



Brief report

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Multilateral stimulation technology as an alternative to hydraulic fracturing for carbonate reservoirs with thin oil rims

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Abstract. The paper considers Multilateral Stimulation Technology, a wellbore stimulation technology designed to enhance oil recovery in carbonate reservoirs with low vertical permeability and low effective oil pay. The purpose of the study is to analyze Multilateral Stimulation Technology efficiency in reservoirs with oil rims thinner than 5 m in highly heterogeneous and fractured rock conditions. The object of research is horizontal and directional wells equipped with radial formation drilling system using retractable needles. The subject of the study is technological features of Multilateral Stimulation Technology application including modifications involving acidizing of the rock ahead of the nozzle and mechanical drilling with turbine-driven mini-bits. The research methods include field data analysis, a review of international and domestic experience, interpretation of field results, as well as a comparative assessment with traditional hydraulic fracturing. The mechanisms of radial laterals formation, the influence of geological factors on technology efficiency, and filtration process modeling features are examined. The study results demonstrate that Multilateral Stimulation Technology provides a controlled increase in reservoir drainage volume, reduces the risk of water and gas breakthrough, and increases well productivity by 2–4 times compared to untreated wells. Acid activation and turbine drilling significantly increase the penetration depth and stability of lateral channels. The technology was found to be most effective in carbonate reservoirs with permeability of 0.1–10 mD and a low Kv/Kh ratio. It is concluded that Multilateral Stimulation Technology represents a promising alternative for developing thin oil rims and hard-to-recover reserves in the Russian Federation, offering a controlled substitute for conventional hydraulic fracturing.

Keywords: multilateral stimulation, Fishbones, carbonate reservoir, thin oil rim, radial laterals, acidizing, mini-bit, turbine drive, low vertical permeability, production stimulation

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Краткое сообщение

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Многосторонняя стимуляция пласта как альтернатива гидравлическому разрыву для карбонатных коллекторов с тонкими нефтяными оторочками

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Резюме. Рассмотрена технология многосторонней стимуляции ствола скважины (Multilateral Stimulation Technology), предназначенная для повышения нефтеотдачи в карбонатных коллекторах с низкой вертикальной проницаемостью и малой эффективной нефтенасыщенной толщиной. Целью исследования является анализ эффективности Multilateral Stimulation Technology при разработке тонких нефтяных оторочек мощностью менее 5 м в условиях высокой неоднородности и трещиноватости пород. В качестве объекта исследования рассмотрены горизонтальные и наклонно-направленные скважины, оборудованные системой радиального вскрытия пласта с использованием выдвигаемых игл. Предметом исследования являются технологические особенности применения Multilateral Stimulation Technology, включая модификации с кислотным разрушением породы перед соплом и механическим бурением мини-долотами с турбинным приводом. Методы исследования включают анализ промысловых данных, обобщение зарубежного и отечественного опыта, интерпретацию результатов эксплуатации, а также сравнительную оценку с традиционным гидроразрывом пласта. Рассмотрены механизмы формирования радиальных каналов, влияние геологических факторов на эффективность технологии и особенности моделирования процессов фильтрации. Результаты исследования показывают, что Multilateral Stimulation Technology обеспечивает контролируемое увеличение



дренируемого объема пласта, снижение риска прорыва воды и газа, а также повышение коэффициента продуктивности скважин в 2–4 раза по сравнению с необработанными аналогами. Использование кислотной активации и турбинного бурения повышает глубину и стабильность проникновения боковых каналов. Установлено, что технология наиболее эффективна в карбонатных коллекторах с проницаемостью 0,1–10 мД и низким отношением Kv/Kh . Сделан вывод о высокой перспективности Multilateral Stimulation Technology для вовлечения трудноизвлекаемых запасов в тонких нефтяных оторочках, а также о целесообразности ее широкого внедрения на месторождениях Российской Федерации в качестве альтернативы неконтролируемому гидроразрыву пласта.

