MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

School of Geology, Petroleum and mining engineering
Department of Petroleum Engineering

Abeldinova Zh. K., Arstanova K. T., Yestemes A. D.

Analysis of the use of polymer gels for flow redistribution

DIPLOMA PROJECT

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
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DIPLOMA PROJECT

Topic: « Analysis of the use of polymer gels for flow redistribution »

5B070800 - Oil and gas engineering

Performed by: Abeldinova Zh.
Arstanova K.
Yestemes A.

Academic adviser
Ismailova J. A., PhD

J.Ismailova

Almaty 2021

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

Метаданные

Название
Analysis of the use of polymer gels for flow redistribution

Автор
Арстанова Камиля, Абельдинова Жазира, Естемес Айбол

Научный руководитель
Джамиля Исмаилова

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→	13
Микропробелы		4
Белые знаки	ß	0
Парафразы (SmartMarks)	a	23

Объем найденных подобий

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

10.40% 10.40% КП1	5.67% 5.67% КП2	0.32% 0.32% КЦ
25 Длина фразы для коэффициента подобия 2	**6893** Количество слов	**41842** 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	https://link.springer.com/article/10.1007/s12182-021-00546-1	117	1.70 %
2	http://www.prrc.nmt.edu/groups/res-sweep/gel-placement-concepts/linearradialflow.html	59	0.86 %
3	https://link.springer.com/article/10.1007/s12182-021-00546-1	39	0.57 %
4	https://link.springer.com/article/10.1007/s12182-021-00546-1	32	0.46 %
5	https://link.springer.com/article/10.1007/s12182-021-00546-1	31	0.45 %
6	http://baervan.nmt.edu/groups/res-sweep/media/pdf/Water%20Shutoff%20version%201%20Seright%20slides.pdf	30	0.44 %

7	https://link.springer.com/article/10.1007/s12182-021-00546-1	30	0.44 %
8	https://link.springer.com/article/10.1007/s12182-021-00546-1	27	0.39 %
9	https://link.springer.com/article/10.1007/s12182-021-00546-1	26	0.38 %
10	http://www.prrc.nmt.edu/groups/res-sweep/gel-placement-concepts/linearradialflow.html	23	0.33 %

из базы данных RefBooks (0.16 %)

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
Источник: Paperity			
1	**Modeling of Gas Production from Shale Reservoirs Considering Multiple Transport Mechanisms** Ruud A. W. Veldhuizen;	11 (1)	0.16 %

из домашней базы данных (0.00 %)

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)

из программы обмена базами данных (0.15 %)

ПОРЯДКОВЫЙ НОМЕР	НАЗВАНИЕ	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
1	**Диссертация Тогузбаева Меруерт.docx** Меруерт Тогизбаева МЕП18-3па (к.п.н., Жайдакбаева Л.К.) **2/12/2020** M.Auezov South Kazakhstan State University (Естественно-Научно-Педагогическая Высшая Школа)	10 (1)	0.15 %

из интернета (10.10 %)

ПОРЯДКОВЫЙ НОМЕР	ИСТОЧНИК URL	КОЛИЧЕСТВО ИДЕНТИЧНЫХ СЛОВ (ФРАГМЕНТОВ)	
1	https://link.springer.com/article/10.1007/s12182-021-00546-1	497 (21)	7.21 %
2	http://baervan.nmt.edu/groups/res-sweep/media/pdf/Water%20Shutoff%20version%201%20Seright%20slides.pdf	100 (10)	1.45 %
3	http://www.prrc.nmt.edu/groups/res-sweep/gel-placement-concepts/linearradialflow.html	88 (3)	1.28 %
4	http://www.prrc.nmt.edu/groups/res-sweep/media/pdf/Use%20of%20Gels%20for%20Water%20Shutoff.pdf	11 (2)	0.16 %

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
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TASK
For completing the diploma project

For students: Abeldinova Zh. K., Arstanova K. T., Yestemes A. D.
Topic: «Analysis of the use of polymer gels for flow redistribution»
Approved by the order of university rector №2131-b from 24.11.2020.
Deadline for completion the work: 18.05.2020.
Initial data for the diploma project: Lab experiment, open source literature datas
Summary of the diploma project:

a) *Relying on literature review it was determined that gel treatment is a good method of reducing permeability in a fractured reservoir.*
b) *During laboratory experiments, the best polymer gel was selected for working in a reservoir conditions at a temperature of 60 degrees. Gel was injected into a fracture to examine the strengths of a gel. After that, water was injected into a fracture to identify the maximum water breakthrough pressure.*
c) *Simulation on Eclipse 100 showed that extraction of hydrocarbons after gel treatment can exist for 10 years.*
d) *Analytical calculations showed the same results as in the laboratory, which allows us to rely on them during further experiments.*

Recommended main literature:

1. *R. S. Seright. (1996). Gel placement concepts.*
2. *R. S. Seright. (February 2003). Filter Cake Formation During Extrusion Through Fractures.*
3. *Root, J. E. (1963). The Behavior of Naturally Fractured Reservoirs. SPE 426.*

SCHEDULE

For the diploma project preparation

Name of sections, list of issues being developed	Submission deadline to the Academic adviser	Notes
Literature review	05.01.2021	Task completed
Laboratory experiment	15.04.2021	Task completed
Building of the simulation model	24.04.2021	Task completed
Analytical calculations	01.05.2021	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	PhD, Ismailova J. A.	05.01.2021	J.Ismailova
Laboratory experiment	PhD, Ismailova J. A.	15.04.2021	J.Ismailova
Building of the simulation model	PhD, Ismailova J. A.	24.04.2021	J.Ismailova
Analytical calculations	PhD, Ismailova J. A.	01.05.2021	J.Ismailova

Academic Adviser J.Ismailova Ismailova J. A.

The task was completed by students: Zh.Abeldinova Abeldinova Zh. K.

K.Arstanova Arstanova K. T.

A.Yestemes Yestemes A. D.

Date «18» May 2020

Content

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Abstract

In this thesis project, we propose to determine the best polymer gel for flow redistribution. The main attention is paid to the selection of the most effective polymer gel, its experimental injection into the core, as well as the application of the results obtained in the laboratory on the reservoir model in the simulation software.

The diploma project is presented in the following parts:

- General information about polymer gels.
- Selection of the most effective polymer based on the experiments performed.
- Check the strength of the gel and its properties by injecting it into the fracture.
- Comparison of the obtained experimental data with analytical and mathematical data.
- Building a 3D model in Eclipse 100 based on data and observing the behavior of the polymer gel at the reservoir scale

Our team conducted an experiment to select a polymer. The experiment lasted several months. Based on the results obtained, the best polymer for the flow redistribution was selected, which was mathematically and analytically justified, taking into account all the available properties and data.

Аннотация

В данном дипломном проекте предлагается определение лучшего полимерного геля для перераспределения потока. Основное внимание уделено выбору наиболее эффективного полимерного геля, экспериментальной закачки его в керн, а также применение полученных результатов в лаборатории на модели резервуара в программном обеспечении симулятора.

Дипломный проект представлен следующими частями:

- Общие сведения о полимерных гелях.
- Выбор наиболее эффективного полимера на основе проведенных экспериментов.
- Проверка прочности геля и его свойств путем закачки его в трещину.
- Сравнение полученных экспериментальных данных с аналитическими и математическими данными.
- Построение 3D модели в Eclipse 100 на основе данных и наблюдение за поведением полимерного геля в масштабах резервуара

Наша команда провела эксперимент для выбора полимера. Эксперимент длился несколько месяцев. На основании полученных результатов был выбран наилучший полимер для перераспределения потока, который был математически и аналитический обоснован с учетом всех имеющихся свойств и данных.

Аңдатпа

Дипломдық жұмыс ағынды қайта бөлу үшін ең жақсы полимер гельді анықтау болып саналады. Ең тиімді полимер гельді таңдауға, оны эксперименттік жынысөзекке айдауға, сондай-ақ алынған нәтижелерді зертханада бағдарламалық жасақтамасында резервуар моделінде қолдануға назар аударылады.

Дипломдық жұмыс келесі бөлімдермен ұсынылған:

- Полимер гель туралы жалпы ақпарат.
- Эксперимент жүргізу барысында ең тиімді полимерді таңдау.
- Гельдің беріктігін және оның қасиеттерін жарықшаққа айдау арқылы тексеру.
- Алынған эксперименттік деректерді аналитикалық және математикалық мәліметтермен салыстыру.
- Eclipse 100-де 3D моделін құру және резервуар масштабында полимерлі гельдің әрекетін бақылау

Біздің топ полимерді таңдау үшін эксперимент жүргізді. Тәжірибе бірнеше айға созылды. Алынған нәтижелерге сүйене отырып, барлық қол жетімді қасиеттер мен деректерді ескере отырып, математикалық және аналитикалық негізделген ағынды қайта бөлу үшін ең жақсы полимер таңдалды.

