PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

DETALHES DA TECNOLOGIA DE CONTROLE DE POÇO DURANTE A OPERAÇÃO EM CONDIÇÕES COMPLICADAS

SPECIFICS OF WELL KILLING TECHNOLOGY DURING WELL SERVICE OPERATION IN COMPLICATED CONDITIONS

ОСОБЕННОСТИ ТЕХНОЛОГИИ ГЛУШЕНИЯ СКВАЖИН ПРИ ПОДЗЕМНОМ РЕМОНТЕ В ОСЛОЖНЕННЫХ УСЛОВИЯХ

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RESUMO

O processo das operações de controle de poços no campo de condensado de petróleo e gás na província de Volga-Ural é complicado devido a diversas condições como reservatório de carbonato fraturado, pressão do reservatório anormalmente baixa, alta relação gasóleo, alto teor de sulfeto de hidrogênio, fraturamento com ácido e tratamentos com ácido clorídrico. Durante o processo de controle de poço, observam-se avanços significativos de gás e perda de fluido neste campo, o que requer uso significativo de composições de bloqueio (até 50-100 m^3 por poço único) e aumenta os custos de serviço do poço. O objetivo deste trabalho foi aumentar a eficiência da extração de poços durante o serviço, estudando os mecanismos que ocorrem perto da zona do poço durante este processo. A aplicação da análise estatística e multifatorial dos processos de abate de poços foi realizada de 2018 a 2019, o que permitiu destacar as principais razões para o baixo sucesso desses trabalhos. Os resultados do cálculo mostraram que o estado de tensão próximo ao poço difere significativamente do campo de tensão regional e varia de acordo com a pressão gerada no poço, que por sua vez afeta a atividade de fraturas próximas ao poço. Os mecanismos revelados que ocorrem perto da zona do poço, juntamente com os testes laboratoriais e piloto das composições de bloqueio, podem ser usados para melhorar as operações de serviço do poço no campo de condensado de petróleo e gás na província de Volga-Ural. Neste trabalho, concluiu-se que é importante usar a abordagem geomecânica para aumentar a eficiência de abate de poços em combinação com um complexo de testes reológicos e de filtragem de laboratório de composições bloqueadoras.

Palavras-chave: *operação de serviço de poço, modelagem geomecânica, análise multifatorial, fluido de emulsão invertida, gel de polímero reticulado.*

ABSTRACT

The process of the well killing operations in the oil and gas condensate field in Volga-Ural province is complicated due to several conditions like fractured carbonate reservoir, abnormally low reservoir pressure, high gas-oil ratio, high hydrogen sulfide content, acid fracturing, and hydrochloric acid treatments requirement. During the well killing process, significant gas breakthroughs and fluid loss are observed in this field, which requires significant usage of blocking compositions (up to 50-100 m3 per single well) and increases the well service costs. The aim of this work was to increase the well killing efficiency during well service by studying the mechanisms that take place near the wellbore zone during this process. The application of statistical and multifactor analysis of well-killing processes were conducted from 2018 to 2019, which allowed highlighting the main reasons for the low success of these works. The calculation results showed that the stress state near the well significantly differs from the regional stress field and varies depending on the generated pressure in the well, which in turn affects the activity of fractures near the wellbore. The revealed mechanisms that take place near the wellbore zone coupled with the laboratory and pilot tests of the blocking compositions can be used to improve the well service operations at the oil and gas condensate field in the Volga-Ural province. In this work, it was concluded that it is important to use the geomechanical approach to increase the well killing efficiency in combination with a complex of laboratory rheological and filtration tests of blocking compositions.

Keywords: *well service operation, geomechanical modeling, multifactor analysis, invert emulsion fluid, cross-*

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linked polymer gel.

АННОТАЦИЯ

Процесс глушения скважин на нефтегазоконденсатном месторождении Волго-Уральской провинции сопровождается осложненными условиями: трещинно-поровый карбонатный коллектор; аномально-низкое пластовое давление; высокий газовый фактор; высокое содержание сероводорода; проведение кислотных гидроразрывов пласта и солянокислотных обработок. На данном месторождении в процессе глушения наблюдаются значительные прорывы газа и поглощения жидкостей пластом, что подразумевает большие объемы закачки блокирующих составов (до 50-100 м^3 на 1 скважину) и, соответственно, приводит к удорожанию данной операции при подземном ремонте скважин. Целью данной работы является повышение эффективности глушения нефтяных скважин в осложненных условиях путем изучения механизмов, происходящих в прискважинной зоне при подземном ремонте. Использование статистического и многофакторного анализа процессов глушения скважин за период 2018-2019 гг. позволило выделить основные причины низкой успешности данных работ. Результаты расчетов показали, что напряженное состояние вблизи скважины существенно отличается от регионального поля напряжений и меняется в зависимости от создаваемого давления в скважине, что в свою очередь влияет на активность трещин вблизи ствола скважины. Выявленные механизмы, происходящие в прискважинной зоне, в сочетании с лабораторными исследованиями и опытно-промысловыми испытаниями блокирующих составов, могут быть использованы для совершенствования процесса организации работ по глушению скважин в условиях нефтегазоконденсатного месторождения Волго-Уральской нефтегазоносной провинции. В данной работе сделан вывод о важности использования геомеханического подхода для повышения эффективности глушения нефтяных скважин в сочетании с комплексом лабораторных реологических и фильтрационных исследований блокирующих составов.

