Intensification of the gas inflow when bringing wells into production

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Abstract. In wells brought into production, the bottomhole formation zone is contaminated. Contamination must be eliminated by acid treatment. The degree of contamination depends on reservoir characteristics and technological parameters of the primary and secondary opening. The intervals of formation permeability were identified; additional measures aimed at cleaning the reservoir from contamination and restoring well productivity should be implemented. Multi-solution acid treatment of the bottomhole formation zone improves productive characteristics of wells with deteriorated properties of the bottomhole reservoir.

1. Introduction
In the bottomhole formation zone (BFZ) of wells, contamination (clogging) of the reservoir occurs due to the penetration of filtrate and solid particles from drilling and other technological solutions [1, 2]. To reduce and / or remove clogging, a number of known methods are used [3–5]. The degree of contamination depends on the reservoir characteristics and technological parameters of the primary and secondary penetration of productive reservoirs [1, 6, 7]. When opening a productive formation by drilling and creating a sump, the time of contact of the drilling fluid with the borehole walls in the oil and gas-saturated reservoir increases for technological reasons and with an increasing sump depth. A long duration of the contact increases the contamination of the near-wellbore zone of the formation with drilling mud filtrate and mechanical particles [8–10]. When drilling with a high-viscosity mud, the repression on the formation increases. In such cases, the correct opening technology, quality of drilling fluids, active chemical agents have a tangible effect on the quality of the formation opening. During the reopening of the productive formation, perforation fluid penetrates into the reservoir, which also degrades the reservoir properties. With good reservoir properties of the perforated productive formation, the above factors contaminate the formation, and a zone of penetration of filtrate and drilling mud particles with a large radius is formed [11-14].

2. Materials and methods
Information from several fields of Western Siberia and measures taken to increase the inflow of fluids from the reservoir were used to assess the quality of the opening of productive formations, the need for hydrocarbon stimulation.
In order to determine the quality of penetration of productive layers, the indicator "relative permeability" (RP) is often used [1, 6]:

\[ \text{OK} = \frac{k_{bhf}}{k_r} \]

where \( k_{bhf} \) – permeability of the bottomhole formation zone with reservoir properties that differ from the natural ones in the remote zone, \( \mu \text{m}^2 \); \( k_r \) – permeability of a remote formation zone with natural reservoir properties, \( \mu \text{m}^2 \).

To assess the quality of reservoir penetration and results of stimulation measures, the results of geological and physical studies (GPS) and hydrodynamic studies of wells (HSW) were used.

3. Results and Discussion

To determine the quality of penetration, calculations were performed for 48 wells of several fields in Western Siberia. In these wells, productive sandstone beds with similar characteristics were drilled (the results of studies and calculations in Table 1 and Figure 1).

The formations of the wells of group 7 have the lowest "relative permeability", the average permeability of the productive formations is \( k_{av} = 10^{-3} \mu \text{m}^2 \), and the maximum one reaches \( 645 \times 10^{-3} \mu \text{m}^2 \). The average permeability of the reservoir in group 7 is higher by 29.2 times than in group 1 (wells that penetrated the reservoirs with the lowest permeability), and \( \text{RP}_{av} \) in group 7 is 13.8 times less than in group 1. The opening of the productive formation (primary and secondary) in wells with such parameters is not performed well enough. Therefore, in such wells, it is necessary to plan activities to restore productivity and stimulate the flow of hydrocarbons.

