MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

Institute of geology, petroleum and mining engineering

Department of Petroleum Engineering

Tekeyev A. A.

Features of hydraulic fracturing in late-stage fields with medium and high water cut

DIPLOMA PROJECT

Speciality 5B070800 – Oil and gas engineering

Almaty 2021

MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

СӘТБАЕВ УНИВЕРСИТЕТІ SATBAYEV UNIVERSITY

School of Geology, Petroleum and mining engineering

Department of Petroleum Engineering

APPROVED FOR DEFENSE

Head of the Petroleum
Engineering Department,
Dairov Zh. K., MSc

____

____

DIPLOMA PROJECT

Topic: « Features of hydraulic fracturing in late-stage fields with medium and high water cut»

5B070800 – Oil and gas engineering

Performed by Tekeyev A. A.

Academic adviser
MSc in Reservoir Evaluation and Management
Baibussinova Zh. B.

____

Almaty 2021

StrikePlagiarism.com SATBAYEV UNIVERSITY

Дата отчета 5/10/2021
Дата редактирования ---

Метаданные

Название
Features of hydraulic fracturing in late-stage fields with medium and high water cut

Автор
Текеев Айдар

Научный руководитель
Жанар Байбусинова

Подразделение
ИГНиГД

Список возможных попыток манипуляций с текстом

В этом разделе вы найдете информацию, касающуюся манипуляций в тексте, с целью изменить результаты проверки. Для того, кто оценивает работу на бумажном носителе или в электронном формате, манипуляции могут быть невидимы (может быть также целенаправленное вписывание ошибок). Следует оценить, являются ли изменения преднамеренными или нет.

Замена букв	ß	0
Интервалы	A→	0
Микропробелы	·	0
Белые знаки	ß	0
Парафразы (SmartMarks)	a	29

Объем найденных подобий

Обратите внимание!Высокие значения коэффициентов не означают плагиат. Отчет должен быть проанализирован экспертом.

КП1	КП2	КЦ
2.74% / 2.74%	1.38% / 1.38%	1.02% / 1.02%

25	14164	92580
Длина фразы для коэффициента подобия 2	Количество слов	Количество символов

Подобия по списку источников

Просмотрите список и проанализируйте, в особенности, те фрагменты, которые превышают КП №2 (выделенные жирным шрифтом). Используйте ссылку «Обозначить фрагмент» и обратите внимание на то, являются ли выделенные фрагменты повторяющимися короткими фразами, разбросанными в документе (совпадающие сходства), многочисленными короткими фразами расположенные рядом друг с другом (парафразирование) или обширными фрагментами без указания источника ("криптоцитаты").

10 самых длинных фраз

Цвет текста

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ И АДРЕС ИСТОЧНИКА URL (НАЗВАНИЕ БАЗЫ)	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
1	**Research of physical and chemical properties of oil and its distillate fractions ofUzen Oil Field.docx** Жазира Успанова **6/13/2019** M.Auezov South Kazakhstan State University (ВШ Химической инженерии и биотехнологии)	86	0.61 %
2	https://onepetro.org/speetr/proceedings/86ETR/All-86ETR/SPE-14653-MS/61736	50	0.35 %
3	https://onepetro.org/speetr/proceedings/86ETR/All-86ETR/SPE-14653-MS/61736	35	0.25 %

4	**Research of physical and chemical properties of oil and its distillate fractions ofUzen Oil Field.docx** Жазира Успанова **6/13/2019** M.Auezov South Kazakhstan State University (ВШ Химической инженерии и биотехнологии)	25	0.18 %
5	**Research of physical and chemical properties of oil and its distillate fractions ofUzen Oil Field.docx** Жазира Успанова **6/13/2019** M.Auezov South Kazakhstan State University (ВШ Химической инженерии и биотехнологии)	21	0.15 %
6	https://onepetro.org/speetr/proceedings/86ETR/All-86ETR/SPE-14653-MS/61736	16	0.11 %
7	**Research of physical and chemical properties of oil and its distillate fractions ofUzen Oil Field.docx** Жазира Успанова **6/13/2019** M.Auezov South Kazakhstan State University (ВШ Химической инженерии и биотехнологии)	16	0.11 %
8	https://onepetro.org/SPEEFDC/proceedings/07EFDC/All-07EFDC/SPE-107604-MS/142163	15	0.11 %
9	**Development of CRM system for distribution company** Баглан Абдрасил, Нұржан Аманбек **6/6/2019** International IT University (Информационные системы)	13	0.09 %
10	**Research of physical and chemical properties of oil and its distillate fractions ofUzen Oil Field.docx** Жазира Успанова **6/13/2019** M.Auezov South Kazakhstan State University (ВШ Химической инженерии и биотехнологии)	12	0.08 %

из базы данных RefBooks (0.11 %)

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
Источник: Paperity - abstrakty			
1	**Experimental stereotypy induced by disturbance of GABA-ergic mechanisms in the caudate nuclei** G. N. Kryzhanovskii,M. N. Aliev;	15 (2)	0.11 %

из домашней базы данных (0.00 %)

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)

из программы обмена базами данных (1.50 %)

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
1	**Research of physical and chemical properties of oil and its distillate fractions ofUzen Oil Field.docx** Жазира Успанова **6/13/2019** M.Auezov South Kazakhstan State University (ВШ Химической инженерии и биотехнологии)	166 (6)	1.17 %
2	**Development of CRM system for distribution company** Баглан Абдрасил, Нұржан Аманбек **6/6/2019** International IT University (Информационные системы)	23 (2)	0.16 %

3	**2020 №3 (31) Серия Полиязычное образование и иностранная филология.pdf** Abai University **3/12/2021** Abai University (Abai University)	14 (2)	0.10 %
4	**TRANSNATIONAL BANKS IN THE SYSTEM OF INTERNATIONAL RELATIONS** TUGLUK MUTLU **5/31/2018** University of Foreign Languages and Professional Languages (Кафедра истории и религиоведения)	10 (1)	0.07 %

из интернета (1.13 %)

ПОРЯДКОВЫЙ НОМЕР	ИСТОЧНИК URL	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
1	https://onepetro.org/speetr/proceedings/86ETR/All-86ETR/SPE-14653-MS/61736	112 (4)	0.79 %
2	https://onepetro.org/SPEEFDC/proceedings/07EFDC/All-07EFDC/SPE-107604-MS/142163	29 (3)	0.20 %
3	https://www.hindawi.com/journals/geofluids/2019/9147048/	13 (2)	0.09 %
4	https://onepetro.org/OIJ/article/2020/10/90/459527/The-application-of-depressant-additives-in-the	6 (1)	0.04 %

Список принятых фрагментов (нет принятых фрагментов)

ПОРЯДКОВЫЙ НОМЕР	СОДЕРЖАНИЕ	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)

MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

School of geology, petroleum and mining engineering

Department of Petroleum Engineering

CONFIRM
Head of the Petroleum
Engineering Department
Dairov Zh. K., MSc
____
____

TASK
For completing the diploma project
For student: Tekeyev A.

Topic: «Features of hydraulic fracturing in late-stage fields with medium and high water cut».
Approved *by the order of university rector № 2131-b from "24" December 2020*
Deadline for completion the work *"10" May 2021*
Initial data for the diploma project: Hydraulic fracturing reports, field and well database, data for repair and insulation works.
Summary of the diploma project:

1. Analysis of the productivity of unsuccessful hydraulic fracturing wells from last 4 years;
2. Identification of development features in wells with high water cut at a late stage of development;
3. Review of technologies aimed at limiting and controlling the growth of fractures along the height;
4. Overview of the water cut forecast model

List of graphic material: presented 20 slides of the presentation
Recommended literature: 23 sources

THE SCHEDULE

For the diploma work preparation

Name of sections, list of issues being developed	**Submission deadline to the Academic adviser**	**Notes**
Literature review	21.02.2021	Task completed
Research methodology	19.03.2021	Task completed
Main part	11.04.2021	Task completed
Findings	20.04.2021	Task completed
Conclusion	30.04.2021	Task completed
References	02.05.2021	Task completed

SIGNATURES

Of consultants and standard controller for the completed diploma project, indicating the relevant sections of the work (project).

The section titles	Consultant name (academic degree, title)	Date	Signature
Literature review	MSc, Baibussinova Zh. B.	21.02.2021	
Research methodology	MSc, Baibussinova Zh. B.	19.03.2021	
Main part	MSc, Baibussinova Zh. B.	11.04.2021	
Findings	MSc, Baibussinova Zh. B.	20.04.2021	
Conclusion	MSc, Baibussinova Zh. B.	30.04.2021	
Normcontroller	MSc, Baibussinova Zh. B.	02.05.2021	

Academic Adviser ________ Baibussinova Zh.

The task was completed by the student: ________ Tekeyev A.

Date: “10” May 2021

ABBREVIATIONS

OWC – Oil - water contact

VEC – Viscoelastic composition

VES – Viscoelastic surfactant

RIW – Repair and insulation work

ARWL – Acoustic rehabilitation of wells and formation

EMA – Electromagnetic action

PPE – Personal protective equipment

RPM – Reservoir Pressure Maintenance

HF – Hydraulic Fracturing

PPA – Proppant added (concentration)

SRP – Sucker Rod Pump

CMC - Critical Micelle Concentration

SAS – Surface – Active Substance

АННОТАЦИЯ

Тема: «Особенности проведения гидроразрыв пласта на месторождениях поздней стадии разработки со средней и высокой обводненностью».

Объем дипломной работы 44 страниц, на которых размещены сорок (40) иллюстраций, восемь (8) таблиц и двадцать (20) формул. При написании дипломной работы использовались двадцать два (22) источника.

Ключевые слова: Гидроразрыв пласта (ГРП), высокая обводненность, ремонтно – изоляционные работы (РИР), технология ограничения трещин, прогноз обводненности.

Объект исследования: Неуспешные скважины месторождения Акку после проведения ГРП и анализ новых технологий по контролю росту трещин по высоте при ГРП.

Цель дипломной работы: Выявление особенностей гидроразрыва пласта в скважинах с высокой обводненностью; обзор технологий, методов и рекомендаций по снижению обводненности.

Дипломная работа состоит из трёх частей:

- геологическая;

- технико – технологическая;

- основная;

В геологической части описывается общие сведения месторождения, геолого – физическая характеристика, литологическая характеристика, запасы нефти.

В технико – технологической части описывается добыча компании, анализ разработки пласта, выбор скважин для проведения ГРП.

В основной части рассматриваются проведение работ по ГРП на месторождении Акку, а именно процесс проведения ГРП и учёт возможных осложнений в процессе ГРП. Также, в этой части рассматриваются расчеты ГРП, анализ результатов неуспешных ГРП на месторождении Акку за последние 4 года, такие как анализ обводненности и продуктивности неуспешных скважин. Проведен анализ особенностей проведения ГРП на поздней стадии разработки месторождения. Приведены технологии ГРП, направленные на ограничение и контроль роста трещины в высоту, описание и принцип их работ. Заключительным подпунктом основной части является модель прогноза обводненности скважин. В модели были рассмотрены и сравнены несколько алгоритмов и их результаты.

ANNOTATION

Topic: “Features of hydraulic fracturing in late-stage fields with medium and high water cut”

The volume of the thesis is 44 pages, which contain forty (40) illustrations, eight (8) tables and twenty (20) formulas. When writing the thesis, twenty-two (22) sources were used.

Key words: Hydraulic fracturing (hydraulic fracturing), high water cut, repair and insulation works (RIW), fracture control technology, water cut forecast.

Object of study: Unsuccessful wells of the Akku field after hydraulic fracturing and analysis of new technologies for controlling the growth of fractures in height during hydraulic fracturing.

The purpose of the thesis: Revealing the features of hydraulic fracturing in high-water cut wells; review of technologies, methods and recommendations for water cut reduction.

Thesis consists of three parts:

- geological;
- technical and technological;
- basic;

The geological part describes the general information of the field, geological and physical characteristics, lithological characteristics, oil reserves.

In the technical and technological part describes the production of company, the analysis of reservoir development, selection of wells for hydraulic fracturing.

The main part deals with hydraulic fracturing works at the Akku field, namely the hydraulic fracturing process and taking into account possible complications in the hydraulic fracturing process. Also, in this part, hydraulic fracturing calculations, analysis of the results of unsuccessful hydraulic fracturing in the Akku field from the last 4 years, such as analysis of water cut and productivity of unsuccessful wells, are considered. The analysis of the features of hydraulic fracturing at the late stage of field development. The technologies of hydraulic fracturing aimed at limiting and controlling the growth of the fracture in height, the description and principle of their work are presented. The final sub-item of the main part is the well water cut forecast model. In the model, several algorithms and their results were considered and compared.

АҢДАТПА

Тақырыбы: "Орташа және жоғары суланууы бар игерудің кеш сатысындағы кен орындарында қабаттарды гидравликалық жаруды жүргізу ерекшеліктерді".

Дипломдық жұмыстың көлемі 44 беттен тұрады, онда қырық (40) иллюстрация, сегіз (8) кесте және жиырма (20) формула бар. Дипломдық жұмысты жазу кезінде жиырма екі (22) дереккөз пайдаланылды.

Түйінді сөздер: қабаттың гидрожарылуы (ГРЖ), жоғары сулануы, жөндеу – оқшаулау жұмыстары, биіктігі бойынша жарықтарды бақылау технологиялары, сулану болжамы.

Зерттеу объектісі: ГРЖ жүргізгеннен кейін Ақку кен орнының сәтсіз ұңғымалары және ГРЖ кезінде биіктік бойынша жарықтардың өсуін бақылау бойынша жаңа технологияларды талдау.

Дипломдық жұмыстың мақсаты: жоғары суландырылған ұңғымалардағы гидравликалық сыну ерекшеліктерін анықтау; сулануды төмендету бойынша технологияларды, әдістер мен ұсыныстарды шолу.

Дипломдық жұмыс үш бөлімнен тұрады:

- геологиялық;
- техникалық-технологиялық;
- негізгі;

Геологиялық бөлімде кен орындарының жалпы мәліметтері, геологиялық – физикалық сипаттамалары, литологиялық сипаттамалары, мұнай қорлары сипатталады.

Техникалық-технологиялық бөлімде компанияның өндірілуі, қаттың игерілуін талдау, ГРЖ жүргізу үшін ұңғымаларды таңдау сипатталады.

Негізгі бөлімде Ақку кен орнында ГРЖ бойынша жұмыстарды жүргізу, атап айтқанда ГРЖ жүргізу процесі және ГРЖ процесінде мүмкін болатын асқынуларды есепке алу қарастырылады. Сондай – ақ, бұл бөлікте ГРЖ есептері, Ақку кен орнындағы соңғы төрт жылдардағы сәтсіз ГРЖ нәтижелерін талдау, мысалы, сәтсіз ұңғымалардың сулануы мен өнімділігін талдау қарастырылады. Кен орнын игерудің кеш сатысында ГРЖ жүргізу ерекшеліктеріне талдау жүргізілді. Сызаттардың биіктігін шектеуге және бақылауға бағытталған гидравликалық сыну технологиялары, олардың жұмысының сипаттамасы мен принципі келтірілген. Негізгі бөліктің қорытынды тармақшасы ұңғымалардың сулануын болжау моделі болып табылады. Модель бірнеше алгоритмдерді және олардың нәтижелерін қарастырды және салыстырды.

LIST OF CONTENT

List of figures

List of tables

INTRODUCTION

Today, the Akku field is at a late stage of development, characterized by a high water cut of the produced products and a drop in oil production rates, and a deterioration in the structure of recoverable reserves. Development of reservoirs heterogeneous in permeability and oil saturation is associated with advanced watering of highly permeable and water-saturated reservoirs, as well as production facilities. The oil of the field is non-Newtonian with a high content of paraffins and asphalt-resinous substances, which caused a positive pour point of oil. Oil viscosity in reservoir conditions ranges from 3.58 to 4.51 mPa·s. During the operation of the field, the initial reservoir pressure decreased from 12.4 to 11.2 MPa, the reservoir temperature changed from 57 to 54 ° C. At the same time, since the late 60s of the 19th century, cold water has been injected, which is possibly the main reason for the fallout of asphalt-resinous substances and the deterioration of the permeability of productive deposits. Contamination of the bottomhole formation zone, high skin factor leads to a decrease in well productivity. In this regard, it becomes necessary to apply effective methods of influencing the bottomhole zone of wells to increase their productivity. The following methods of oil production intensification are widely used at the field:

- Physical methods - hydraulic fracturing, acoustic impact (ARWL), electromagnetic action (EMA);
- Chemical methods - repair and insulation works (RIW), viscoelastic composition (VEC), hydrochloric acid treatments.

In such developed fields, with such complications, it is necessary to implement measures to improve the efficiency of oil recovery of producing wells operating low-permeability remote areas of formations, as well as to level the injectivity profile and intensify the injectivity of injection wells and oil production.

In order to intensify oil production at the field, various methods of influencing the bottomhole zone of wells are used. The most effective of them with a success rate of 75% is hydraulic fracturing (hydraulic fracturing). One of the important factors in the success of hydraulic fracturing is the correct selection of wells. The analysis carried out in this work shows that the method of selection of wells for forced withdrawal can be applied to select wells that are promising from the point of view of hydraulic fracturing. (Ogly, 2014), (M. I. Kurbanbaev, 2013)

1. GEOLOGICAL PART

1.1 General information about the Akku field

The Akku deposit is located in the steppe part of South Mangyshlak and is administratively part of the Karakiyan district of the Mangistau region of the Republic of Kazakhstan.

The region is sparsely populated. The regional center, Aktau city, is located 150 km from the Akku deposit (Fig. 1).

The relief of the territory has a complex structure due to strong dissection. The central part is occupied by a vast plateau, composed mainly of Sarmatian limestones and having a regional slope in the southwest direction. The maximum absolute elevations in the north reach 260 m, and in the southern part they decrease to 200 m

There are no watercourses, even drying up, on the territory of the field. In some lowlands, after rain or snowmelt, water remains for a short time. On the territory of the deposit, at the bottom of some large hollows, there are passable and impassable salt marshes.

South Mangyshlak is rich in local building materials: clays, sands and limestone - shell rock, which is an excellent wall material, and its reserves are very large.