Ключевые слова: *глушение скважин, геомеханическое моделирование, многофвкторный анализ, жидкости глушения, инвертно-эмульсионный раствор, сшитый полимерный состав.*

1. INTRODUCTION:

Development complexity of the oil and gas condensate field in Volga-Ural province is primarily due to geological characteristics since carbonate fractured reservoirs with a high gas-oil ratio and high hydrogen sulfide content dominate in productive formations. The presence of fractures in the creation requires a unique, differentiated approach to planning operations for killing wells associated with the choice of the type of blocking composition. Currently, manufacturers of chemical reagents offer many brands of various blocking compositions for well killing operation, but not all of them satisfy the requirements for such technological fluids. Therefore, the correct selection of blocking compositions for killing wells requires careful laboratory research for specific objects of the planned application. Failure to comply with the above conditions when planning activities at the well may lead to the loss of significant volumes of process fluids, increase the repair and response time, which, ultimately, will lead to an increase in the cost of well service operations (Ling and Yumashev, 2018; Yemelyanov et al., 2019 a,b). Thus, the justification of using blocking compositions for well killing in the conditions of oil and gas condensate field in the Volga-Ural province is especially important in connection with the difficult geological, technological and technical conditions for the operation of production wells: fractured carbonate reservoir, abnormally low formation pressure, high gas-oil ratio, high hydrogen sulfide content, acid fracturing and hydrochloric acid treatments requirement (Zambrano *et al.*, 2018; Lushpeev and Margarit, 2018; Gil-Martín *et al.*, 2017).

In such complicated conditions, the main task is to control the fluid loss during well killing operations. In world practice, two basic physical principles are used to reduce fluid loss during well service: increasing the blocking fluids viscosity and Blocking of pores (fractures) and channels of filtration by solid particles (Dandekar, 2013; Rogachev and Kondrashev, 2016; Petrov *et al.*, 2008; Ryabokon, 2009; Galimkhanov, 2019; Volkov, 2019). These principles are implemented in blocking compositions, which are aqueous solutions, emulsions, crosslinked polymer gels, and dispersed systems with solid or gas phases (Figure 1) (Islamov *et al.*, 2019).

Calculation of the stress state of the rock in the near-wellbore zone based on geomechanical modeling can make a significant contribution to the optimization of well killing processes. Among the works on the assessment of the stress state in the near-wellbore zone can be distinguished (Elchin *et al.*, 2019; Lakatos *et al.*, 2013; Fischer *et al.*, 1973;

Dorman and Udvary, 1996; Bouts *et al.*, 1997; Orlov *et al*., 1991; Musabirov *et al*., 2019).

2. MATERIALS AND METHODS:

2.1 Multifactor analysis of the well killing efficiency

Modern methods of data analysis were used to assess different factors that influence the killing of wells efficiency. They allowed finding factors that have a significant effect on the result of geological and technological procedures. Algorithm for analysis can be divided into several steps. The first step is selecting factors that can theoretically influence the success of operation and which are available for analysis. It is important to choose geological and physical factors describing properties of the bed near the well`s area and technological factors relating terms of root properties of well-killing success.

The criterion of "well-killing success" can take two values: "successfully" - if the well was successfully well killed in 1 cycle, and "unsuccessfully" - if the well was not well killed in 1 cycle.

The next step is forming of dataset with experimental observations. The first steps of evaluation in construction the mathematic model are creating correlation matrix and factors selection with its construction results; the elements are definitely having a linear relationship with an experimental value (coefficient of correlation over 0.5 at the scale of Chaddock (Tague, 2000; Gmurman, 2003; Cameron and Trivedi, 2013; Chaddock, 1925)). The next step is a search of the mathematic model by stepwise regression (Cameron and Trivedi, 2013), which will describe a change of observable value objectively (selected on a coefficient of determination (Saunders et al. 2012) with its scaled analog considering the complexity of the model). The following step is the comparison of the model`s predictions with real values. A principal diagram of the selected analysis is shown in Figure 2 (Legkokonets *et al*., 2018).

