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Identification of Water Production Mechanism in One of Iran's Oil Fields and Treat it with Gel Injection

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ABSTRACT

In this study, the problem of water production in one of Iran's oil reservoirs will be examined. First, using the flow rate diagram of oil and water production, the water production problem will be examined according to time. Then, after confirming the occurrence of water production problem, the mechanism of water production will be investigated using Chan diagnostic diagrams and the created sector model. The results of this study indicate that firstly, the problem of water production in the well under study is observed, and secondly, according to the Decline-curve analysis diagrams, Recovery plot, Chan derivative diagram and schematic shape of the fluid flow movement, it shows the mechanism. Water production is a channel flow process, underwater injection. A gel treatment at early time with 25% of water cut was studied, for that it was modelled a gel treatment after 500 days of production. The main observation is that by increasing the concentration of injected gel, the rate of oil production increases and the rate of water production decreases. The concentration evaluated concentration was from 0 to 100 (lb /bbl) of solution, a stabilization concentration was not observed. Finally, first by identifying the type of water production mechanism for this reservoir in Iran, it has been determined that it has water production through the canal and then by using a simulation of gel injection, the water production rate has decreased and the oil production rate has increased.

Introduction

To control water production, it is necessary to determine the cause and the source of the produced water. Then the best treatment for water control is selected according to the identification of the type of problem [1]. There are two ways to identify water production:

1-Production history
2-Production logging tools

Types of water production identification methods by production history:

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Recovery Plot

A type of semilogarithmic graph is plotted according to the ratio of water to oil (WOR) to the volume of cumulative oil production oil. As oil production increases, so do water production. It reaches the economic range (WOR), and until the amount of water produced exceeds the economic range, there is no need to control the production water, shown in Fig. 1:

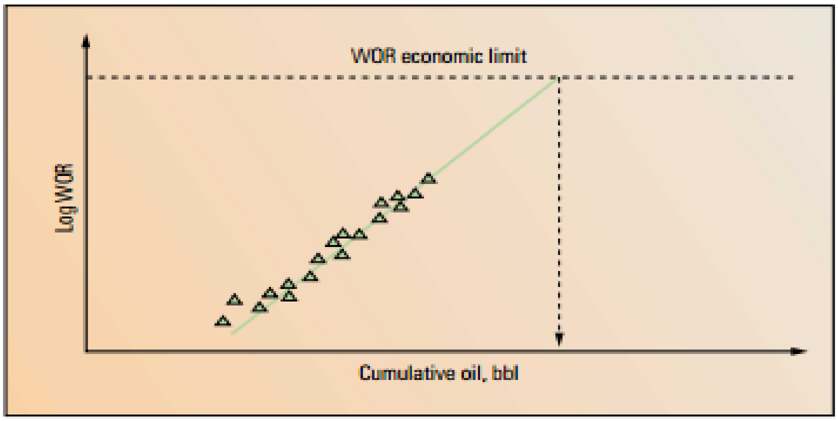

Fig.1. Recovery plot [1]

Production History Plot

A logarithmic chart that is plotted in terms of oil and water production flow rate versus time.

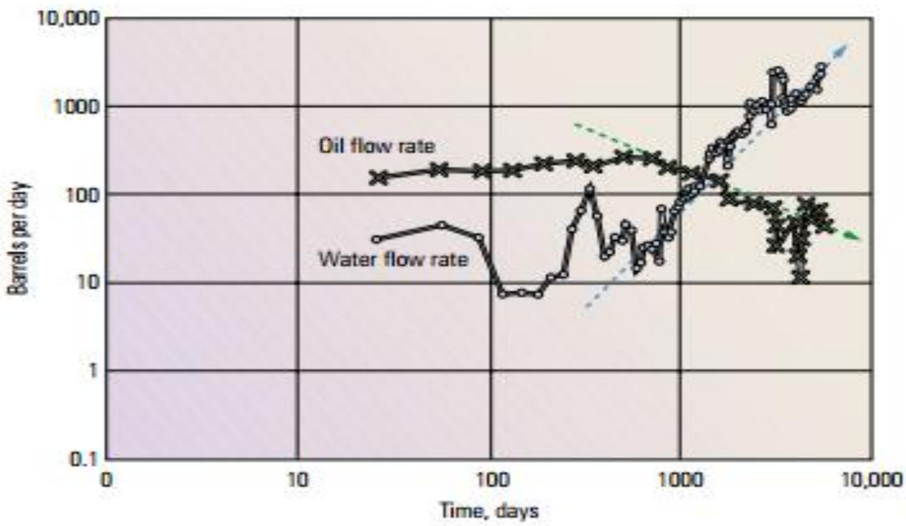

Fig. 2. Production history plot [1]

Fig. 2 shows that when the oil flow rate decreases, the chart is downward and the water flow rate increases, meaning that the chart is upward and increasing, indicating water production in the production well.

Decline-Curve Analysis

A semilogarithmic graph shows the volume of oil produced by cumulative oil and water production flow rate. In this diagram, when the production is in the form of a straight line diagram, it is shown in Fig. 3 that the discharge from the reservoir takes place as usual, and when there is a change in the slope of the diagram, it indicates the production of water [1].