| Group of wells | Average \( OC_{av} \) in the group, % | Limits of changes in \( OC \) in the group, % | Average permeability \( k_{av} \) in the group, \( \times 10^{-3} \mu \text{m}^2 \) | Limits of changes in permeability \( k \) in the group, \( \times 10^{-3} \mu \text{m}^2 \) |
|---------------|--------------------------------------|---------------------------------------------|------------------------------------------|---------------------------------------------|
| 1             | 162.7                                | 44.4–760                                    | 10.0                                     | 4–14                                       |
| 2             | 208.8                                | 3.8–889                                     | 20.3                                     | 15–33                                      |
| 3             | 18.4                                 | 11.5–50                                     | 53.0                                     | 40–78                                      |
| 4             | 38.5                                 | 6.5–147.5                                   | 117.4                                    | 104–134                                    |
| 5             | 31.5                                 | 2.1–68.8                                    | 152.9                                    | 140–169                                    |
| 6             | 13.5                                 | 3.3–24                                      | 277.0                                    | 173–195                                    |
| 7             | 11.8                                 | 2.8–22                                      | 291.8                                    | 200–645                                    |

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Dependence of the \( OC \) parameter on permeability of the bottomhole formation zone \( k \). The dashed line is a trend line.
The geological and production information indicates a tangible effect of the permeability value on the quality of opening of the reservoir. The following conclusions can be drawn:

- formations with relatively low permeability during opening by drilling and perforation are less prone to mudding, in comparison with highly permeable formations, which allows for self-cleaning of the bottomhole formation zone during standard development, without additional measures;
- during the secondary opening of the productive formation with permeability in the range from $40 \times 10^{-3} \mu m^2$ to $100 \times 10^{-3} \mu m^2$ and more than $120–150 \times 10^{-3} \mu m^2$, additional measures are required to clean up the bottomhole formation zone from contaminants, stimulate the flow of hydrocarbons and restore the well productivity;
- it is very important to predict the value of permeability and porosity of the productive formations in the wells being drilled in order to correctly select the technology for the primary and secondary opening; this will ensure a higher quality of the productive formation opening.

A number of wells after drilling and re-opening of productive formations do not reach the operating mode and/or do not reach the design level of productivity. For example, the wells No. XXX of the Yamburg gas condensate field (YGCF) have a different and heterogeneous section of the productive formations (Table 2). Some of the wells could not be put into operation using a standard inflow challenge; the planned productivity was not achieved. The best reservoir properties are typical of the strata drilled in wells 4, 5, 9. The strata with a high productivity were opened in wells 1, 3, 6, 7, and in well 8, the most dissected section (17 reservoirs with an average effective thickness of 1.4 m) with low permeability was opened.

**Table 2.** Reservoir characteristics of productive formations, which were penetrated in the wells # XXX YGKM

| No of the well | Summary characteristics of formations according to the GPS data, penetrated by perforation | The worst penetrated formation by the GPS data | The best penetrated formation by the GPS data |
|---------------|-----------------------------------------------------------------------------------------|---------------------------------------------|---------------------------------------------|
|               | Effective formation thickness, m | Permeability, $\times10^{-3}$ μm² | Porosity, % | Effective formation thickness, m | Permeability, $\times10^{-3}$ μm² | Porosity, % |
| 1             | 28.4 | 27.6 | 15.9 | 6.0 | 82.5 | 17.2 |
| 3             | 16.4 | 44.2 | 16.5 | 12.6 | 23.6 | 16.7 |
| 3*            | 5.2  | 123.9 | 17.1 | 2.0  | 188.5 | 16.9 |
| Total for 3   | 12   | 63.4 | 16.6 | 3.2  | 188.5 | 16.9 |
| 4             | 21.6 | 60.3 | 16.2 | 1.2  | 188.5 | 16.9 |
| 5             | 24.2 | 106.0 | 15.4 | 60.2 | 15.8 |
| 6             | 16.6 | 125.3 | 16.4 | 23.8 | 15.1 |
| 7             | 20.0 | 60.3 | 16.2 | 24.4 | 16.5 |
| 8             | 15.1 | 60.2 | 16.7 | 17   | 63.3 |
| 9             | 12   | 60.3 | 16.2 | 9    | 63.3 |