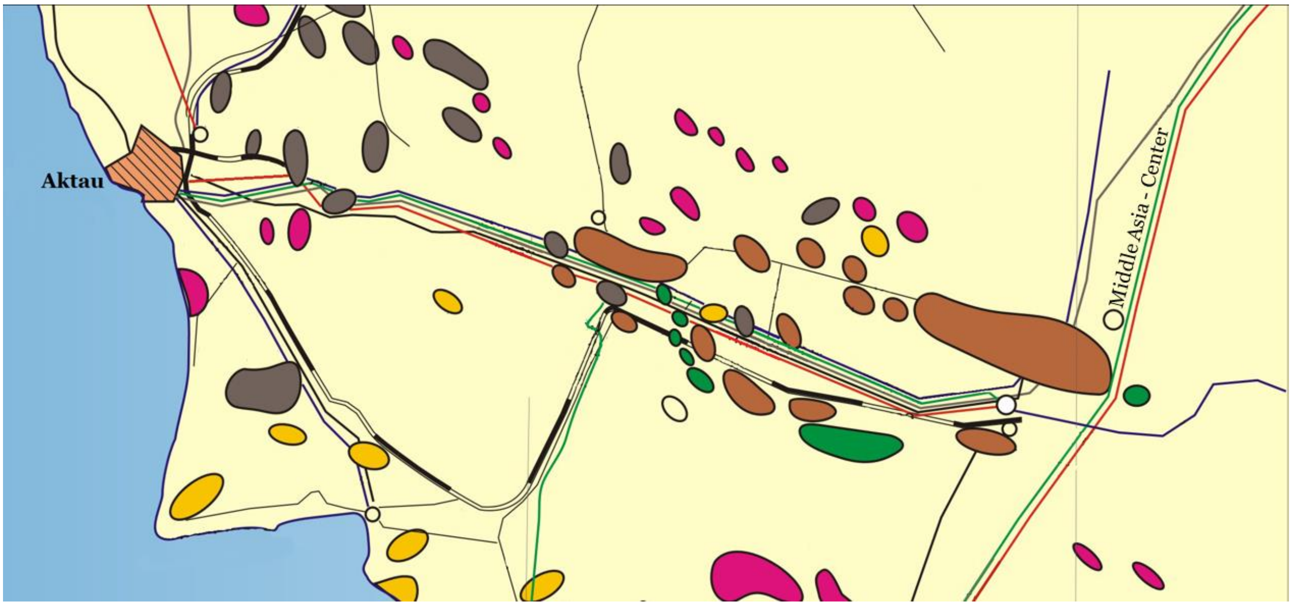

Figure 1. Location of the Akku field

1.2 Geological and physical characteristics of the field

The Akku field is tectonically confined to the Zhetybai-Uzen tectonic step.

The Zhetybai-Uzen tectonic step, being a structural element of the second order, is confined to the northern side part of the South Mangyshlak trough and extends from northwest to southeast to 200 km with a step width of about 40 km.

The largest local structure of the Zhetybai-Uzen step is a gentle anticlinal fold, the axis of which extends from east-southeast to west-northwest.

Along the top of the Jurassic productive strata, stratigraphically attributed to the Callovian stage of the Upper Jurassic, the dimensions of the gentle anticlinal fold are 45 by 10 km, the uplift amplitude is about 300 m. The northern wing is gently sloping with rock dip angles of 30 °, and the southern wing is steeper with dip angles of 5-60 °. The field have six domes.

Based on seismic data, drilling and testing of exploration and production wells, disjunctive faults were established within the structure, which are quite clearly recorded with depth. The most reliable are three faults.

The fault carried out in the structure roof, which separates the area called the Central Block from the Main vault and controls reserovoirs in the “F”th horizon, has an almost submeridian strike and amplitude of about 40 meters, with the fall of the thrower plane by west at an angle close to 900.

Drilling at the Akku field uncovered a sedimentary complex 4500 m thick participation of rocks of Triassic, Jurassic, Cretaceous, Paleogene, Neogene and Quaternary ages.

Triassic deposits are represented only by the lower section: the Indian and Olenek stages. The structure of the deposits of the Indian stage is dominated by red-colored coarse-grained tuffaceous-terrigenous rocks (sandstones, tuffaceous sandstones, siltstones). Deposits of the Olenek stage are represented by two strata: variegated siltstone-mudstone and gray-colored carbonate-terrigenous.

Jurassic deposits are transgressively overlaid on the eroded surface of the Triassic complex of rocks. The Jurassic system includes the lower, middle and upper sections.

Undivided Lower Jurassic deposits are represented by alternating sandstones, siltstones, argillite-like black carbonaceous clays.

The Middle Jurassic deposits are represented by continental, coastal-marine and marine formations. The composition includes deposits of the Aalenian, Bajocian and Bathonian stages. Lithological deposits of the Middle Jurassic are represented by alternation of sandstones, siltstones with subordinate interlayers of mudstones and clays.

Upper Jurassic deposits are represented by Callovian and Oxfordian stages. The section of the Callovian stage is represented by a clay stratum, in the lower part of which there are interlayers of sandy-silty rocks. The section of the Oxfordian Stage is composed of argillaceous-marl rock strata, and the marl members are confined to the top of the stratum.

On the eroded surface of the Jurassic complex of rocks, there is a stratum of Cretaceous deposits. In the chalk section, the lower and upper sections are distinguished. The boundary between Cretaceous and Jurassic rocks is very clear, due to the difference in their lithological composition. The lower section is represented by the Neocomian superstage, the Aptian and Albian stages, while the upper section is represented by the Cenomanian, Turonian, Santonian, Campanian, Maastrichtian and Danish stages. The deposits of the lower section are composed of terrigenous deposits: sandstones, clays, siltstones and marls; there are rare interlayers of limestones. Upper Cretaceous deposits are composed mainly of shallow marine formations. According to lithological features, the stratum is clearly subdivided into two parts: the lower terrigenous and the upper, predominantly chalk-marl.

In the section of the Paleogene system, there are two divisions - Eocene and Oligocene. Eocene sediments are represented by calcareous-marl strata, Oligocene - a homogeneous stratum of greenish-gray dense calcareous clays.

Neogene sediments occur with erosion and angular unconformity on Paleogene sediments. The section contains Middle Miocene deposits in the volume of the Tortonian and Sarmatian stages. The section is represented by clays, marls, limestones and fine-grained sandstones.

1.3 Lithological characteristics of rocks

The rocks composing the productive horizons are characterized by both vertical and lateral lithological variability, which is a consequence of the formation of sediments in a complex environment of coastal shallow waters.

Reservoirs containing oil deposits in the Akku field are medium- and fine-grained sandstones and coarse-grained siltstones. connection with a low content of clay matter. The most high-capacity and permeable reservoirs are associated with such rocks in the composition of the productive strata.

The main rock-forming components of the productive horizons of the Akku field are mainly fragments of stable (siliceous, mica-siliceous, quartzite) and unstable (clay, mica-argillaceous and effusive) rocks, quartz grains and pelitized feldspars, mica leaves (muscovite and biotite)

The shape of the grains is angular or semi-rounded. The median grain diameter varies from 0.05 to 0.3 mm, its average values for “A”-“F” horizons are from 0.063 to 0.087 mm. Sorting of fragments is usually weak, however, there are interbeds of well-sorted sandstones and siltstones.

A feature of the reservoirs of the productive horizons of the Akku field is high clay content, which means the content of a fraction less than 0.01 mm in size, where, in addition to the clay minerals themselves (kaolinite, chlorites, hydromicas, etc.), reaching 60-70% of the fraction less than 0.01 mm, a significant portion is made up of fine-grained particles of feldspars, micas, and other readily disintegrating minerals. The content of the fraction less than 0.01 mm in many samples of reservoir rocks is also increased due to clays participating in microallocation with terrigenous interlayers.

Among the reservoirs of oil and gas, represented by sandy-silty rocks, researchers have established 6 lithotypes, which were distinguished based on the grain size, amount, composition and types of cement, as well as the degree of secondary rock transformations.

The first group is composed of fine sandstones - and medium-grained with a silt fraction content of no more than 7%, weakly clayey (no more than 10%), loose and poorly cemented; they have a limited distribution, occur in the form of lenses and interlayers.

The second group includes medium and fine-grained sandstones, with silt fraction content from 8 to 23%, weakly and moderately cemented; they are locally traced in the form of interlayers and lenses.

The third group is composed of medium-, fine-grained silty sandstones (no more than 10%), clayey (8–12%), unevenly carbonate, moderately cemented; they can be traced in a number of areas.

The fourth group is formed by fine-grained sandstones with an admixture of medium-grained sandy material, silty and silty (2-25%), unevenly clayey (4-36%), weakly and unevenly carbonate, moderately cemented; they are most developed.

The fifth group is composed of silty sandstones, unevenly clayey (7-38%), weakly and unevenly carbonate, medium and densely cemented; they can be traced mainly in the form of interlayers and lenses among sandstones.

The sixth group includes siltstones, unevenly sandy (1-28%), clayey (10-42%), unevenly carbonate, tightly cemented; they are present in zones of facies replacement of sandy rocks.

The reservoir rocks of the Akku field are characterized by loose packing of detrital grains due to both a high cement content and a low degree of epigenetic transformations. Characteristic is the alternation of sandy interlayers up to 1-3 cm thick with varying degrees of cementation, from strongly cemented to weakly cemented and loose. These interlayers, having a homogeneous granulometric and mineralogical composition, differ significantly in the nature of the cement, filtration-volumetric properties and saturation, which causes micro-heterogeneity of individual areas.

1.4 Oil reserves

At the end of the first decade of the 21st century, 3,878,500 tons of oil were produced from the Akku field. The distribution of oil production by horizons is as follows: (%)

“A” horizon -27.5;

“B” horizon - 39.9;

“C” horizon - 12;

“D” horizon - 10.9;

“E” horizon - 5.7;

“F” horizon - 1.7;

The “A”-“B” horizons are characterized by the highest oil and liquid production. The oil produced from them amounted to 64% of the total oil produced from the field. Average daily flow rate of one production well in the field along the horizons from 3.1 to 5.4 tons / day. for oil, from 6.7 to 15.8 tons / day. by liquid. The “A”-“B” horizons are divided by rows of injection wells into 64 self-developed blocks. Blocks, even within the same horizon, differ significantly from each other by the initial balance recovered reservoir reserves and the properties of productive formations, the degree of drilling, and therefore oil and liquid production varies over a wide range. Characteristics of oil and liquid withdrawals by operation methods as: the main oil production from the field (97%) is carried out by downhole pumping (SRP) and gas-lift operation. Despite the fact that the stock of gas-lift wells accounts for only 9.2% of the total production stock, oil production by the gas-lift method is 16.6%, and liquid production is 24% of the total production from the field. This is explained by the fact that the average oil and liquid production rates for gas-lift wells are 3 - 3.5 times higher than for wells equipped with deep pumps, the number of which reaches 92.7% of the total produced fund.

2. TECHNICAL - TECHNOLOGICAL PART

2.1 Production of oil company

Company produced 5,480 thousand tons (111 thousand barrels per day), which is 1% less compared to last year, mainly due to a decrease in production from the rolling stock of wells. Production volume for the year decreased by 1% or by 75 thousand tons, mainly due to natural depletion of reserves. The reasons for this decrease are an increase in water cut as a result of disturbances in production casing and an increase in downtime of wells as a result of disturbances in the operation of underground equipment. Oil production from the commissioning of new wells at company for the year amounted to 297 thousand tons compared to 314 thousand tons a year earlier due to a smaller number of days worked by wells.

In the reporting period, overhaul of 989 wells at company provided 212 thousand tons of additional production, in previous year 949 well workover provided 259 thousand tons. The production accounting method was also changed from metered production to park production. Also, since the year, such works as the elimination of the accident, bottomhole cleaning, repair and isolation works have been referred to the current workover of wells (Current Workover) to maintain the oil production of the carryover stock. (JSC "KazMunayGas", 2017)

In the next year, company produced 5488 thousand tons of oil. We can say that the company managed to maintain the level of oil production, which they promised to do in the year.

In the first quarter of the next year, company produced 1,350 thousand tons of oil (110 thousand barrels per day), which is 1% higher than in the first quarter of the year. In the quarter of the year, company produced 1,335 thousand tons (109 thousand barrels per day) (JSC "Exploration Production KazMunayGas", 2018), (JSC "Exploration Production KazMunayGas", 2017)

2.2 Reservoir Development Analysis

Reservoir development analysis includes determining the degree of reserves development, increasing productivity as a result of hydraulic fracturing, the expected impact on the gas factor or water-oil factor, geology and rock properties of the productive interval and adjacent formations, the effect of the fracture on the nearest wells, and a review of other available information.

The current operating conditions of the well affect the outcome of each hydraulic fracturing treatment. Therefore, the availability of more complete information about the reservoir is necessary to select candidates for hydraulic fracturing. Some parameters must be considered without fail: (Jennings A. R., 2003)

- High gas-oil or water-oil factors
- Interference with offset wells
- Geomechanical barriers
- Reason for low productivity

2.3 Selection of wells for hydraulic fracturing

The selection of wells for hydraulic fracturing should be based on the geological model of the reservoir. For each well, it is necessary to take into account the results of geophysical studies, as well as all information obtained as a result of hydrodynamic studies, field material. The degree of reliability of the initial ideas about the geological structure of the reservoir determines the validity of the decisions made on the choice of wells for hydraulic fracturing.

The selection of wells candidates for hydraulic fracturing can be generally divided into three main stages.

1. Clarification of the current parameters of the wells, preliminary calculation of the effect of hydraulic fracturing and the creation of a list of candidate wells:
- carrying out a set of special studies at priority wells to determine the location, direction and conductivity of the fracture;
- conducting geophysical research and hydrodynamic studies, field analysis: reservoir energy reserve and effective oil-saturated reservoir thickness, sufficient for a significant and long-term increase in well production after hydraulic fracturing;
- selection of the planned equipment layout and determination of the target bottomhole pressure;
- Identification of the best candidate wells that provide cost recovery for hydraulic fracturing and take into account economic efficiency.

2. Analysis of the current state of development for each candidate well:
- exclusion of risky wells for geological reasons: the risk of a breakthrough into a water or gas-saturated horizon close to the OWC, the possibility of injected water breakthrough, etc.;
- assessment of residual recoverable reserves per well, taking into account the existing development system, exclusion of candidate wells that penetrated formations with low residual reserves; depletion of recoverable reserves, which, as a rule, should not exceed 30%;
- formation permeability, which usually should not exceed 0.03 micron^2 with oil viscosity up to 5 mPa * s (in higher permeability formations, local hydraulic fracturing is effective, which gives a significant effect mainly as a means of treating the bottomhole zone); identification of lenses and productive zones of the reservoir that were not drained or poorly drained earlier and the subsequent

creation of extended hydraulic fractures, providing communication of the well with these zones;

- it is necessary to consider not only the increase in the flow rate of each well due to hydraulic fracturing, but also the influence of the relative position of the wells, the energy capabilities of the object.

3. Well technical condition analysis:

- analysis of the technical condition of the well from the point of view of hydraulic fracturing: determination of the perforation interval, the depth of the packer;
- formation of measures to prepare wells for hydraulic fracturing;
- final selection of downhole equipment and determination of the effect of hydraulic fracturing.

Based on the above, the following sequence of actions is recommended when selecting wells for hydraulic fracturing:

1. Analysis of geological-physical and field information; building a detailed geological model of the object;
2. Determination of fracture orientation;
3. Calculation of the optimal fracture parameters - length and conductivity;
4. Identification of wells with contaminated bottomhole zone;
5. Preliminary selection of wells for hydraulic fracturing;
6. Creation of geological and mathematical model of the object;
7. Calculation of the base case development (without hydraulic fracturing);
8. Calculation of the variant with hydraulic fracturing in all wells;
9. Comparison of the base case and the option with hydraulic fracturing:

- identification of wells in which hydraulic fracturing does not lead to a significant increase in oil production;
- identification of undeveloped areas of the reservoir and design of additional hydraulic fracturing in producing wells to drain these areas;
- identification of areas characterized by low reservoir pressure, and design of additional hydraulic fracturing in injection wells.

10. Creation of new options with hydraulic fracturing, calculations, comparison of options with each other and with the basic option;
11. Selection of several, technologically effective options.
12. Performance of technical and economic calculations taking into account the costs of hydraulic fracturing; selection of the recommended option.

Generalized criteria for well selection for hydraulic fracturing

Well:

- no break or collapse of the string;
- no behind-the-casing flows;
- good the quality of the cement ring in the perforated interval and 15 - 20 m up and down from it.

Only technically sound wells are suitable for hydraulic fracturing.

Geology:

- the effective oil-saturated thickness of the formation is more than 5-6 m;
- the minimum thickness of the shale section is 6 m;
- the thickness of natural barriers separating the productive reservoir from the higher or underlying, gas or water-saturated formations must be at least 4.5-6.0 m.

Development status:

- presence of residual recoverable reserves;
- low the effectiveness of other stimulation methods;
- the liquid flow rate of the well under consideration is significantly lower than the potential and in comparison with neighboring wells;
- distance to the injection line and OWC - 500 m;
- current water cut - up to 90%. A vertical fracture develops in height, usually by growing upward; there may be water or gas-oil contact in the direction of fracture development, therefore, it is undesirable to carry out hydraulic fracturing in production wells producing products with a high water or gas content (more than 90%).
- In the process of hydraulic fracturing at the Akku field, a systematic author's oversight of implementation, which will allow prompt action to be taken to improve its effectiveness. (Mironov, 2018), (JSC "KazNIPImunaigas", 2018)

The problems of selecting wells for hydraulic fracturing at a late stage of field development are:

- High density of wells. On the Akku field, wells are located on average every 200 meters (Fig. 2);
- Depletion of reserves or reservoir;
- A large number of wells with previously performed hydraulic fracturing.