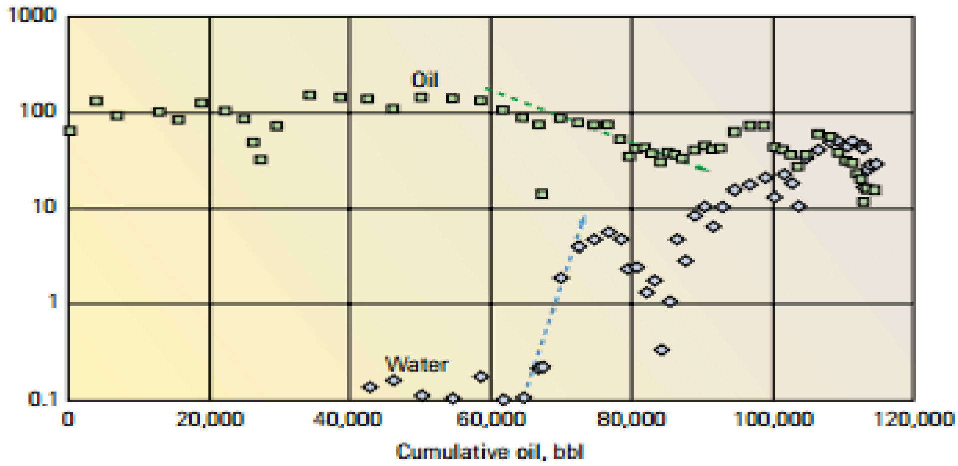

Fig. 3. Decline-curve analysis [1]

Diagnostic Plots

Diagnostic diagrams are a set of pre-prepared graphic patterns obtained by WOR versus time in logarithmic coordinates. If these diagrams are used with the help of information received from good drilling and well testing, the operator can understand the drastic changes in water production and the rapid occurrence of a breakthrough in the fractures and problems of water production. One of the benefits of this type of diagram is the recognition of water production problems due to coning and channeling. Fig. 4 is an example of this type of chart.

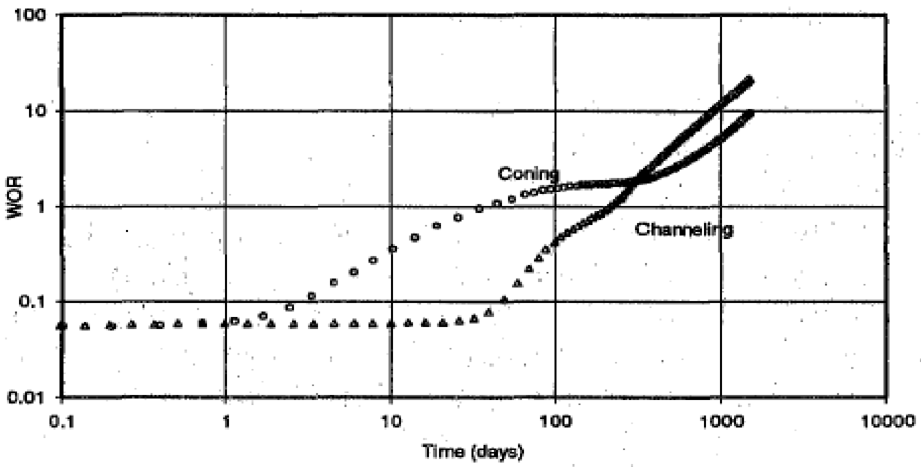

Fig. 4. Diagnostic plots [2]

Fig. 4 shows that the water breakthrough earlier during coning because in the channel mode, due to parameters such as permeability and how the fluid saturation distribution affects the velocity of fluid flow in the channel, it delays the breakage. According to the graph lines, when the Coning phenomenon occurs, the increase in water production is less than the channeling mode. This is due to the radial expansion of the coning relative to its vertical expansion; that is, when our horizontal permeability is greater than the vertical permeability, the comicality expands radially. As a result, the water flow reaches the perforations later. However, in the channel mode, due to the permeability parameter and the distribution of fluid saturation, the channel's water movement speed reaches the channel more and faster. If these two types of phenomena are plotted on a logarithmic diagram, their shape is as follows [2]:

