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Assessment of the efficiency of near-wellbore zone treatment

Ocena skuteczności oczyszczania strefy przyodwiertowej

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ABSTRACT: The article discusses issues related to methods of treatment of the bottomhole zone of wells and assessment of its effectiveness. Analyses of a large volume of field material have shown that the most effective treatments for oil fields at a late stage of operation include injection of solvents, the use of acid-containing micro-emulsions, acid treatment, and the use of foam systems. The study proposes a method for identifying the factors that have the greatest impact on the efficiency of geological and technical activities. This approach allows for the correct selection of wells for treatment and the evaluation of the effectiveness of the measures implemented, aiding in determining their potential for further use. For production wells selected for near-wellbore treatment, it is crucial to accurately assess the economic efficiency post-treatment. This requires evaluating changes in the permeability of the near-wellbore zone following treatment. Therefore, in these wells, the "pressure build-up curve" (PBC) is recorded both before and after treatment. The increase in current production due to acid treatment of the near-well zone is determined by comparing production levels before and after treatment. The overall increase in oil production is determined by comparing the well's production curve prior to development with the actual curve following development. When treating the bottomhole zone, it is essential to consider the well as part of a larger system of interacting objects, where improving the characteristics of one object does not necessarily enhance the operation of the entire system. The effectiveness of treating the bottomhole zone with solvents is significantly influenced by factors such as the percentage of resins in the product, the specific gravity of oil before treatment, the specific gravity of the solvent, and the viscosity of the oil.

Key words: oilfield, production, bottomhole zone, solvents, foam systems.

STRESZCZENIE: W artykule omówiono zagadnienia związane z metodami oczyszczania strefy przyodwiertowej i oceną ich skuteczności. Przeprowadzone analizy dużej ilości materiału złożowego wykazały, że najskuteczniejszymi metodami oczyszczania złóż ropy naftowej na późnym etapie eksploatacji są: zatłaczanie rozpuszczalników, stosowanie mikroemulsji zawierających kwasy, oczyszczanie kwasami oraz stosowanie systemów pianowych. W opracowaniu zaproponowano metodę identyfikacji czynników, które mają największy wpływ na efektywność działań geologiczno-technicznych. Podejście to pozwala na właściwy dobór odwiertów do oczyszczania oraz ocenę skuteczności wdrożonych działań, pomagając w określeniu ich potencjału do dalszego wykorzystania. W przypadku odwiertów wydobywczych wytypowanych do oczyszczania strefy przyodwiertowej kluczowe jest przeprowadzenie oceny, jak oczyszczanie wpłynie na późniejszą rentowność tych odwiertów. W tym celu niezbędne jest oszacowanie zmian przepuszczalności strefy przyodwiertowej po oczyszczeniu. Z tego względu w tych odwiertach rejestruje się „krzywą narastania ciśnienia" zarówno przed, jak i po oczyszczaniu. Zwiększenie bieżącego wydobycia w wyniku oczyszczania kwasem strefy przyodwiertowej jest określane poprzez porównanie poziomów wydobycia przed i po oczyszczaniu. Ogólny wzrost wydobycia ropy naftowej jest określany poprzez porównanie krzywej wydobycia z odwiertu przed zagospodarowaniem z rzeczywistą krzywą po zagospodarowaniu. Podczas oczyszczania strefy przyodwiertowej istotne jest, aby traktować odwiert jako część większego systemu współdziałających obiektów, w którym poprawa charakterystyki jednego obiektu niekoniecznie poprawia działanie całego systemu. Na skuteczność oczyszczania strefy przyodwiertowej rozpuszczalnikami znaczący wpływ mają takie czynniki jak procentowa zawartość żywic w produkcie, ciężar właściwy ropy przed oczyszczaniem, ciężar właściwy rozpuszczalnika oraz lepkość ropy.

Słowa kluczowe: pole naftowe, produkcja, strefa przyodwiertowa, rozpuszczalniki, systemy pianowe.

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Introduction

The issue of enhancing development efficiency is closely associated with the discovery of new fields and the stabilization of oil and gas production in mature fields.

Stabilization of oil production in mature fields can be achieved by implementing advanced methods that increase oil production. One such progressive methods is the treatment of the bottomhole zone of wells using various methods which, when used rationally, can significantly improve the oil recovery factor.

In recent years, the treatment of the bottomhole zone of wells with non-Newtonian systems has gained widespread use.