The analysis of the well killing efficiency at the oil and gas condensate field in the Volga-Ural province was carried out in two main directions that have different criteria for the effectiveness of well-killing operation (Figure 3) (Legkokonets *et al*., 2018):

1. Multifactor analysis of the well killing efficiency (with the criterion of effectiveness "Ramp-up time of the operation mode").
2. Analysis of the reasons for repeated well killing (with the effectiveness criterion "Number of well-killing cycles").

Moreover, multifactor analysis was carried out only according to data for 2018-2019.

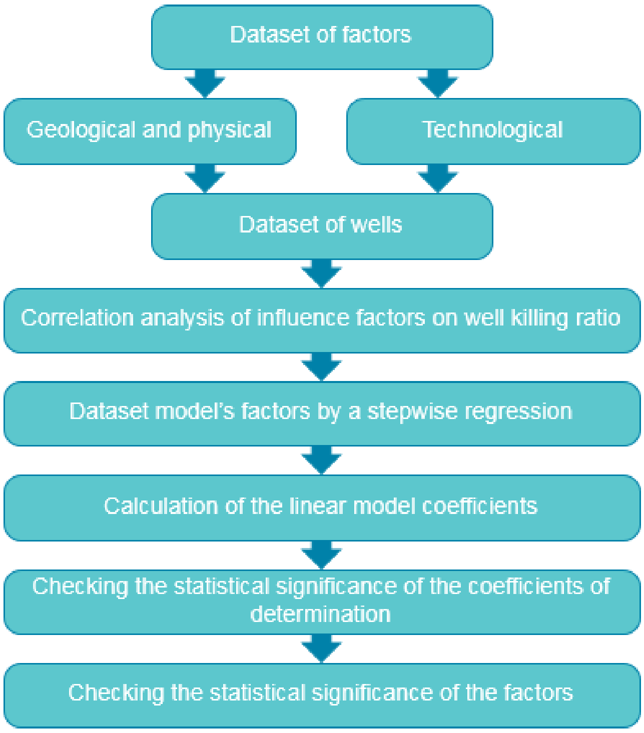

***Figure 2**. Analysis workflow* (Legkokonets *et al*., 2018)

Multifactor analysis was carried out on a sample of wells No.1, compiled according to the following criteria:

1. The number of well-killing cycles – 1.
2. Excluded wells that have taken measures to oil production intensification, which could affect the criterion for the effectiveness of response time (acid treatment, hydraulic fracturing, sidetracking, drifting gas, regime change, optimization of underground equipment, etc.).
3. Excluded wells with a fluid flow rate of less than 1 m^3/day.
4. Wells are excluded that lack data for at least one of the selected factors.
5. Wells are excluded where the method of operation is a flowing (small sample of wells).
6. Wells entered from drilling excluded.

Analysis of the reasons for repeated well killing was carried out on a sample of wells No.2, which include:

1. The number of well-killing cycles – 1.
2. Wells entered from drilling excluded.

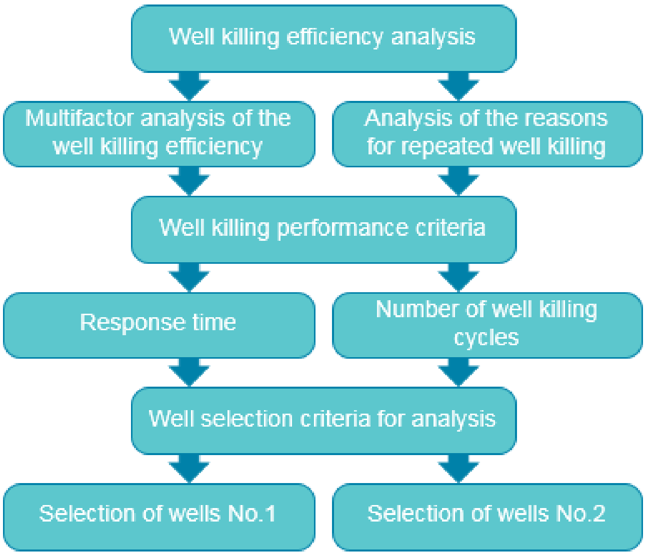

***Figure 3**. Flow chart analysis of the well killing efficiency (Legkokonets et al., 2018)*

2.2 Geomechanical analysis of the well killing efficiency

Productive horizons P_{IV}-P_V of the oil and gas condensate field in Volga-Ural province are presented by fractured carbonate reservoir. Therefore, the correct quantitative assessment of the conductive activity of fracturing is a criterion for the success of well killing. A geomechanical approach was used to evaluate the activity of fractures.