Introduction

The work introduces the concept of disproportionate permeability reduction—where polymers and gels can reduce permeability to water more than to oil or gas. Describes the properties of the formed gels when they squeezed through the fractures and how those properties can be useful in the treatment of matching problems caused by fractures. Also examines the effectiveness with which gel block the fractures after placing gel—particularly the impact of fluids administered after the treatment.

The relevance of the project is that almost 40% percent of sedimentary reservoirs are carbonate rocks. Carbonate rocks are naturally fractured, heterogeneous, permeability and porosity differs all over the rock. These fractures makes channeling in the rock, through which water can easily flow as a result in high water cut. To prevent it, gel treatment technology can be used. Gel will work as a blocking agent, by filling all the fractures, therefore reduction in permeability of fractures.

To perform the analysis for the polymer gel which in turn can redistribute the flow we must select the polymer itself. To do this, we conduct a bottle test that will determine which of the polymers we work with can be the best. The best polymer gel will be used in a further experiment to pump it into the fracture.

A characteristic feature of polymer molecules is their ability to form polymer gels. Polymer gels are polymer-solvent systems (the presence of solutes or several solvents), in which there is a spatial grid of cross-linked polymer molecules that can hold a large amount of solvent.

The interaction of polymers with other substances almost always occurs in the presence of a solvent. A swollen polymer in a solvent is not a substance, a system consisting of at least two substances: a polymer and a solvent. To prepare the polymer gel, it is necessary to use a polymer solution, to which a crosslinking agent (chromium acetate) is subsequently added.

Polymer gel is characterized by a significantly higher viscosity, or rather a complete lack of fluidity, from conventional solutions, as well as from polymer solutions. We know that the dissolution of polymers almost always goes through the gelation stage, which is observed at the initial stage of the dissolution process.

In this work, we will choose the appropriate polymer type, looking at molecular weight, behavior in brine with different salinity in a reservoir conditions, experiments on a core sample will also be conducted.

After receiving the results of experiments that were conducted in the laboratory, we will compare this data with other sources. In our case, we will use a software Eclipse 100 to build a model and also observe how our gel will behave during a long period of time to make a forecast. It can be noted that analytical calculations are also present.

1. Literature review

A review of Gel Placement Concepts.

The purpose of gel treatments and similar treatments with blocking agents is to reduce drainage through fracture or areas of high permeability without significantly impacting hydrocarbon productivity.

Basic calculations using the Darcy equation reveal three important facts.1 First, gelants and similar fluid blocking agents can penetrate a significant distance into all open zones. Second, an acceptable gelant placement is much easier to achieve in linear flow than in radial flow. Third, if flow is radial, then hydrocarbon-productive zones must be protected during gelant placement. Calculations using the Darcy equation reveal that an acceptable gel placement is much easier to achieve in linear flow (e.g., wells with fractures) than in radial flow (e.g., wells without fractures). In vertical fractures that cut through multiple zones, we might want to exploit gravity and density differences to place gel in the lower part of a fracture, thereby reducing water influx from the lower zones while leaving the upper part of the fracture open to oil flow.

These facts mean that excess channeling and water production problems can be treated much more readily if they are caused by linear-flow phenomena, such as vertical fractures, fractured systems, or flow behind pipe. Even so, placement of blocking agents is very important in linear flow as well as in radial flow. When flow is radial (e.g., unfractured wells), field engineers would be well-advised not to apply blocking-agent treatments in wells with radial flow unless hydrocarbon productive zones are protected during placement of the blocking agent. (R. S. Seright P. , 1996)

Water shutoff and conformance improvement.

Large volumes of saline water are produced during oil and gas production. Produced water is generally a nuisance that adds cost to hydrocarbon production. There are lifting costs (associated with lifting the water from the formation to the surface), processing costs (associated with oil/water separation), and disposal costs (associated with injecting water into a disposal well, if the water is not recycled for waterflood use). Further, produced water can accentuate costs associated with corrosion, scale formation, sand production, formation damage, and environmental spills. One might consider half of the produced water as useful, in that it is reinjected for waterflooding operations (to displace oil). For the other half, it seems only a detriment. Despite the costs and nuisance associated with water production, most operators choose to live with it.

The easiest excess water production problems to fix occur right at the wellbore—including flow behind pipe, casing leaks, and isolated water zones. Cement is the most common water-control material, especially since it is used for all completions. Problems with flow behind pipe exist if the primary cement placement was inadequate or if the primary cement fails (separates from the pipe or formation) after completion of the well. Deviated or horizontal wells present a special challenge for water control. On the one hand, the well can be drilled exclusively in the hydrocarbon zone of interest—thereby, theoretically avoiding water zones. Water inflow from an underlying formation can be uneven because of variations in formation thickness, vertical permeability, and placement of the well. Casing leaks are most commonly treated with either cement or mechanical devices. For very small leaks, cement often is ineffective—again because of limitations in penetrating small openings. Gels have been used at times to treat these small leaks.

The case where water cusps through matrix (no fractures) from a nearby aquifer to a production will and the cases where water channels through matrix (no fractures) from a nearby injection well to a production well. The above problems are generally very difficult and/or expensive to correct. In concept, the coning and cusping problems could be solved by reducing the production rate enough so that gravity prevents the water from rising into the well.

There are an immense number of materials that have been proposed for conformance improvement or water shutoff. Effectively reducing excess water production or channeling within a reservoir requires that the operator has significant knowledge of the reservoir and conformance-improvement materials before application. You should hold onto your wallet if someone tries to sell you a chemical that they claim can be injected into any well without precautions and will shut off water. (Randy Seright, 2021)

Water Shutoff Production Engineering. Randy Seright.

First, we would like to pay attention to distinctions between polymer flooding and gel treatments.

Polymer floods use polymer solutions, whereas during the gel treatments crosslinker is being added to the polymer solution. Also, during the polymer flooding, polymer penetration should be mostly in low-k zones, while during gel treatment gelant penetration should be in high-k zones. Gelant is a bond of polymer and crosslinker before gel formation or gelation. Gel strength depends on polymer and crosslinker concentration. Polymer flooding is better to use in matrix, where fractures do not form tough channeling, in such a way polymer solution increases the mobility ratio. Gel treatments are best to use in fractured reservoir, after gelation, gels can't flow through porous rock.

We reduce water production in order to reduce operating expenses and increase HC production.

Gelants can penetrate into all open zones, that is why gelant placement is easier to achieve in linear flow(fractured wells), than in radial flow(unfractured wells), where oil-productive zones must be protected from gelant penetration into the well. Stronger the polymer concentration and crosslink density- higher the viscosity of a gel. Larger the gelation time- larger the radius of penetration of a gel. With increasing the temperature gelation time becomes shorter.

HPAM polymers at higher temperature will quicker hydrolyze risking in formation of gel syneresis. Higher the polymer concentration- lower the gelation time. Strong gels reduce k of a rock, while weak gels restrict flow in low-k rocks

Treating fractures with gelants and gels.

Pressure behavior in a fracture during gel extrusion: pressure gradient become stable after gel breaks through until the end of a fracture. The pressure gradient for gel extrusion differs inversely with the square of fracture width. Pressure gradient is not sensitive to temperature.

Capillary pressure can prevent gelant entering the zone with high oil saturation, but in the field, the pressure drop between injection and production wells is high enough so capillary effects will not inhibit from entering the oil-wet zones. As for wettability, with higher pressure gradients the depth of gelant penetration will also increase. (R. S. Seright R. H., 2003)

A Strategy for Attacking Excess Water Production

Many engineers neglect to start by diagnosing or analyzing a problem. But in this case, they may misdiagnose. Instead of a category A problem, it can give a category C and spend more time and money to solve these problems. But this article provides step-by-step instructions on how to identify problems correctly.

The first thing to do is to find out what caused the problem. This can be caused by fractures or fracture-like features, when it is necessary to determine the fluid flow as linear or radial. It can also be caused by the flow behind the pipe or leaks. Having solved these problems, you can continue to think about what properties our agent or the correct volume of the agent should have.

After solving these problems and analyzing them, we can put these problems in a certain category. For example, with a problem with casing leaks. This problem is in different categories A and B, because we have the same problem but with different features. It is in the size of the casing leak and the size of the flow channel behind the casing leak. To solve this problem we have to take different substances.

However, gel treatment is the most common and more complex problems are solved by this. These problems can be classified as category C. This of course depends on the faults and fractures. And you can also note the pressure gradient. If this parameter reaches the minimum value, it can push the gel through the fracture and after extrusion, the gel becomes not sensitive to flow.

There are also problems with which you should not use the gel. These problems can be classified as category D. In the treatment of cone problems or three-dimensional cone formation. The gel does not reach the water zones at the bottom of the well. Although the gel has a gravitational force, it can not pass through the oil whose viscosity is too low, which was formed in the well. This can be the case when the viscosity is high and the gel is introduced slowly.

In conclusion, I want to say that the attacking to excess water can be solved without problems, only you need to follow some instructions.