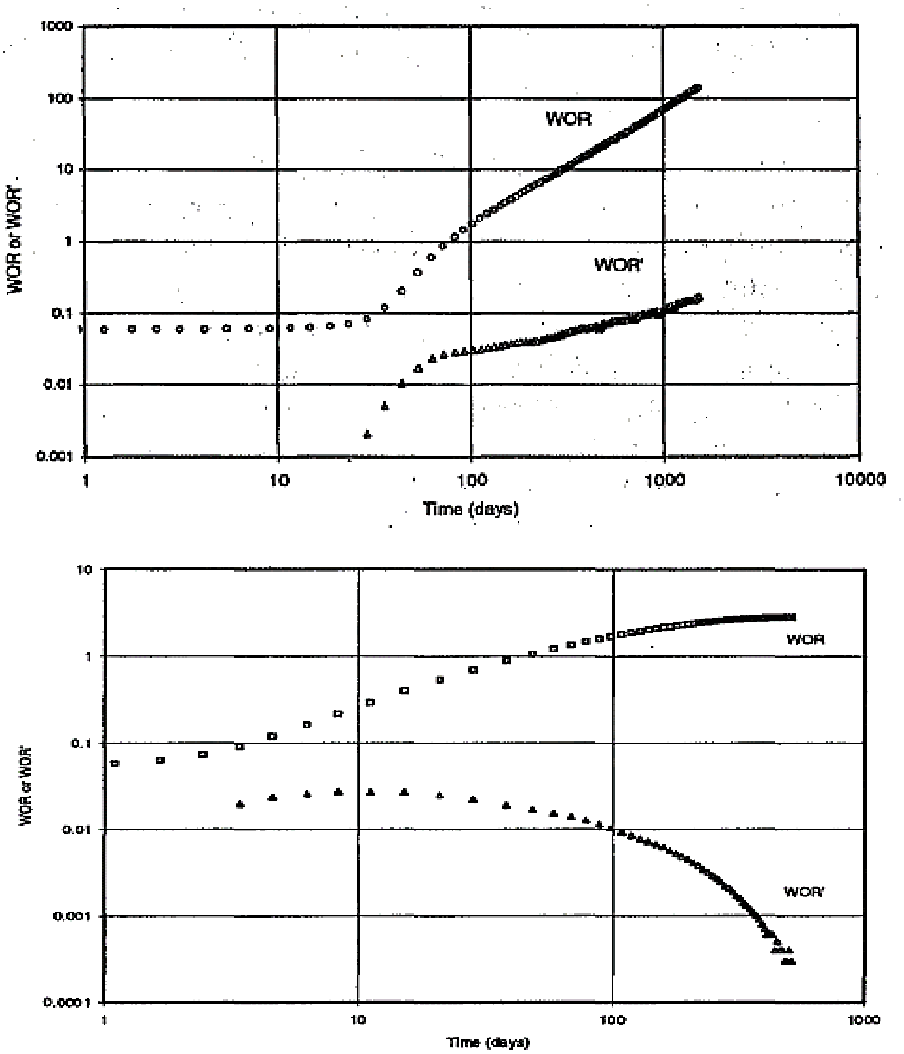

Fig. 5. Diagnostic plot of water coning and channeling WOR comparison [2]

According to Fig. 5, the slope of the graph in logarithmic mode is negative for Coning and positive for the Channel

Use Production Logging Tools (PLT)

Baldowf in 2004 [3] and Motan in 2008 [3] showed that using PLT accurately identifies water cut and profile information. In this case, water production areas are identified using a set of different logs. These logs detect the water production area, according to the multiphase concept. Then, according to the holdup concept, they detect the amount of water cut by using the principle that the higher the density, the more waste that can be. He obtained the amount of water cut.

Due to the high penetration depth into the reservoir, chemical gels are very suitable candidates for controlling water production from cracks and channels that transmit water flow. Water control by the chemical method is one of the common methods that use water-based polymer to close the flow of water produced by the formation into the well. In various forms, gels have proven to be one of the most effective and popular ingredients for reducing water production problems, helping to improve and treat problems by reducing permeability [4].

Fragachan [5] examined the control of extra water by mineral gels in fractured reservoirs. It showed that to treat high temperature use mineral gel is useful in silicate gel, it is also applicable to coning treatments. Liang et al. [6] investigated the blocking agents and observed that gels reduce the permeability to water in a higher proportion than the reduction to the permeability to oil or gas. Gels are liquid-based systems made with solid structural properties. In other words, most of the gel systems are fluid-based systems, where the liquid part of a solid three-dimensional structure, the solid mass of the gel [7]. Polymer gel treatment is an effective treatment to reduce water production. Polymer gel can flow into fractures; it can also withstand the pressure difference near the wellbore. In the case of high permeability with high water saturation to reduce water permeability and prevent water channels, a polymer gel when is mixed with Cross linker agent form a solid gel [8, 9], that can block the permeable channels. Sodium silicate is used for water control operations, and before doing so, it can be diluted to reduce the viscosity and to increase the penetration depth in the desired area. The degree of dilution of this fluid is the controlling factor in calculating the final strength and time of attachment of the gel plug [10]. Silica can also be used as a polymer with other chemicals; it comes in the form of a polymer and makes a gel plug. The silicate reacts with water and forms suspensions. Because the silicate dissolution strength depends on the size of its components, the particle size of this material plays an important role in forming the gel. It should be noted that with decreasing particle size, the solubility of this material increases [11].

Fig. 6 shows a general schematic of the sedimentation and gelation of silicate particles, which slowly become stable over time and form a stable gel. Using a Rheometer device, measurement of gelation time showed that with increasing silica concentration, the time of gelation decreases [12]. The existence of a fracture and channels can lead to the transfer of water from the lower layers to the wells and increase the percentage of water production [1].