The rock, in a natural occurrence, is in severe stress conditions due to vertical and horizontal stresses associated with the weight of the overlying rocks, as well as tectonic and chemical processes. A well, like a rock excavation, is a local stress concentrator. The stress state in the neighborhood of the well will differ significantly from the regional stress field far from it. The conductive activity of the fracture near the well depends on the values and orientation of the near well bore stress field, as well as on the spatial orientations of the fracture relative to the path of the well (Alzayer *et al.*, 2019).

According to the data of microimages, zones with two characteristic fracture distributions are present in the reservoir (Figure 4) (Ovcharenko *et al.*, 2017). Ordered fracturing prevails in the south-western and north-eastern region of the oil and gas condensate field in the Volga-Ural province. In contrast, multidirectional fracturing is characteristic in the central zone of the reservoir.

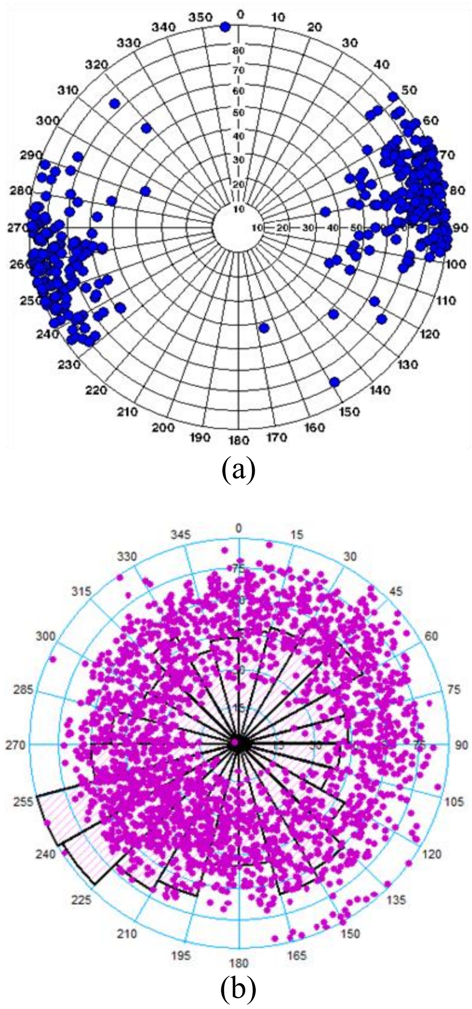

***Figure 4.** Typical fracture orientation distribution types for oil and gas condensate field in the Volga-Ural province: (a) ordered fracturing; (b) multidirectional fracturing (Ovcharenko et al., 2017)*

These features of the observed natural fracture are associated with tectonic regimes that existed in the field at the time of fracture formation and are a separate topic for research that is beyond the scope of this article (Maxwell *et al.*, 2016).

3. RESULTS AND DISCUSSION:

Analysis of the well-killing efficiency in production wells at the oil and gas condensate field in the Volga-Ural province for 2018-2019 showed an increase in the efficiency of well killing in 2019 relative to 2018 (Figure 5) (Islamov *et al.*, 2019). It should also be noted that the decrease in the share of unsuccessful well killing operations for geological reasons, which indicates the success of the planned activities.

Analysis of the influence well-killing fluids on the ramp-up time depending on the method of their operation was carried out only for wells that did not have a change in the method of operation, and there was no effect on the bottom-hole formation zone in the after well service period. Also, only wells that were well killed with an invert emulsion fluid (IEF) or a crosslinked polymer gel (CPG) from the first cycle were analyzed. The analysis showed that IEF have the least negative effect on production wells during well killing process (Figure 6).

