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Assessment of the results of acid implosion stimulation of the near-wellbore area based on statistical data

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Abstract. Assessment and planning of actions aimed at restoring and increasing well productivity are particularly important for objects in carbonate reservoirs. Consideration of the conditions of implementation allows to increase the efficiency. The paper summarizes the conditions and technological results of the highly efficient acid implosion stimulation (AIS) of the near-wellbore area of the oil wells of a specific production facility. The technology combines producing hydrochloric acid baths and using an implosion device that ensures repeated depression and impact stimulation. The method of multiple regression was used to determine the dependencies of the efficiency of the AIS on the geotechnical parameters that characterize the geophysical properties of a formation, the technological specifics of operation of the formation and the well, and the stimulation technology. Comparing the results of geostatistical modeling for the AIS and hydrochloric acid treatment allowed to identify the differences in the nature of the factors' impact on the results of applying these technologies. AIS efficiency increases along with the deterioration of geotechnical conditions of usage and repeated stimulation is possible on different stages of well operation. The nature of the connections between the conditions and the results of AIS implementation can be considered when selecting new objects of stimulation (wells, reservoirs) and determining the design of stimulation.

1. Introduction

Extraction of oil from low-production facilities in carbonate deposits is maintained and (or) intensified by stimulation of the near-wellbore areas using hydrochloric acid solution.

Much experience of implementing such kind of stimulation in different technological variants has been gained; for example, it can be carried out in the following way: hydrochloric acid treatment (HAT) – targeted HAT (THAT) – deep HAT (DHAT) – complex stimulation, for example, shockwave stimulation (SWS) – acid fracturing (AF) – use of stimulating acid compositions (SAC). Varying the nature and scope of stimulation ensures the gain in oil flow.

Industry standards provide for a statistical assessment of the trend in the dynamics of the performance indicators of a well (group of wells). The degree of deviation of the actual data obtained after the treatment of the basic values characterizes the size of effect.

It should be noted that it is important to assess the conditions of using the technology, distinguishing between the geophysical and technological parameters. Results of the analysis and summary of the efficiency of stimulation technologies using hydrochloric acid compounds are available [1-3].

Knowledge and consideration for the conditions of the efficient application of each technology for particular production facility ensures:

- the realization of the potential possibilities of a technology;
- the possibility to compare the conditions of use of different technologies with the goal of selecting the most efficient variants;
- the possibility to disseminate the experience of effective stimulation in wells of similar production facilities.

Solving these goals improves the results of separate actions as well as the process of production as a whole.

2. Materials and methods

The paper summarizes the conditions and results of acid implosion stimulation (AIS) [4] of 50 vertical and directional wells of the Kizel horizon of the Bavly oilfield. This technology is a variant of the shockwave stimulation for oil wells that extract from carbonate deposits. It is also proposed for horizontal wells [5]. According to the current experience, complex stimulation of the near-wellbore are is more efficient.

The low-permeability heterogeneous fractured-porous reservoirs of the Kizel horizon are saturated with sulfurous highly resinous waxy highly-viscous heavy oil. The average depth to the top is 1240 m, the effective oil- and water-saturated thicknesses are 5.78 and 7.11 m respectively, the net sand ratio is 0.488, the sand-shale ratio is 1.558, the porosity ratio is 0.11, the initial oil saturation is 0.634, the permeability is 0.005-0.010 μm^2, the in situ oil viscosity is 20.8 MPa/s. Heterogeneity is the main geological reason that complicates oil extraction in carbonate reservoirs.

Test production of the Tournaisian stage was carried out in 1957-1959. The low oil flow rates were obstructing the assignment of the status of an independent production facility to the Kizel horizon. The flow rates were maintained at the level of one ton per day by using hydrochloric acid treatment and increased to 3-10 t/day by using the technologies of AOCC (creating artificial oil-collecting cavities) and THAT.

Conventional hydrochloric acid treatment increases the degree of heterogeneity of the reservoir due to the sharp rise in the permeability of fractures in the acid effect area.

Unlike the conventional HAT, AOCC involves performing four- to sevenfold large-volume acid baths with gradually rising (by 10-15%) volumes of hydrochloric acid that were pressed into the annular space without injecting into the near-wellbore area. Well flow increases 1.5-2 times, moreover, the lesser the initial flow, the larger the relative effect; the effect lasts at least a year. In order to clear the near-wellbore areas of the reaction products, treatment could be augmented by well drainage using a well test package (WTP).