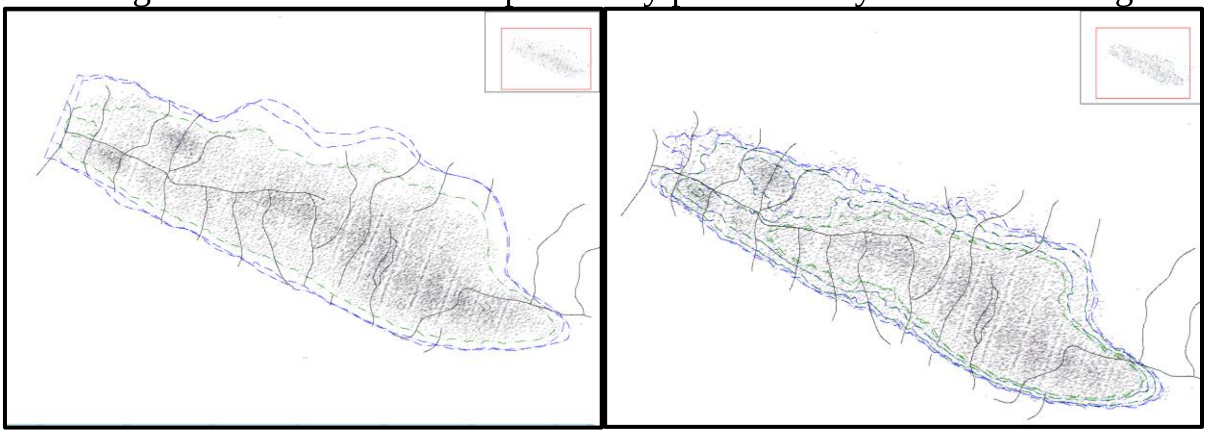

Figure 2. Location of wells in the considered horizons of the Akku field

3. MAIN PART

3.1 Hydraulic fracturing works at the Akku field

3.1.1 Hydraulic fracturing process

All chemicals and proppant must be approved for use with the Customer.

Prior to the start of injection, the hydraulic fracturing fleet supervisor must assemble the entire crew for briefing at the exit from the well area

- It is necessary to calculate all team members, determine the exact number of people who are at the well site, including the Customer and all representatives of other organizations;
- It is necessary to designate a safe area where persons who will not take part in the hydraulic fracturing process should be located;
- It is necessary to describe the ways and means of evacuation from the bush area, as well as those responsible for the evacuation, and identify evacuation vehicles;
- It is necessary to inform the personnel about the action plan in case accidents;
- Check for PPE on team members;
- Explain fire safety measures and inform the team about the location of first-aid kits;
- Attach instructions with signatures to the field report after hydraulic fracturing;
- The foreman of the hydraulic fracturing team should tell about the technological plan for hydraulic fracturing (maximum working pressure, maximum proppant concentration, proppant weight by fractions, injection rate, volume of water required for hydraulic fracturing, and so on).

Proppant start-up: Before starting fracturing, the proppant auger must be full. The start of operation of the auger should be selected in such a way as to avoid artificial extension of the pillow stage.

If it is not technically possible to feed the capsulated and live breaker through different dry additives feeding systems, then it is necessary to weigh and prepare the required breaker mass for each stage of work before the start of hydraulic fracturing (the moment of transition from encapsulated to live is critical);

Before starting work, the blender operator must be instructed by the fracturing technician on the procedure for the last proppant stage in order to avoid the formation of a proppant tail during the displacement stage. The process residual of proppant in the well should not exceed 300 kg;

In preparation for the displacement stage, the foreman responsible for hydraulic fracturing must receive confirmation from the pump supervisor (operator responsible for controlling the fracturing process on the street, checking the operation of equipment, monitoring the tightness of the wellhead and lines) that the supply of proppant from the sand carrier to the basket is stopped / finished. After that, a confirmation should come that the cart is empty. At this point, the fracturing engineer must monitor the density meter reading. The moment of the beginning of the displacement stage, the hydraulic fracturing contractor should consider the moment when the most recent maximum proppant concentration is reached before the concentration drops.

The volume of the displacement stage must be calculated and verified by the fracturing engineer and the Contractor's fracturing foreman independently of each other prior to the start of test pumping based on the packer sheet, as well as the volumes in the elements of the Contractor's surface line from the flow meter installed in the line. If the result does not match, the sale must be re-calculated by the engineer and the foreman, and in the final version, before the start of work, the volume of the under-sale must be agreed with a representative of the Company. The default underdelivery volume standard is 200 liters. (JSC "MangystauMunayGas", 2016), (JSC NC “KazMunayGas”, 2018)

3.1.2 Consideration of possible complications during hydraulic fracturing

Complications during hydraulic fracturing are possible primarily due to gas or water breakthrough through fractures. The thickness of the natural barriers separating the productive reservoir from the higher - or lower-lying gas - or water-saturated formations, as a rule, should be at least 4.5 - 6 meters. A vertical fracture develops in height, usually by growing upward; in the direction of the fracture development, there may be a water - or gas - oil contact. In production wells producing products with a high water or gas content, as a rule, it is undesirable to carry out hydraulic fracturing. (Kanevskaya, 1999)

3.2 Calculation of hydraulic fracturing parameters

Calculation of the main parameters of the process and selection of the required amount of equipment for hydraulic fracturing:

To calculate the bottomhole fracture pressure $\mathrm{P}_{\mathbf{bottom.frac}}$ when using a non-filtering fluid, you can use the following formula (when pumping 1 м^3 fracturing fluid) (Mishchenko, 1989)**:**

$$\frac{\mathrm{P}_{bottom.frac}}{\mathrm{P}_h} * \left(\frac{\mathrm{P}_{bottom.frac}}{\mathrm{P}_h} - 1\right)^3 = 5{,}25 * \frac{1}{(1-v^2)} * \left(\frac{E}{P_h}\right)^2 * \frac{Q * \mu_{ff}}{\mathrm{P}_h} = \mathrm{x}$$

$$\frac{\mathrm{P}_{bottom.frac}}{\mathrm{P}_h} * \left(\frac{\mathrm{P}_{bottom.frac}}{\mathrm{P}_h} - 1\right)^3 = \mathrm{x}$$

$$\frac{P^*_{bottom}}{\mathrm{P}_h} = \sqrt[3]{\mathrm{x}} + 1, \quad (1)$$

Где $\mathrm{P}_h - horizontal\ component\ of\ rock\ pressure, MPa$

$$\mathrm{P}_h = \mathrm{P}_v * \frac{v}{(1-v)}, \quad (2)$$

$v - Poisson's\ ratio +\ of\ rocks\ (v = 0.2 - 0.3);$

$P_v - vertical\ component\ of\ rock\ pressure, MPa$

$$P_v = \rho_п * g * L_c * 10^{-6}, \quad (3)$$

$$\rho_r - \ Density\ of\ rocks\ above\ the\ productive\ horizon, \frac{kg}{m^3} -$$

$$- \left(\rho_r = 2600 \frac{kg}{m^3}\right);$$

$$E - modulus\ of\ elasticity\ of\ rocks\ (E = (1-2) * 10^4\ MPa);$$

$$Q - breakdown\ fluid\ injection\ rate, \frac{m^3}{s}\ (in\ accordance$$

$$with\ the\ characteristics\ of\ the\ pump\ unit);$$

$$\mu_{bf} - breakdown\ fluid\ viscosity, Pa * s$$

For an approximate estimate of the bottomhole fracture pressure when using a filter fluid, you can use the formula:

$$P_{bottom.frac} = 10^{-2} * K * L_{wb}, \quad (4)$$

$$where\ K - coefficient, taken\ equal\ to\ (1.5 - 1.8)\ MPa\ /\ m$$

When pumping fluid - sand carrier pressure at the wellhead (P_{wh}):

$$P_{wh} = P_{bottom.frac} - \rho_{sc} * g * L_{wb}\ (\text{или}\ P_{stat}) + P_{friction}, \quad (5)$$

$$where\ \rho_{sc} - density\ of\ the\ sand\ carrier, \frac{kg}{m^3}$$

$$\rho_{sc} = \rho'_{sc} * (1 - \beta) + \rho_s * \beta_p, \quad (6)$$

$$where\ \rho'_{sc} - density\ of\ the\ fluid\ used\ as\ a\ sand\ carrier, \frac{kg}{m^3};$$

$$\rho_s - density\ of\ sand, \frac{kg}{m^3}\ \left(\rho_s = 2500 \frac{kg}{m^3}\right);$$

$$\beta_p - volumetric\ concentration\ of\ sand\ (proppant)\ in\ the\ mixture$$

Volumetric concentration of sand (proppant) in the mixture:

$$\beta_s = \frac{\frac{C_p}{\rho_p}}{\frac{C_p}{\rho_p} + 1}, \quad (7)$$

$$C_p - concentration\ of\ sand\ in\ 1\ \text{м}^3\ liquid, kg/m^3\ (C_p = 250 - 300\ kg/m^3);$$

Pressure loss due to friction of fluid - sand carrier:

$$P'_{friction} = \frac{8\lambda Q^2 * L_{wb} * \rho_{sc}}{\pi^2 d_{inner}^5}, \quad (8)$$

$$where\ \lambda - coefficient\ of\ hydraulic\ resistance:$$

Hydraulic resistance coefficient, for turbulent mode, when Re> 1530:

$$\lambda = \frac{0.3164}{\pm Re}, \quad (9)$$

Coefficient of hydraulic resistance, for laminar mode, when Re <1530:

$$\lambda = \frac{64}{Re}, \quad (10)$$

Reynolds number:

$$Re = \frac{4Q\rho_{sc}}{\pi d_{\text{вн}} * \mu_{fs}}, \quad (11)$$

$$Q - injection\ rate, \frac{m^3}{s}; \mu_{fs} - fluid\ viscosity\ with\ sand, Pa * s;$$

$$\mu_{fs} = \mu'_{sc} * \exp(3.18 * \beta_s), \quad (12)$$

$$\mu'_{sc} - the\ viscosity\ of\ the\ liquid\ used\ as\ a\ sand\ carrier, Pa * s$$

If Re> 200, then the friction pressure loss according to the formula above is increased by 1.52 times:

$$\text{P}_{friction} = 1{,}52 * \text{P}'_{friction}, \quad (13)$$

Required number of pumping units:

$$N = \frac{\text{P}_{wh}Q}{\text{P}_{op} * Q_{feed} * K_{tc}} + 1, \quad (14)$$

$$where\ \text{P}_{op} -\ unit\ operating\ pressure;$$

$$Q_{feed} -\ unit\ feed\ at\ a\ given\ \text{P}_{op};$$

$$\text{К}_{tc} - unit\ technical\ condition\ factor\ (\text{К}_{tc} = 0{,}5 - 0{,}8);$$

$$Q - breakdown\ fluid\ injection\ rate, \frac{m^3}{s}$$

Required volume of fracturing fluid (when pumping into oil-well tubing)

$$V_{frac.fluid} = 0{,}785\ d^2_{inner} * L_{wb}, \quad (15)$$

The minimum injection rate of breakdown fluid is determined by the formulas:

For a horizontal fracture:

$$Q_{min.r} \geq\ 10^{-3}\frac{\pi R_f \omega_0}{\mu_{ff}}, \quad (16)$$

For a vertical fracture:

$$Q'_{min.r} \geq 10^{-3}\frac{h\omega_0}{\mu_{ff}}, \quad (17)$$

$$where\ R_f - the\ radius\ of\ the\ horizontal\ fracture, m;$$

$$\omega_0 - width\ (opening)\ of\ a\ fracture\ on\ the\ borehole\ wall, m;$$

$$\mu_{ff} - breakdown\ fluid\ viscosity, Pa * s;$$

$$h - formation\ thickness, m$$

In the case of fracturing the formation with a non-filterable liquid, the actual rate of injection of liquid Q can be taken equal to Q_{min}

When fracturing with a filtering liquid, the actual rate of liquid injection $Q \geq Q_{min}$

The amount of proppant Q_p per hydraulic fracturing is assumed to be 8 - 10 tons. With a proppant concentration in 1 m^3 of fluid C_p the volume of fluid is:

The volume of proppant carrier fluid is determined by the ratio:

$$V_p = \frac{Q_p}{C_p}, \tag{18}$$

The total volume of the pumped liquid is determined by the form:

$$V_{fluid} = V_{break.f} + V_{frac.f} + V_p, \tag{19}$$

The total time of the fracturing process can be determined using the ratio:

$$t = \frac{V_{fluid}}{Q}, \tag{20}$$

$$Q - breakdown\ fluid\ injection\ rate, \frac{m^3}{s}$$

3.3 Analysis of hydraulic fracturing results in the Akku field from last 4 years.

3.3.1 Analysis of water cut of unsuccessful hydraulic fracturing wells

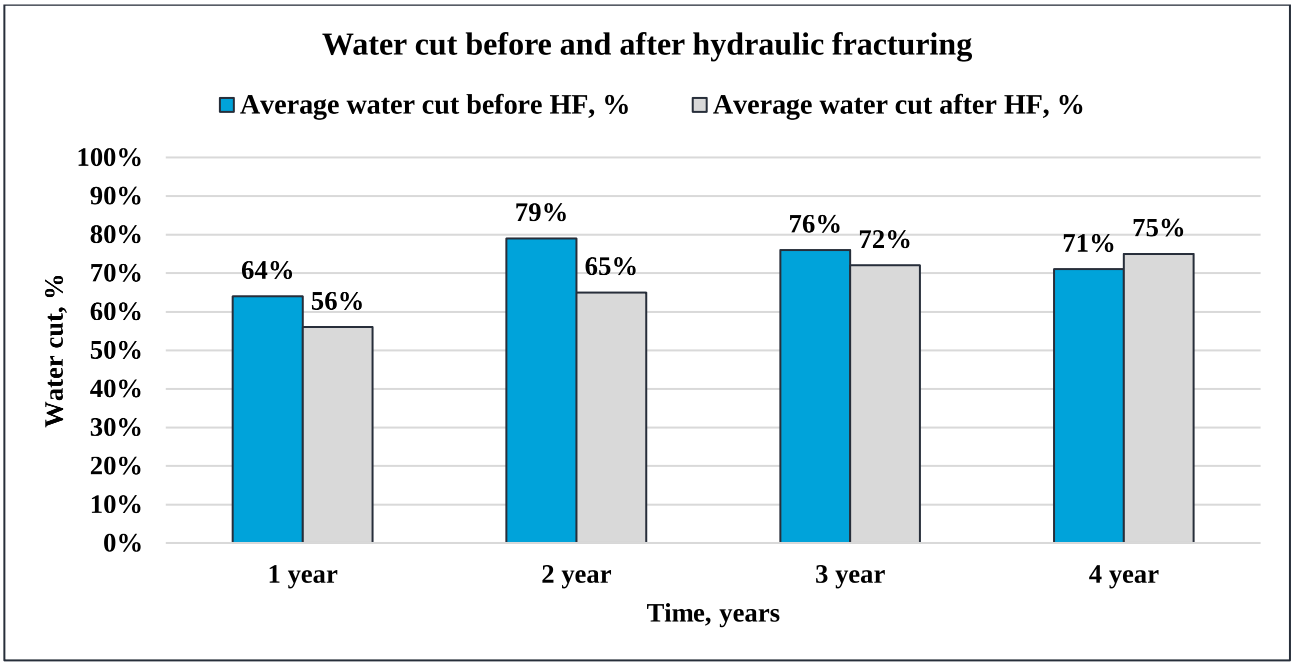

Figure 3. Average water cut before and after hydraulic fracturing for 4 years

The slide shows a graph of the water cut of the wells before and after hydraulic fracturing. The average water cut of the wells after hydraulic fracturing is lower than before, since, in particular, measures were taken to isolate the inflow of water in the reservoirs before hydraulic fracturing.

The nuance is that in last year the water cut after hydraulic fracturing is higher. This can be explained by the fact that unstable sampling was carried out during the pandemic.

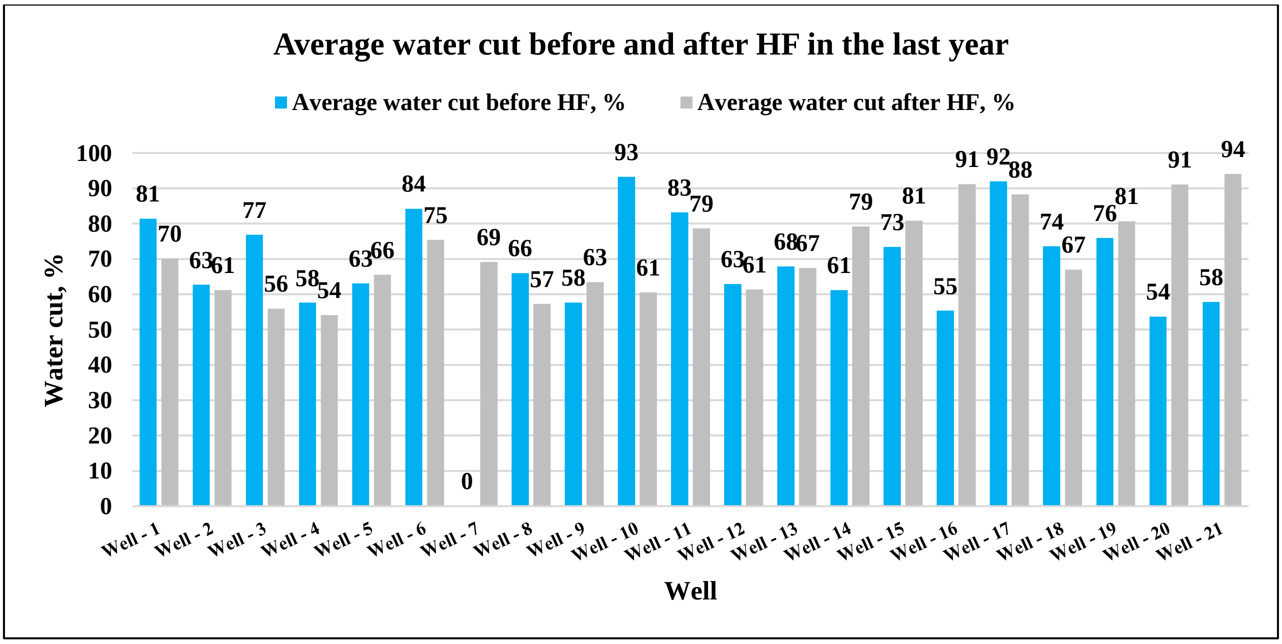

Figure 4. Average water cut of unsuccessful wells before and after hydraulic fracturing in the last year

In the last year, 55 hydraulic fracturing jobs were carried out to increase oil growth, however, as can be seen from the graph above, only half were successful, only 51% of success. Indicators of average water cut for wells after hydraulic fracturing differ and therefore it is difficult to determine the nature of water cut. Average water cut of wells after hydraulic fracturing both decreases and increases.