Ключевые слова: многосторонняя стимуляция, Fishbones, карбонатный коллектор, тонкая нефтяная оторочка, радиальные каналы, кислотная обработка, мини-долото, турбинный привод, низкая вертикальная проницаемость, интенсификация добычи

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Introduction

The development of carbonate reservoirs with low effective oil pay and the close location of water-oil and gas-oil contacts is one of the most difficult challenges of the oil and gas industry [1, 2]. In such conditions, the use of hydraulic fracturing is often accompanied by uncontrolled crack growth and premature well flooding [3].

Numerous studies indicate a decrease in the efficiency of hydraulic fracturing in naturally fractured and stratified reservoirs due to their high sensitivity to the stress state of the reservoir [4, 5]. As a result, there is a water cut increase, a decrease in oil recovery, and an increase in operating expenses [6].

As an alternative approach, the multilateral stimulation technology, implemented in Fishbones and Multilateral Jetting Stimulation Technology (MJST) systems, has been developed in foreign practice [7, 8]. This technology is based on designing a system of radial lateral channels that provide mechanical connection of the well and remote zones of the formation (Fig. 1).

Recent work has shown that the geometry of such systems can be described effectively using embedded discrete cracks of the EDFM (Embedded Discrete Fracture Model)¹ [9–11]. This made it possible to consider the lateral channels as an analogue of controlled microcracks.

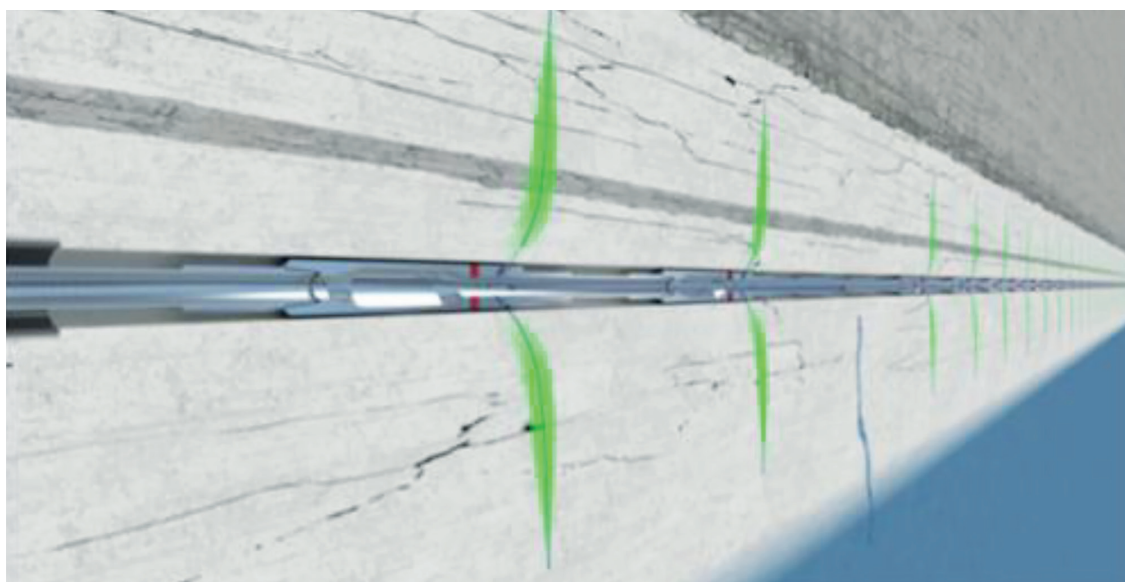


Fig. 1. Needles in activated position, monitoring of the distance to the unwanted fluid
Рис. 1. Иглы в активированном положении, контроль расстояния до нежелательного флюида

¹ Moinfar A. *Discrete fracture modeling of tight and naturally fractured reservoirs: PhD thesis*. Stanford: Stanford University; 2013, 240 p.



The relevance of this study is determined by the need to systematise the accumulated experience of using the MST (Multilateral Stimulation Technology) and assess its potential for developing thin oil rims in conditions typical for deposits in the Russian Federation [12].

The purpose of this work is a systematic analysis of the effectiveness of the multilateral stimulation technology in developing carbonate reservoirs with thin oil rims, as well as substantiation of its advantages over traditional methods of inflow intensification, including hydraulic fracturing, based on the analysis of modern research and field data [13, 14].