In the case of AIS, the preliminary stage of treatment includes clearing the production column of heavy oil deposits (HOD). Partial pressing of the solvent into the near-wellbore area of the formation is possible.

The main stage includes the performance of repeated hydrochloric acid baths. The initial specific flow of the acid solution per meter of the perforated thickness of the formation is two times smaller than for the conventional HAT.

After each acid bath, the near-wellbore area and shaft of the well can be cleared of reaction products and remains of the acid by flushing, swabbing, or implosion stimulation by a shockwave device (a sucker-rod pump with a sealed bottom part and holes in the pump's casing). The pump's plunger is moved by a workover rig. A change of tactics is possible: from pumping out the products of the acid's reaction with the formation to the dynamic mode of reaction during the reaction of the acid solution with the formation.

All operations are performed in the well-killing fluid (oil) [6].

The shockwave device (vacuum pump) constructively ensures both effects of the implosion stimulation: the depression stimulation and the water hammer effect on the near-wellbore area of the formation [7]. Transporting the particles away from the near-wellbore area requires a sharp increase in the fluid velocity. Water hammer pressure depends on the properties of the well fluid and the depth of the perforated interval. As indicated by the experience of well operation, cement rock is not disintegrated after the treatments. The advantage of this technology is the frequency of stimulation. The average frequency of pressure impulses is 50 per hour.

Over 300 treatments were carried out in the period between 1997 and 2010, including no less than 100 treatments in horizontal wells. Treatment results were intermittently summarized [8]. Assessment of AIS results includes the comparison with the basic level of 600 tons of incremental oil recovery achieved with the method of AOCC.

To summarize the experience of using AIS using the multiple regression technique, it is proposed to use the technological efficiency indicators as independent variables: the absolute y_1 (t/day) and the relative y_2 (%) initial oil flow gains, the absolute y_3 (%) and the relative y_4 (%) decrease in the water cut, the incremental oil recovery $y_5 = \Delta Qo$ (t), $y_6 = T$ (days) [9].

The following were selected as the independent variables influencing the AIS efficiency: the effective oil-saturated thicknesses of the formation in the well $H_{o.e.,}$ m; the average thickness of oil-saturated streaks in the well H_s, m; the number of oil-saturated streaks in the well n, units; 4. Weighted average of the formation porosity ratio according to GIS data m, %; oil saturation K_o, units; share of the reservoir formations to the total formation thickness K_f, units; height to the aquifer h_h, m; time from well operation start to AIS t, days; maximum well flow before AIS $q_{o.max}$, t/day; well flow at the moment of AIS q_{o1}, t/day; water cut of the well product at the moment of AIS f_1, %; cumulative oil production at the moment of AIS $Q_{o.cum}$, t; current formation pressure at the moment of AIS P_{fr}^{cur}, MPa; relative reduction of the formation pressure at the moment of AIS (relation of the current formation pressure to the initial one) $P_{fr}^{cur}/P_{fr}^{ini}$, %; heavy oil deposit solvent volume (to clear the production column without overflush) V_{HODs}^{wll}, m^3; heavy oil deposit solvent volume (for overflush) V_{HODs}^{fls}, m^3; volume of the inhibited hydrochloric acid, V_a, m^3; concentration of the inhibited hydrochloric acid C, %; number of acid injection cycles, $n_{a.c.}$, units; total number of double plunger strokes of the device $n_{d.s.}$, units; number of swabbing operations n_{swab}, units; AIS multiplicity N, units.

3. Results, Discussion

The results of the multiple correlation for the efficiency parameters of the acid implosion stimulation in the wells of the Kizel horizon of the Bavly oilfield are presented in the table. For the regression equations, the constraint force for the relative reduction in water cut of the product is noticeable, for other indicators it is high.

For the selected group of wells, the generalized conditions of implementing the technology are characterized by the following average parameters: oil flow: 1.9 t/day, fluid flow: 2.3 t/day, fluid water cut: 18.7 %. The average efficiency indicators were: initial oil flow gain: 1.6 t/day, incremental oil recovery: 1778 t, duration of effect: 42 months.