This behavior of average water cut can be explained by the fact that there was a breakthrough water into the well, the cause of which may be the growth of a fracture or, the water cut in this well was already high enough, and, after hydraulic fracturing, it began to increase due to the fact that the well is located in a highly permeable zone or due to poor sealing of the strings and other reasons.

Low reservoir pressure caused the failure of the “Well-1”, the water cut before and after hydraulic fracturing was unchanged, and no significant increase in fluid flow rate was obtained. Recommended workover for cleaning the bottom hole at the injection well "Yu-2", completed packs G and D;

Also, the low reservoir pressure was the reason for not achieving the planned indicators at the well "Well - 2", there was a suspicion of a decrease in pressure, the area is operating without Maintaining Reservoir Pressure (RPM). It is recommended to measure the reservoir pressure, transferring well "M" for injection with a return to the horizon "B";

Due to the high water cut of the "B" unit at the well "Well - 3", the well was unsuccessful. Earlier, the institute recommended the workover of the RIW of the watered intervals. At the end 5th month of the last year, during Well Servicing an explosive packer was installed at a depth of 1201 m. It is recommended to operate in the current mode.

3.3.2 Analysis of the productivity of unsuccessful hydraulic fracturing wells

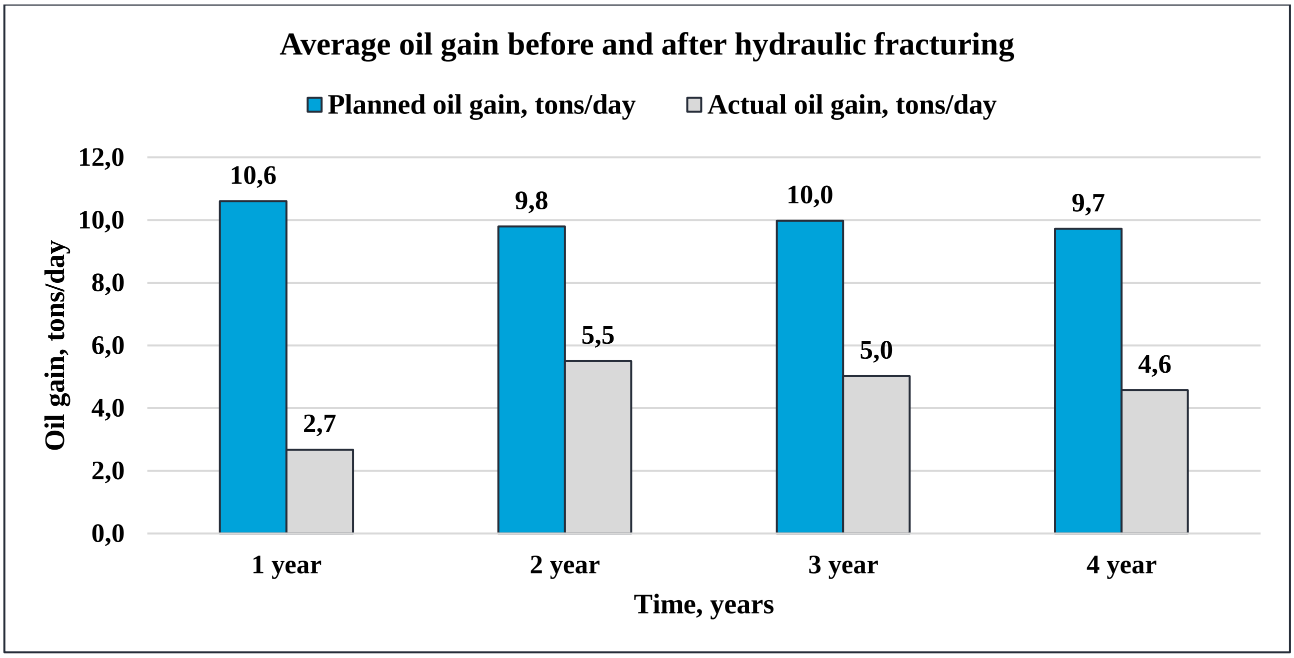

Figure 5. Average oil growth before and after hydraulic fracturing for 4 years

The slide shows a graph of the average oil growth in unsuccessful wells after hydraulic fracturing. They are considered unsuccessful because they failed to achieve the planned oil growth targets.

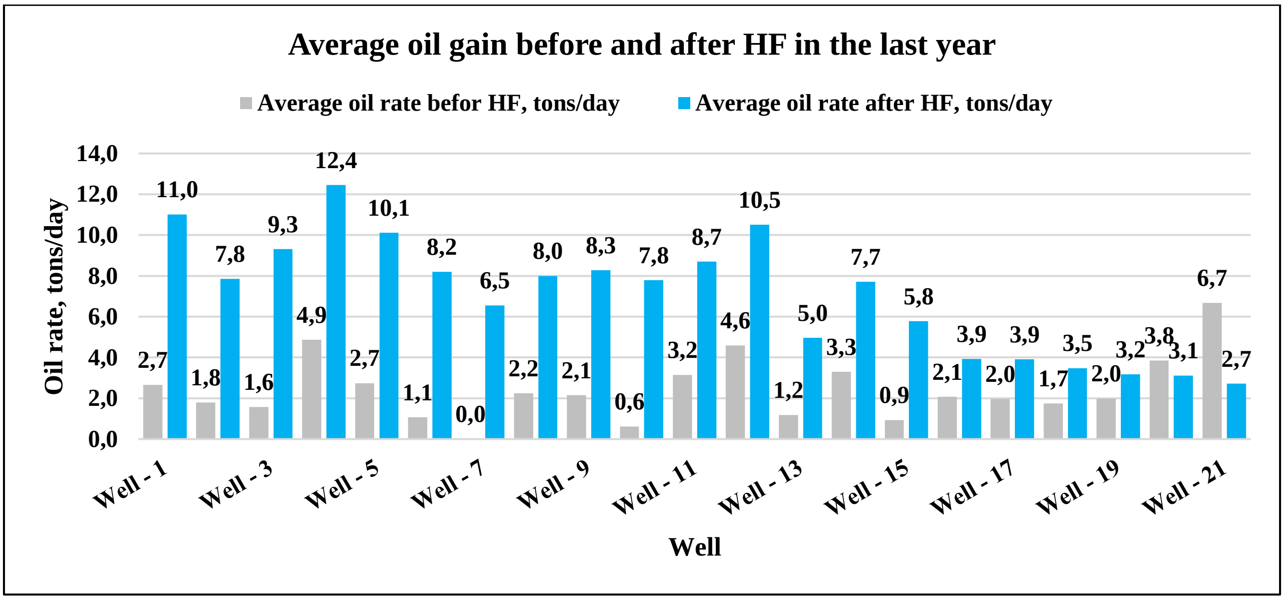

Figure 6. Average oil growth of wells before and after hydraulic fracturing in the last year

In the last year, at the wells "Well - 13" and "Well - 16" it can be seen that their average production rates, on the contrary, have decreased. A possible reason for the decrease in oil production rate is the high water cut of the wells. Let's consider wells before using hydraulic fracturing with fluid flow rate. Hydraulic fracturing data are presented in table 1.

On the example of wells "Well - 13" and "Well - 16"

Table 1. Average indicators before and after fracturing

Well	Horizon	Average indicators before geological and technical measures			Average indicators after geological and technical measures		
		Q_{fluid}, m^3/day	WC, %	Q_{oil}, tons/day	Q_{fluid}, m^3/day	WC, %	Q_{oil}, tons/day
Well - 13	B	10	54	3,8	42	91	3,1
Well - 16	B	19	58	6,7	55	94	2,7

According to the results of the work, it was revealed that after the application of this measure, oil production at the well "Well - 13" decreased by 1.23 times, it is worth noting that the inflow of water increased by 1.69 times. Also, after applying hydraulic fracturing, oil production at Well-16 decreased by 2.48 times, and water flow into the well increased by 1.62 times.

After such disappointing results, wells will be fail due to two reasons:

1. Failure to achieve the planned indicators of oil growth, the values of which are shown in Table 2;
2. High water cut.

Table 2. Comparison of planned and actual indicators of oil production

Well	Park growth, t / day		
	Plan	Fact	% of success
Well - 13	7,5	-0,46	-6
Well - 16	9,8	-3,57	-37

Reasons for the failure of hydraulic fracturing wells from last 4 years.

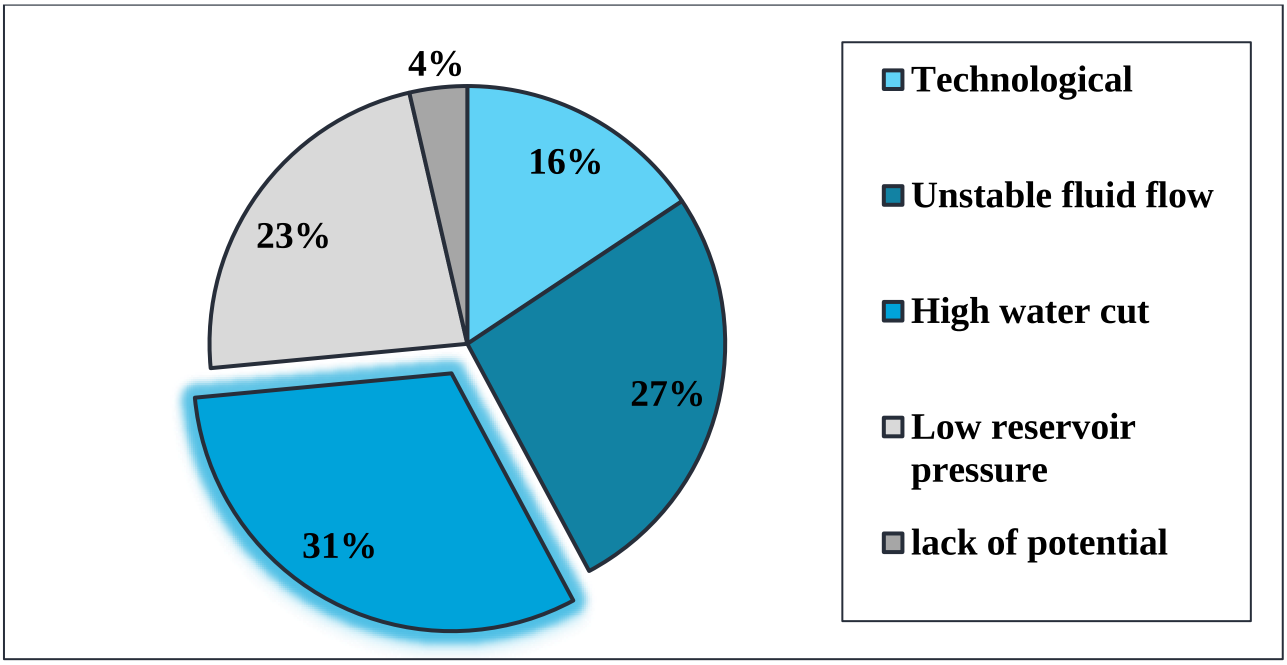

Figure 7. Reasons for the failure of wells

3.4 Features of hydraulic fracturing at a late stage of field development

Among the geological and technical measures that are used in the process of field development, which are at the late stages of development, a significant part is repair and isolation work in production and injection wells, as well as work to maintain and increase the injectivity of injection wells and work on development. This justifies the need to create a selection algorithm - candidate wells for RIW. Many individual geological and technical measures are carried out in small volumes, and some of them are carried out in the conditions of certain fields. The plan for the scope of geological and technical measures, first of all, should go from their purpose - guaranteeing the planned levels of oil reserves production from productive intervals, the implementation of oil production targets, as well as issues of labor and environmental protection. Most of the oil fields that are at a late stage of development have significant current depletion of reserves, high water cut, high density of wells and a large number of undeveloped wells. Effective workover in such conditions can significantly reduce the rate of natural decline in oil production at the field and get a decent profit. RIW occupies an important place in the workover.

In the recent past, RIW was determined by the installation of cement bridges or the injection of reagents, for example, polymers. The main argument for failures in the fight against water cut was an inadequate understanding of the problems and, as a result, the choice of the wrong decisions. Success in RIW largely depends on:

1. Correct selection of wells - candidates for RIW and the quality of well logging;
2. Correct choice of RIR technology;
3. Selecting the correct insulating material correctly for the type of rock in the field or formation of interest.

RIW planning includes:

Arguments for the selection of wells - candidates for RIW using different methods, which are mainly aimed at determining the causes of flooding:

- Finding the discrepancy between the oil flow rate and the amount of water in the well production or, in another way, the degree of water cut;
- Execution of a series of geological and geophysical studies for selected wells in order to find out:
- Composition and profile of fluid inflow from the reservoir in wells that do not flow;
- Intervals of water flow and others:
- Naturally, the very conduct of the RIW (isolation of individual flooded intervals or formations, elimination of water flows outside / behind the casing and casing leaks using modern technologies and equipment, as well as high quality grouting materials: cement mortars with special chemical additives, resins and other insulating solutions.

The primary factor for determining the technology and plugging material is the nature of the wells watering. According to this factor, RIW can be divided into the following types:

- Isolation of behind-the-casing flows from both upstream and downstream aquifers;
- Restriction of bottom water inflow;
- Elimination of breakthrough formation and injection waters in highly permeable intervals within the oil strata;
- Increased oil recovery of productive formations through leveling the injectivity profile in injection wells;
- Water isolation works that are carried out in production and injection wells at the same time. (Gabdulov R. R., 2009).

Applied RIW works on isolation of water-cut intervals at the Akku field are:

- Proppant filling of underlying flooded layers;

- Installation of cement bridge;
- Installation of blast packer. (Kozlovsky, 1984)

Table 3. Results of repair and insulation work (RIW) at hydraulic fracturing wells from the last 4 years

Name of Well	Repair and insulation works (RIW)				
	Q_{oil}, tons/days		Water cut, %		Type of work/ add. information
	Before	After	Before	After	
Well - 1	0,57	5,80	99	77	RIW (Isolation)
Well - 2	5,70	7,42	89	88	VEC
Well - 3	1,87	3,07	98	94	RIW (Isolation of watered intervals)
Well - 4	0,00	1,98	100	95	RIW (Isolation of water influx by cementing)
Well - 5	0,47	8,65	99	45	RIW (Isolation of water influx by cementing)
Well - 6	2,39	2,96	96	91	RIW (Isolation of watered intervals)
Well - 7	6,14	6,86	87	89	RIW (Isolation)
Well - 8	3,54	6,12	91	82	VEC
Well - 9	1,25	4,54	93	62	RIW (Explosion – Packer)
Well - 10	2,18	11,06	96	76	RIW (Isolation of watered intervals)

Above is a table 3 with the results of RIW for wells with hydraulic fracturing for last 4 years. So, we can observe that in the wells where prospecting and exploration work was carried out, including those with chemical additives such as VEC, oil production increased, and water cut decreased. I took an interval of 3 months. That is, one month before the RIW and one month after the RIW.

3.5 Hydraulic fracturing technologies aimed at limiting and controlling the growth of the fracture in height

Failure to contain fracture height growth during hydraulic fracturing treatments often renders uneconomical results, which drastically alter pay-out, overall hydrocarbon recovery and profitability. Problematic production of water from outside the zone of interest can rarely be reversed. Here the operator incurs the additional expense of water disposal and decreased hydrocarbon inflow at the wellbore.

If the proppant is not contained in the zone of interest, excessive fracture height results in narrowing the propped width. The treatment will not be optimum; it may not be economical.

Several methods of restricting fracture height during hydraulic treatments have been tried where lithological barriers are known to be weak or nonexistent.

Common techniques for height growth control include:

- J-FRAC technique;
- Fracturing with ClearFRAC;
- FiberFRAC technique;

- Restricting fluid viscosity and density to minimize pressure applied to barriers.

3.5.1 J - FRAC

Self-placing mix of course-fine proppant, pumped between or inside of pad and normal proppant stages, that “bridges” and “seals” pressure from (and fluid entry to) barrier zones.

J-Mix is a material, mix of specially defined size proppants mixed in a special ratio for ideal packing.

Ken Nolte’s JunkFRAC technology consist of the following: Pump J-Mix only between pad and main proppant at 1 PPA (120KgPA), total J-Mix volume should be about 10% of job size. For ideal proppant packing basic structure “actual” proppant should be ¾ of total volume, filled with optimum sizes for hexagonal proppant packing, smaller and smallest proppants should be 1/6 of total volume, each.

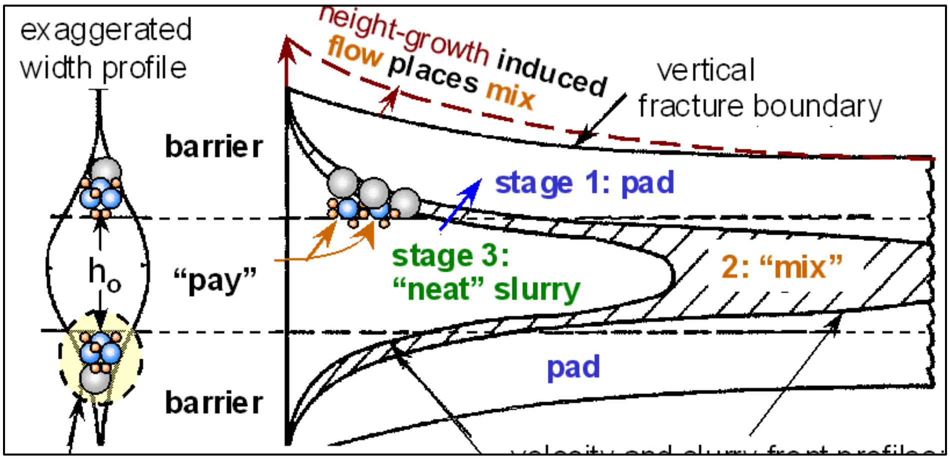

Figure 8. Pumping mix of proppants

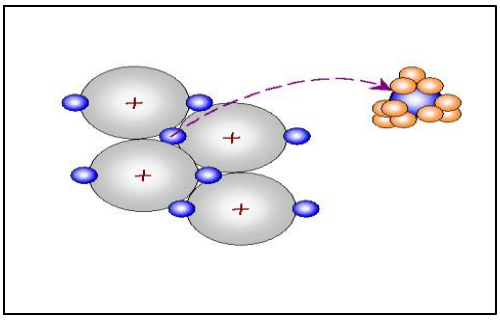

Figure 9. Proppant packing with J-FRAC

Biggest proppant purpose is to create “mechanical bridge” and two smaller sizes are needed for “pressure seal”, without pressure seal fluid flows through, dehydrating proppant in pay.

