Operation of gas wells under conditions of intensive carrying out of mechanical impurities

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Abstract: The presence of a sand plug at the bottom hole of a gas well has a significant impact on its production capabilities, which entails a reduction in the gas production capacity throughout the entire field. To solve this problem, it is necessary to carry out timely measures to clean the bottom hole of the sand, and also to optimize the operating mode of the well so that not only to keep the gas production at the proper level, but to reduce the carrying out of mechanical impurities. The work of a gas well under conditions of sand plug formation was considered. Based on the two-term law of non-linear gas filtration to the well, a mathematical model of accumulation of a sand plug at the bottom was developed, which was consistent with the field data.

1. Introduction
The West Siberian oil and gas region is the largest development center, rich in huge reserves of gas and gas condensate fields located in its depths.

The intensive nature of the development with high rates of reserves production over the past decades led the largest gas and gas condensate fields (Medvezhye, Urengoyskoye, Yamburgskoye, Vyngapurovskoye, Komsomolskoye and others) to depletion the resource base and, accordingly, the drop in production opportunities and attractiveness.

The total active well stock in the gas fields of Western Siberia compounds thousands of units, over a third of which require ongoing or major repairs, which is the result of inadequate control and the lack of timely optimization of the production wells.

The problems of most cases are directly related to an intensive drop in reservoir pressure, which leads to water flooding of the reservoir system, the bottom hole zone of the reservoir, the production, the deterioration of the productive characteristics of the reservoir and the subsequent destruction of its structure.

The natural carrying out of mechanical impurities on the surface with the fall of reservoir pressure is aggravated by the ever increasing formation of a sand plug at the bottom hole of the well, which, combined with water seepage, leads to a sharp increase in resistances, an intensive drop in gas production, up to a transition to hydrate operation and shutdown.

In this connection, there was a need to create effective mathematical models and methods for optimizing the technological mode of well operation.

2. Research
• Analysis of the formation of the sand plug at the bottom hole of the well and the mathematical justification of its influence on the gas production process.
• Analysis and mathematical description of gas flow along the wellbore in the perforation interval, taking into account the formed sand plug.
• Analysis and description of the mathematical calculation of the profile of the gas inflow to a vertical well with the change in the size of the sand plug.
• Algorithmic presentation of the process of gas inflow to the well.

In order to more accurately describe the gas wells operation under the conditions of formation of a sand plug on the bottom hole, studies were carried out on the actual accumulation of sand in the control group of wells in a certain oil and gas condensate field in Western Siberia. The development of this field began in the 1980s, but due to forced exploitation in the mid-1990s it moved to the stage of the falling production.

At the current stage of the development of the Cenomanian gas deposit of the N field, the majority of wells operate under conditions of low reservoir pressure and reduced productivity [1], caused by the water flooding of gas-bearing interlayers and by intense sand ingress.

The decrease in the average daily gas production rate for a number of reasons led to a significant decrease in the total gas extraction (Figure 1).

![Figure 1. Dynamics of decrease in gas production.](image)

One of the precautionary measures that will help maintain the gas production rate or reduce its fall the intensity to control the accumulation of sand on the bottom hole and determining the permissible well operating conditions to minimize its negative impact.

As of early 2016, the total Cenomanian well stock in the field was over 1200 units, of which slightly more than 1000 units refer to the producing well stock.

During the field operation, geophysical studies were carried out to determine the current total depth in 384 wells. The results of these studies showed that over 23% of the wells were transferred to low-yield well stock due to the presence of a sand plug on the bottom hole, which the size exceeded the perforation interval by more than 50%.
First of all, the presence of sand plugs at the bottom hole of the wells is due to the fact that, during their long operation in the bottom hole reservoir zone, the rock tends to disintegrate, resulting in a large number of mechanical impurities entering the wellbore together with the gas-liquid mixture.

Subsequently, at insufficient up-flow rate, sand particles settle along the wellbore and wall of the borehole to the bottom hole, as a result, conditions arise for the accumulation of a sand plug at the well bottom hole.

The depth of descent of the tubing also influences the process of sand accumulation. On the basis of conducted field research, it can be noted that more intense sand plugs accumulate in the wells, where the elevator column has a large diameter and is lowered to the upper holes of the perforation interval.

It should be noted that the accumulated information on measurements of the current total depth, which allows to determine the actual value of the sand plug, is very small. In this regard, it is impossible to give an accurate estimate of the degree and nature of the formation of sand plugs at the bottom holes of gas wells.

Selection of wells for analysis was carried out on the basis of active sand accumulation at the bottom hole and its influence on daily gas production. Over the past 10 years, gas production for this wells group has decreased significantly from 600-800 to 100-200 thousand m³/day. In Figure 2 the dynamics of well production associated with the carrying out of mechanical impurities is shown.