The value of the standardized regression coefficient β_i (Beta coefficient) in the regression equation allows to compare the relative contribution of each independent variable x_i to the forecast of the dependent variable y_i. If the regression coefficient under x_i is positive, the larger the increment of x_i, the higher the efficiency indicator (the dependence is reverse for the relative reduction of the formation pressure at the moment of treatment).

In the table of results, variables are arranged in groups. Variables x_1-x_7 characterize the formations' geophysical properties, x_8-x_{14} represent the technological features of formation and well operation, and x_{15}-x_{22} describe the technology of stimulation. The last group includes formation pressure because shockwave parameters are determined by the pressure under which the implosion chamber is filled.

Table. Regression results for the acid implosion stimulation efficiency results

Independent variable x_i		Standardized regression coefficient β_i (Beta) in the equation of the dependent variable y_i					
		$y_1=q_{o2}-q_{o1}$, t/day	y =($q_{o1}-q_{o2})/q_{o1}$, %	$y_3=f_1-f_2$, %	$y_4=(f_1-f_2)/f_1$, %	$y_5=\Delta Q_o$, t	y_6=T, days
x_1	$H_{o.e.}$, m	0.324133	0.257049	0.174384	0.0171720	-0.095078	0.074699
x_2	H_s, m	-0.673359	-0.287439	-0.266647	-0.170245	-0.502504	-0.505040
x_3	n, units	-0.541403	-0.243624	-0.188612	-0.209742	-0.310833	-0.571884
x_4	m, %	-0.170979	-0.030628	-0.016057	0.044790	0.256696	0.217586
x_5	k_o, %	0.380733	0.513021	0.239775	0.123159	0.097602	0.270255
x_6	K_f, units	0.031574	-0.067259	-0.118125	-0.169824	0.259262	0.100274
x_7	h_a, m	0.342425	0.227825	0.161388	0.181552	0.209843	0.098126
x_8	t, days	-0.199559	-0.185831	-0.033720	0.035352	-0.157483	-0.304115
x_9	$q_{o.max}$, t/day	-0.133041	-0.221302	-0.159393	-0.144560	-0.260711	-0.074126
x_{10}	q_{o1}, t/day	-0.371522	-0.669459	-0.200904	-0.119357	-0.305493	-0.510880
x_{11}	f_1, %	-0.293429	-0.115043	0.755201	0.368589	-0.460469	-0.417861
x_{12}	$Q_{o.cum}$, t	-0.012593	-0.016488	-0.019920	-0.029119	0.159910	0.081370
x_{13}	P_{fr}^{cur}, MPa	0.114131	0.186732	0.048396	-0.082726	0.315996	0.262930
x_{14}	$P_{fr}^{cur}/P_{fr}^{ini}$, %	-0.156861	-0.077568	0.020273	-0.062364	-0.300482	-0.115533
x_{15}	V_{HODs}^{wll}, m^3	0.113788	0.070580	0.018511	0.018711	0.486919	0.493898
x_{16}	V_{HODs}^{fls}, m^3	0.513624	0.406237	0069892	0.207858	0.219217	0.065865
x_{17}	V_a, m^3	-0.273462	-0.293030	-0.481777	-0.393381	-0.299892	-0.505713
x_{18}	C, %	-0.074684	-0.038642	-0.175803	-0.219959	0.141882	0.101993
x_{19}	$n_{a.c.}$, units	0.081101	0.121277	0.248363	0.222220	0.058505	0.429127
x_{20}	$n_{d.s.}$ units	-0.115220	-0.097781	0.246300	0.215227	-0.057316	-0.141056
x_{21}	n_{swab}, units	0.102690	0.095223	0.352113	0.298452	0.010464	0.149608
x_{22}	N, units	0.215681	0.164907	-0.065105	0.001332	0.291404	0.074699

A number of parameters have the same or almost the same nature of influence on all parameters of efficiency. Indicators improve in case of increasing the effective oil-saturated thicknesses of the formation in the well $H_{o.e.}$, oil saturation K_o, height to the aquifer h_h, relative reduction of the formation pressure at the moment of AIS relation of the current formation pressure to the initial one) $P_{fr}^{cur}/P_{fr}^{ini}$, heavy oil deposit solvent volume to clear the production column V_{HODs}^{wll} and that for overflush V_{HODs}^{fls}, the number of acid injection cycles $n_{a.c.}$ and swabbing operations n_{swab}, as well as in case of reducing the average thickness of oil-saturated streaks H_s and their number n in the well, the maximum well flow before AIS $q_{o.max}$, well flow at the moment of AIS q_{o1}, volume of the inhibited hydrochloric acid V_a and its concentration C.