This idea was taken to prevent height growth. In Western Siberia, where highly conductive treatments Tips Screen Out are placed with emphasis on large mesh sizes ISP proppants usage, fracture height growth is considered to be a major cause of premature Screen Outs.

Some changes to technique were made:

First of all, proppant sizes and ratios were changed mostly to make it operationally easy, two types J-FRAC* material were created and standardized – J-Mix and JES-Mix (see table 4). J-Mix can be pumped during the PAD (200KgPA) and/or on the first proppant stages up to 400KgPA. Additionally, J-Mix/JES-Mix can be used not only for height growth control, however, for near wellbore restriction removal (bad perforations, etc.), as multi fracturing prevention treatment for horizontal wells fracturing (used be pumped in the first half of the PAD to plug micro fractures and then create main fracture).

Table 4. J-Mix vs. JES-Mix

	Height growth control	Near wellbore restriction removal	Multi Fracturing prevention
J-Mix	++	+	++
JES-Mix	++	++	+

Research was done on information from two Sibneft' oilfields:

1. Vyngapurovskoe
2. Sutorminskoe

Vyngapurovskoe oilfield (BV8 formation)

- Brown oilfield was put on flow in 1983, average WC 50%
- BV8 Formation consists of several sub -formation which are isolated by depth, can be very laminated
- BV8 Formation can be separated by strong shale interlayer
- Permeability varies from k<1 to 2 md; Porosity on average is 18%
- Net thickness varies from well to well (from 3 to 15 m)
- Initial reservoir pressure varies from 260 to 270 atm
- More than 50% of candidate wells are over pressured (up to 400 at) due to water injector system used by Sibneft to maintain reservoir pressure necessary to sustain production
- Extremely low formation stress contrast - high probability of unrestricted fracture height growth

Preservoir, Pclosure, Pnet analysis

Main idea of this analysis was to find dependence of P_{net} from $P_{reservoir}$ and get imagination of fracture height growth

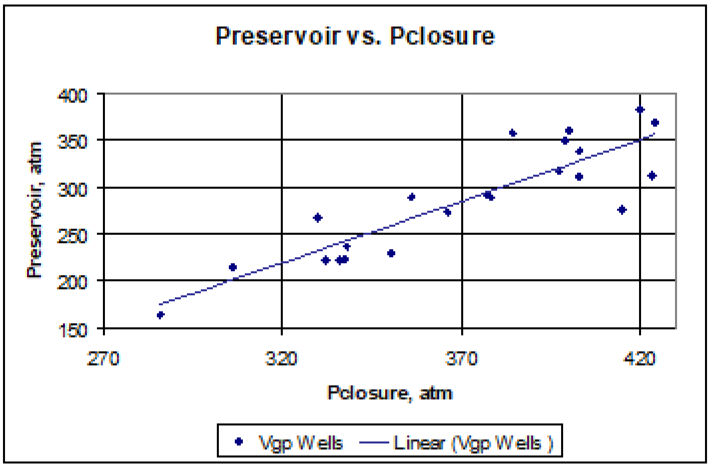

Figure 10. P_reservoir vs P_closure

From $P_{reservoir}$ vs. $P_{closure}$ graph (trend line), it is clear that when $P_{reservoir}$ increasing, Pclosure increasing as well.

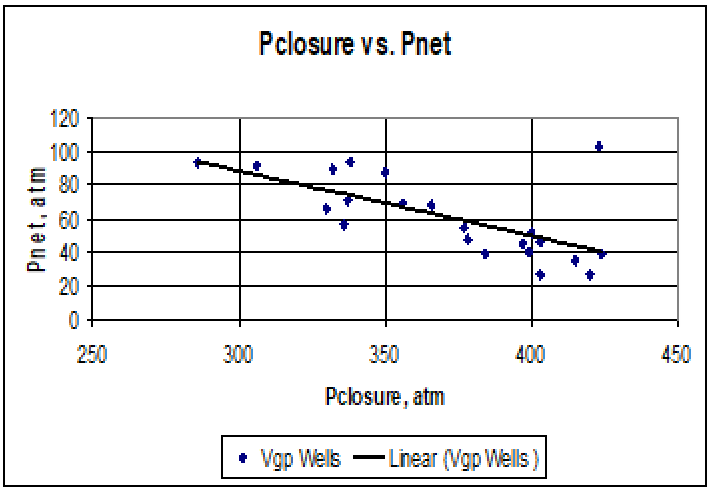

Figure 11. P_closure vs P_net

From $P_{closure}$ vs P_{net} graph we can find that when $P_{closure}$ is increasing, P_{net} is decreasing. This is a proof of height growth due to over pressurized formation on Vyngapurovskoe oilfield.

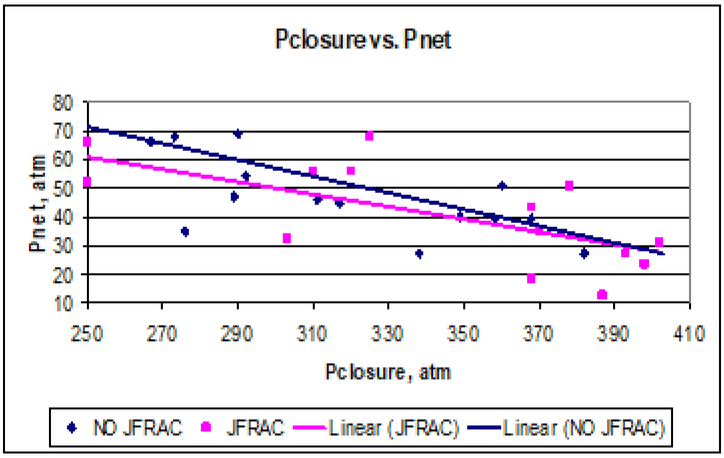

Figure 12. P_closure vs P_net

From $P_{closure}$ vs P_{net} graph two trendlines have intersection at $P_{closure}$ 390 atm, which means that if Pclosure found after DataFRAC* will be more than 370 atm (with 20 atm as safety factor, that also proved by Screen Out analysis from bottom plot $P_{closure}$ vs P_{net} – most of Screen Outs occurred on jobs where $P_{closure}$ was more than 370 atm, at the same time majority of the jobs done with J-FRAC* were pumped succefully). J-FRAC* technology to avoid premature Screen Out due to unrestricted fracture is **strictly** recommended. J-FRAC* is also recommended as soon as $P_{reservoir}$ is higher than $P_{reservoir}$ initial (overpressurized well).

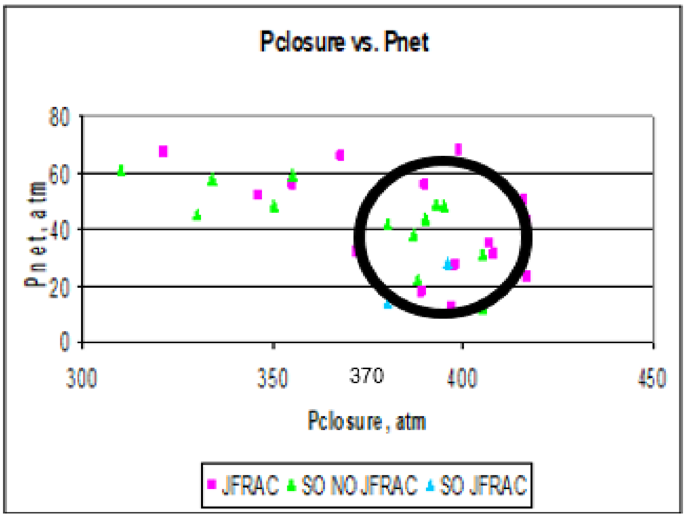

Figure 13. P_closure vs P_net

<u>Vyngapurovskoe oilfield Screen Out Analysis:</u>

Schlumberger performed 54 fracturing treatments during 2005 on Vyngapurovskoe oilfield, 36 treatments were done without J-FRAC* and 18 wells were fractured with J-FRAC*. All Screen Out reasons were divided on two groups Screen Out due to mechanical (operational) problem and Screen Out due to height growth, near-wellbore problem etc.

On wells fractured without J-FRAC* 12 (twelve) Screen Outs occurred 10 (ten) of them were on overpressurized wells. Screen Out Rate for non-J-FRAC* wells is 33.3%

On wells fractured with J-FRAC* 2 (two) Screen Outs occurred 1 (one) of them was on overpressurized well. Screen Out Rate for J-FRAC* wells is 11.1%

So, J-FRAC* technology allow Schlumberger decrease Screen Out rate as much as three times

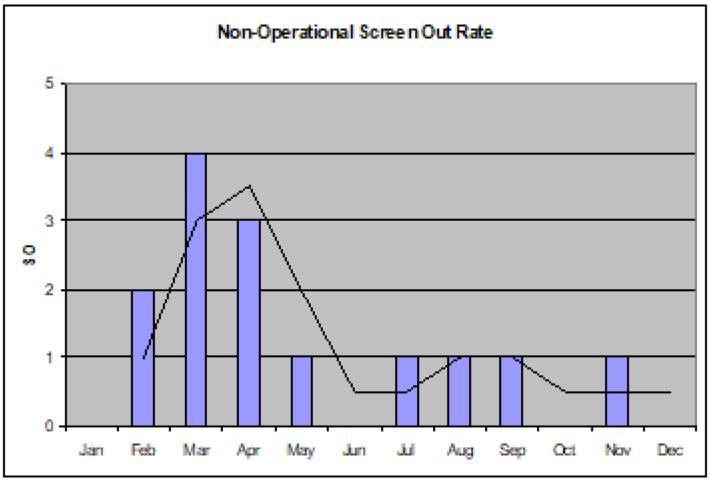

Figure 14. Non – Operational Screen Out Rate

Screen Out Analysis, Sutorminskoe Oilfield:

Schlumberger performed 16 fracturing jobs on 2005

- 6 (six) treatments were done without JFRAC*
- (three) non-operational Screen Outs
- Screen Out rate 50%
- 10 (ten) treatments were done with JFRAC*
- 1 (one) non-operational Screen Out
- Screen Out rate 10%

Table 5. Results of work with and without J-FRAC technology at the Sutomirskoye field

Analysis done on 41 well fraced on Sutorminskoe Oilfield in 2005			
Average WC wells fraced without J-FRAC*		Average WC wells fraced with J-FRAC*	
WC before Frac	WC after Frac	WC before Frac	WC after Frac
37.90%	66.50%	61.20%	77.00%
Average WC increase 28.6%		Average WC increase 15.8%	

- Effective stimulation of high risk candidates
- Fracturing treatment on oilfields that are predisposed to unrestricted fracture height growth and **were not fractured before**
- Sibneft' save up on Vyngapur non-Screen Out wells in Q1 2006 - ***120K $***
- Sibneft' save up on Sutorma non-Screen Out wells in Q1 2006 - ***60K $***
- (Gataullin, 2006)

3.5.2 FiberFRAC

The essence of FiberFRAC technologies is the use of self-destructive fibers in the working fluid. The fibers create a reinforcement that is outside of the fracturing fluid, which improves proppant transfer and retention in the fluid during operation. After the completion of the injection of this technology and the fracture is closed and the well can be re-operated, these very fibers begin to dissolve under the influence of the formation fluid and temperature. The time it takes for the fibers to dissolve depends on the formation temperature and is 10 days on average. Metal decomposition substances are “washed out” from the fracture together with the formation fluid. The main benefit of FiberFRAC technology is improved proppant transport during fractionation. During the standard process, the proppant tends to settle due to gravity. In the case of a decrease in the injection of the gelling agent and / or the use of special cross-link retarders, the proppant remains in an almost linear gel with a low viscosity for the first 1.5 - 2 minutes after the injection of the working fluid. When using FiberFRAC, the proppant remains suspended in the working fluid much longer, and, thus, the entire half-length and height of the fracture is fixed, the efficiency of fractionation increases, and the skin effect decreases. Increasing the effective thickness of the fracture half-length is especially important for reservoirs with poor reservoir properties.

After stopping the injection of the fractional liquid, the deposition of the proppant continues until the fracture closes as a result of liquid seeping through its walls. FiberFRAC fibers keep the proppant in suspension for an extended period of time, which improves fracture geometry and ensures more even distribution of the proppant. The technology can also limit the fracture height. The technology is especially relevant when water-saturated intervals are located near it. Depending on reservoir pressure and permeability, vertical fracture breakthrough into the water-saturated interval can significantly increase the water cut. Usually, fracture growth is controlled by pumping rate and proppant weight, but in this case, the hydraulic fracturing design will not be the best and the flow rate of the well may not match its potential.

Reducing the viscosity of the fractional fluid and lowering the internal pressure, as a result, is a more promising method for limiting the growth of the fracture in height. However, viscosity reduction affects the ability of the working fluid to transport proppant. Despite this, FiberFRAC significantly reduces the viscosity of the fractional fluid without affecting its ability to transport proppant.

Proppant pack conductivity growth is a major fractionation problem that affects the final well productivity. FiberFRAC can solve this problem in two ways. Firstly, the consumption of the thickener is reduced due to this technology, with the help of which it is possible to provide better proppant transportation in fluids with a lower viscosity of the fraction. Low polymer concentration indicates less residual fouling of the proppant pack and its higher conductivity compared to conventional fractionation.

The second advantage is that self-destructive fibers are used. After hydraulic fracturing, they can dissolve in the fracture under the influence of reservoir temperatures. Fibers based on this technology are composed of crystallized acid, and their decomposition after fractionation causes a decrease in the hydrogen value (pH). In this outcome, the polymer chains in the working fluid are destroyed and the viscosity decreases, which facilitates its exit from the fracture. This effect is very important for those fracture zones that are far from the wellbore, where the concentration of the destructive substance may not be sufficient for the outflow and resolution of the gel. The only drawback or limitation for using this technology is a tank temperature of at least 79 degrees C to dissolve the fibers. (I. V. Sidorov, 2010), (Schlumberger, 2014), (Uzbakiev, 2019)

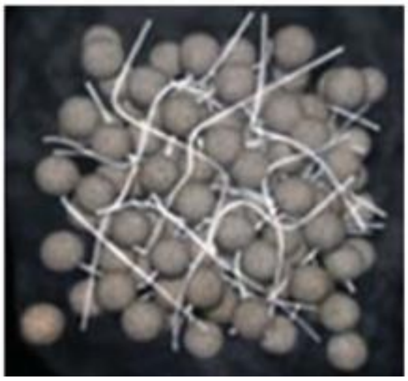

Figure 15. Proppant transportation scheme using FiberFRAC technology

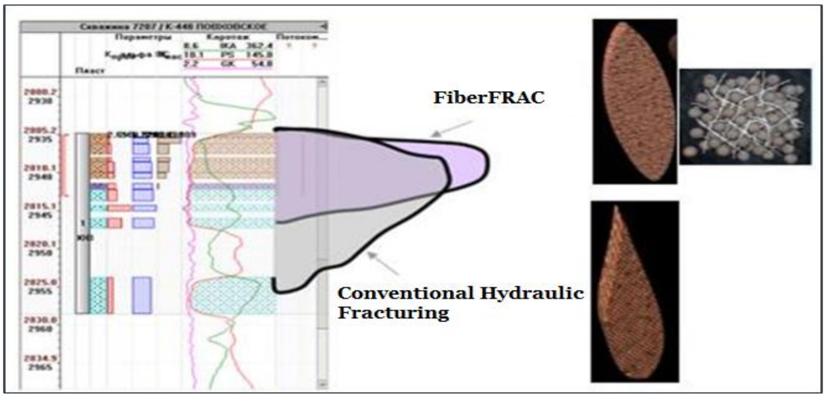

Figure 16. Fracture development options for different technologies

3.5.3 ClearFRAC

Since the time of the last century, in domestic and foreign practice during hydraulic fracturing, the role of fracturing fluids has often been played by aqueous solutions of polymers, such as gaura resin, hydroxypropyl guar, biopolymers, hydrolyzed polyacrylamide, and others. During the fracturing operation with the use of such fluids, a serious problem may arise in the deterioration of the reservoir properties due to clogging of the pore space of the formation and the resulting fractures with the remaining products of the polymer gel not completely destroyed. In addition, the high viscosity of polymeric fluids, which is necessary to contain the proppant in volume, makes it difficult to transfer the proppant deep into the formation with a low permeability value. In this case, fractures are created in the low-permeability reservoir, which mainly grow in height along the formation, while the main goal in treating a section with poor filtration properties is to create a long conductive fracture that will grow and grow as deep as possible into the pay interval.

To avoid difficulties, it is recommended to use low-viscosity fracturing fluids that do not contain polymer components. In our time, such fracturing fluids in the development of steel systems based on viscoelastic surfactants (VES). Due to the diphilic structure of surfactant molecules, they tend to self-association in solutions, which is shown in the formation of micelles. There is a surfactant concentration called the critical micelle concentration (CMC), which is beneficial for the formation of micelles in the bulk of the aqueous phase. As a result, long worm-like surfactant micelles are formed due to the optimal ratio of surfactant (SAS) and electrolyte concentrations in an aqueous medium, which ultimately form a complex three-dimensional network structure in solution, which is characterized by viscoelastic properties due to growth and interlacing with each other. (fig. 17).