2. Experimental study

2.1. Methodology description

5 polymers were selected for the bottle-test experiment:

Table 1. Properties of 5 polymers

Properties	**Description/value**				
Name	FLOPAAM 3630S CH1271	FP307	FP 5115	FP 5205	FLOPAM AN 905 SH
Type	HPAM	HPAM	HPAM	HPAM	HPAM
Molecular Weight	17.2 mln Da	6-7 mln Da	≥ 14 mln Da	13.5-19.5 mln Da	17 mln Da
Hydrolysis degree, %	30 %	5 %	10 %	20 %	25 %

All experiments were carried out in water with a salinity of 70 g / l, or 60 g/l - NaCl, 5 g/l - CaCl2, 5 g / l - MgCl2. We prepared 50 grams of polymer solution with a concentration of 0.5%. This concentration is taken from the practice of our laboratory technician. Then (0.5/100) * 50g=0.25g - is the weight of the polymer. CL = (0.05/100) * 50g=0.025 g. Since chromium acetate in the laboratory is in the form of an aqueous solution with a concentration of 0.25%. To obtain 100% chromium acetate, it is needed to take 0.1 g of an aqueous solution of chromium acetate. Mass (of brine) = 50-0. 25-0. 1=49.65 g.

First, we prepared a polymer solution. To do this, we combined the polymer with mineralized water. Then this solution was put on a magnetic stirrer for 24 hours to completely dissolve the dry polymer.

Fig. 1. Polymer solution on a magnetic stirrer

After 24 hours, cross linker should be added. Before adding the cross linker, the solution with chromium acetate must be stirred on a magnetic stirrer for a while to get a homogeneous mixture. After that, 0.1 g of chromium acetate solution was added to the polymer solution.

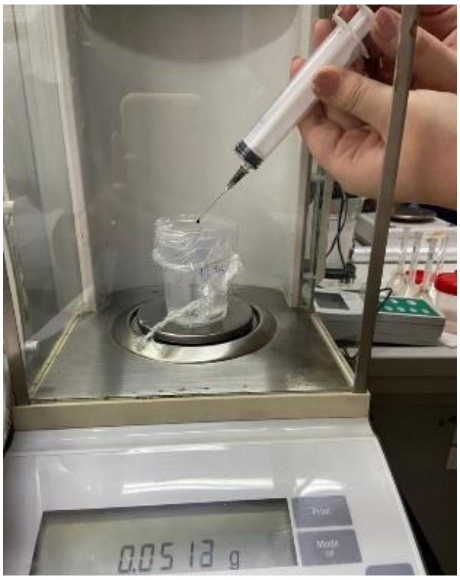

Fig. 2. Adding a cross linker

After that, the solution was put on a stirrer and stirred for 10 minutes. After that, the resulting solution was poured into a jar and put in a drying box for 24 hours to solidify and form a gel. This procedure was performed for each polymer and the behavior of the gel was monitored. Below are the drawings of the gels for 3-7 days.

18.01.21 19.01.21 20.01.21 22.01.21 25.01.21

Fig. 3. First polymer FLOPAAM 3630S, 05/13, LOT CH1272

20.01.21 21.01.21 22.01.21 25.01.21 26.01.21

Fig. 4. FP 307, 01/14, 5% hydrolysis, MW 6-7 million Da

21.01.21 22.01.21 25.01.21 26.01.21 27.01.21

Fig. 5. FP 5115, MW >14 million Da, 10% hydrolysis

28.01.21 29.01.21 30.01.21

Fig. 6. FP 5205, MW 13.5-19.5 million Da, 20% hydrolysis

28.01.21 29.01.21 30.01.21

Fig. 7. FLOPAM AN 905 SH

Gel strength was determined using the method proposed by R. Sydansk.

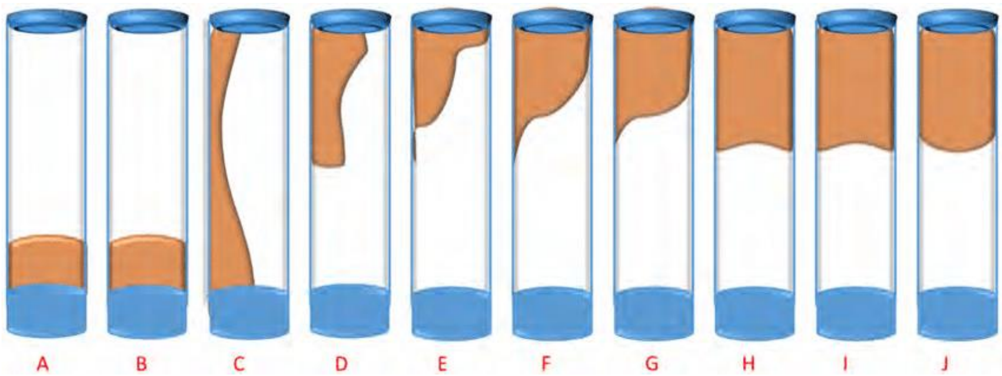

Fig. 8. Gel strength code (R. D. Sydansk)

According to the results of the study, it was determined that the best candidate for subsequent tests was polymer number 2, FP 307. Properties of this polymer presented in the Table 2. The strength of the polymer gel was determined using the figure above, its strength equal to letter G.

Table 2. Properties of polymer FP 307

Properties	Description/value
Type	HPAM
Molecular weight	6-7 mln Da
Hydrolysis degree, %	5 %

Next part of the experiment is injection of polymer gel into fracture.

We chose a limestone as a core sample, as limestone is a good example of carbonate rock that can be characterized by high heterogeneity, because of large number of natural fractures and caverns. This distribution of fractures results in heterogeneous porosity and permeability.

Fig. 9. Core sample

Properties of core sample presented in the table below:

Table 3. Properties of core sample

Parameters	Core sample
Length, cm	7
Diameter, cm	3
Porosity, %	12
Permeability, D	21.7

The core sample was cut along the axis. M(A1)=18.65 g, M(A2)=26.3 g.

Fig. 10. Core sample

The core section was washed with distilled water to get rid of small parts from the rock matrix and put in a drying box for a day at a temperature of 80C. After that a metal spacer (plate) and a core sample were glued with epoxy glue, leaving the necessary distance for a fracture (1 mm), then left for 24 hours for the glue to dry. Plate thickness 0.7 mm. Mass of dry core with a plate is 46.63 g.

Fig. 11. Bonding of the core and the metal plate

The model was saturated with brine under vacuum for 24 hours. M of core with water= 54.17 g, M por=7.54 g. Based on the mass difference, knowing the density of water, we calculated the volume, and then the porosity.

V_{por}=m (pore) / water density=7.54 g/1051cm3=7.17 cm3

The volume of the fracture is calculated by knowing the geometric parameters.

$V_{fracture}$ = 2.2 cm*4.4*0.1+2.9*0.5*0.1=11.13 cm3

$V_{opened\ pores}$=7.17+11.13=18. 3cm3

V_{core}=3.14*8.41/4=32. 35cm 3

Porosity=18.3/32.35=0.566=56.6%

The permeability is determined by filtering water through the model at different speeds and determining the steady-state pressure drop.

k=3.985 D

k=4.75 D

k=1.85 D

The dead volume is Vm=1.5857 cm3, the dead volume of the input tubes is 1.3 cm3. Saturation of the supply tube occurred at a flow rate of 1 cm3 / min.

The polymer gel was pumped at a constant flow rate and at a constant pressure recording at the inlet to the model. When the gel is detected at the other end of the model and the pressure is set, we understand that the fracture is completely filled with gel, stop pumping, wait one day. Water injection is carried out at a constant flow rate. Pressure is the main parameter that we register. A sharp drop in pressure is a water breakthrough. You need to pump at a small expense. Some of the water will pass through the packing ring. 0.2-0.5 ml/min flow rate. It is necessary to take a flow rate of 0.43 ml / min. Coning pressure 3.4 Mpa=500 psi.

The temperature on the core holder is 60 degrees, and in the box - 40 degrees.

All filtration studies on core flooding were carried out at the CIF-S core testing facility. It was used to determine the filtration and reservoir parameters of the rock sample, the oil displacement coefficient at certain pressures and temperature conditions (Figure 12). The installation is managed using a personal computer with a special program.

It consists of the following elements:

-main electronics

-unit core holder with belt heater

-main and auxiliary hydraulic pumps

-pressure and temperature sensors.