No of the well | Effective thickness, m | Permeability, $\times10^{-3}$ μm² | Porosity, % |
|---------------|------------------------|---------------------------------|-------------|
| 1             | 2.6                    | 0.4                             | 13.0        |
| 3             | 2.2                    | 0.6                             | 13.6        |
| 3*            | 1.2                    | 60.2                            | 16.7        |
| Total for 3   | 2.2                    | 0.6                             | 13.6        |
| 4             | 2.0                    | 0.2                             | 13.5        |
| 5             | 1.6                    | 0.4                             | 13.0        |
| 6             | 4.4                    | 0.6                             | 14.0        |
| 7             | 1.0                    | 0.4                             | 13.0        |
| 8             | 1.6                    | 0.4                             | 13.2        |
| 9             | 2.4                    | 3.9                             | 15.2        |
After the introduction of highly productive layers BU91 in well No. 3, its general characteristics have significantly improved.

In wells No. 3, 5, 6 of the YGCF, prior to commissioning, stimulation of the inflow of hydrocarbons was carried out by the method of multi-solution acid treatment using acid compositions based on hydrochloric and hydrofluoric acids with the addition of surfactants, drying agents and solution stabilizers with reaction products (to prevent precipitation). The results of multi-solution acid treatments and a comparison of the operating parameters of wells after development (before acid treatments) and gas inflow stimulation into wells No. XXX are presented in Tables 3 and 4.

**Table 3. Operating modes of wells No. XXX YGKM**

| No of the well | After well completion (before acidizing) | Mode 1 | Mode 2 |
|---------------|----------------------------------------|--------|--------|
|               | Absolute free flow rate, thousand m³ | Washer diameter, mm | Temperature °C | Gas flow rate, thousand m³ | Washer diameter, mm | Temperature °C | Gas flow rate, thousand m³ |
| 1             | 5.69                                   | 559    | 11.0   | 24.6   | 309    | 17.5 | +26.0   | 465 |
| 3             | 3.27                                   | 345    | 11.0   | 18.9   | 241    | 17.4 | +21.6   | 302 |
| 3*            |                                       |        |        |        |        |      |        |     |
| 4             | 3.77                                   | 338    | 11.0   | 24.4   | 241    | 17.0 | +25.0   | 294 |
| 5             | 3.16                                   | 301    | 11.0   | 21.4   | 227    | 17.0 | +23.7   | 283 |
| 6             | 4.53                                   | 420    | 11.0   | 23.7   | 278    | 17.0 | +24.0   | 364 |
| 7             | 3.80                                   | 372    | 11.0   | 20.5   | 261    | 17.0 | +20.5   | 334 |
| 8             | 4.68                                   | 447    | 10.9   | 25.2   | 283    | 17.0 | +25.3   | 404 |

| No of the well | After acid treatment |
|---------------|----------------------|
|               | Mode 1                |
|               | Washer diameter, mm   |
|               | Temperature °C        |
|               | Gas flow rate, thousand m³ |
| 1             | acid treatment was not carried out |
| 3             | 3.7                   |
| 3*            | 3.8                   |
| 9             | 3.3                   |
| 4             | acid treatment was not carried out |
| 5             | 5.8                   |
| 6             | 3.3                   |
| 7             | acid treatment was not carried out |
| 8             | acid treatment was not carried out |
| 9             | acid treatment was not carried out |
Table 4. Results of hydrodynamic studies of wells No. XXX YGKM

| No of the well | 1   | 3   | 3*  | 4   | 5   |
|----------------|-----|-----|-----|-----|-----|
| After development (before acid treatment) Filtration coefficient A | 189.23 | 405.66 | BU$_{ij}$ added | The well worked in a hydration mode, therefore it has not been investigated | 251.87 |
| Filtration coefficient B | -0.0363 | -0.3375 | | | 0.0518 |
| After acid treatment Filtration coefficient A | Acid treatment was not carried out | 265.00 | 206.19 | 169.76 | Acid treatment was not carried out |
| Filtration coefficient B | 0.0115 | 0.1854 | | | 0.0066 |