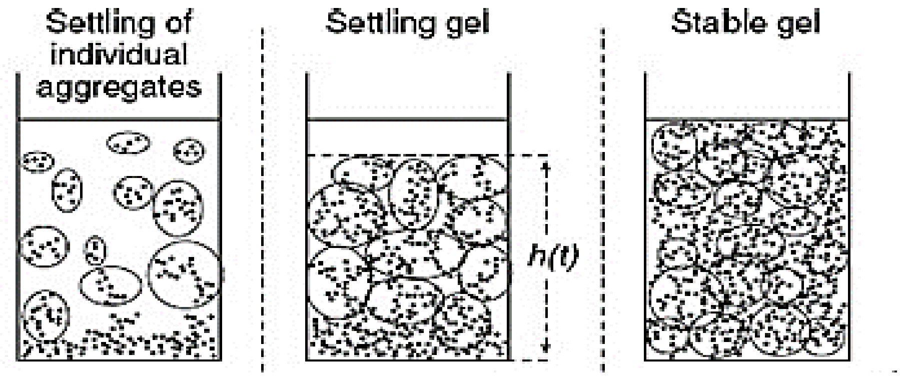

Fig. 6. Schematic form of gel formation [12]

Serightet et al. [13] a study of treatments with gel to reduce canalization in high-transferable natural fractured reservoirs, observed the treatment with gel is beneficial to control the water production. A high-density gel should also be injected for treatments in naturally fracture reservoirs. However, the treatments with gels of low gel concentration have not been helpful. Herbas et al. [14], in an examination of the gel treatments based in laboratory experiments and reservoir simulations of the chemical reactions, modeled the gelation process in Eastern Venezuela's wells, which reduced the amount of water cut by 38%.

Herbas [15] investigates the control of water production by simulating gel injection using Eclipse software for black oil and according to the reservoir characteristics, using gel injection caused the recovery factor to increase from 1.68 to 3.2% and the production from 118617 to 227485 barrels in three years after controlling water production, which is measured in the laboratory. It matched perfectly. Investigating the prevention of water production using Colloidal Dispersion Polymer Gel, The amount of produced water increased from 78% to 57%. Finally, it was shown that polymer gel dispersed as colloidal successfully reduces the water produced [15].

Also, the study of chemical methods to prevent excess water production in a heavy oil well in Oman showed that, the combination of microgels and RPM gels slightly reduced the permeability for oil while greatly reducing the permeability for water [7].

The purpose of this project was to help to control excess water production in a well located in Iran. Using simulation, it was decided to use real data and identify the cause of water production, and then to control the water produced using thcase-control method. The need to be addressed and the results to be used for operational implementation.

Model Setting

The reservoirs in the underground have unique characteristics. Some properties may change during the exploitation of the reservoir, as fluid compositions, pressures, and saturations. Theoretically, if the correct information describes the characteristics of the reservoir rock entered the simulation model, a representative history match can be achieved [7]. In this study, to history match the reservoir numerical model, the oil-water relative permeabilities were adjusted; initially, a model for an Iranian field was simulated considering the field parameters obtained from wells data, cores, fluids, etc.

Due to the inconsistency observed initially history matching the production rates, the oil, and water relative permeability parameter was adapted to the actual production flow by tuning some water to oil relative permeability. As a result, the model calculated production that matched the historical production data; hence, it was concluded the tuned model should be able to generate consistent predictions. This process is described as the history matching.

The field production history and the parameters obtained with the history-matched model are shown in Figs. 7 and 8.