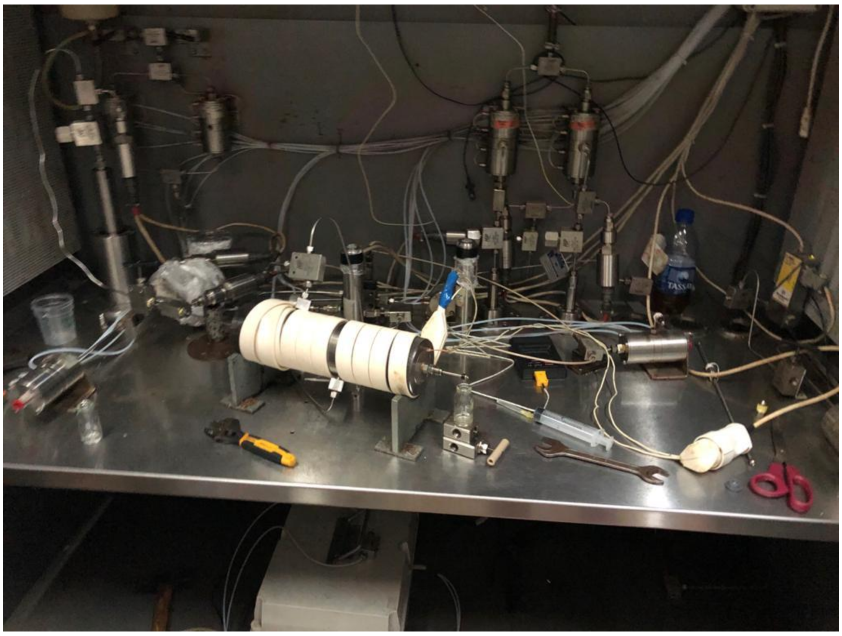

Fig. 12. Core study facility

After the experiment, we received such data:

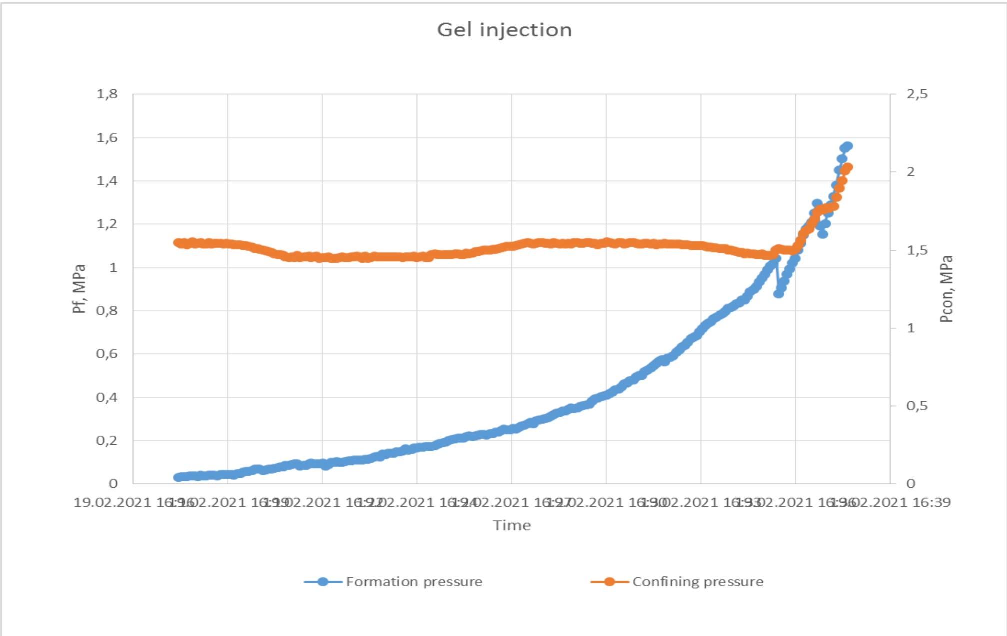

Fig. 12. Recording of reservoir and confining pressure during gel injection

In total, 8.753 cm3 of gel was injected into the system without taking into account the dead volume.

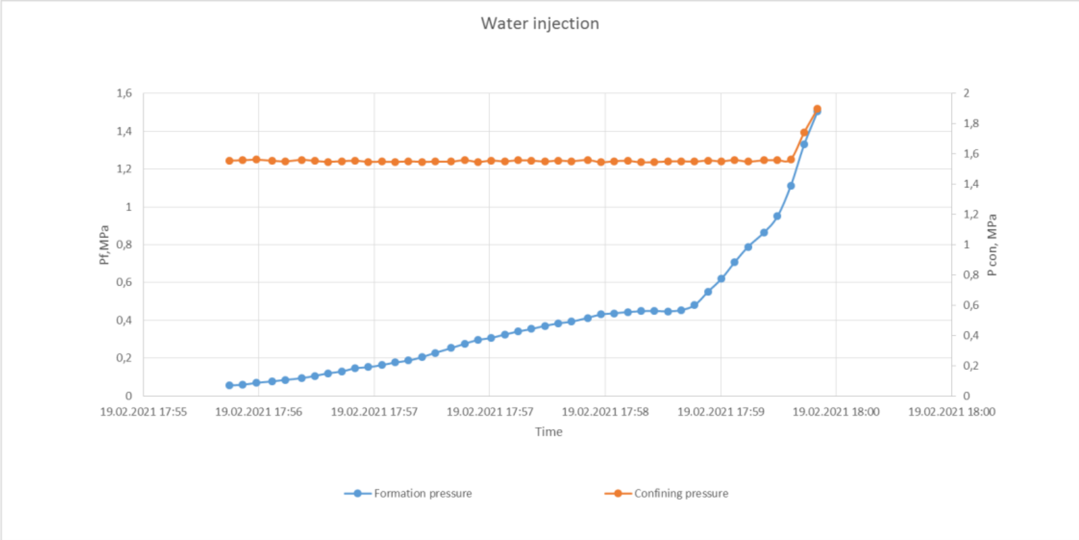

Fig. 13. Recording of reservoir and confining pressure during water injection

In this experiment, there is a confining pressure (the pressure of the overlying rocks) and a reservoir pressure (the pressure of the fluid inside our fracture) the difference between the two pressures is the effective pressure. Our fracture collapsed at an effective pressure of 1.5 Mpa. This suggests that limestone is a very weak fracture. The gel did not enter the fracture because the fracture collapsed at an effective pressure of 1.5 MPa. The width of the fracture was not enough. Water passed through this fracture at small pressure differences, but the gel could not be pumped. We show that the gel does not go into all the fractures. Measuring the width of this fracture is problematic. This is just a collapsed fracture, its width may be less than 0.1 mm. We couldn't push through our gel. The core length is 0.05. (If we divide the pressure drop by the core length and we get the gradient of our pressure)

Pressure gradient=1.5/0.05=30 MPa

Fig. 14. Closed fracture

Then we tried to reduce the Confining pressure to 1.5 Mpa.

Fig. 15. Core after the 2 experiment

Thus, we conducted 2 experiments, in the first case, the confining pressure (mountain) was 3.4 MPa, at which the fracture collapsed at the beginning of the experiment, we noticed this by a sharp change (increase) in pressure. With such a large pressure drop. We couldn't push our gel into the fracture. (If we were pumping the solution, it would come in, but we were pumping the gel).

The next stage was the production of a selfmade core holder.

New core holder:

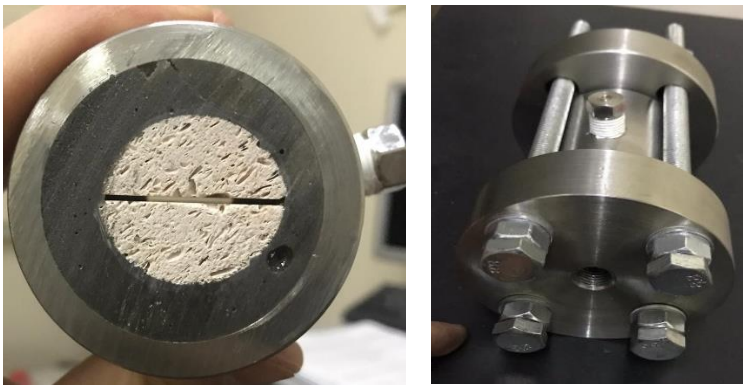

Fig. 16. New core holder and core sample

On the right picture, there is a connection in the center of the sleeve for the pressure tap. Core parameters are the following:

Core length = 7cm

Core diameter = 3cm

Metal sleeve OD = 5.6cm

Metal sleeve ID = 4.3cm

The advantages of working with a self-made core holder are that the core is coated with epoxy glue before use to eliminate the penetration of water into the rock and the core is filled in the core holder with epoxy resin, which allows you not to use the confining pressure, and the pressure inside the fracture is also recorded.

The fracture width was made 1 mm, as in previous experiments.