Influence of a part of the variables is minimal, for example, that of cumulative oil production at the moment of AIS $Q_{o.com}$. As a rule, the relative reduction in the formation pressure at the moment of treatment is in the group of parameters with a smaller degree of influence.

Increasing the effective thicknesses of the formation $H_{o.e.}$ has a positive effect on the efficiency of the acid implosion stimulation except for the incremental oil recovery, for which this parameter has an insignificant negative impact. The possibility to move the device along the perforated interval ensures the targeted nature of stimulation.

Increasing the weighted average of the reservoir porosity thickness m reduces the initial oil flow gain as a result of AIS.

Using a solvent increases AIS efficiency. Injection of a part of the solvent volume into the formation was carried out in fave wells out of 50 in the studied group.

Acid concentration has a lesser impact on the results. According to the recommendations for selecting objects for main acid compositions for non-deep, superficial treatments, acid baths, and oil-collecting cavities at the average permeability (at least 0.03 μm^2) and porosity (at least 7%), it is possible to use hydrochloric acid with the concentration of 15%.

The positive effect of repeated stimulation is explained, among other things, by the increase of the radius of impact that is accounted for by increasing the specific flow of acid for further cycles.

During AIS, it is possible to observe the different nature of the influence of independent variables on oil flow gain, incremental recovery, and the absolute $y_3=f_1-f_2$ and relative $y_4=(f_1-f_2)/f_1$ decrease in the initial product water cut. This concerns, first of all, the stimulation design parameters. The total number of the device plunger's double strokes $n_{d.s.}$ is insignificant but has a negative effect in the oil flow gain and the incremental oil recovery and, conversely, positively affects the initial reduction in the water cut in the well's product. Furthermore, the contribution to regression for water cut of the well product at the moment of AIS is positive for the decrease of water cut $y_3=f_1-f_2$ и $y_4=(f_1-f_2)/f_1$ and negative for other efficiency indicators, which means that the higher the water cut in the fluid at the moment of AIS, the more significant its reduction during the initial stage of the efficient period but the less the initial oil flow gain, its incremental recovery, and the duration of the effect.

The nature of the influence of independent variables on the absolute $y_1=q_{н2}- q_{o1}$ and relative y $=(q_{o1}-q_{o2})/q_{o1}$ initial oil glow gains and the incremental oil recovery $y_5 = \Delta Qo$ can be considered separately and compared with the results for HAT [10-12].

Both technologies are marked with the increase of the mentioned efficiency indicators with the increase in oil saturation K_o, current formation pressure at the moment of AIS P_{fr}^{cur}, relative reduction of the formation pressure at the moment of AIS relation of the current formation pressure to the initial one) $P_{fr}^{cur}/P_{fr}^{ini}$ and the decrease in time t from well operation start to the moment of the stimulation.

Unlike HAT, the indicators for AIS improve with the decrease of the average thickness of oil-saturated streaks in the well H_s (i.e. with the degradation in the formation's collecting properties), maximum well flow before the treatment $q_{o.max}$, well flow at the moment of treatment q_{o1}, volume of the inhibited hydrochloric acid V_a and its concentration C, as well as with the increase of the stimulation multiplicity N.

The higher efficiency of AIS in wells with degraded collection properties is explained by the formation of new cracks and opening of the existing ones, which ensures a higher influx of fluid from the formation to the wellbore.

The absence of a clear negative influence of multiplicity on AIS results can be related to the fact that implosion affects not only the solid rock mass but also the fluid saturating it, and this effect increases with the increase of the formation's permeability relative to the system inside it.

4. Conclusion

The influence of geotechnical parameters on the results of acid implosion stimulation of near-wellbore areas of a particular production facility has been justified. Unlike HAT, the efficiency of stimulation increases with the decrease in geotechnical conditions. This type of stimulation can be recommended for repeated application in low-flow wells on different stages of operation.

Factoring in the dependencies during selection of wells with a specific geological and industrial character of the technological parameters of stimulation design allows to fulfill the potential of stimulation for the chosen production facility.

Comparing the conditions of application of different technologies ensures the selection of the most efficient options.

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