![Figure 2. Dynamics of well production taking into account the carrying out of mechanical impurities.](image_url)

As can be seen, the trend to the drop in production is monitored for all the wells under investigation, which, as indicated earlier, is associated with water flooding of gas-bearing interlayers and intense sand ingress. As it is known, the wells operation in high depression modes promotes a more intensive flow of sand material and water from the reservoir into the bottom hole space, where a dense sandy overlap of the perforation interval is formed depending on the particle size and conditions on the up-flow. Under these conditions, when the bottom hole cleaning suggests already stopping the well for the major workover service, re-launching may not ensure the previous gas production rates, which is due to the aggressive operating conditions of the wells and the lack of timely decisions to monitor the wells condition at the bottom hole.

In Figure 3 the dependence of the carrying out of mechanical impurities on the gas production rate is shown.
Figure 3. Dependence of gas production rate on sand content.

The presented dependence characterizes the increase in the volume of the extracted sand with the increase in the daily gas production.

The uncontrolled formation of sand plug, especially under conditions of high gas production rate, leads to an irreversible process of intensive growth of the sand plug. Under given conditions, there is a direct need for periodic implementation of measures to eliminate it.

The larger and denser the sand plug is, the more time and effort are needed to clean the bottom hole, which is accompanied by production loss and an increased risk of lowering the potential of the well [2].

Such periodicity of well operation is characterized by the concept of workover interval. In most cases, the planned workover interval assumes a bottom hole condition with a 50% overlap in the perforation interval. The increase in the workover interval only leads to additional gas production losses.

In Figure 4 a clearly expressed example of the volume of losses on the well as a result of idle time for the well workover is graphically shown.
According to the results of gas-dynamic studies of the given well, the identified stops were caused by the formation of a sand plug on the bottom hole. The decision to carry out repairs is often caused by a sharp drop in gas production at the well. Thus, according to the presented example, the estimation of the volume of losses was 38 mln. m³ of gas. Such wells require an instrument for tracking and operative evaluation of the sand plug size without intervention on its technological mode.

Under conditions of a small amount of information, carrying out the major repairs to increase gas production is not always justified. Based on this, a method was developed to determine the sand plug size at the bottom hole of the well, which will solve the problem of conducting the repair work and determine the permissible conditions for the operating wells, which will enable not only to maintain the gas production rate, but also to reduce the impact of the sand plug on the well productivity ($P$):

$$
\Delta P_i = e^{-\frac{2L_z \cos(\alpha)}{RT}} \left( P^2 + \left( \frac{\mu}{k_{ap}} + \frac{bk_{m}}{\pi r_c^3 k} \right) \left( \frac{m_zRT}{\pi r_c^3 k} \right)^2 \frac{\pi r_c^2 k}{m \cdot \cos(\alpha)} \right) - \frac{\pi r_c^3 k}{m \cdot \cos(\alpha)} \left( \frac{\mu}{k_{ap}} + \frac{bk_{m}}{\pi r_c^3 k} \right) \left( \frac{m_zRT}{\pi r_c^3 k} \right)^2,
$$

where $\Delta P_i$ - pressure drop at the i-th section of the perforation interval, Pa; $R$ - individual gas constant, (J/kg K); $m_z$ - the interval mass flow rate, kg/s; $z$ - gas compressibility coefficient; $k_{ap}$ - coefficient of permeability m²; $bk$ - coefficient of hydraulic resistance during filtration in a porous medium according to the Minsky formula; $r_c$ - well radius, m.
To check the efficiency of the developed method, three wells were selected (Table 1), taking into account the following conditions:

- conducting geophysical surveys on candidate wells;
- different amount of operating production rate;
- the presence of hydrodynamic studies with the determination of the coefficients $a$ and $b$;
- different percentage of overlapping of the perforation interval with a sand plug.

In addition to these parameters, information was used on geophysical studies with the determination of the average permeability and porosity both for the entire thickness of the reservoir as a whole and for working interlayers in particular.

| Criterion                              | Well No. 1 | Well No. 2 | Well No. 3 |
|----------------------------------------|------------|------------|------------|
| Perforation interval, m                | 62         | 73         | 73         |
| Current production rate, thousand m$^3$/day | 502        | 640        | 820        |
| Reservoir pressure, MPa                | 4.821      | 4.858      | 4.900      |
| Reservoir temperature, ºC              | 25.4       | 25.4       | 25.4       |
| Bottom hole pressure, MPa              | 4.676      | 4.709      | 4.780      |
| Coefficient $a$                        | 0.005      | 0.006      | 0.040      |
| Coefficient $b$                        | 0.00044    | 0.00600    | 0.00015    |
| Sand plug size, m                      | 31.6       | 25.2       | 14.6       |
| Average permeability on the reservoir, mD | 402        | 401.5      | 939        |

The work of the proposed method consists in determining the sand plug size according to the algorithm given below.

Further evaluation of the effectiveness of the developed algorithm is carried out by comparing the calculated and actual results obtained on the basis of field research.