Fig. 17. Core preparation process before the experiment

The next step is to check the core in the core holder for leaks, during which no leaks were detected. After that, we started injection of a gel and registered the pressure. The gel injection begins:

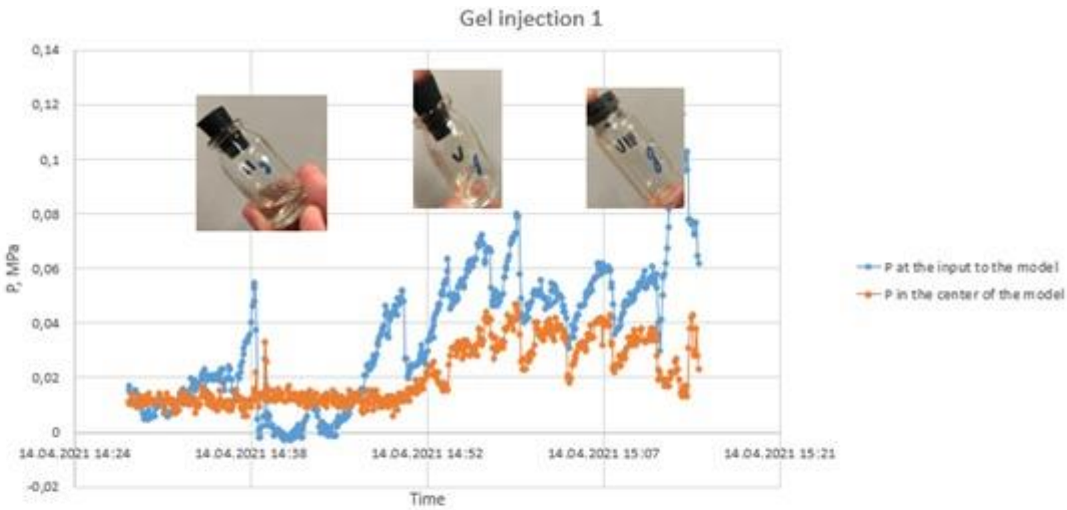

Fig. 18. Inlet Pressure and in the center of the model during gel injection 1

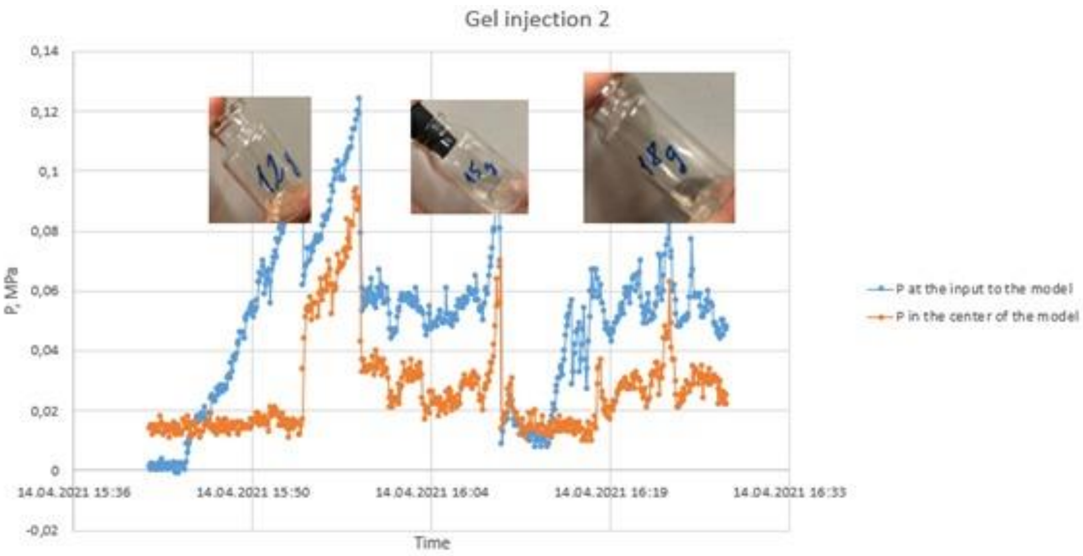

Fig. 19. Inlet Pressure and in the center of the model during gel injection 2

The gel was injected in 2 sets. Since after the first approach, we did not notice the steady-state pressure and at the exit from the model in the jars, we saw a watery gel, which shows that the gel gives off water and still comes out on its own to the surface, so the viscosity of the gel is insufficient.

At the initial stage of injection, the gel was concentrated inside the fracture and gave off water, so we saw water at the exit of the model. Total gel volume of 38 cm3, or 20 pore volumes of the fracture, was injected.

After the gel is injected, water must be pumped to test the gel for strength.

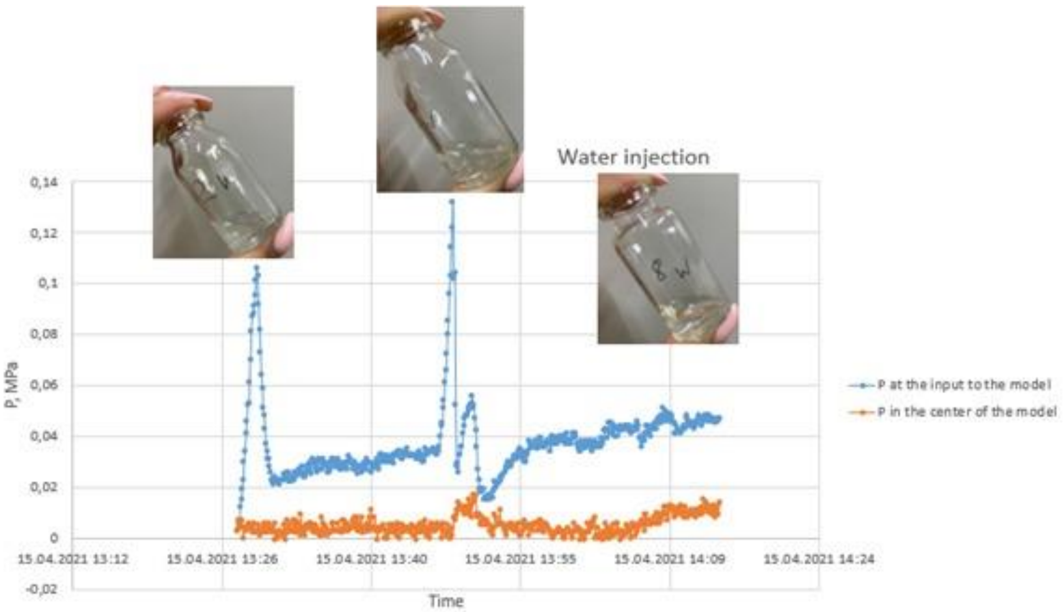

Fig. 20. Inlet Pressure and in the center of the model during water injection

2.2. Results of the experimental study

According to the results of the study, it was determined that the best candidate for further tests was polymer number 2, FP 307 with a molecular weight of 6-7 million Da and a degree of hydrolysis of 5%.

Regarding the rest of the polymers:

First: On the second day, we saw the formation of water, the effect of syneresis, in the following days, the amount of water increased, and on the fifth and following days, the gel "fell" at all.

Third: On the second day, there was no strong return of water, but on the fifth day, the gel "fell".

Fourth: a day later, the gel showed itself to be not the most stable, according to the code above, this is C, in the following days, the strength of the gel did not increase.

Fifth: on the second day, the strength of the gel according to the table, corresponded to the D. In the following days, the strength of the gel remained the same.

At the end of first two experiments, our team concluded that:

The pressure of 1.5 Mpa is sufficient for this fracture to be in a closed state, the polymer gel cannot penetrate these fractures with a concentration of 0.5 %. The experiment showed that the polymer gel does not enter the limestone fracture at an effective pressure of 1.5 MPa and 3.4 MPa.

Thus, to work with limestone, you need to use a homemade core holder, which allows the fracture not to collapse.

While working with a self made core holder, water was also supposed to be pumped in two sets, but after the end of the first one, we built a schedule and saw the steady pressure, which allowed us not to continue pumping water.

At the initial stage of water injection, pure water was released from the model, which shows that there is an empty space in the fracture through which the water breaks. At the reservoir pressure P=0.091 Mpa (P in the center=0.056 MPa), a breakthrough occurs, the gel left the model together with the water. This means that this pressure value is sufficient for the gel to breakthrough. On the graphs, this can be seen by the sharp increase in pressure.

The maximal post flush pressure drop between the center of the model and the outlet was equal to 0.017MPa = 2.46psi;If we divide 2.46psi by the L/2, were L is the core length, we get the gel rupture pressure gradient → 2.46psi/0.1148ft = 21psi/ft

2.3. Analytical calculations

Analytical calculations were made using experimental output of formulas proposed by R. S. Seright:

1. Estimating the extrusion radius for a given gel volume for a radial fracture cutting a (horizontal) well:

$$\frac{dr}{dt} = \frac{[q_{tot} - 2\pi r^2 * 0.05t^{-0.55}]}{(2\pi r w_f)}$$

$$= \frac{[0.0000027 - 2 * 3.14 * \quad ^2 * 0.05 * 1.543^{-0.05}]}{(2 * 3.14 ** 1)}$$

Where:

$\frac{dr}{dt}$ – final average factor of gel concentration, C/Co

q_{tot} – injection rate, BPM (bbl per minute)

r – final radius of gel penetration, ft

t – total injection time, hours

w_f – fracture width, mm

$Total\ injection\ time = 1.53$ hours

Final radius of penetration=0.001

2. Estimating the extrusion distance for a given gel volume in a two-wing fracture:

$$\frac{dL}{dt} = \frac{[q_{tot} - 4h_f L * 0.05t^{-0.55}]}{(2h_f w_f)}$$

$$= \frac{[0.0000027 - 4 * 0.22966 * 0.1 * 0.05 * 1.543^{-0.05}]}{(2 * 0.22966 * 1)} = 9.4$$

Where:

$\frac{dL}{dt}$ – final average factor of gel concentration, C/Co

q_{tot} – injection rate, BPM (bbl per minute)

h_f – fracture height, ft

L – final distance of gel penetration, ft

t – total injection time, hours

w_f – fracture width, mm

L – final distance of gel penetration, ft=0.1

3. Converting permeability to an effective wormhole or tube radius

$$r = (8k)^{0.5} = (q\mu/\Delta p)^{0.25} = \left(\frac{17760 * 0.976}{21}\right)^{0.25} = 400.9$$

r – wormhole radius, μm

q – flow rate, ml/h

μ – viscosity, cp

Δp – pressure gradient, psi/ft

If we have the permeability value, then we can calculate the radius of the tube. To do this we use the data pressure gradient which was detected through the maximum pressure drop after flushing between the center of the model and the outlet which is divided by half the length of the core

r – wormhole radius, μm=400.9

3. Numerical simulation

After laboratory experiments our team decided to apply results obtained from the experiments to a reservoir. To make this we constructed a 3D model. Model was created in a widely known software Eclipse 100.