Materials and methods

The source database. The authors use the method of analytical literature review, which includes systematisation and critical analysis of modern foreign and domestic publications on the technology of multilateral well stimulation and radial formation drilling:

- publications on MST and MJST in SPE and SOCAR Proceedings [7, 8, 15];
- materials by Fishbones AS and Schlumberger² [16, 17];

- results of laboratory tests of acid systems [18];
- hydrodynamic modeling data [9–11];
- reports on field tests³ [12, 19].

In contrast to the experimental studies presented in the primary sources, this work summarises the results and interprets them in relation to the conditions of the carbonate reservoirs of the Russian Federation⁴ [20].

The design of the MST system. The MST system includes couplings with radial channels, retractable needles, hydraulic chambers, acid-soluble elements, and a cutting tool for restoring the bore section [16].

After installing the liner and the liner packer, hydraulic activation is carried out. As a result, the needles are introduced into the formation under the influence of the pressure from the power fluid [7].

Acid penetration technique. The acid modification of the MST uses hydrochloric acid supplied under pressure through needle nozzles (Fig. 2) [18].

The acid destroys the carbonate matrix, reducing the penetration resistance and forming expanded channels [21]. The tests were carried out in pressure chambers with extrapolation to formation conditions [18].

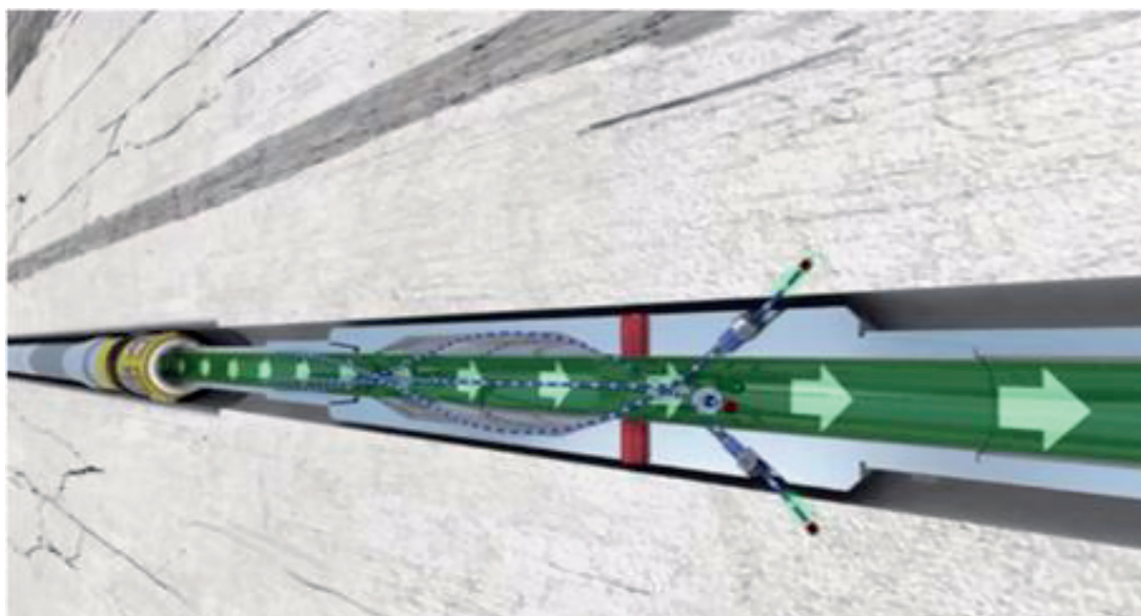


Fig. 2. Introduction of needles into the formation by pumping hydrochloric acid under pressure
Рис. 2. Внедрение игл в пласт благодаря прокачиванию под давлением соляной кислоты

²Schlumberger. *Fishbone wells Technical Report*. Houston; 2014, 80 p.

³Deloitte. *Oilfield service market review*. London; 2019, 120 p.

⁴Ahmed T. *Reservoir engineering handbook*. 2010, 1472 p.



The mechanical drilling technique. In the mini-bit modification, turbine drives, operating by pumping the solution, are used (Fig. 3) [8].

This system ensures stable drilling of dense limestones and dolomites with minimal lateral drift [17].

Hydrodynamic simulation. Triple porosity models using the EDFM were used to analyse filtration processes [9, 10].