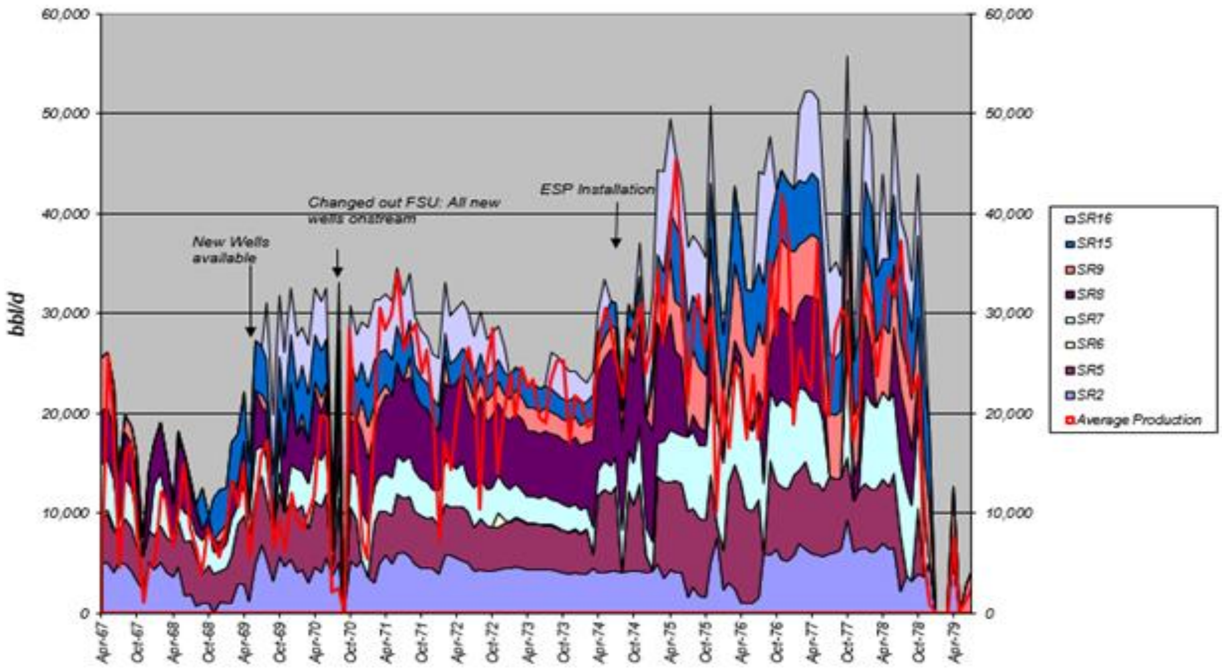

Fig.7 Oil production history

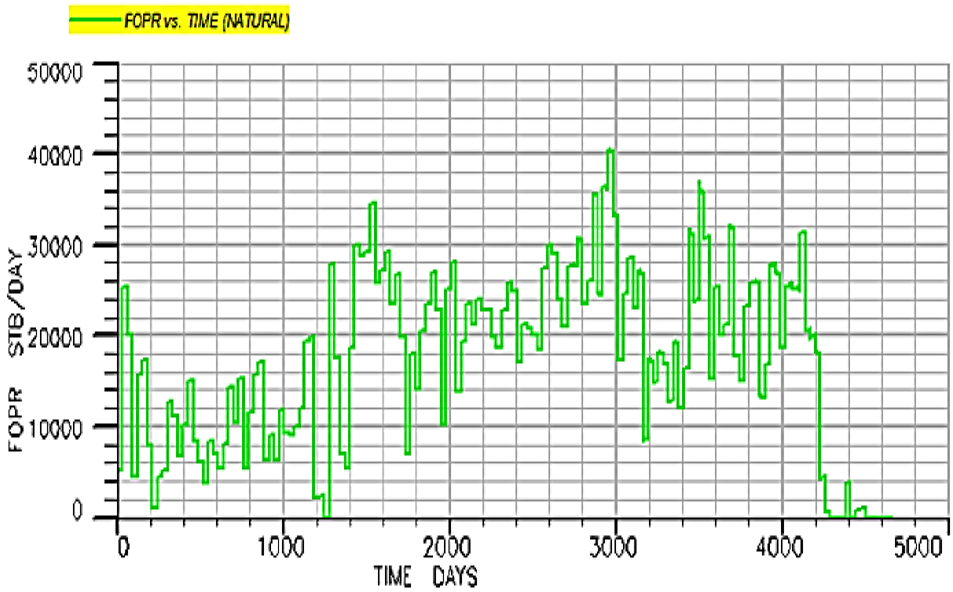

Fig. 8. Oil production diagram of the reservoir in History Matching mode (FOPR on the Y-axis represents the rate of oil production vs. Time on the X-axis)

You need to mention here if the reservoir pressures were honored in the history match process.

Relative Permeability Changes for History Matching

According to a sensitivity analysis done to history match the field data, changes in the discharge flow are more affected by adjusting the relative permeability's for water and oil, ; therefore, some adjustments were incorporated before a good history match was achieved.

Before the history matching, the water, oil relative permeability curves are shown in Fig. 9, and the modified water, oil relative permeability curves are in Fig. 10.

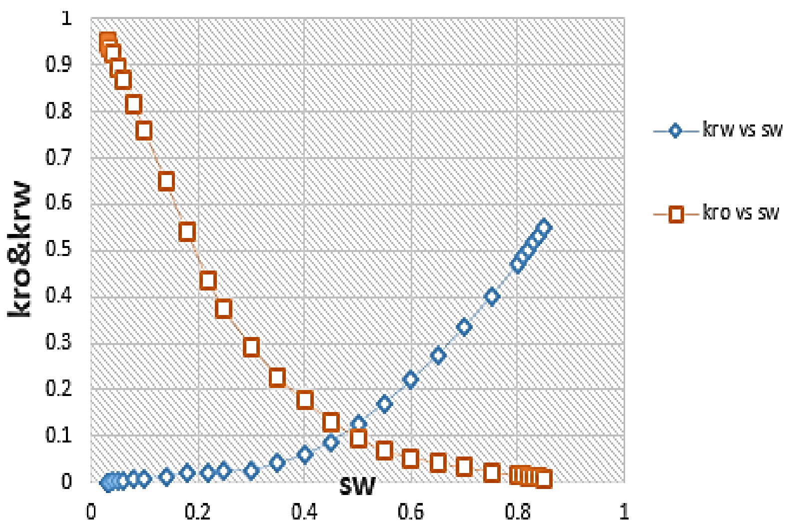

Fig. 9. The relative permeability diagram of the model before history matching

Sw on the X axis represents water saturation and Kro & Krw on the Y axis represent the relative permeability of oil & water.