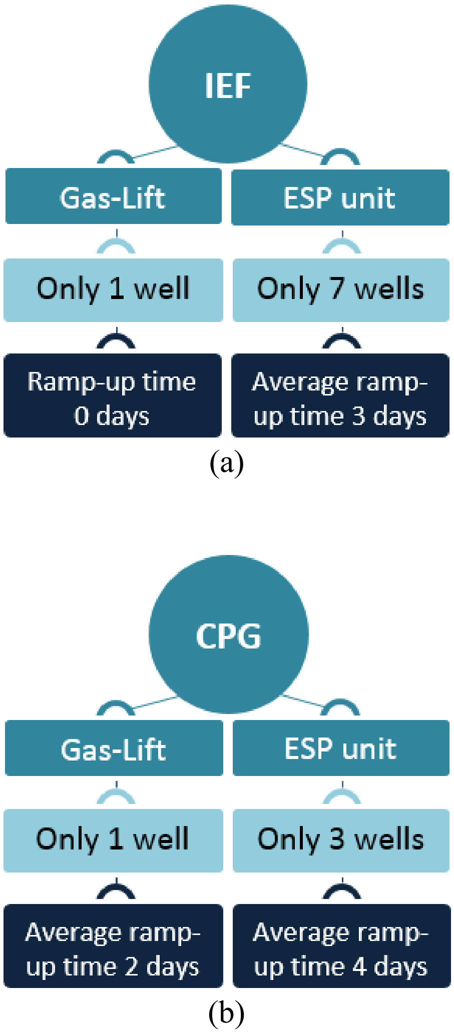

***Figure 6**. Analysis of the influence of well-killing fluids on the ramp-up time depending on the method of their operation: (a) invert emulsion fluid; (b) crosslinked polymer gel*

Based on multifactor analysis, it was possible to determine the parameters that have the most significant impact on the success of well killing. Among the analyzed factors were data obtained by the results of geophysical and hydrodynamic studies of wells and direct measurements, as well as data collected by the results of geological, hydrodynamic, and geomechanical modeling. Figure 7 shows the most important of them (Legkokonets *et al*., 2018):

- fracture intensity for fractures of various types (different geometry);
- azimuth of well;
- fracture opening;
- volume of invert emulsion fluid – injected volume of blocking composition;
- volume of crosslinked polymer gel – injected volume of blocking composition.

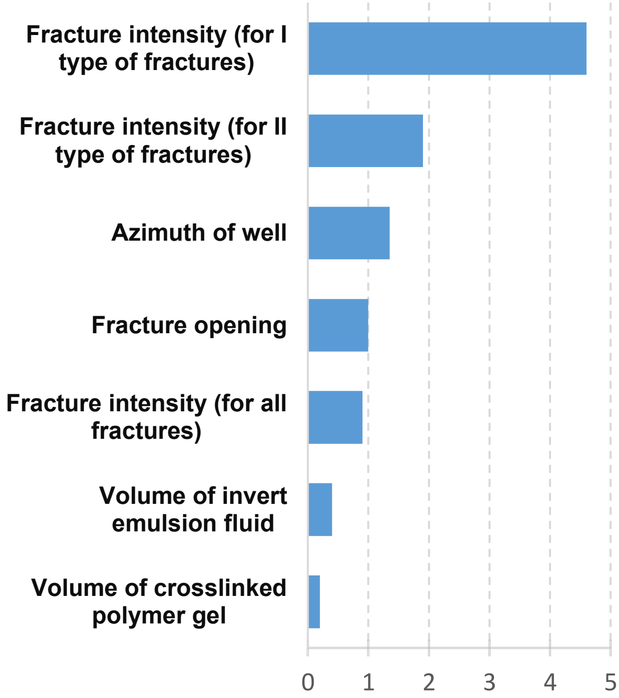

***Figure 7.** Diagram of the influence of factors on the success of well killing*

In that framework, an example of well No.1007-1 of the oil and gas condensate field in the Volga-Ural province using geomechanical tools was used to analyze the conductive activity of fractures crossing its horizontal wellbore. The calculation was carried out with a reservoir pressure anomaly coefficient of 0.8. The well is located in a region with a low fracture density, and the distribution of the fracture propagation is an ordered type (Figure 4a). In the analysis, two wells with the type of fractures (I and II) were considered (Table 1).

***Table 1.** Characteristics of fractures for well No.1007-1*

Type	Azimuth of the falling fractures	Fracture strike azimuth	Angle of incidence
I	260°	170°	80°
II	230°	140°	60°

Type I fracture (Figure 8) presents the fracture extension, which is most prevalent for well No.1007-1 (Ovcharenko *et al*., 2017).

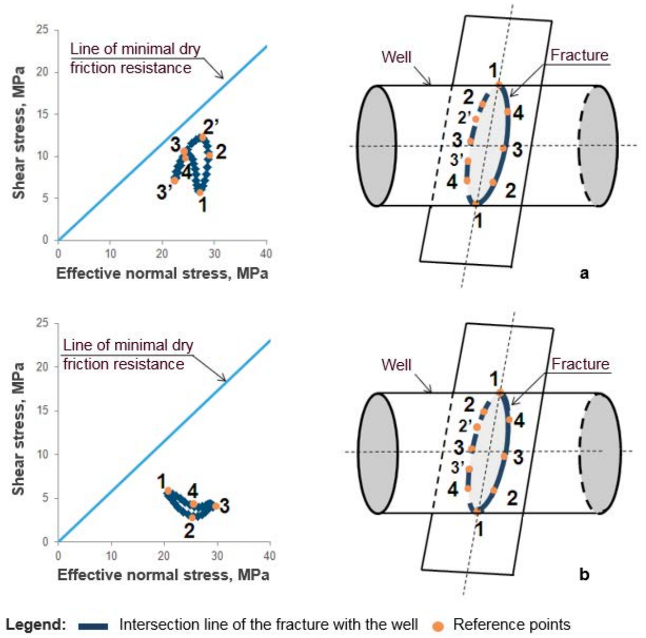

Figure 8. *I type fracture stress diagram:* (a) during the operation of the well (depressed); (b) during well-killing process (at a pressure of injection well-killing fluid)