Several key factors have been identified that influence the efficiency of these treatments. Understanding these factors allows for the correct selection of wells for treatment and the accurate evaluation of the effectiveness of the treatment, as well as determining the potential for further application of such methods.

As is well known, one of the primary methods for enhancing the oil recovery factor in studied fields involves treating the bottomhole zone of wells with various reagents (Mirzajanzade and Stepanova, 1977; Alvarado and Manrique, 2011).

The effectiveness of these treatments is predetermined by numerous factors related to both natural conditions and process technology, the correct choice of wells for specific activities, the development of wells after treatment, etc. It should be noted that taking into account the influence of all factors with the simultaneous impact of their various combinations on the effectiveness of processing methods presents significant difficulties. In this regard, at the present stage of studying the problem, it is advisable to identify and study the nature of the influence of the main factors that have the most significant impact on the effectiveness of processing methods.

The increase in production by restoring permeability in low-producing wells may not be economically viable, primarily due to the applied technology. In low-flow wells (depleting fields), the investment per ton of production should be as low as possible after using bottomhole zone restoration methods, so that the cost of additional purchased oil is also minimized. It is more appropriate to apply innovative technologies that require little investment in such wells. The purpose of the proposed work is to clarify certain aspects of the effective bottom zone development, taking these cases into account.

The analysis of the results of the applied methods for the treatment of the bottomhole zone of wells showed that the main types of treatment of the indicated area, the purpose of which is to displace residual oil, are: foam injection, treatment of the bottom of wells with acid-containing micro-emulsions, treatment of the bottom of wells with solvents (oil, kerosene, condensate, etc.), heating the zone with hot oil, using polymer solutions, etc. (Larry, 1988; Alvarado and Manrique, 2011).

Methodology

It should be noted that the effectiveness of the methods is primarily determined by the increase in oil production, which on average is: up to 2.0 t/day when pumping solvents, up to 1.5 t/day when pumping foam, approximately up to 1.0 t/day when pumping polymer solutions (Thomas and Ali, 1999).

However, some studies report a double-digit increase in oil production after applying certain methods (Salavatov et al., 2016; Abdullayev et al., 2022). For example, the developed composition and method, which increases the degree of cleanup of the near-wellbore zone and oil production, involves, in order to displace the treatment solution deep into the near-wellbore zone, first pumping a solution based on chromic anhydride into the near-wellbore zone, followed by the injection of a mixture containing low alcohols (methyl, ethyl, butyl, propyl, etc.) and turpentine.

With this sequence of solution injections, a thermochemical reaction occurs, releasing a huge amount of gases (aldehydes). These gases act as a "high pressure source" in the near-wellbore zone, pushing the treatment mixture deeper into the formation and covering a greater depth. Subsequently, the temperature rises above 100°C, promoting the dissolution of heavy oil components in the near-wellbore zone, thereby increasing the permeability of the near-wellbore zone and the well flow rate (Salavatov et al., 2016; Abdullayev et al., 2022).

It should also be noted that the studies (Salavatov et al., 2016; Abdullayev et al., 2022) show that the presence of oil and petroleum products intensifies the thermochemical reaction that occurs when the components of the solutions used in the proposed technologies for cleaning the bottomhole zone come into contact (the reaction temperature additionally increases by 6–10°C). As a result, the cleaning time of the wellbore zone is reduced, and heavy oil components quickly melt and turn into liquid, ensuring high-quality cleaning of the wellbore zone. Additionally, the reaction releases aldehyde gases, which enables the reaction to affect the deeper layers of the wellbore zone. This results in a higher efficiency of the technology used.

The effect of the above methods of influence on the bottomhole zone of the well is determined by the increase in the current production, the price of additional oil obtained, and the costs associated with the method applied. These indicators characterize the economic effect of the development of the bottomhole zone of the well and at the change in permeability of this zone.

In production wells selected for near-wellbore treatment, it is crucial to accurately determine the economic efficiency after treatment. To do this, it is necessary to assess how the permeability of the near-wellbore zone changes after treatment. Therefore, the "pressure build-up curve" (PBC) is recorded both before and after treatment in these wells, and the permeability of the bottomhole zone is determined and compared using the constructed graphs for both cases. Based on this comparison, the degree of permeability restoration in the near-wellbore zone is clarified. This allows for conclusions about the rate of oil filtration into the well and enables the calculation of the increase in oil production from the well (Wilson, 2018).