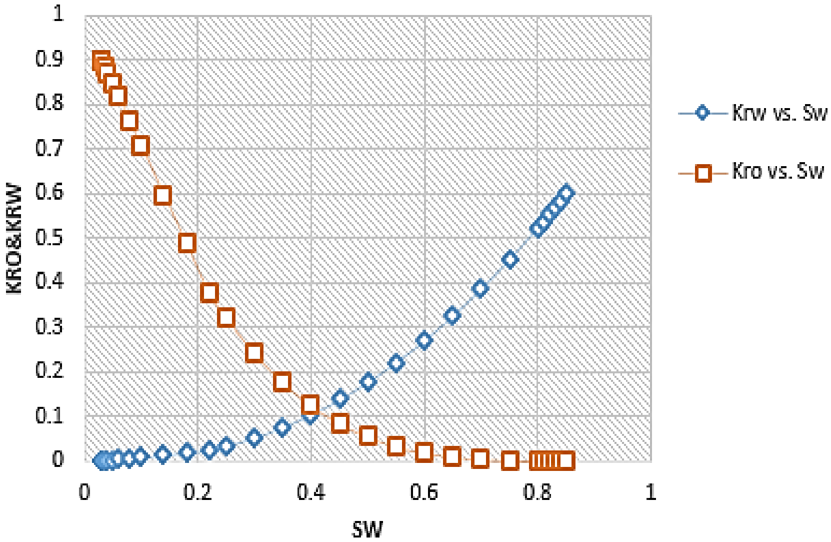

Fig. 10. The relative permeability diagram of the model after history matching

During the historical adaptation, as shown in Figs. 9 and 10, the relative permeability graph of the reservoir has changed from oil-wet to water-wet.

Simulation Model

To simulate the gel injection to reduce water production in one of the field wells, a numeric model was built using the Eclipse simulator, Fig. 11. The sector behaves similarly to the model obtained from the history matching, due to having the same petro-physical and dynamic characteristics as the model obtained from the model history matching. Thus, the accuracy and behavior of the sector will be similar to the whole of the reservoir.

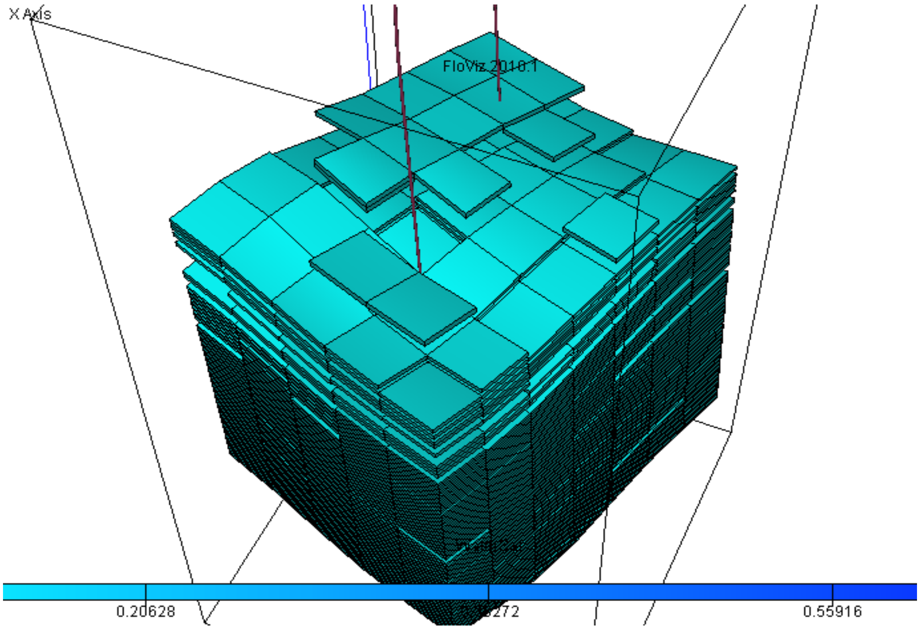

Fig. 11. Schematic Eclipse Model in 3D View

The three-dimensional structure of the model is in the form of tiny layers interstratified. In some places, there were assigned null values due to the lack of porosity and permeability. The Dimensions of each block grid are DX 328 ft(L), DY 328 ft (W), DZ 328 ft (H).

Petro-Physical Characteristics of the Model

The depth of the reservoir is from 6774 to 7307 feet, the pressure before the production was 3610psi reservoir; the production from the reservoir caused pressure in the produced layers to 1284 psi. Because the reservoir is heterogeneous, the permeability range is from 100 up to 12000 md and the porosity variation from 10 up to 25%. The Primary Properties of the Reservoir are shown in Tables 1 and 2.