Type I fracture activity analysis results in the conditions of dynamic (when the well is working on a depression) and static (after well-killing process) are presented in Figures 8a and 8b. The dependence shown in the figures describes the value of normal and shear stresses at the line of intersection of the surface of the fracture with the cylindrical wellbore wall. The straight line represents the so-called line of minimum dry friction resistance for rocks in the interval of the target reservoir (Rahman and Bobkova, 2016; Shatalova *et al*., 2015; Yemelyanov *et al*., 2019; Maulana *et al*., 2019). If at the fracture point the combination of standard and shear stress exceeds the line of minimum dry friction resistance, then this region of the fracture experiences displacement along the surface, and in this region the fracture becomes conductive due to the tensile strain arising. As can be seen from Figures 8a and 8b, the "reference points" 1, 2, 3, and 4 are located below the straight line in both cases: both in depression and well-killing process. Thus, the fracture of the I type of well No.1007-1 does not fall into the active conducting state in the considered range of bottom hole pressures.

Type II fracture (Figure 9) represent the least prevailing direction of fractures for well No.1007-1 (Ovcharenko *et al*., 2017). The results of the analysis of the conductive activity of a Type II fracture under dynamic and static conditions (when the well is working on depression, hydrostatic pressure, and repression) are presented in Figures 9a-9c. According to the results obtained, the combination of normal and shear stress exceeds the line of minimum dry friction resistance of a given rock (red dots) on depression and at a pressure of injection of the well-killing fluid, i.e., in dynamics, this fracture is in an open (active conducting) state. The active zones of the fracture crossing the wellbore are indicated by red dots (Figures 9a and 9c). As can be seen from Figure 7a, when the depression is active, there is a part of the crack, to which points 2’, 3, 4, 4’ belong. In static conditions (after well-killing process), the fracture is entirely in a closed (non-active) state (Figure 9b).

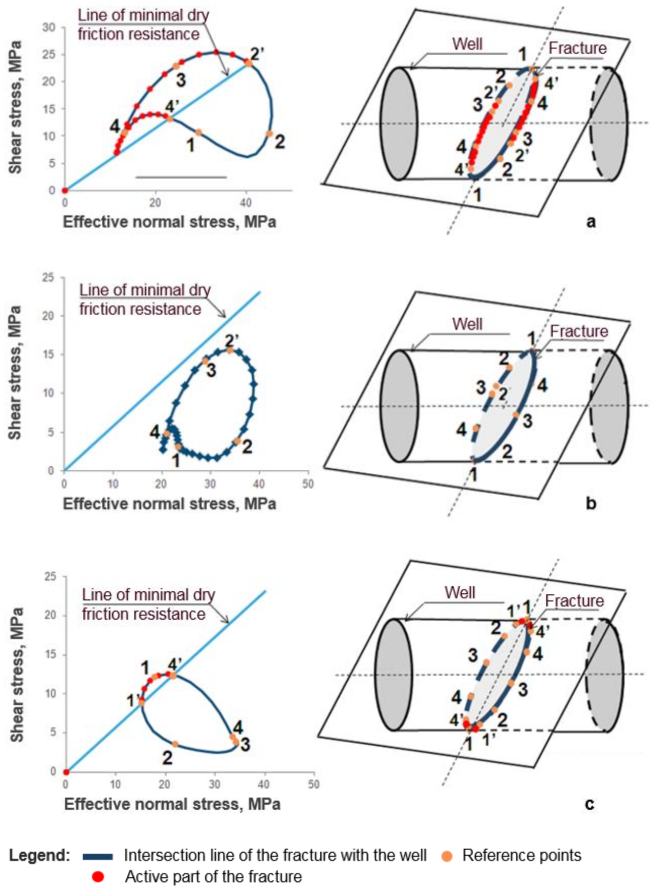

Figure 9. *Type II fracture stress diagram: (a) during the operation of the well (depressed); (b) during well shutdown process (at hydrostatic pressure); (c) during well-killing process (at a pressure of injection well-killing fluid)*

When squeezing the well killing fluid into the well, the bottom hole pressure rises, and the fracture again goes into the active (open) state. However, according to the results presented in Figure 9c, the location of the core relative to the wellbore walls (points 4’-1-1’) has changed at the fracture. It is logical to assume that the blocking composition during well-killing operation (when creating repression) penetrates into the zone of the fracture that is not active during well operation (points 4'-1-1'). When a well is discharged after well killing, a breakthrough of gas from a fracture region that is not fixed by a blocking composition (points 2'-3-4-4') is possible. It can be assumed that for this well, all well killing processes were successful due to the low intensity of fractures of this type (Kumar *et al*., 2019).