The simulation included:

- reconciliation of mining history;
- sensitivity analysis;
- optimization of the number of channels;
- assessment of drainage zones [11].

Results and discussion

The presented results are based on a set of field data, the results of hydrodynamic simulation and laboratory studies of the interaction of acid solutions with carbonate rock.

Field implementations. According to published data, the MST and MJST systems have been implemented in more than 120 wells in North America, Norway and the Middle East [7, 15, 16].

The technology has been used in production and injection wells, including offshore fields [17].

The effectiveness of radial formation drilling. Field data show a steady increase in oil production and a decrease in the skin factor [7, 12].

Radial channels effectively bypass the damage zones of the bottomhole zone, forming equal inflow distribution [4].

Sensitivity analysis. Sensitivity analysis revealed the influence of the number of channels on the cumulative production [11].

It was found that an increase in the number of branches to 8–12 provides the maximum increase, which leads to the saturation effect [11].

With 15 channels, the productivity index exceeded the basic version by 3.3 times [11].

Laboratory and bench tests. Tests of acid systems revealed the dependence of the dissolution rate on pressure and temperature [18, 21].

Additionally, the results of laboratory studies of the interaction of hydrochloric acid with carbonate cores, conducted during modelling of formation conditions, were used. It was found that using solutions of hydrogen chloride (HCl) with a concentration of 12–15%, a more intensive dissolution of the carbonate matrix occurs with the formation of solution channels and an increase in permeability by 2–5 times compared with the initial values.

It has been shown experimentally that the rate of dissolution of carbonate rocks depends on their mineral composition and textural features. The most intense dissolution was observed in rocks containing an increased amount of dolomite and characterised by a developed secondary porosity system (Fig. 4).

The experimental results showed that acidizing intensely destroys the carbonate rock matrix. In the number of samples, the degree of the rock dissolution exceeded 80%, which indicates a significant change in the structure of the pore space.

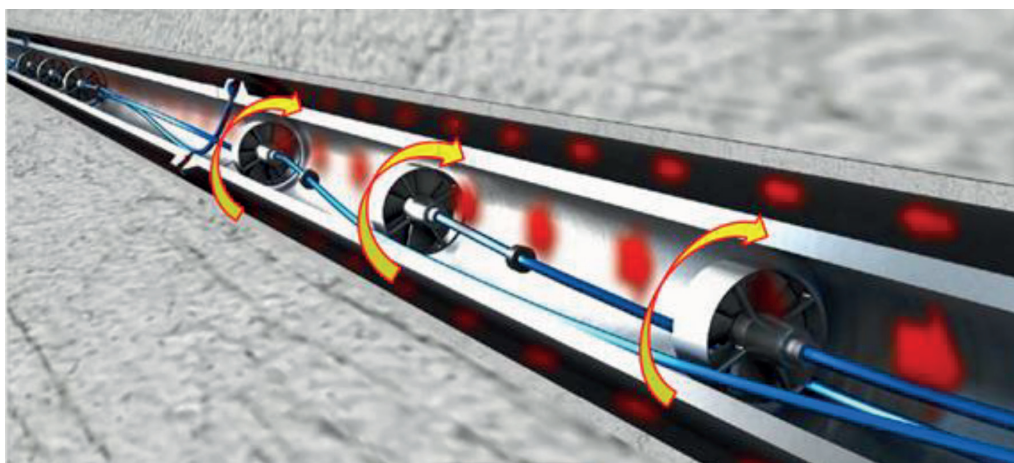


Fig. 3. Turbine drives (mini-bit modification)
Рис. 3. Турбинные приводы (модификация с мини-долотами)

