the experience of calculating minimum allowable production rates of the Urengoyskoye and Medvezhye oil and gas condensate fields, it is safe to say that the method of A.A. Tochigin shows the highest accuracy in calculating key parameters [41].

Figure 5 shows the algorithm for calculating operating parameters for a well operated under conditions of water and sand production.

According to the algorithm, the Q_{MR} parameter is to be calculated first. Such parameters as the minimum gas velocity required to remove the liquid, liquid density and surface tension coefficient shall be taken into account [42].

Then the $Q_{MA}(\Delta P)$ parameter is calculated based on the formation flow coefficient, formation pressure and maximum allowable reservoir drawdown.

The $Q_{MA.sand}$ parameter is calculated for the condition when the abrasive wear of the equipment does not exceed permissible levels of solids content in the produced gas [43–45]. The calculation is carried out under the condition of equality between the actual and permissible erosional velocity of the pipe wall. The calculation is based on the hardness, as well as angularity and penetration coefficient of particles, quantitative content of solids in the gas flow, particle velocity and the inside diameter of the pipe at the wellhead [44].

Then, the calculated values of $Q_{MA}(\Delta P)$ and $Q_{MA.sand}$ are compared. If $Q_{MA}(\Delta P) > Q_{MA.sand}$, then we adopt the convention that $Q_{MA} = Q_{MA.sand}$, otherwise we accept that $Q_{MA} = Q_{MA}(\Delta P)$.

Then, the obtained values of Q_{MA} and Q_{MR} are compared:

- if $Q_{MA} < Q_{MR}$, then the gas production rate shall be maintained as $Q_G < Q_{MA}$. In this case, the risks of water accumulation in the bottomhole zone and water loading of the well persist. It is recommended to inject surfactants into the well and perform blowdowns in order to prevent these complications:
- if $Q_{MA} > Q_{MR}$, then Q_G shall be kept between Q_{MR} and $Q_{MA}(\Delta P)$.

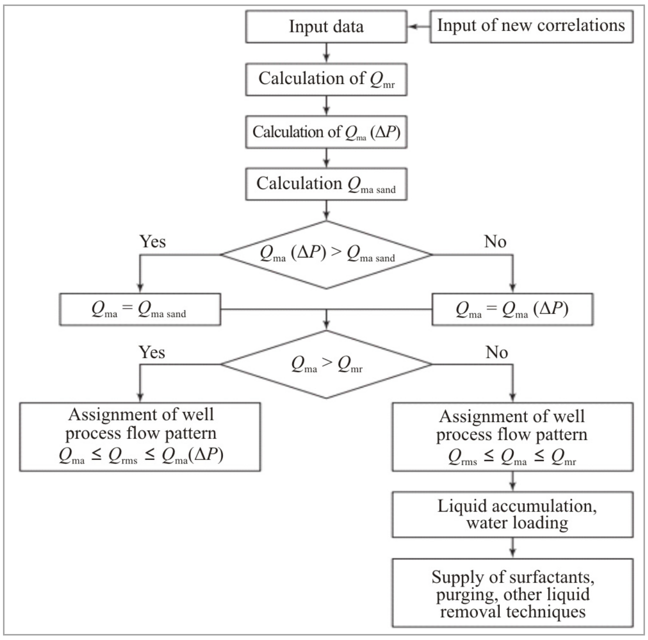

Fig. 5. Algorithm for calculating well operating parameters in conditions of water and sand production

Based on the research results, an algorithm was proposed for calculating operating parameters for gas wells operated in complicated conditions. The analysis also justifies the parameters for choosing the optimal operating mode of a gas well; this mode would imply no sand production with subsequent disabling of downhole and wellhead equipment, maintaining of the integrity of the bottomhole zone, and no water loading of the well.

The given recommendations can be used to improve the efficiency of gas wells operation and predict their trouble-free operation.

Conclusion

This paper defines the main causes of sand production in gas wells and describes its negative consequences for gas field equipment, as well as methods for solids production control. The authors propose an algorithm for calculating operating parameters for gas wells operated in complicated conditions. The analysis also justifies the parameters for choosing the optimal operating mode of a gas well; this mode would imply no sand production with subsequent disabling of downhole and wellhead equipment, maintaining of the integrity of the bottomhole zone, and no water loading of the well.

The findings of the researches for optimizing technologies that prevent complications during well operation will allow to predict the prerequisites of sand production, which is important for the effective field development in general and trouble-free operation of wells and underground/surface equipment of gas fields in particular.

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