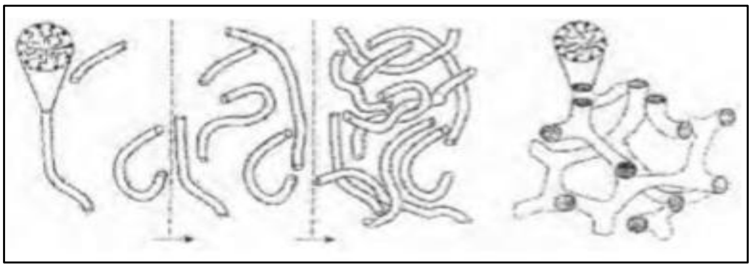

Figure 17. Formation of Viscoelastic Network out if Cylindrical Micelles

The resulting gel, due to the elastic structure, restrains the proppant in the volume and, containing significantly lower viscosity values in comparison with polymer fluids, transfers the proppant to a deeply processed productive interval (Fig. 18). An important feature of VES solutions is the reversibility of creating worm-like micelles, which have the property of breaking down upon contact with the hydrocarbon phase. As a result, the viscoelastic system loses its viscous properties and easily enters the surface together with the produced formation fluids, leaving behind highly conductive proppant packs in the formation.

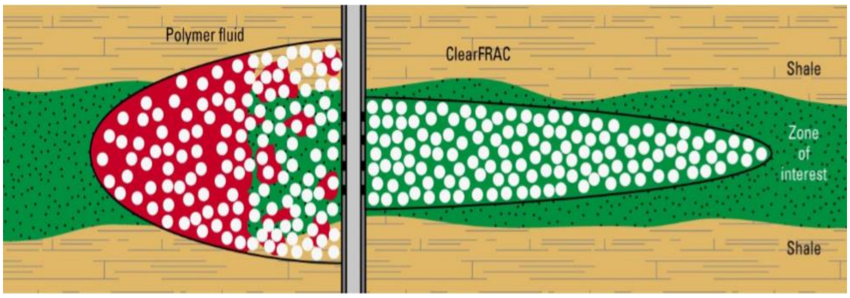

Figure 18. Formation of Fractures during Hydraulic Fracturing by a Polymer Fluid and a Viscoelastic Gel (ClearFRAC)

In the course of the work, a proposal was made to carry out mathematical modeling - to create hydraulic fractures with a fracturing fluid based on VES and a cross-linked polysaccharide gel using the FracPRO simulator. The Hydraulic Fracture Simulator is software for analyzing the creation of fractures during hydraulic fracturing. The hydraulic fracturing simulator is designed to solve certain problems that are associated with modeling the development of a fracture in a reservoir, taking into account such aspects as: geological structure of the reservoir, dynamics of fracturing fluid movement and proppant transfer, geomechanical properties of rocks. To determine and compare the effectiveness of the use of fracturing fluids based on VES and cross-linked polysaccharide gel, two hydraulic fracturing options were simulated under the same reservoir conditions and identical proppant injection designs (Fig. 19). The results of hydraulic fracturing modeling showed that the use of a viscoelastic gel as a working fluid ultimately leads to the formation of a conductive fracture, which spreads less vertically (2.5 m less than when using a polymer gel), and to a denser and more uniform packing of the proppant pack. in the fracture. As a result, the liquid based on VES showed itself at a good level, taking into account such properties as the ability to maintain rheological characteristics, containment of the proppant in the volume, stability under mechanical stresses, fracture with the hydrocarbon phase in case of contact. (M. A. Silin, 2017), (Schlumberger, 2005)

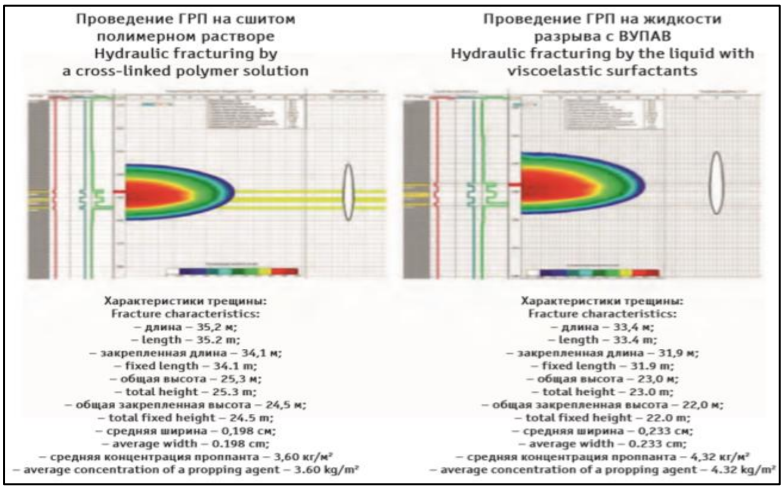

Figure 19. Modelling of Hydraulic Fracturing by a Cross – Linked Polysaccharide Gel and a Viscoelastic Surfactant Solution

An example of using ClearFRAC technology:

In 1997, in the Mesa Verde Formation in Rock Springs, Wyoming, two identical low guar (25 lb / 1000 ft) guar fluid injection wells were compared in a first well, and, VES fluid injection at the second well. Both wells had three zones (Lower, Middle and Lewis). The logs were identical in the pay zones and beyond. In the first well, where conventional hydraulic fracturing was performed, based on standard practice, the buffer stage was 32%, while 81% of the calculated proppant volume was injected into the formation. A total of 4 ppa stages were carried out as the well was showing signs of dropout, stage 5 was delayed and 6 ppa was not considered. The reason for the rejection of the ppa stages is the increase in bottomhole pressure at the entry into the perforation during the 4 ppa stage.

When injecting polymer fluid into the upper zone, the pad volume was increased to 36% and the process was modified to increase the stage to 5 ppa and place 217,000 lbs of proppant. Details in the picture 20.

	Lower Almond		Middle Almond		Lewis		Total		Average/well	
	VES	Guar	VES	Guar	VES	Guar	VES	Guar	VES	Guar
Proppant Volume (lb)	86K	140K	106K	121K	118K	217K	310K	478K	103	159
Fluid Volume (bbl)	1049	1727	951	1609	877	2084	2877	5420	959	1806
Pad Volume (bbl)	354	662	427	714	164	723	945	2099	315	700
Conductivity (md/ft)	511	394	1096	270	908	697			838	453
Frac Length (ft)	369	385	438	435	204	385			337	401
Frac Height (ft)	97	167	80	203	127	245			101	205
Cumilative Production for first six months (MMscf/D)							222,151	162,568		

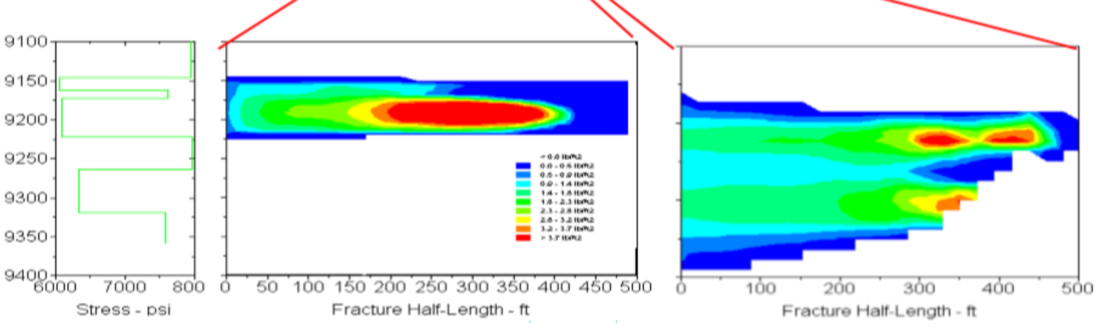

Figure 20. A comparison of job parameters and fracture simulations for polymer and VES fluid

Further, in the adjacent well, hydraulic fracturing was carried out with the help of VES. The efficiency of the VES fluid in the lower zone was 50%, while as a guar-based fluid it was 42%. A 40% pad was used for the lower zone, and fluid was pumped at 25 barrels per minute (bpm) until completion of the job. The proppant concentration was up to 6 ppa. The average pressure was 7000 psi for the VES fluid, while the average pressure for the polymer based fluid was 7850 (psi). The top two zones were also pumped to completion as planned with cushion volumes of 32% and 20% respectively. Such small pad volumes were associated with increased fluid efficiency using VES.

The pressure after completion of work on two wells showed that the two lower zones had equal calculated fracture lengths during both polymer and VES treatment. The figure above lists the amount of fluid and proppant used during the job and the calculated fracture properties, which are based on post-job pressure histories.

The main difference between the crosslinked polymer system and the VES is the final fracture height. For all treatments using guar, the fracture height was more than double that of the VES. This is due to the high viscosity of polymer fluids. (fig. 21). The results showed that similar fracture lengths can be obtained using VES fluids due to the smaller volumes of fluid and proppant. The results showed that in the wells, where hydraulic fracturing with fluids was carried out, VES's were cleaned faster than hydraulic fracturing with polymer fluid. Production from the well with VES showed 2.8 MMSCF / d, while production with a liquid with a low guar content showed 1.3 MMSCF / d.

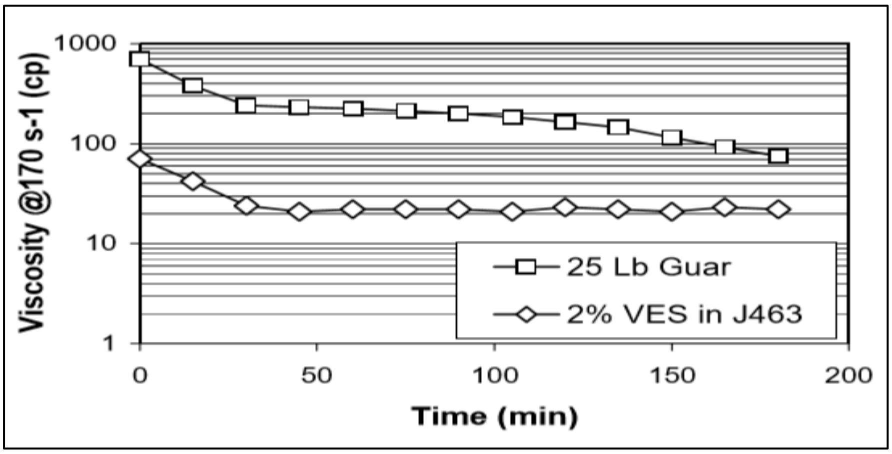

Figure 21. A comparison of the theologies between polymer and VES fluids

VES fluids provide significant benefits and improved performance for low and high permeability oil and gas wells. VES fluids have unique properties and require special fracture treatment design as opposed to gallons to replace gallons of fluid with traditional polymer-based systems. In developing such fracture treatments, it is necessary to explore the wide range of benefits of the VES system. The use of VES fluids can lead to a higher conductivity of the proppant pack, a longer effective fracture length, a smaller increase in fracture height due to lower viscosity and lower friction pressure, which makes it possible to successfully perform unconventional works (hydraulic fracturing using coiled tubing).

Field results have shown that VES fluids provide the following advantages / benefits over conventional polymer fluid systems:

- Due to the combination of very high fluid efficiency (~ 85%) и 100 residual conductivity for proppant pack, non-damaging viscoelastic surfactant fracturing fluids provide very high effective (productive) fracture length;
- Similar conductivity of the proppant pack compared to polymer-based systems can be obtained with VES fluids with significantly less proppant;
- Using a low viscosity fluid that is capable of efficiently transporting proppant minimizes unnecessary fracture height growth;
- When pumping VES liquids, lower costs for hydraulic power or higher pump performance can be achieved as a result of lower friction pressure;
- Significant time savings on the rig, faster well clean-up, earlier well-production and higher production rates were achieved through the use of VES fluids.
- (Mathew Samuel, 2009)

Here we have prices of each technology, which directed to control fracture height

Table 6. Addition information of technologies

	Price	QHSE Requirements	Availability	Additional equipment
J-FRAC*	**2.5k $/ton**	**Std 5**	**Yes**	**No**
ClearFRAC*	**898$/m3**	**Std 5**	**Yes**	**No**
SlickWater / FiberFRAC*	**350$/m3**	**Std 5**	**Yes**	**No**

3.5.4 Organosilicon compounds

There are plugging materials based on organosilicon compounds - compositions that include alkoxysiloxanes (AKOR, VTS - 1, and VTS - 2). However, these compositions have a number of negative aspects. It is preferable to use AKOR at high temperatures, therefore, in the range of 20 - 30 ° C, the hardening time is greatly slowed down. However, due to the presence of titanium or ferric chloride in AKOR, it is corrosive and can harden prematurely during storage. Organosilicon fluids have a number of advantages, such as good filterability in the formation, resistance of the plugging mass to temperature and formation fluids. During the RIW with plugging compounds based on organosilicon compounds, conditions were identified when this technology can be used:

- Terrigenous type of reservoir;
- Temperature should not exceed 150 ° C in the interval of RIW;
- High water cut of the well - 99%

Table 7. Results of waterproofing works with AKOR-BN formulations in 2002-2007.

Field	Impact technology	Number of treatments	Success %	Add. oil production, tons
Akku	**VEC + AKOR**	**35**	**77,15**	**22806**
Akku	**AKOR**	**1**	**100**	**15**

Figure 22. AKOR-BN material: Result of reaction with oil and water

AKOR BN materials are basic reagents. They can be used in a commercial form (factory readiness) or on their basis to prepare various insulating compounds and compositions.

AKOR BN in its commercial form forms a gel upon contact with formation water, it is easily diluted with water in the required proportions. The resulting composition has an adjustable gelation time, which depends:

- On the pH of the medium (the maximum gelation time for the AKOR BN formulations at pH = 2-3, and the minimum at pH = 7),
- From formation temperature (the higher the temperature, the faster the gelation),
- From the porosity of the formation structure (the lower the porosity, that is, the larger the contact surface, the faster the gelation)

The gelation time of the formulations increases with the volume of added water

Technological advantages of the technology:

- High degree of factory readiness of materials of the AKOR-BN group;
- Ease of preparation of compositions based on AKOR-BN;
- Stability of properties of AKOR-BN materials and compositions based on them;
- Use of standard equipment when carrying out work;
- The technology is selective and easily adaptable for each type of water shut-off work;
- The duration of one well-operation is: from 6 hours to 10-15 days (when performing complex RIW)

A widespread problem in the joint exploitation of several layers (interlayers) is water breakthrough through a highly permeable reservoir, bounded from above and below by aquicludes. In this case, the source of water can be active edge water, or the front of injected water.

The technology assumes 2 options for solving these problems:

- Injection of the calculated volume of the water shut-off composition into the reservoir and its subsequent resale without reinforcement or with cement reinforcement;
- Preliminary blocking of the perforation interval with subsequent opening of the reservoir - watering agent, injection of the water shut-off composition there, if necessary - reinforcement with cement mortar, and then opening the oil reservoir. If the size of the bridges is sufficient for the use of packer systems, it is recommended to use directional injection of a water shut-off composition into the reservoir - a water-supply, without preliminary blocking.

Before isolation **After isolation**

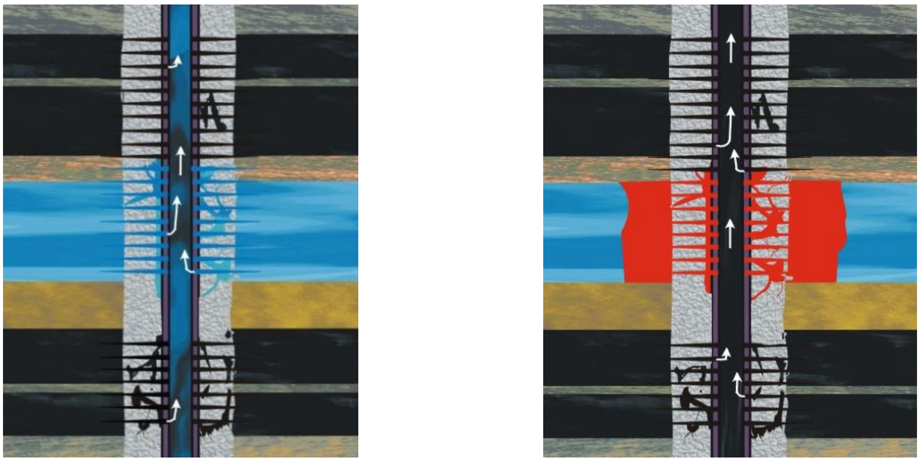

Figure 23. Isolation of watered intervals

Bottom water flow problem occurs when oil-water contact is near the bottom perforations. In reservoirs with relatively high vertical permeability, this phenomenon has the character of coning.

This problem can be solved by alternating injection of formulations based on AKOR BN with different gelation characteristics through existing technological holes. The first portion is supplied with the minimum injection rate and the maximum re-pumping rate, and the number of portions and their volume depends on the geological and technical properties of the formation. As a result, batch injection of this type will make it possible to create a sufficiently long, reliable water barrier with the lowest flow rate of the injected material (AKOR BN)

Before isolation **After isolation**

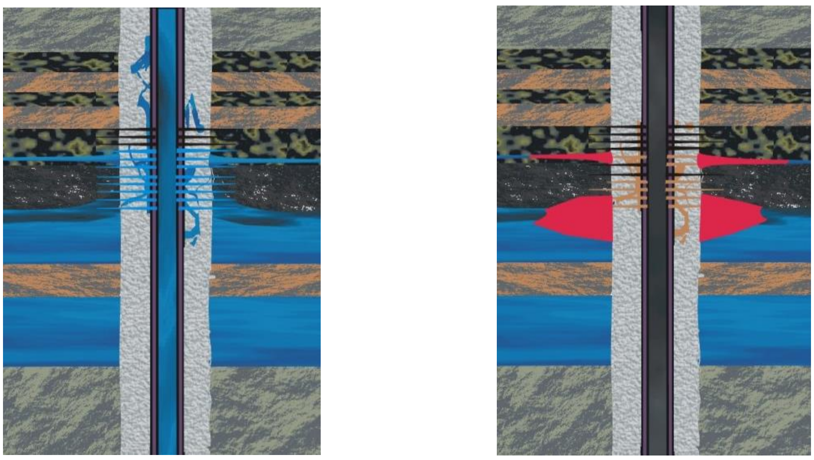

Figure 24. Isolation of bottom water inflow

To eliminate the ingress of the composition of the AKOR BN material into the productive interval during isolation of the casing leakage, it will be necessary to separate the leakage in the casing and the perforation interval using sanding, installing a cement bridge, explosion - a packer or a two-packer system; find out the injectivity of the leakage interval and, if, in case of its nonexistence, it is necessary to carry out acid treatment.