Simulation model could be described by equation of Mass balance:

$$-\nabla M = \frac{\partial}{\partial t}(\varphi\rho) + Q$$

Where $-\nabla M$ is Mass Flux(in-out); $\frac{\partial}{\partial t}(\varphi\rho)$ gives an accumulation; Q is a rate of injection(+) or production(-)

Boundary conditions for equation above are :

$$P(0) = P_{in}; P(t_{max}) = 0$$

Our work consider two cases: waterflooding and injection of a polymer in order to prove the efficiency of gel treatment.

3.1. Eclipse 100 model description

To create a simulation model, the idealized Warren and Root model was used as a basis. As this is a carbonate reservoir, DUALPERM and DUALPORO keywords is needed to use.

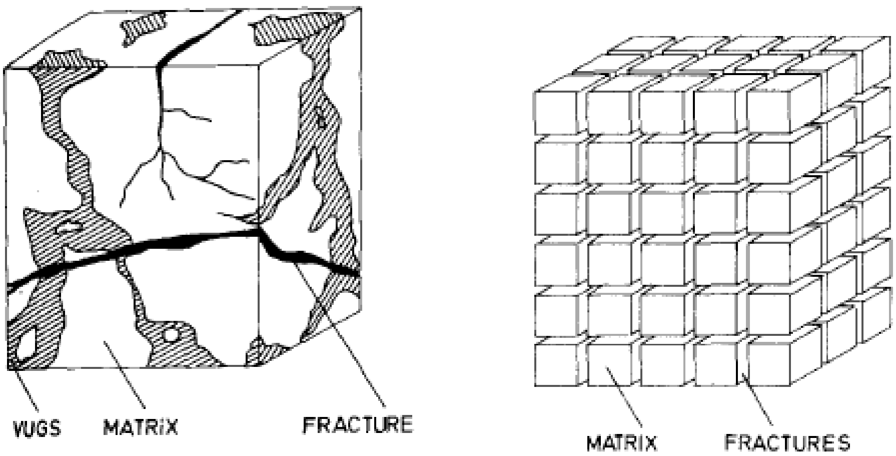

Fig. 21. Actual reservoir vs idealized reservoir model

The model consists from 100 blocks in total: 5 in x direction, 5 in y direction, 4 in z direction blocks. Number of blocks is indicated in keyword DIMENS. The dimensions of the grid blocks in the x, y, z direction are marked in the GRID section with the keywords DX, DY, DZ. The model size is 100×100×10 feet.

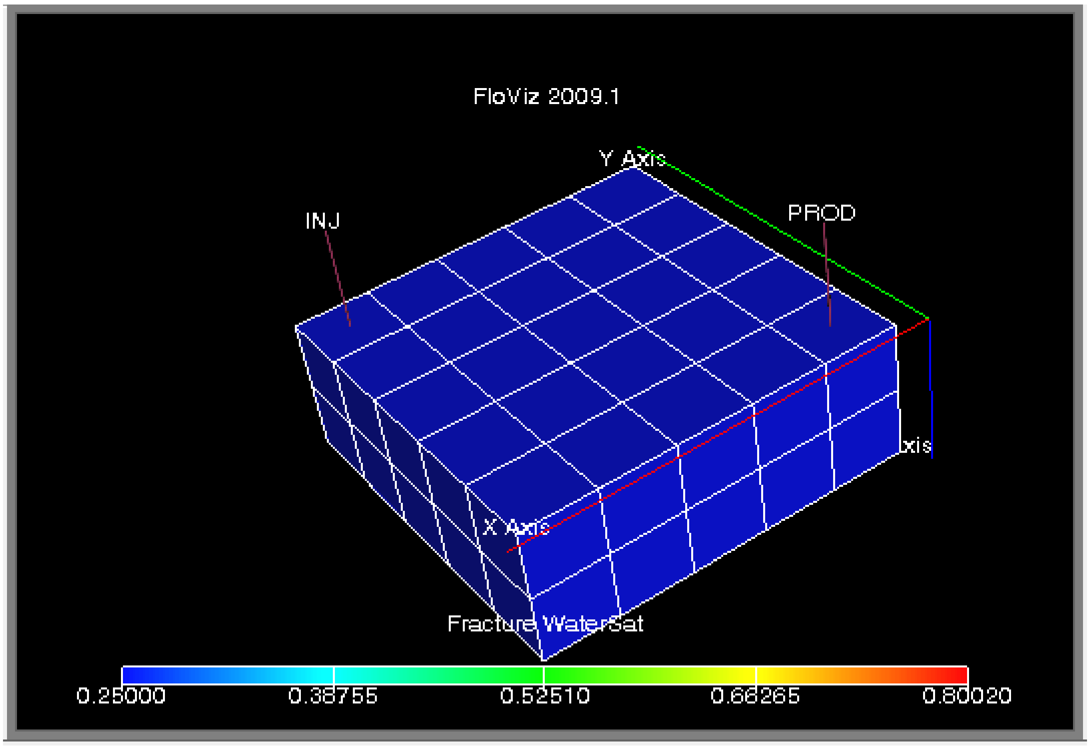

Figure 22. 3D model

Modeling of injection a polymer gel could be possible by adding a POLYMER keyword in the RUNSPEC section, polymer properties is added in the PROPS section using keywords PLYVISC, PLYADS, PLYROCK, PLYMAX, TLMIXPAR and by adding a keyword WPOLYMER in SCHEDULE section.