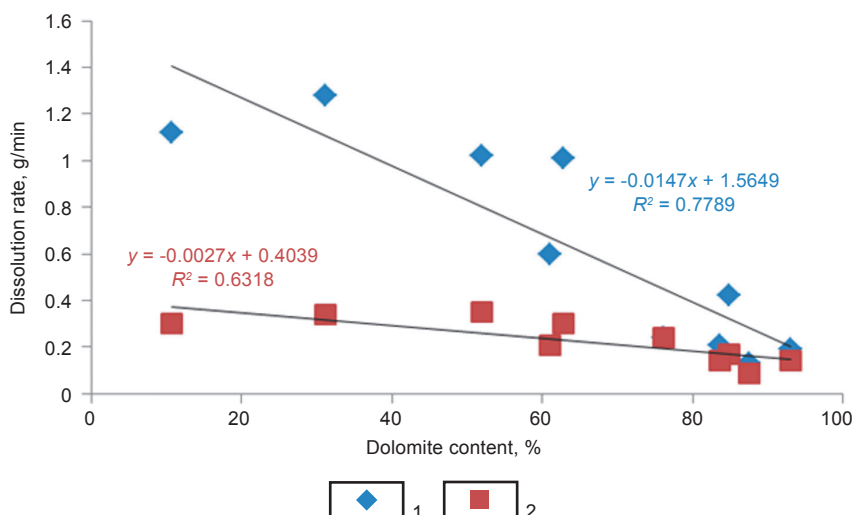


Fig. 4. Degree of rock dissolution vs time of exposure to hydrochloric acid:

1 – reaction rate in 15 min; 2 – reaction rate in 1 hour

Рис. 4. Зависимость степени растворения породы от времени воздействия соляной кислоты:

1 – скорость реакции за 15 мин; 2 – скорость реакции за 1 ч

As can be seen from Fig. 5, acidizing leads to the rock destruction and the formation of directional solution channels, providing a sharp increase in permeability. This mechanism is key in the implementation of the acid modification of the MST and provides a reduction in needle introduction resistance.

The results obtained are consistent with foreign studies of acidizing of carbonate reservoirs, where the formation of so-called wormholes is noted, providing an effective fluid influx [22, 23].

A comparative analysis with the modelling results of hydraulic formation fracturing showed that when using hydraulic formation fracturing, there is a high probability of a crack going beyond the oil zone, which leads to premature flooding of products.

At the same time, the use of MST technology ensures a localised impact on the formation and the development of channels strictly within the pay zone. Calculations show that when using the

MST, the reserve involvement ratio increases by 20–35% compared to hydraulic formation fracturing during the development of thin oil rims.

The results obtained are confirmed by foreign studies, which note the advantage of controlled radial channels over hydraulic fractures in conditions of high reservoir heterogeneity [24, 25].

Tests of the cutting tool have confirmed stable operation at axial loads up to 1,500 kg [17].

Comparison with hydraulic formation fracturing. Unlike hydraulic formation fracturing, the geometry of the MST channels is set structurally and does not depend on the stress field [3, 5].

It ensures a high level of controllability of the stimulation process and minimises the risks of water and gas breakthrough [6].

Configuration optimisation. The presence of a production saturation point indicates the need for optimal design of the number of channels [11].



Fig. 5. Changes in the structure of the carbonate core before (a) and after (b) acidizing

Рис. 5. Изменение структуры карбонатного зерна до (a) и после (b) кислотного воздействия



An excessive number of branches increases a capital cost index without a proportional increase in production [8].

System reliability. The development of control systems for the removal of solid particles made it possible to adapt the technology to soft cretaceous rocks [15].

It reduces the risk of clogging and a collapse of channels [17].

Limits of the technology. The main limits of the MST are the following:

- the complexity of scaling laboratory data [18];
- dependence on the quality of drilling fluids [7];
- the need for a drilling rig for the MJST [8];
- high demands on engineering maintenance [12].

Conclusion

Based on the analysis of literature sources and field data, it has been established that the multilateral stimulation technology is an effective tool

for increasing oil recovery in carbonate reservoirs with thin oil rims [7, 12].

The main conclusions:

1. The MST provides controlled expansion of the formation drainage zone [8, 16].
2. Radial channels allow us to bypass damaged areas and reduce the skin factor [4].
3. Acid and mechanical modifications expand the scope of the technology [17, 18].
4. The EDFM modelling confirms the existence of an optimal number of channels [9–11].
5. The increase in the productivity index reaches 3–4 times [11].
6. The technology is promising for implementation in the fields of the Russian Federation [12, 19].

Thus, the MST can be considered as a scientifically based alternative to traditional hydraulic formation fracturing in the development of hard-to-recover reserves of carbonate reservoirs.

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