In the analysis, we used the distribution of fractures obtained using the interpretation of the microimager. For wells that did not have this well logging complex, it is proposed to use the statistical distribution of fracture orientations obtained from the geomechanical fracture model.

Knowing the active zones in the fracture, it is possible to qualitatively determine the places and nature of the penetration of blocking compounds in the bottom hole formation zone by conducting a set of laboratory rheological and filtration studies.

4. CONCLUSIONS:

1. To increase the efficiency of well killing at the oil and gas condensate field in the Volga-Ural province, to make an informed choice of the most effective blocking compositions and technologies for their application is necessary, which is recommended taking into account the analysis of field data, the results of geomechanical modeling, laboratory studies, and also based on the results of pilot field tests.

2. Geomechanical modeling confirmed the results of the multifactor analysis, which indicated a close relationship between the success of well-killing operation, the well path, and the type of fracturing.

3. The stress state near the well differs significantly from the regional stress field and varies depending on the generated pressure in the well, which in turn affects the activity of fractures near the wellbore.

4. The presence of the image of resistances or a calibrated geomechanical model of fracturing allows us to predict actively conducting sections of fractures near the wellbore at various values of downhole pressure.

5. An integrated approach to solving the problems of well killing in complicated geological, physical, and technological conditions for the development of oil and gas condensate field is needed, consisting in a combination of geomechanical modeling methods with laboratory and field tests.

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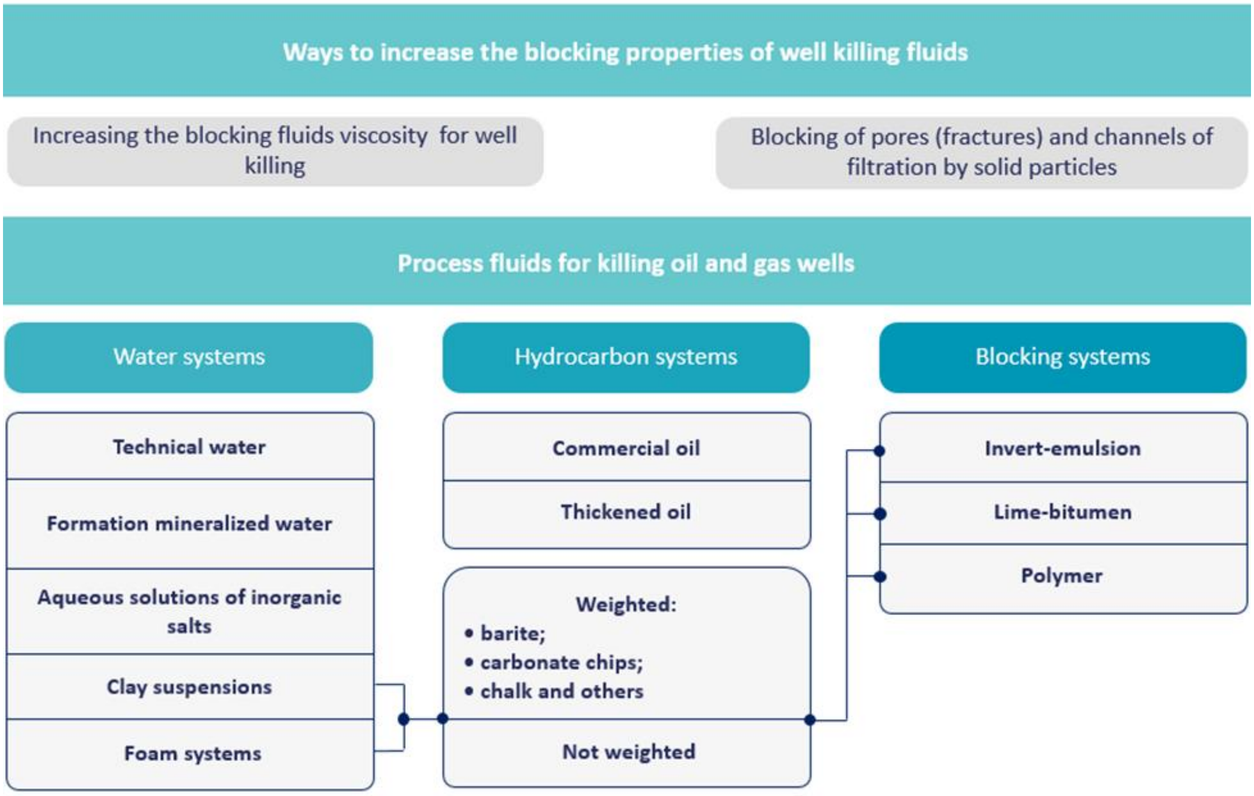