Table 1. Primary Properties of the Reservoir

Initial Reservoir Pressure (psi)	3610
Reservoir Temperature (°F)	180
Reference Depth (feet subsea)	6774
Oil Gravity (°API)	14
Oil Viscosity (cP)	25
Brine Salinity (PPM)	1200

Table 2. Rock Properties 3-D Model

Layers	Rock Type	Porosity (%)	Permeability (mDarcys)
1-17	Sandstone	17	0-2000
18-36	Sandstone	10	300-2500
37-68	Sandstone	17	400-3000
69 -98	Sandstone	19	100-12000
99-120	Sandstone	20	200-6000
121-150	Sandstone	25	1000-8000
150-164	Sandstone	35	1000-12000

At first, must determine the cause of high water production. The model's oil and water production charts are as shown in Fig. 12, where the production of high water and oil production decreases and the total chart of the produced fluid is constant. This indicates that water will later replace the oil produced and that the rate of oil production in the well will decrease.

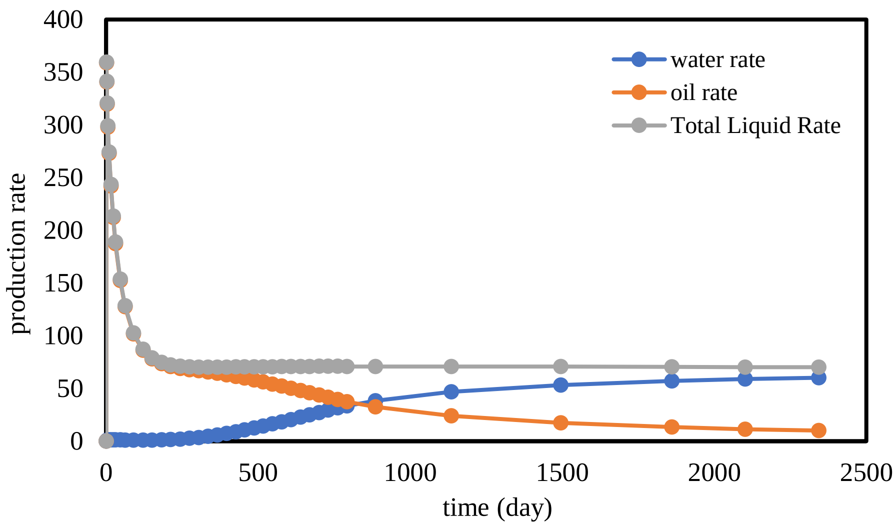

Fig 12 Fluid and water and oil production chart (X axis represents time by day and production rate on the Y axis represents production rates by barrel)

Identify the cause of water production

The Recovery plot diagram for this model is in Fig. 13, which shows that water production has exceeded the economic range. The proportion of water produced is about eight times higher than the oil produced. The economical range for the model is defined as the production of water per barrel of oil produced. That is, the ratio of water to oil is equal to one. By plotting the Production history plot according to Fig. 14, it can be seen that water production has increased oil and production has increased over 2300 days of good production, and the model has high water production.

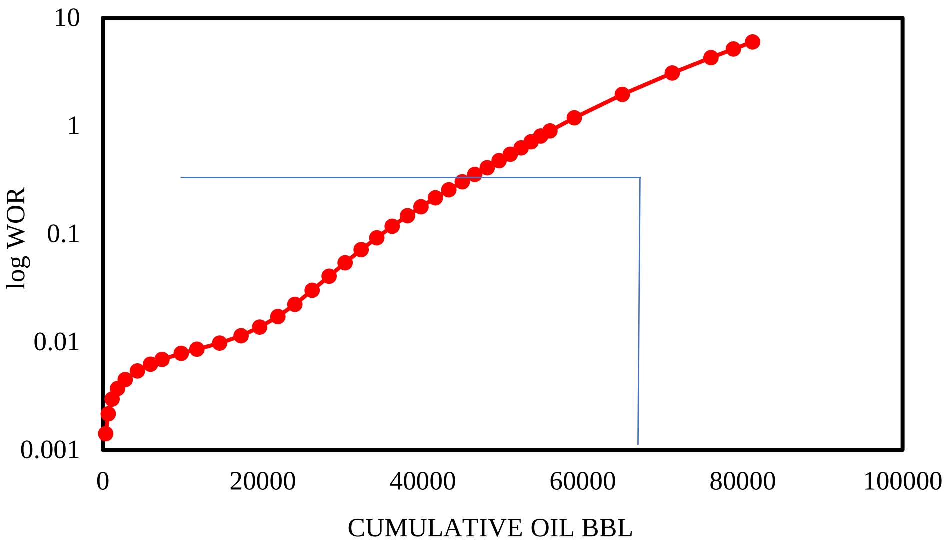

Fig 13. Recovery plot for model (X axis represents the cumulative production oil and log WOR on the Y axis represents the logarithm of the ratio of water to the produced oil, respectively)