For example, the increase in current production as a result of acid treatment of the near-wellbore zone is determined by comparing production before and after treatment. The overall increase in oil production is determined by comparing the well's production curve before development with the actual curve after development. The average monthly production decline rate for the period before development is calculated and displayed as a dotted line on the current well production diagram.

For instance, to restore the permeability of the bottom zone of well "A" using a thermochemical effect, laboratory experiments were conducted using a formation model that simulates the oil, brine, formation temperature, and permeability of the bottom zone. The process of filtering the oil in the model was carried out, and after sufficient deterioration of conductivity, recovery was achieved using a composition consisting of chromic anhydride, methyl alcohol and a solvent. The result of the process is presented in the form of a graph (Figure 1).

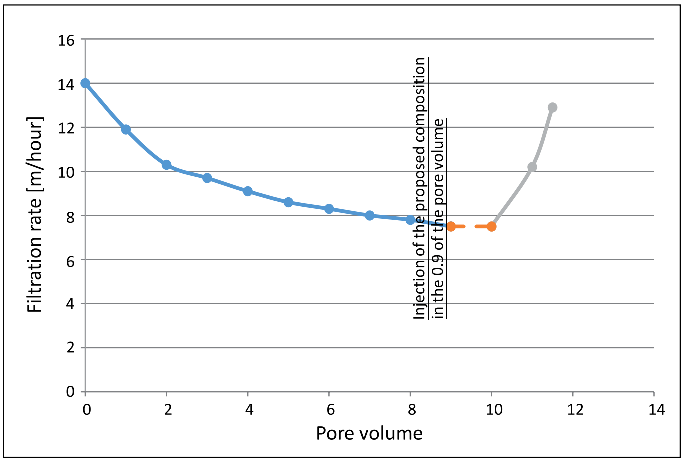

Figure 1. The dynamics of oil filtration rate depending on the volume passing through the porous medium

Rysunek 1. Dynamika szybkości filtracji ropy w zależności od objętości przepływu przez ośrodek porowaty

According to the laboratory studies, the result of the application work carried out in well "A" met expectations. The results are presented in Table 1.

To determine the amount of additional oil produced, the theoretical production that the well could achieve before development should be subtracted from actual production. Changes in the permeability of the wellbore zone can be identified from research materials (Mirzajanzade et al., 2010). The time between well repairs, which indicates the effectiveness of the methods used in the areas under consideration, also increases.

The effectiveness of bottomhole zone treatment mainly depends on the correct selection of wells, high-quality well preparation, and the applied technology.

However, in most cases, the effectiveness of the measures taken to treat the bottomhole zone is evaluated only by the production rate of the wells, without considering the production rate of neighbouring wells. Furthermore, wells are often selected based on flow rate (oil), which in many cases makes the process ineffective.

In view of the above, treating the bottomhole zone requires considering more than just a single well. It is essential to plan technological operations and evaluate the effects, with the understanding that this large system is composed of interacting objects, and improving the characteristics of one object does not necessarily mean improving the operation of the entire system. The structuring of a system involves dividing an integral object into indivisible elements and establishing connections in time and space.

Therefore, taking into account the interaction of wells operating at the same facilities when applying reservoir stimulation technologies to increase the oil recovery factor, and methods of treating the bottomhole zone to intensify well production, will lead to more accurate results in calculating economic efficiency. There are many known methods for checking the connection between wells, and it would be appropriate to study the correlation relationship, which is more commonly used.

Table 1. Geological and technical data of wells before and after thermochemical treatment of the bottomhole zone (offshore field)

Tabela 1. Dane geologiczne i techniczne odwiertów przed i po obróbce termochemicznej strefy przyodwiertowej (złoże przybrzeżne)

Well number	Horizon	Bottomhole [m]	Screen [m]	Operation method	Suspension	Production [tons per day]			
						before treatment		after treatment	
						oil	water	oil	water
"A"	Fasila Suite	505	504–494	Gaslift	1 string – 2.5" – 494 11 string – 1.5" – 243	7.0	3.0	24.0	–

Below, we propose a methodology for assessing the effectiveness of the measures taken, aimed at identifying the main factors influencing the process of the bottomhole zone treatment, allowing to improve the selection of wells for treatment.

To assess the effectiveness of the measures taken, geological and operational characteristics of the wells were collected, which are presented in Tables 2–4.

Table 2 shows data on the wells in field I, where the bottomhole zone was treated with foams. Tables 3 and 4 provide geological and field data for wells in fields II and III, where the bottomhole zone was treated with solvents.