In order to avoid a sharp water cut of the production after hydraulic fracturing, it can be solved by injecting AKOR BN material through the existing perforation interval in finished form or in the form of a water-filled composition, with further re-injection into the formation with a kill fluid or other process fluid, in a volume equal to calculated pore space between proppant particles. (Stroganov V. M., 2016)

3.6 Model of prediction water cut with time

In the course of the thesis, it was revealed that high water cut poses a great threat to companies and to avoid this problem and prevent it in the future, an attempt was made to create a water cut forecast model based on machine learning. Because high water cut in late stage wells directly affects oil production, which is a top priority for all companies. The research carried out proves that the problem of water cut is of increased importance in the future.

I took 100 wells of the Akku field for the model. The model was trained for 75 wells, and for the remaining 25 wells I made a water cut prediction test.

Main criterion of this type of model – Euclidean distance, in the other words it means distance between wells (the nearest wells). Below I illustrated pictures and tables with results of this algorithm and compared with other types of regressors, like linear, ridge, lasso, with their average errors.

The results of the Training and Test set are shown below. The first column is predicted water cut; the second column is real water cut; the third column is the difference between the forecast and the real value. On training - the model was trained by the random method on 75 wells. On the test, the model calculated its forecast of water for 25 wells.

Table 8. Input parameters of model

Parameters	Units
Cumulative oil production	tons
Oil rate	tons/days
Average water cut of well during the month	%
Water cut of well after Hydraulic Fracturing until the end of the year	%
Number of days worked (before water cut)	days
Location of wells: X, Y	degree (°)

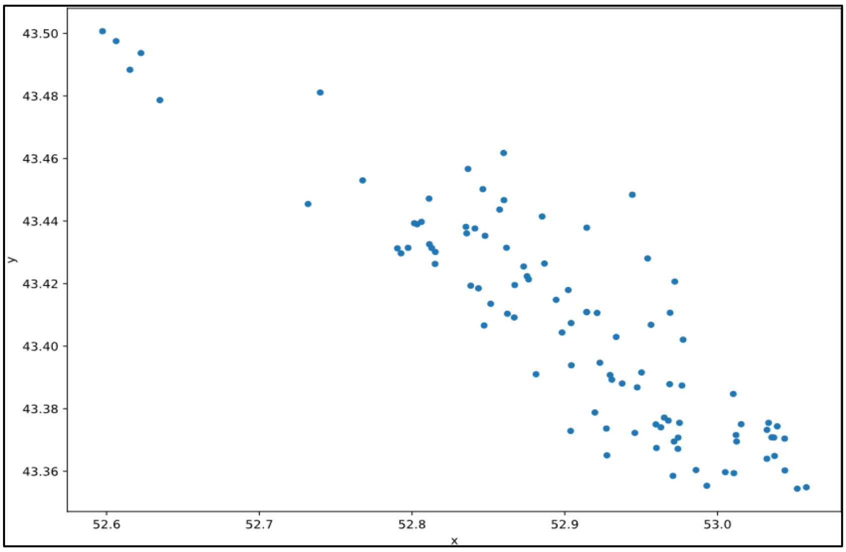

Figure 25. Location of selected wells with input coordinates

Red – horizon “A”

Green – horizon “B”

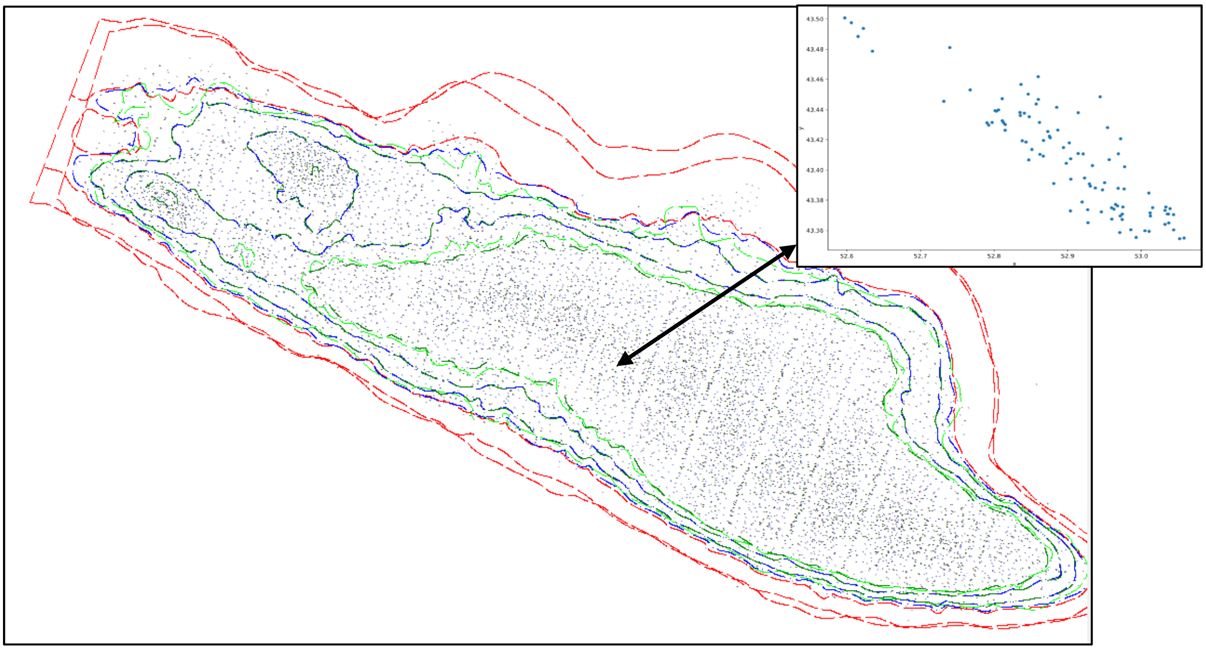

Figure 26. Location of selected wells on map of Akku field

Well	Cum Prod	Days	In prod	Q oil	wct_average	wct_after_HF	Top perf	Bottom perf	x	y
Well - 1	424.317287	307.666667	1	0.647250	92.235361	80.703467	1184.0	1188.0	52.960008	43.367463
Well - 2	2528.643478	312.975833	1	14.886199	53.779291	54.079597	1158.0	1178.0	52.971536	43.369509
Well - 3	732.004791	338.381250	1	5.646744	78.265094	88.261475	1184.9	1198.3	52.739880	43.481100
Well - 4	2121.161882	277.843750	1	14.312953	63.107702	65.525935	1222.4	1246.5	52.944218	43.448417
Well - 5	2090.240051	288.955000	1	10.367446	71.001956	75.404133	1124.0	1150.0	52.937570	43.388061
...	...	...	...	...	...	...	...	...	...	...
Well - 96	3529.823164	298.000000	1	17.771443	64.255166	66.484846	1142.4	1177.0	52.902279	43.417954
Well - 97	1831.380748	228.000000	1	14.508730	68.915904	67.602902	1150.0	1196.0	52.815072	43.426292
Well - 98	1563.542250	133.000000	1	16.595811	64.077653	68.420262	1135.0	1171.0	52.974206	43.370747
Well - 99	2952.083284	261.000000	1	16.267198	72.579716	75.988275	1130.6	1150.0	52.950257	43.391586
Well - 100	2367.355696	207.000000	1	15.960918	65.309651	59.447409	1062.0	1098.0	52.975109	43.375485

Figure 27. Table of data

Well	Cum Prod	Days	In prod	Q oil	wct_average	wct_after_HF	Top perf	Bottom perf	...	90	91	92	93	94	95
Well - 1	424.317287	307.666667	1	0.647250	92.235361	80.703467	1184.0	1188.0	...	0.063021	0.052516	0.044128	0.072415	0.026023	0.076694
Well - 2	2528.643478	312.975833	1	14.886199	53.779291	54.079597	1158.0	1178.0	...	0.070596	0.040947	0.041247	0.061052	0.018636	0.084519
Well - 3	732.004791	338.381250	1	5.646744	78.265094	88.261475	1184.9	1198.3	...	0.188060	0.294555	0.239655	0.315032	0.254698	0.174244
Well - 4	2121.161882	277.843750	1	14.312953	63.107702	65.525935	1222.4	1246.5	...	0.047957	0.104331	0.045125	0.122032	0.069124	0.051834
Well - 5	2090.240051	288.955000	1	10.367446	71.001956	75.404133	1124.0	1150.0	...	0.032571	0.077174	0.038683	0.097777	0.039156	0.046249
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Well - 96	3529.823164	298.000000	1	17.771443	64.255166	66.484846	1142.4	1177.0	...	0.013978	0.120378	0.067071	0.140808	0.080464	0.000000
Well - 97	1831.380748	228.000000	1	14.508730	68.915904	67.602902	1150.0	1196.0	...	0.100461	0.205413	0.154672	0.226021	0.166258	0.087605
Well - 98	1563.542250	133.000000	1	16.595811	64.077653	68.420262	1135.0	1171.0	...	0.072078	0.038297	0.040272	0.058524	0.016851	0.086034
Well - 99	2952.083284	261.000000	1	16.267198	72.579716	75.988275	1130.6	1150.0	...	0.040774	0.066024	0.026721	0.086595	0.026791	0.054746
Well - 100	2367.355696	207.000000	1	15.960918	65.309651	59.447409	1062.0	1098.0	...	0.070329	0.037848	0.035724	0.058372	0.012033	0.084308

Figure 28. Euclidean distance

Below shows the results of the Training and Test samples. The point is to predict the number of days until the well is flooded. For example, if the well has been in production for 300 days and the water cut is 90%, then the model will make a prediction for how long (days) the well will reach 90% water cut. The model needs some work - this is the simplest model, also, compared with other types of algorithms.

3.6.1 Random Forest Regressor

Prediction quantities of days to water cut with RFR

```
Predicted values from train data:
R2 train: 0.9597
MAE train: 16.504
MSE train: 426.9538
Predicted values from test data:
R2 test: 0.531
MAE test: 64.0675
MSE test: 6270.4087
RMSE:79.18591207426151
```

Figure 29. Average error of RFR

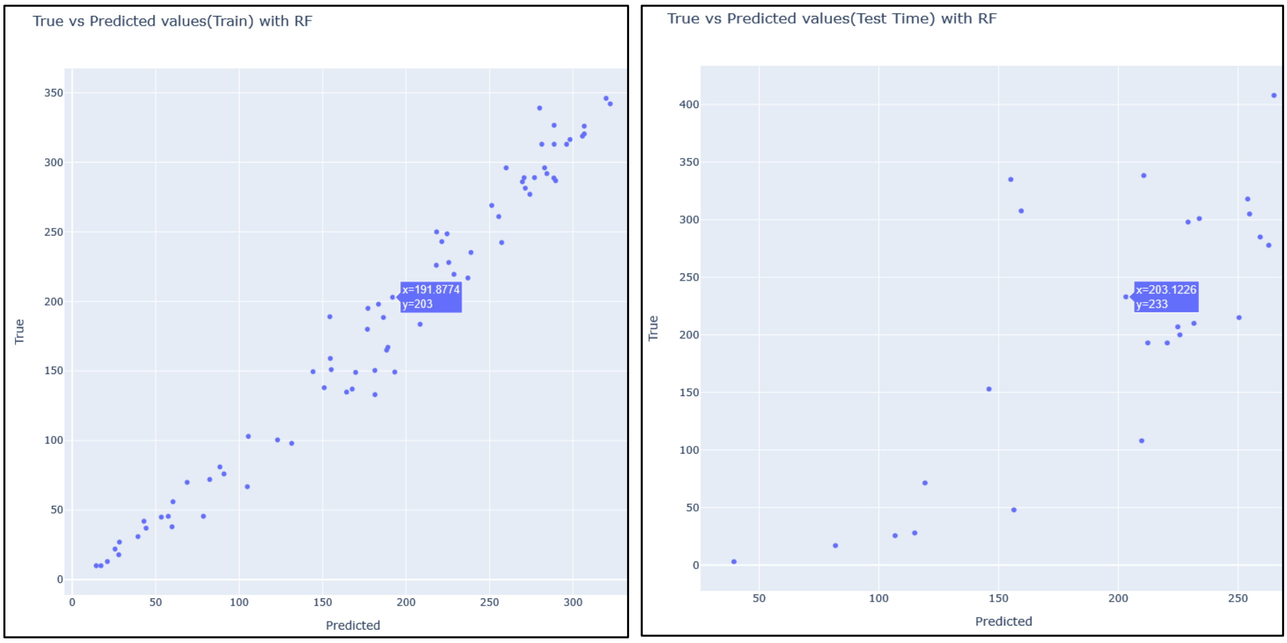

Figure 30. Comparative results with graphs of RFR

Well	wct predicted, days	wct actual, days	difference
Well - 12	186.4	188.5	2.1
Well - 49	25.6	22.0	-3.6
Well - 63	288.6	313.0	24.4
Well - 40	60.3	56.0	-4.3
Well - 35	68.8	69.9	1.1
...	...	...	...
Well - 34	123.0	100.5	-22.5
Well - 41	57.5	45.5	-12.0
Well - 31	208.4	183.6	-24.8
Well - 99	255.5	261.0	5.5
Well - 6	298.1	316.4	18.3

Well	wct predicted, days	wct actual, days	difference
Well - 60	254.0	318.0	64.0
Well - 43	106.8	25.6	-81.2
Well - 3	210.6	338.4	127.8
Well - 28	224.8	207.0	-17.8
Well - 29	231.5	210.0	-21.5
Well - 76	212.3	193.0	-19.3
Well - 59	265.0	408.0	143.0
Well - 69	259.2	285.0	25.8
Well - 53	81.9	17.0	-64.9
Well - 75	250.4	215.0	-35.4
Well - 4	262.8	277.8	15.1
Well - 74	203.1	233.0	29.9
Well - 36	119.3	71.4	-47.9
Well - 48	115.0	28.0	-87.0
Well - 81	220.4	193.0	-27.4
Well - 30	225.7	200.0	-25.7
Well - 95	156.4	48.0	-108.4
Well - 13	146.0	152.9	7.0
Well - 57	39.5	3.0	-36.5
Well - 1	159.4	307.7	148.2
Well - 93	209.7	108.0	-101.7
Well - 61	155.1	335.0	179.9
Well - 62	233.8	301.0	67.2
Well - 96	229.1	298.0	68.9
Well - 64	254.8	305.0	50.2

Figure 31. Results of Train and Test datasets of RFR

The essence of the model with RFR is that a certain number of numerators are used. We set the number of these numerators ourselves, the so-called n estimator. The essence of this model is that each numerator gives its own results, and the overall result of the model is summed up and the average value of the numerator is given. Since this model is an ensemble model, its computational power is quite simple, so we can use an unlimited number of numerators, thereby choosing the best number and quality of the number of numerators.

3.6.2 Linear Regression

Prediction quantities of days to water cut with linear regression

```
Predicted values from train data:
R2 train: 1.0
MAE train: 0.0
MSE train: 0.0
Predicted values from test data:
R2 test: 0.2474
MAE test: 84.716
MSE test: 10061.1961
RMSE:100.30551379793738
```

Figure 32. Average error of linear regression

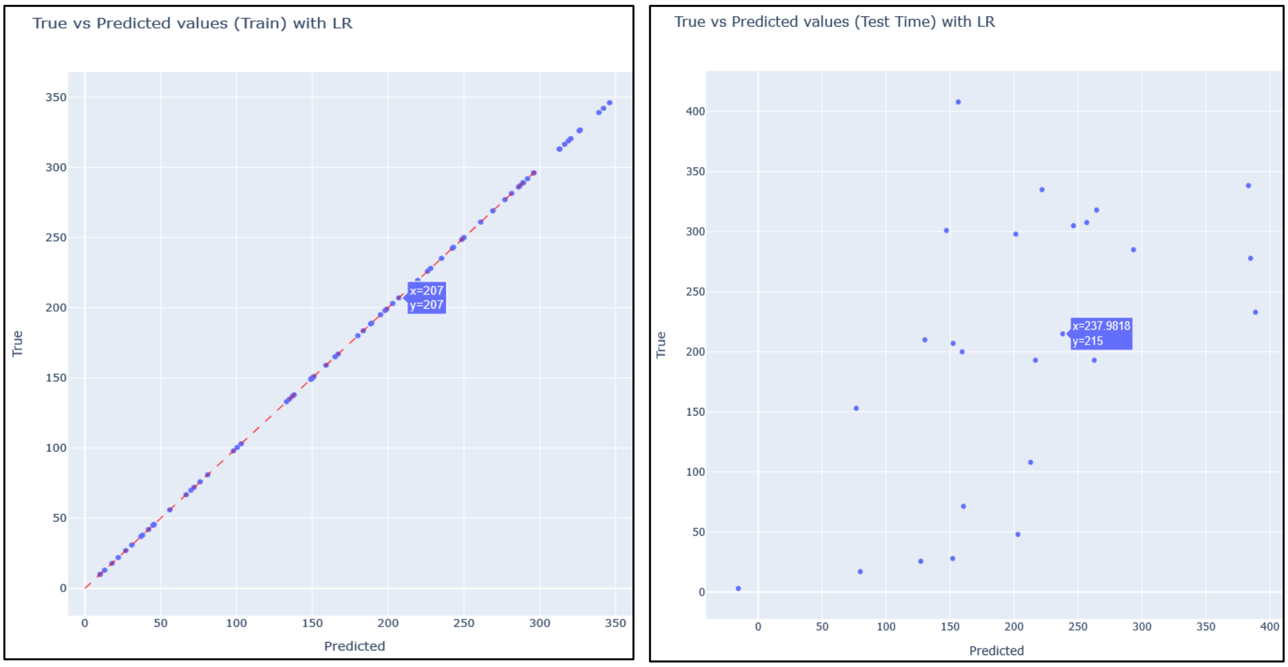

Figure 33. Comparative results with graphs of linear regression

Well	wct predicted, days	wct actual, days	difference
Well - 12	188.5	188.5	0.0
Well - 49	22.0	22.0	0.0
Well - 63	313.0	313.0	-0.0
Well - 40	56.0	56.0	0.0
Well - 35	69.9	69.9	0.0
...	...	...	...
Well - 34	100.5	100.5	-0.0
Well - 41	45.5	45.5	0.0
Well - 31	183.6	183.6	-0.0
Well - 99	261.0	261.0	0.0
Well - 6	316.4	316.4	-0.0

Well	wct predicted, days	wct actual, days	difference
Well - 60	264.4	318.0	53.6
Well - 43	127.0	25.6	-101.4
Well - 3	383.2	338.4	-44.8
Well - 28	152.3	207.0	54.7
Well - 29	130.2	210.0	79.8
Well - 76	262.6	193.0	-69.6
Well - 59	156.3	408.0	251.7
Well - 69	293.3	285.0	-8.3
Well - 53	79.7	17.0	-62.7
Well - 75	238.0	215.0	-23.0
Well - 4	384.8	277.8	-107.0
Well - 74	388.7	233.0	-155.7
Well - 36	160.4	71.4	-89.0
Well - 48	151.9	28.0	-124.0
Well - 81	216.6	193.0	-23.6
Well - 30	159.3	200.0	40.7
Well - 95	202.9	48.0	-154.9
Well - 13	76.6	152.9	76.4
Well - 57	-15.6	3.0	18.6
Well - 1	256.7	307.7	50.9
Well - 93	212.9	108.0	-104.9
Well - 61	221.8	335.0	113.2
Well - 62	147.0	301.0	154.0
Well - 96	201.2	298.0	96.8
Well - 64	246.3	305.0	58.7

Figure 34. Results of Train and Test datasets of linear regression

Linear regression is the simplest model of all. Its essence is to find a certain linear relationship between the objective function and the parameter. Our task is to use a multiple linear regression model. That is, we have one objective function and parameters are more than two (2). The peculiarity of this model is that it is quite easily applicable in production, but due to its simplicity, the so-called parameter - variance suffers.