Table 4. Results of hydrodynamic studies of wells No. XXX YGKM (continue)

| No of the well | 6   | 7   | 8   | 9   |
|----------------|-----|-----|-----|-----|
| After development acid treatment Filtration coefficient A | 308.17 | 219.92 | 259.09 | 185.90 |
| Filtration coefficient B | 0.0334 | 0.0028 | 0.0145 | 0.0910 |
| After acid treatment acid treatment Filtration coefficient A | 290.69 | Acid treatment was not carried out | Acid treatment was not carried out | Acid treatment was not carried out |
| Filtration coefficient B | 0.0205 | | | |

The results show that the expected inflows were not achieved, primarily in wells No. 5 and No. 3, 6, 4. In well 4; the gas inflow made it possible to operate the well, but the characteristics of the layers opened are better than in wells No. 1, 8, 9, and the productive performance (Q / ΔP2 parameter in Table 3) is the worst among these four wells. This is due to the clogging of the bottomhole formation zone by deep penetration of drilling mud filtrate and perforation fluid due to the good reservoir properties of the formations. In well No. 5, which has characteristics close to well No. 4, clogging has led to the impossibility of bringing the well to the operating mode without additional works.

Successful acidizing of the bottomhole formation zone in well No. 5 (Table 3) suggests that a similar impact in well No. 4 with similar reservoir properties (Table 2) could give similar results. The bottomhole formation zone in wells No. 1 and 8 was polluted to a shallower depth, which is confirmed by the coefficients "A" and "B" (Table 4); therefore, self-cleaning by the gas flowing to the bottom occurred. Wells No. 7 and 9, which have good reservoir properties of the bottomhole formation zone (Table 2), were brought into production independently (as a result of self-cleaning and good permeability and low clogging of the bottomhole zone) (coefficients "A "And" B "in Table 3).

After perforation and development, wells No. 3 and No 6 had the lowest productivity (Q / ΔP2 parameter in Table 3), despite the fact that the reservoir characteristics of their BHP are comparable to the characteristics of the formations in well No. 7. Higher ballard formation is confirmed by the values of coefficients "A" and "B" (see Table 4). The acid treatment carried out on the bottomhole formation zone of wells No. 3 and 6 allowed them to reach the level of productive characteristics of the operation mode of well No. 4 (see Tables 3 and 4); their productivity increased by 14.1% and 6.6%, respectively. The introduction of highly productive formations BU91 in well No. 3 increased productivity by 4.3%, but it was less than expected. The additionally opened formations have better
productivity (see table 2). This can be explained by the deep clogging of the BU91 formations. If perforation followed by acid stimulation was made throughout the interval, the result could have been better.

After the gas production intensification, all three treated wells (3, 5, 6) were brought into operation.

4. Conclusion
1. Acid stimulation made it possible to improve the productive characteristics of wells No. 3 and 6, while well No. 5 achieved the highest productivity value for cluster No. XXX.
2. For well No. 3, it was possible to achieve a better result if BU91 was penetrated simultaneously with other formations and acid stimulation was carried out on all formations (in this case, BU91 clogging can be reduced).
3. In all wells No XXX, the bottomhole formation zone is clogged. The contamination must be eliminated by acid stimulation or using another method.
4. The degree of clogging of the bottomhole formation zone is associated with the technological parameters of the primary (drilling) and secondary (perforation) opening of the productive formations, as well as reservoir characteristics of the formations. The results of well stimulation works are consistent with the conclusions made in the first part of the article, which gives grounds to speak of the need to predict the permeability and porosity of productive formations in drilled wells in order to select a more correct technology for formation opening.
5. When opening in wells formations with permeability from $40 \cdot 10^{-3}$ to $100 \cdot 10^{-3}$ $\mu m^2$ and more than $140–150 \cdot 10^{-3}$ $\mu m^2$, additional measures should be planned to clean up the bottomhole formation zone and restore well productivity. All wells with a permeability of more than $40 \times 10^{-3}$ $\mu m^2$ should be investigated, the quality of penetration should be determined, and if self-cleaning of the formation does not occur, measures should be taken to restore productivity.

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