Figure 1. *Main types of well killing fluids (Islamov et al., 2019)*

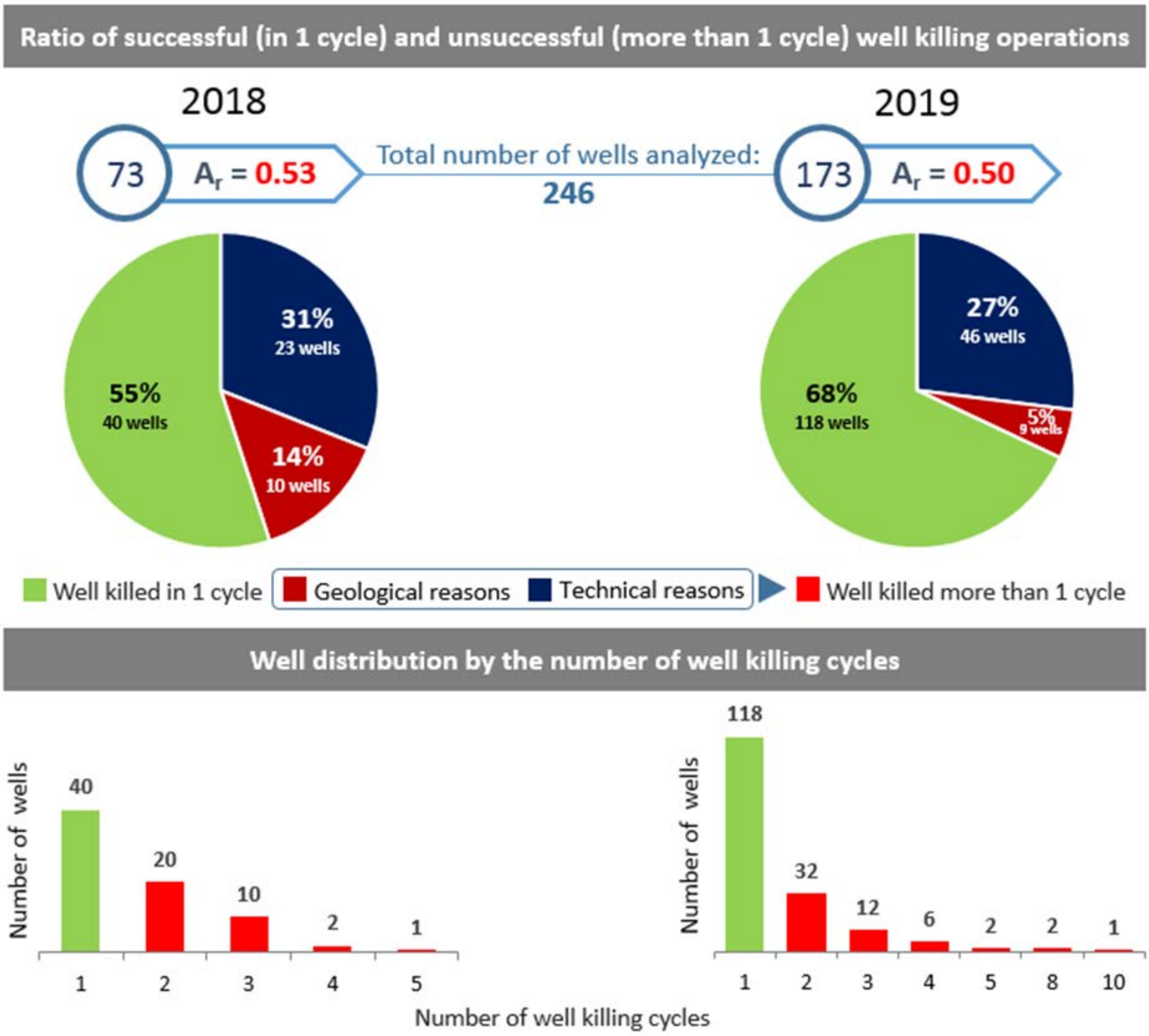

Figure 5. *Well killing results at the oil and gas condensate field in the Volga-Ural province for 2018-2019 (Islamov et al., 2019)*