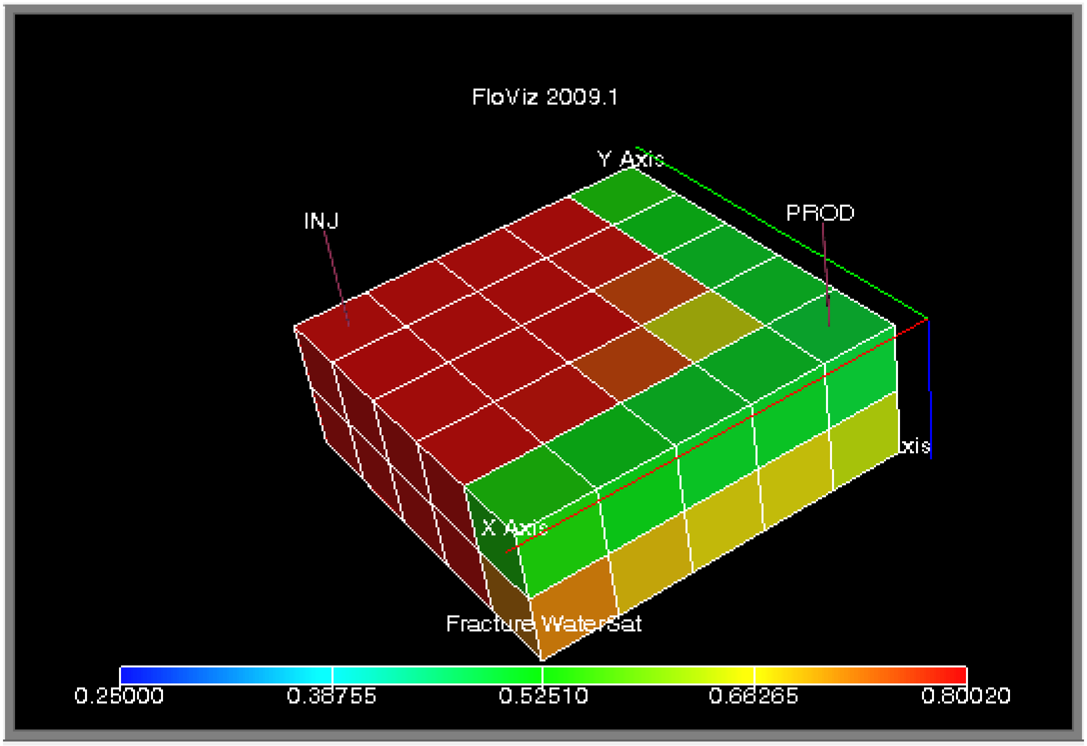

Figure 23. 3D model while injecting a polymer gel

3.2. Discussions and results of simulation model Eclipse 100

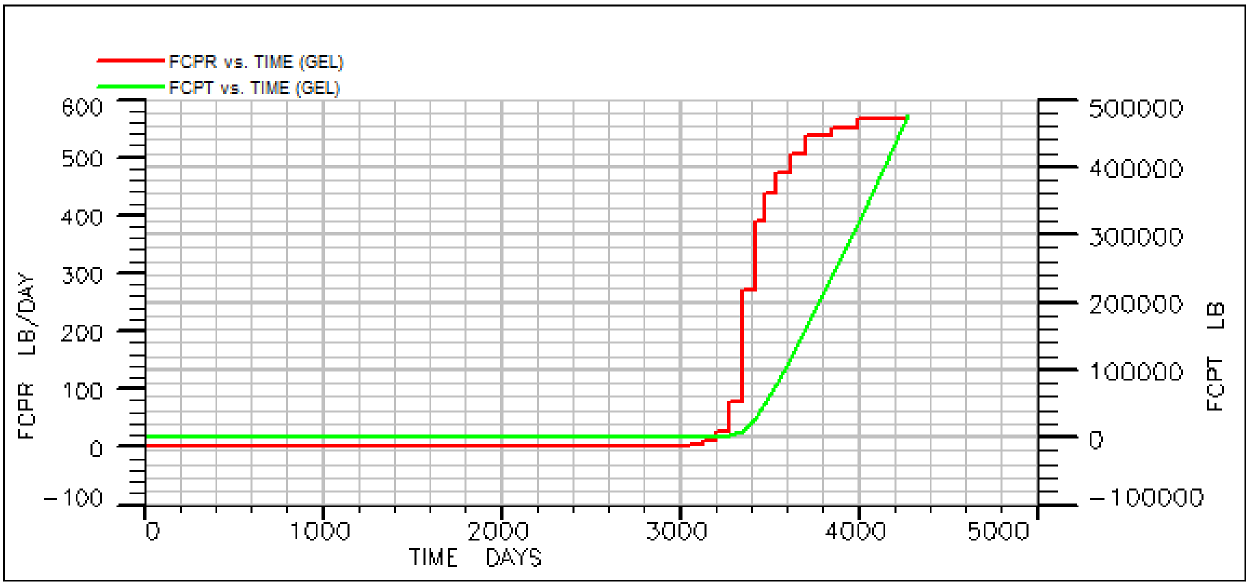

Figure 24. Field Polymer Injection Rate(red) and Field Polymer Injection Total(green) vs Time

From the graph above, it can be noticed that injection of polymer remains constant up to 3000 days, later it sharply decreases up to 550 lb/day. This graph can help to calculate amount of polymer should be injected.

The graphs below present compared results of Field Oil Production Rate, Field Oil Production Total, Field Water Production Rate, Water Cut results after waterflooding and gel injection.

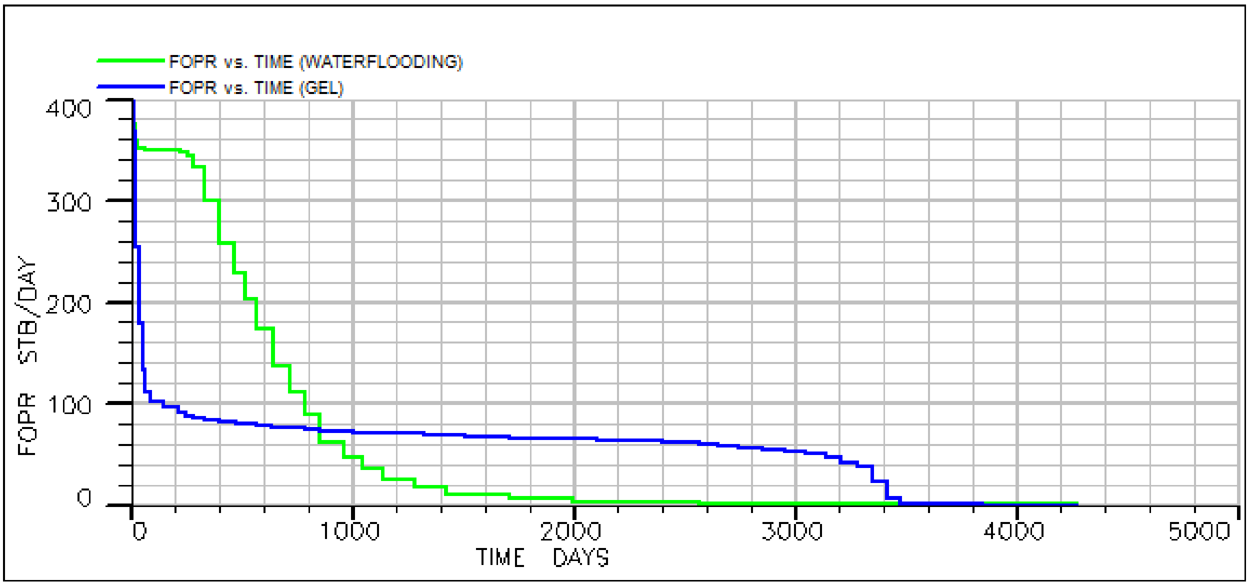

Figure 25. Field Oil Production Rate vs Time for WF(green) and GT(blue)

From the graph above, it can be seen that oil production during water flooding is effective for up to 800 days, then there is a sharp drop in oil production, while oil production during polymer injection does not decrease so sharply, which allows to produce oil up to 3200 days.

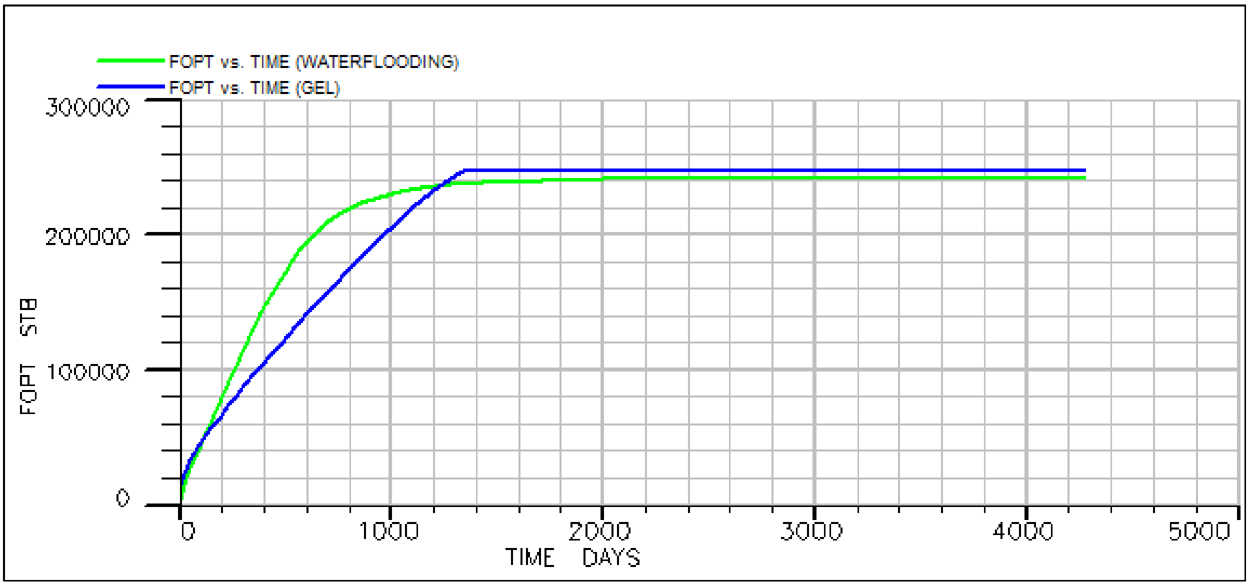

Figure 26. Field Oil Production Total vs Time for WF(green) and GT(blue)

As for Field Oil Production Total, starting from day 1200, the effectiveness of the polymer gel is visible on the graph.