The influence of factors affecting the effectiveness of methods was assessed through correlation analysis of statistical data (Mirzajanzade et al., 1977). It was assumed that, in general, the following factors can influence the efficiency of bottomhole zone treatment:

Reservoir depth (H), thickness of the perforated area (h_{per}), oil viscosity (η_{oil}), specific gravity of oil (γ_{oil}), percentage of resins in the product, volume of injected solvent (V_s), specific gravity of the solvent (γ_s), reagent injection pressure (P_{inj}), time for completion of wells after treatment (t_{comp}), percentage of water in the product (W), operating mode of wells after treat-

Table 2. Geological and field data for wells where the bottomhole zone was treated with foams

Tabela 2. Dane geologiczne i złożowe dla odwiertów, w których strefa przyodwiertowa została poddana oczyszczaniu z zastosowaniem systemów pianowych

Data	α	h_{perf}	H	η_{oil}	% of resins	γ_s	γ_{oil}	P_{inj}	t_{comp}	$\%W$	$R_{w.ag.}$	V_s
α	1.0000											
H_{perf}	–0.0856	1.0000										
H	–0.0575	–0.2152	1.0000									
η_{oil}	0.1188	–0.4053	–0.1854	1.0000								
% of resins	0.3247	0.1721	–0.3526	0.2962	1.0000							
γ_s	0.1282	0.0491	–0.1701	0.3030	0.2370	1.0000						
γ_{oil}	0.2214	–0.0771	–0.4412	0.6005	0.5364	0.2017	1.0000					
P_{inj}	–0.0132	0.1562	0.0569	–0.1500	0.0706	–0.0328	–0.4212	1.0000				
T_{comp}	–0.0078	–0.2246	–0.0292	0.0920	–0.1302	–0.0344	0.2740	–0.4522	1.0000			
$\%W$	–0.0065	–0.0559	–0.3177	0.5761	0.6842	–0.0396	0.6452	0.0876	–0.0418	1.0000		
$R_{w.ag.}$	0.0981	–0.2777	0.0907	0.1247	0.1642	0.6038	0.0834	0.0844	0.0637	–0.0271	1.0000	
V_s	–0.0805	0.1440	0.3301	–0.5286	–0.6889	0.1895	0.7066	0.1922	–0.0693	–0.8794	0.1342	1.0000

Table 3. Geological and field data for wells of field II where the bottom-hole zone was treated with solvents

Tabela 3. Dane geologiczne i złożowe dla odwiertów złoża II, w których strefa przyodwiertowa została poddana oczyszczaniu rozpuszczalnikami

α	H	h_{perf}	η_{oil}	γ_{oil}	% of resins	V_s	γ_s	P_{inj}	t_{comp}	$\%W$	S	n	d
1.0000													
0.1576	1.0000												
0.2340	0.1403	1.0000											
0.0047	0.5575	0.1413	1.0000										
0.2235	–0.3186	0.2766	–0.1841	1.0000									
–0.0235	–0.1818	–0.1176	0.2509	0.1772	1.0000								
–0.0219	–0.0012	0.2696	0.1314	0.1740	0.2918	1.0000							
0.3668	0.4911	–0.0174	0.0521	–0.0471	0.0344	0.0271	1.0000						
0.1606	0.2706	0.3881	–0.1479	0.1960	–0.1281	0.3023	0.3030	1.0000					
–0.4843	0.0982	–0.5336	–0.0345	0.3470	0.2506	–0.2691	0.0662	–0.3603	1.0000				
–0.0886	0.0970	0.2231	0.2587	–0.2596	–0.0413	0.2769	–0.1071	0.1328	0.1038	1.0000			
0.0022	–0.1979	–0.1852	0.2815	0.1551	0.3870	0.1027	–0.3544	0.2810	–0.1628	0.0969	1.0000		
0.1284	–0.2154	–0.1102	–0.3097	0.1818	–0.3622	–0.0837	–0.1258	–0.1958	–0.1961	0.0313	–0.0386	1.0000	
–0.4740	–0.2463	–0.1406	–0.0736	0.1831	–0.0171	0.1417	–0.2114	–0.0357	0.2934	–0.2934	–0.0681	–0.0618	1.0000

Table 4. Geological and field data for wells of field III where the bottom-hole zone was treated with solvents

Tabela 4. Dane geologiczne i złożowe dla odwiertów złoża III, w których strefa przyodwiertowa została poddana oczyszczaniu rozpuszczalnikami