Calculation of the sand plug size is performed using the average permeability at the effective thickness of the reservoir.

According to the investigated field under the laboratory conditions, the true value of the permeability of the gravel packing was not determined. During the study of sand formation, the empirical value of the permeability of gravel packing, which is 2000 D [3], was established.

In the process of modeling the current operating mode of each well, taking into account the presence of a sand plug at the bottom hole, an inflow profile and diagrams were obtained for the distribution of the main characteristics of the gas flow (flow rate and pressure loss).

In Figure 5 the gas inflow profile for the well No. 1, taking into account the current operating mode and the presence of a sand plug at the bottom hole is shown.
Figure 5. Profile of the gas inflow for the well No. 1.

According to the presented diagrams of the gas flow distribution, the following conclusions can be drawn:

1. This distribution shows that the maximum inflow of gas falls on the upper perforations, which are free of sand.

2. The change in the dynamics of the gas inflow for each section of the perforation free from the sand plug is of minimal value, due to insignificant pressure losses.

3. With a fixed permeability value throughout the working interval of the reservoir, the change in mass production starting from the bottom hole of the well depends on the calculated hydraulic pressure losses, especially in the perforation interval.

4. The profiles of the gas inflow in the section of the wellbore filled with a sand plug are described for each well by a parabolic dependence (Figure 6), which is mainly due to the gas filtration in the pore space (sand plug) by a quadratic law.
Figure 6. Profile of gas inflow for the investigated wells.

Calculation of the main distribution of pressure losses is confined directly to the estimated interval of the sand plug, as shown in Figure 7.

Figure 7. Distribution of pressure losses for the perforation interval of the well No. 1.
3. Results and discussion

According to the dynamics of the change in pressure losses for each well, the following conclusions can be drawn:

1. Losses increase from the bottom hole to the wellhead, which is due to the flow rate, since the gas flow rate in the tube changes from laminar to turbulent with the flow rate increasing (increase in the Reynolds number).

2. Under conditions of the increasing flow rate, the hydraulic pressure losses also directly depend on the presence of an aggressive medium (sand and water ingress), which leads to additional resistances during the gas filtration in each hole in the "reservoir – bottom hole - wellbore" system.

3. Under conditions of sustained permeability and productivity of each perforation hole, in the absence of additional resistance at the bottom hole of the well, a uniform decrease in the operating depression in the perforation interval is observed. When there is a sand plug, the main redistribution of pressure losses occurs at the overlapped intervals of the reservoir.

As a result of the work, the value of the sand plug for each well was estimated (Table 2).

Table 2. Estimation of the sand plug size for each well.

| Permeability value | Well No. 1 | Well No. 2 | Well No. 3 |
|--------------------|------------|------------|------------|
| Sand plug size, m  | Sand plug size, m | 31.6       | 25.2       | 14.6       |
| Percentage of discrepancy, % | Percentage of discrepancy, % | Data obtained as a result of estimation | 30.2 | 4.4 | 24.4 | 3.2 | 14.7 | -0.7 |
| Data obtained as a result of well logging | | | |

Visualization of the comparison of calculated parameters is presented on the following histogram (Figure 8).

Figure 8. Comparison of estimated and actual values of the sand plug size.
As a result of the research, the following conclusions can be drawn:

1. Comparison of the calculated and actual values of the sand plug size shows that the maximum discrepancy on the average does not exceed 5%, which indicates the agreement of the results of field research and mathematical modeling of the well operation.

2. Based on the comparison of the estimations results, it can be argued that the use of uniform permeability for the reservoir during the simulation of the sand plug is optimal (Table 2). Since the estimation of the model depends on the amount of the given permeability, averaging its value for the reservoir minimizes the effect of highly productive interlayers, the inhomogeneity of their distribution in the perforation interval of the reservoir, and also reduces the sensitivity of the final calculation to its oscillations, which leads to simplification of the model and obtaining a more optimal result.

3. Using the adapted mathematical model of the well operation, the filtration coefficients $a$ and $b$ can be estimated. The dynamics of these coefficient changes describes the state of the bottom hole reservoir zone, in other words, the possible presence of sand and liquid plugs.

To verify the stability of the estimation of the studies performed and to assess the possibility of using the obtained results to determine the optimal gas production rate, it is necessary to compare the estimated and actual data on the basis of the indicator diagrams. This comparison will allow to identify the errors obtained during the research.

4. **Conclusion**

In the course of the work, the following provisions were developed and considered:

1. A mathematical model of the reservoir-well system was developed, complicated by the presence of a sand plug along the perforation interval.

2. Analysis of the formation of the sand plug at the bottom hole of the well and the mathematical justification of its influence on the gas production process.

3. Analysis and mathematical description of gas flow along the wellbore in the perforation interval, taking into account the formed sand plug.

4. Algorithmic presentation of the process of gas inflow to the well.

**References**

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