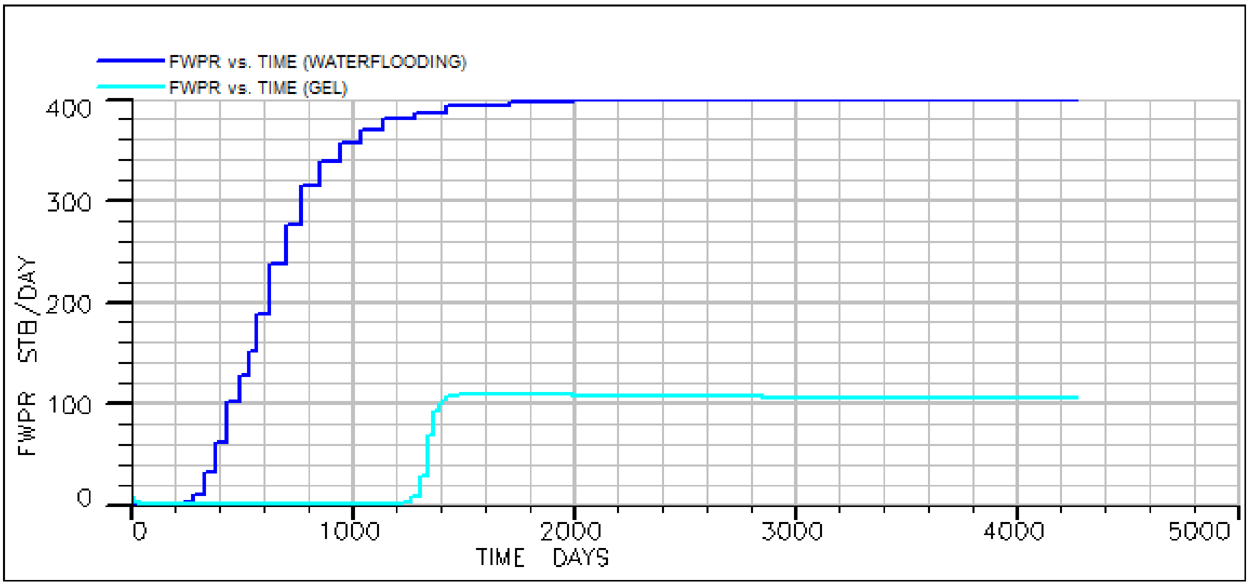

Figure 27. Field Water Production Rate vs Time for WF(blue) and GT(light blue)

As for Field Water Production Rate, water production does not occur until 1200 days, and then water production increases to about 100 barrels per day and becomes constant for the life of the reservoir. Water production during water flooding increases sharply, starting from day 200 and becomes constant at 400 barrels per day from 1800 days until the end of the life of the reservoir.

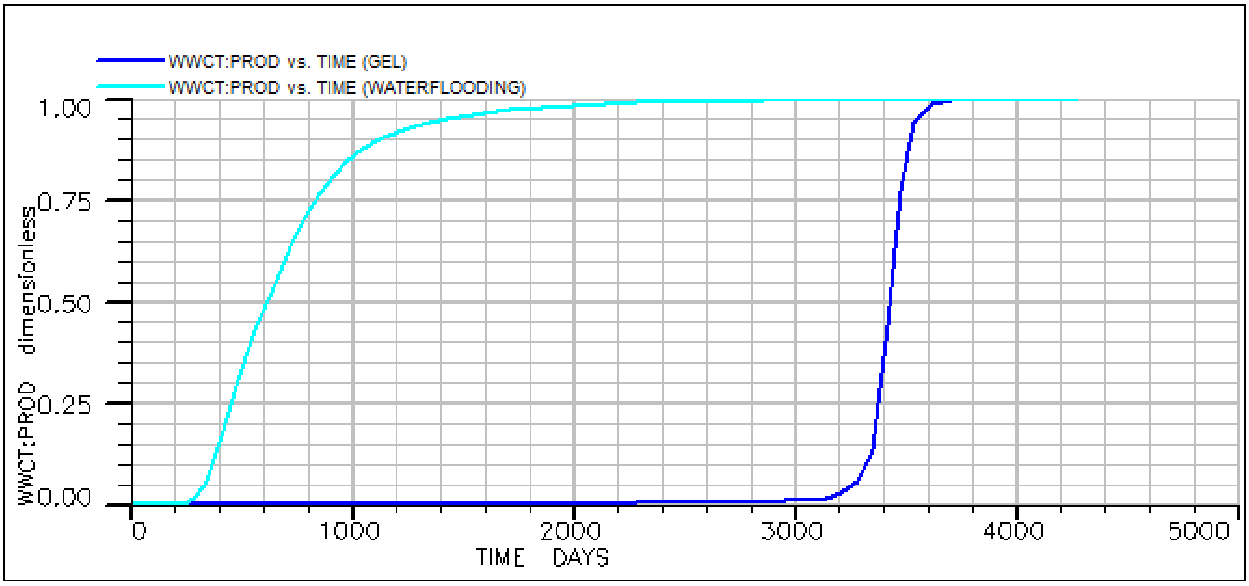

Figure 28. Water Cut vs Time for WF(blue) and GT(light blue)

The use of polymer gels is necessary to reduce water cut in the first order, which is typical problem for fractured reservoirs. The graph shows that the water cut of the reservoir during water injection increases sharply from day 200, while when injecting polymer gel, the water content is almost zero up to day 3000.

Working with Eclipse 100 software helped to analyze the efficiency of the gel treatment. Gel treatment should be used in high permeable zone in the first order to decrease the water cut, we can get it by pumping gel into fractures, and wait until gelation occurs. From the graphs it is clearly that gel treatment is effective, we saw benefit in oil production as well as decrease in water production and zero water cut during long period of life of the reservoir.

4. Economic justification

After conducting laboratory work, we determined that the best candidate for subsequent tests was the polymer FP 307 with a molecular weight of 6-7 million Da and a degree of hydrolysis of 5%. In this experiment, we prepared 50 grams of polymer solution with a concentration of 0.5%. This concentration is taken from the practice of our teacher in the laboratory. Since chromium acetate in the laboratory is in the form of an aqueous solution with a concentration of 0.25%, to obtain 100% chromium acetate, it is necessary to take 0.1 g of an aqueous solution of chromium acetate. In 2003, the polymer cost $ 5.71 per pound. The polymer particles are designed to swell as they pass through the heat front in highly permeable wetlands, which leads to the diversion of subsequently injected water/liquid substances into less permeable oil reservoirs. In general, polymer feeding is a much less complex, less risky, and more cost-effective method than deep profile modification.

For polymer flooding, it is important to recognize the amount of using materials. This item possibly to measure by using DATA-folder and formula:

$$M_{pol} = V_{inj} * n$$

The mass of polymer injected we obtained from the Figure 24: 480000 lbs

Where: M_{pol} – mass of using polymer, lb;

V_{wat} – cumulative volume of injected solution, stb;

n – polymer concentration in injected well, lb/stb.

The next step is evaluating OPEX and CAPEX expenditures for each year. Since we did laboratory tests it will be difficult for us to determine these values. But we can take the approximate data.

For estimating the costs on polymer flooding, using formula:

$$Cost\ on\ polymer\ (\$) = \frac{M_{pol} * C_{factor} * Price\ of\ polymer}{Number\ of\ year}$$

$$Cost\ on\ polymer\ (\$) = \frac{480000 * 0.0005 * 5.71}{11} = 124.5\ \$$$

Where: C_{factor} – converting factor from lb to tones.

The next step is constructing the project cash flow. Firstly, it should find the value of gross revenue by the following formula:

$$Revenue\ (\$) = Production * Oil\ price = 250000 * 65.48 = 16370000\$$$

The penultimate is subtracting net cash flow or cash surplus, by using formula:

$$Net\ Cash\ Flow\ (\$) = Revenue - Expenditures$$

Expenditures on gel treatment can be calculated by knowing the number of wells that will be gel treated.

According to the data that we have in 2018, one well treatment cost about 7-

10 thousand dollars. Given that the national exchange rate of the tenge has decreased by 1.3 times compared to 2018, it can be assumed that the cost of this operation is currently 9-12 thousand dollars.

Conclusion

During working on a thesis work, we learned a lot about gels, polymers, their main properties and behavior in a reservoir. The main results of the work are as follows:

1) Enhanced oil recovery is provided by gel-forming compositions. These compositions are capable of spatial structuring in porous media to form chemically crosslinked gels. And they are usually solutions of polymers and crosslinking agents in water with a concentration not exceeding 1.5 %. When heated in layers, the solutions form a strong elastic gel. These gels were analyzed in this diploma project.

2) The most appropriate polymer type in our work with concentration of 0.5% is FP 307, MW =6-7 mln Da. This type showed itself as the strongest polymer gel during 5-7 days of gelation in a 70 g/l brine.

3) Limestone is a weak rock type, that is why, working with a core holder that contains confining pressure will not show a good result, twice we noticed a collapsed fracture, while using a self-made core holder showed pretty good results.

4) Analytical calculations of injection time, length of extrusion proved by data obtained in the laboratory.

5) Modeling on Eclipse 100 software showed application laboratory work on a reservoir scale. In result, we got a profit in oil production, decrease in water cut and water production. We could see the amount of polymer should be injected. Working with simulation software is good for making future predictions for a long period of time and to prove the results obtained in a laboratory conditions.

We have done a long and great job in the analysis of polymer gels. A lot of mistakes were made, but we corrected them. For the first time, we did experiments for several months. During these months of work, we used our theoretical knowledge in practice, even in the laboratory. As well as the analysis of this data, were compared by several variants of this study. Comparing these studies, we made conclusions and corrected mistakes.

It was not difficult for us to do analytical or mathematical calculations. Because we already had data on our work. But difficulties arose when performing laboratory experiments. As we said earlier, our core collapsed and the fractures closed. But we solved this problem by making a core holder and continued the experiment. All the actions and data that we received were presented in the form of analysis, tables and figures.

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