α	H	h_{perf}	η_{oil}	γ_{oil}	% of resins	V_s	γ_s	P_{inj}	t_{comp}	$\%W$	$R_{w.ag.}$
1.0000											
0.3350	1.0000										
–0.5174	–0.5939	1.0000									
–0.2426	–0.3093	0.5610	1.0000								
–0.4448	–0.5427	0.9305	0.0143	1.0000							
–0.1835	0.1434	0.1070	–0.1476	–0.0038	1.0000						
0.1503	0.6430	–0.3914	–0.2195	–0.3642	0.1413	1.0000					
–0.5456	0.3292	0.7967	0.4066	0.7317	0.1181	0.3717	1.0000				
0.3276	0.2846	–0.4253	0.0449	–0.2346	0.0174	0.1447	–0.3382	1.0000			
0.2913	–0.3118	0.6123	0.5564	0.6623	0.0328	0.1546	0.3449	0.0975	1.0000		
0.1870	0.4345	0.0111	–0.1103	–0.0489	0.0649	–0.1985	0.2011	–0.0644	–0.2795	1.0000	
–0.1112	–0.2687	0.0663	–0.0368	0.0434	–0.1937	0.3331	0.2218	–0.2088	0.1208	–0.2537	1.0000

ment, stroke length of the pump plunger (S), number of strokes (n), pump diameter (d), specific gravity of the working agent, and other data characterizing operating conditions.

The values of pairwise correlations between the ratio of flow rates before and after treatment and the above factors were calculated (Ballinas, 2014; Panait et al., 2018; Litvin et al., 2020).

The value of pair correlation was assessed using the following formula:

$$R_{xy} = \frac{\sum (x_i - \bar{x})(\alpha_i - \bar{\alpha})}{\sqrt{\sum_{i=1}^{N} (x_i - \bar{x})^2 \sum_{i=1}^{n} (\alpha_i - \bar{\alpha})}} \tag{1}$$

where:

x_i – the values of one of the factors,

$\bar{x}$ – the average value of the factor.

Such changes in these factors and the found significant values of pair correlation coefficients are presented in Tables 1–4.

The significance of the influence of individual factors was assessed by the magnitude of the pairwise correlation between the flow rate ratio and each factor. Factors were considered significant if the absolute value of the pairwise correlation exceeded the threshold corresponding to the 95% significance level. According to the results of the analysis, the main factors that significantly impact the flow rate ratio when treating a bottomhole with solvents are:

- for field I (horizon II) – percentage of resins in the product, specific gravity of the solvent, and time of well development after treatment;
- for field II – specific gravity of oil, specific gravity of solvent, injection pressure.

When treating the bottomhole with foams at field III, the main influencing factor was found to be the percentage of resins.

The effect on well productivity of a combination of all factors taken in various patterns was also studied. The joint influence of a group of factors assessed by calculating the value of the correlation ratio (CR) (Liu et al., 2018).

The combination of factors with the highest correlation ratio was selected. A change in the value of the correlation relationship was then determined by adding some factors and excluding others from the group under consideration (Gutorov, 2012, Shaheen et al., 2012). If this procedure resulted in noticeable increase, the change was considered positive. Thus, from all possible combinations, the pattern with the largest value of the correlation ratio was selected.

As a result, a correlation matrix of factors with the most significant impact on the studied parameter was obtained (Farias, et al., 2010; Castro and Morales, 2016; Temizel et al., 2016).

The value of the correlation ratio for the specified combination of factors is:

- for field III – 0.69;
- for field I (horizon II) – 0.78

for field II – 0.83. Excluding any of these factors results in a significant decrease in the value of the correlation ratio (CR).

Conclusions

1. The effectiveness of treating the bottomhole zone of wells with solvents is significantly influenced by factors such as the percentage of resins in the product, the specific gravity of oil before treatment, the viscosity of oil, and the specific gravity of the solvent.

2. Identification of these factors enables the correct selection of wells for treatment based on the impact on the bottom-hole zone of the well, as well as the evaluation of the effectiveness of the treatments performed.
3. Thermochemical methods are more effective for treating the near-wellbore zone of wells. These methods benefit from exothermic reactions that in the near-wellbore zone that release of gases, allowing the treatment to penetrate deeper into the formation. Additionally, their effectiveness is enhanced when wells are selected appropriately for near-wellbore zone treatment.

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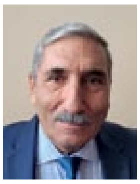

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