3.6.3 Ridge Regression

Prediction quantities of days to water cut with Ridge regression

```
Predicted values from train data:
R2 train: 0.7858
MAE train: 39.1099
MSE train: 2271.2631
Predicted values from test data:
R2 test: 0.3617
MAE test: 69.806
MSE test: 8532.9759
RMSE:92.37410848798976
```

Figure 35. Average error of ridge regression

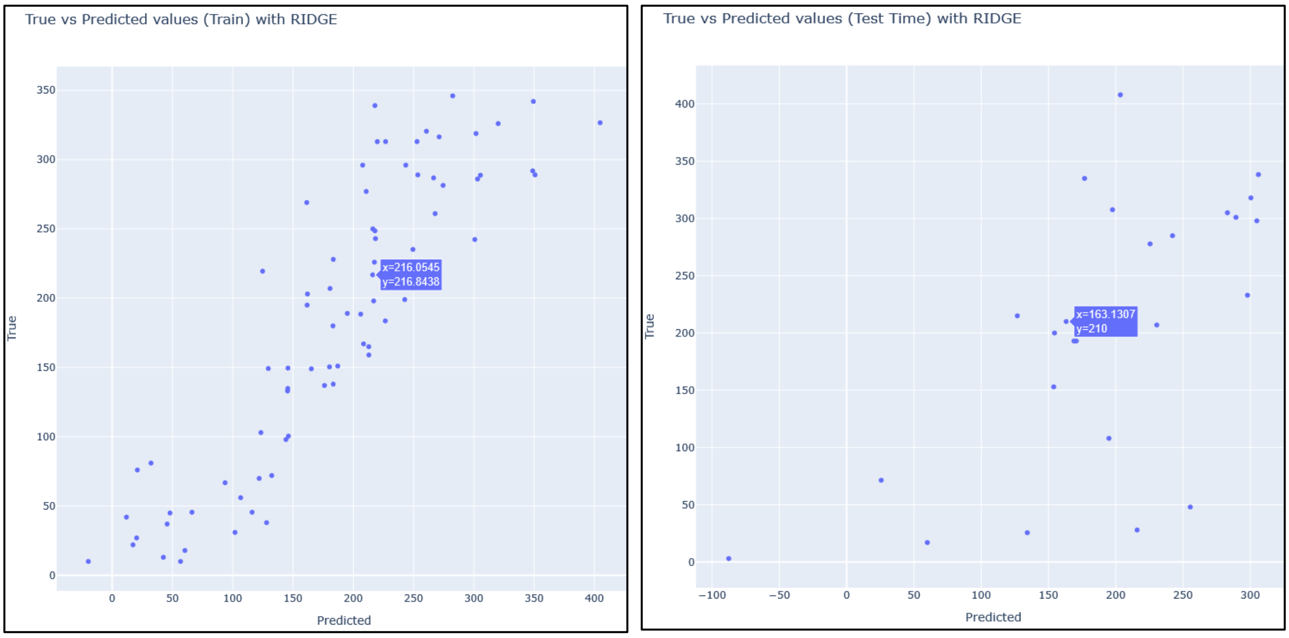

Figure 36. Comparative results with graphs of ridge regression

Well	wct predicted, %	wct actual, %	difference
Well - 12	206.1	188.5	-17.7
Well - 49	17.3	22.0	4.7
Well - 63	226.8	313.0	86.2
Well - 40	106.5	56.0	-50.5
Well - 35	121.9	69.9	-52.0
...	...	...	...
Well - 34	146.2	100.5	-45.7
Well - 41	66.2	45.5	-20.7
Well - 31	226.5	183.6	-43.0
Well - 99	267.9	261.0	-6.9
Well - 6	271.2	316.4	45.2

Well	wct predicted, %	wct actual, %	difference
Well - 60	300.4	318.0	17.6
Well - 43	134.2	25.6	-108.6
Well - 3	306.0	338.4	32.4
Well - 28	230.4	207.0	-23.4
Well - 29	163.1	210.0	46.9
Well - 76	168.9	193.0	24.1
Well - 59	203.4	408.0	204.6
Well - 69	242.2	285.0	42.8
Well - 53	59.9	17.0	-42.9
Well - 75	126.8	215.0	88.2
Well - 4	225.5	277.8	52.4
Well - 74	297.9	233.0	-64.9
Well - 36	25.6	71.4	45.8
Well - 48	215.9	28.0	-187.9
Well - 81	170.6	193.0	22.4
Well - 30	154.4	200.0	45.6
Well - 95	255.4	48.0	-207.4
Well - 13	153.9	152.9	-0.9
Well - 57	-87.7	3.0	90.7
Well - 1	197.6	307.7	110.1
Well - 93	194.9	108.0	-86.9
Well - 61	176.8	335.0	158.2
Well - 62	289.3	301.0	11.7
Well - 96	304.8	298.0	-6.8
Well - 64	283.0	305.0	22.0

Figure 37. Results of Train and Test datasets of ridge regression

This model is a more complicated type of linear regression. The essence of this model is to optimize and improve the estimates of this model when using L2 data regulation.

3.6.4 Lasso Regression

Prediction quantities of days to water cut with Lasso regression

```
Predicted values from train data:
R2 train: 0.7855
MAE train: 39.0484
MSE train: 2274.8655
Predicted values from test data:
R2 test: 0.3591
MAE test: 69.8735
MSE test: 8568.4492
RMSE:92.5659179314827
```

Figure 38. Average error of lasso regression

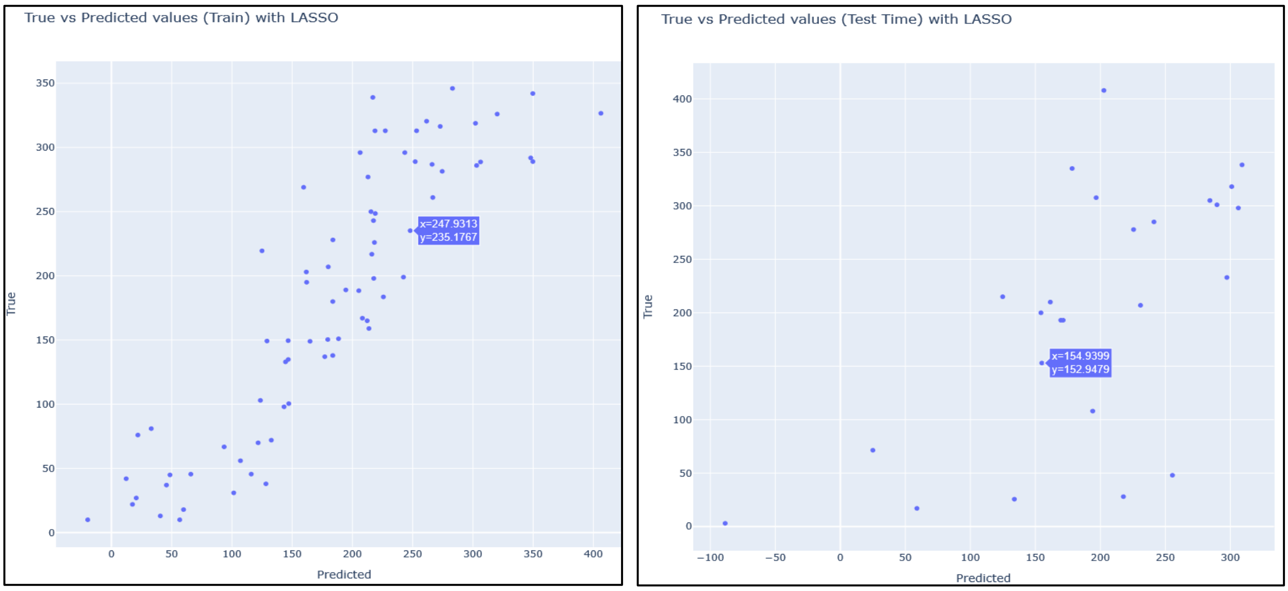

Figure 39. Comparative results with graphs of lasso regression

Well	wct predicted, %	wct actual, %	difference
Well - 12	205.3	188.5	-16.8
Well - 49	17.4	22.0	4.6
Well - 63	227.3	313.0	85.7
Well - 40	107.0	56.0	-51.0
Well - 35	121.7	69.9	-51.8
...	...	...	...
Well - 34	147.2	100.5	-46.7
Well - 41	65.8	45.5	-20.3
Well - 31	225.7	183.6	-42.1
Well - 99	266.7	261.0	-5.7
Well - 6	272.9	316.4	43.5

Well	wct predicted, %	wct actual, %	difference
Well - 60	301.0	318.0	17.6
Well - 43	133.8	25.6	-108.6
Well - 3	308.9	338.4	32.4
Well - 28	230.8	207.0	-23.4
Well - 29	161.5	210.0	46.9
Well - 76	169.5	193.0	24.1
Well - 59	202.6	408.0	204.6
Well - 69	241.2	285.0	42.8
Well - 53	58.9	17.0	-42.9
Well - 75	124.8	215.0	88.2
Well - 4	225.5	277.8	52.4
Well - 74	297.3	233.0	-64.9
Well - 36	25.0	71.4	45.8
Well - 48	217.7	28.0	-187.9
Well - 81	171.3	193.0	22.4
Well - 30	154.3	200.0	45.6
Well - 95	255.4	48.0	-207.4
Well - 13	154.9	152.9	-0.9
Well - 57	-88.6	3.0	90.7
Well - 1	196.7	307.7	110.1
Well - 93	194.0	108.0	-86.9
Well - 61	178.2	335.0	158.2
Well - 62	289.6	301.0	11.7
Well - 96	306.1	298.0	-6.8
Well - 64	284.2	305.0	22.0

Figure 40. Results of Train and Test datasets of lasso regression

This model is a more complicated type of linear regression. The essence of this model is to reduce the weights of certain parameters to zero when using data regulation. Thus, choosing certain parameters and building a model on them.

3.6.5 Conclusions on the model

Based on the above results of all models, we can definitely say that the ensemble method is the most optimal for our task, since we have a small amount of data and because of this we have to do cross-validation between the data. And the most optimal of the above models for cross-validation is RandomForestRegressor. All model estimates are given above.

Prediction of well performance parameters is possible by various methods. Some of them are very complex and labor-intensive (geological and hydrodynamic models), others are simple and fast (mathematical balance, production decline curves).

This example of building a model and comparing the forecast with real data allows us to conclude that even a very simple the "no bells and whistles" model predicts well performance parameters well. This model for forecasting water cut is the simplest and requires many modifications. The model does not take into account a lot, for example, such parameters as geology, reservoir properties or lithotypes. However, if you work further to improve this model, you can achieve good results that will definitely help in the oil and gas industry.

CONCLUSION

The current state of development at many oil fields is determined by the increasing need for RIW in the wells, which are one of the main means of ensuring the expedient development of fields. The main factor in the modern development and operation of fields is the awareness of water cut problems and their solution.

The success of RIR largely depends on the solution of the tasks set as:

- Correct selection of wells for conducting RIW, quality assurance of geological and geophysical studies of wells;
- Selection of the correct insulation material and RIW technology

To clarify the problems in the planning of RIR, it is necessary to analyze the work performed in order to clarify the area of the solved problems (geological or technical).

The main factor for the choice of technology and plugging material is the nature of wells watering.

Today an abundance of methods and criteria has been developed for selecting potential wells - candidates for RIR implementation, each of which has its own advantages and disadvantages. The definition of a method or criterion depends on the solution of the task, which may depend on time, scale, labor costs and other tasks.

RIW (Repair and Insulation Work) is an effective method to combat water cut in wells during hydraulic fracturing. For most of the wells, where the pre-fracturing workover was carried out, a decrease in water cut was observed. To improve the efficiency of hydraulic fracturing in late-stage fields with medium and high water cut, it is **recommended to:**

- ➢ Carry out a careful selection of candidate wells in order to prevent or limit the possibility of hydraulic fracture propagation into water-cut intervals;
- ➢ Perform maintenance and survey work on water-cut intervals in wells where it is possible to isolate them before hydraulic fracturing;
- ➢ Apply technologies to contain the growth of hydraulic fractures in height, such as:
- Non – polymer frac fluids;
- Viscoelastic fluids during fracturing;

- Low – viscosity frac gel with added fibers;
- Low viscosity gels;

Creation of barriers with special, low – permeability proppant packs

Apply technologies to reduce water cut after hydraulic fracturing, such as:

- Phase permeability modifiers (PPM) during fracturing;
- Hydrophobic coated proppants

REFERENCES

1. Gabdulov R. R., N. V. (2009). Generalization of the experience of selection of potential wells - candidates and technologies for repair and isolation works. *OJSC NC "Rosneft"*, 22-26.

2. Gataullin, A. (2006). *J – FRAC as a first step to obtain desired fracture geometry*. Noyabrsk: Shlumberger.

3. I. V. Sidorov, R. R. (2010). Analysis of technologies for proppant fixation in hydraulic fractures.

4. Jennings A. R., E. J. (2003). Hydraulic fracturing application.

5. JSC "Exploration Production KazMunayGas". (2017). *Financial results*. Retrieved from https://kase.kz: https://kase.kz/files/emitters/RDGZ/rdgz_reliz_270417_1.pdf

6. JSC "Exploration Production KazMunayGas". (2018). *Press release. Operating results*. Retrieved from https://kase.kz: https://kase.kz/files/emitters/RDGZ/rdgz_reliz_250418_1.pdf

7. JSC "KazMunayGas". (2017). *Integrated annual report*. Retrieved from https://kase.kz: https://kase.kz/files/emitters/RDGZ/rdgzp_2017_rus.pdf

8. JSC "KazNIPImunaigas". (2018). Analysis of the development of the Uzen field. Aktau.

9. JSC "MangystauMunayGas". (2016). *Regulation on quality control when performing hydraulic fracturing of JSC "MangystauMynauGas"* . Retrieved from https://www.mmg.kz: https://www.mmg.kz/zakup/other/AjexFileManager/ajax/php/upload/file/kartbaev/reglament_po_kontrolyu_kachestva_grp.pdf, 2016;

10. JSC NC “KazMunayGas”. (2018). Regulation on quality control during preparatory and final works and execution of hydraulic fracturing in JSC NC “KazMunayGas”. Aktau, Kazakhstan.

11. Kanevskaya, R. D. (1999). *Mathematical modeling of the development of oil and gas fields using hydraulic fracturing.* Moscow: LLC "Nedra-Business Center".

12. Kozlovsky, E. A. (1984). *Mining encyclopedia.* Moscow: "Soviet encyclopedia".

13. M. A. Silin, L. A. (2017). Non-polymer process fluid for hydraulic fracturing based on viscoelastic surfactants. *Oilfield Chemistry*.

14. M. I. Kurbanbaev, S. S. (2013). Analysis of the effectiveness of existing methods for intensifying the production of non-Newtonian oil at the Uzen field.

15. Mathew Samuel, D. P. (2009). Viscoelastic Surfactant Fracturing Fluids: Applications in Low Permeability Reservoirs.

16. Mironov, S. V. (2018). Hydraulic fracturing design. *Academic Journal of Western Siberia*.

17. Mishchenko, I. T. (1989). *Calculations in oil production.* Moscow: "NEDRA".

18. Ogly, Y. T. (2014). Increasing the efficiency of additional reserves recovery using hydraulic fracturing at a late stage of field development.

19. Schlumberger. (2005). *ClearFRAC.* Retrieved from https://www.slb.com: https://www.slb.com/-/media/files/stimulation/product-sheet/clearfrac-co2.ashx

20. Schlumberger. (2014). *FiberFRAC.* Retrieved from https://www.slb.com: https://www.slb.com/-/media/files/stimulation/product-sheet/fiberfrac_ps

21. Stroganov V. M., S. A. (2016, February 5). *"Tvikor". Effective technology of waterproofing works using organosilicon materials of the AKOR - BN group.* Retrieved from http://nitpo.tilda.ws: http://nitpo.tilda.ws/page6893137.html

22. Uzbakiev, R. M. (2019). Hydraulic fracturing technologies aimed at limiting and controlling the growth of fractures along the height.