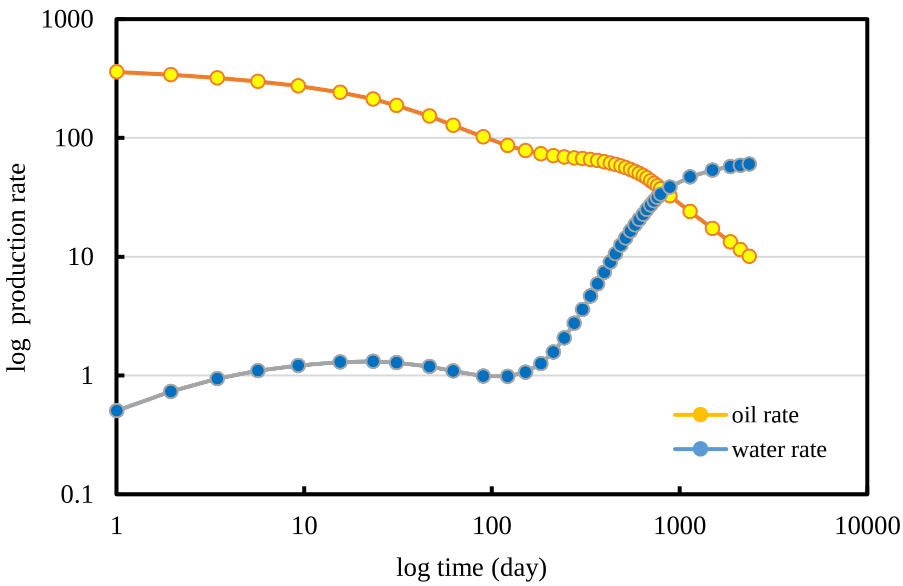

Fig. 14. Production history plot for model (X axis represents the logarithm of time and log production rate on the Y axis represents the logarithm of the production rate)

The Decline-curve analysis diagram, as shown in Fig. 15, shows that when production is in the form of a straight line diagram, the discharge from the reservoir is normal, and when there is a change in the slope of the graph, it indicates water production.

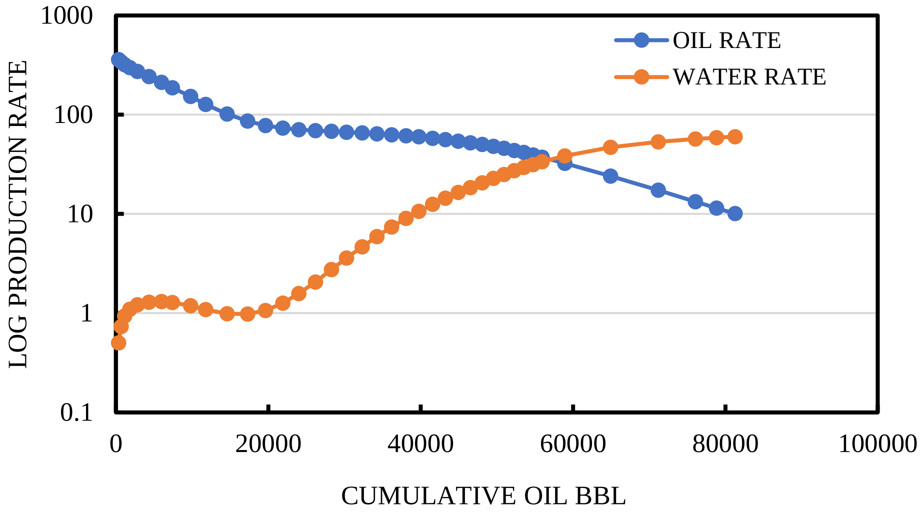

Fig. 15. Decline-curve analysis for model

By drawing the Chan plot diagram for the model's output data as shown in Fig 16, by drawing the water-to-oil ratio, the diagram is as follows according to the timing diagram because the ratio of water to oil has increased rapidly.

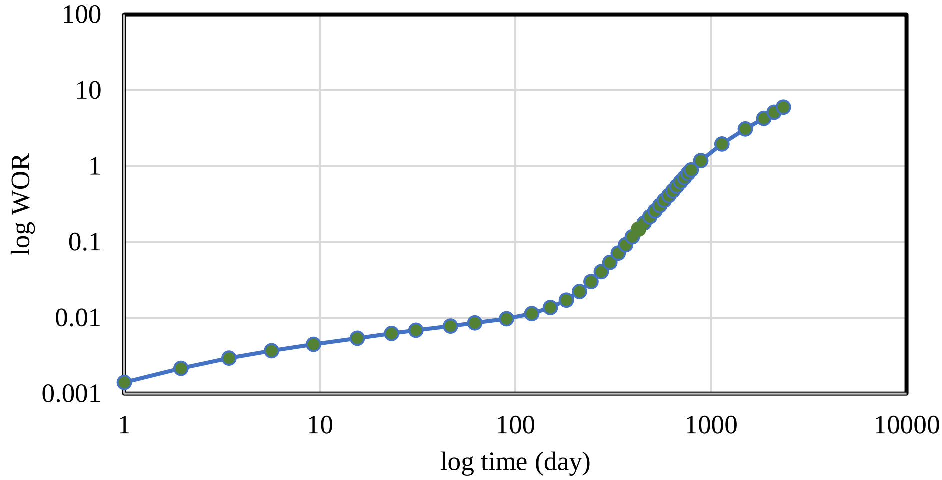

Fig. 16. Chan plot for model

Also, by drawing a diagram deriving the ratio of water to oil, the diagram is following Fig. 17, which shows that the reason for water production is related to canalization, and the sudden chart of Saudi Arabia is due to canalization.

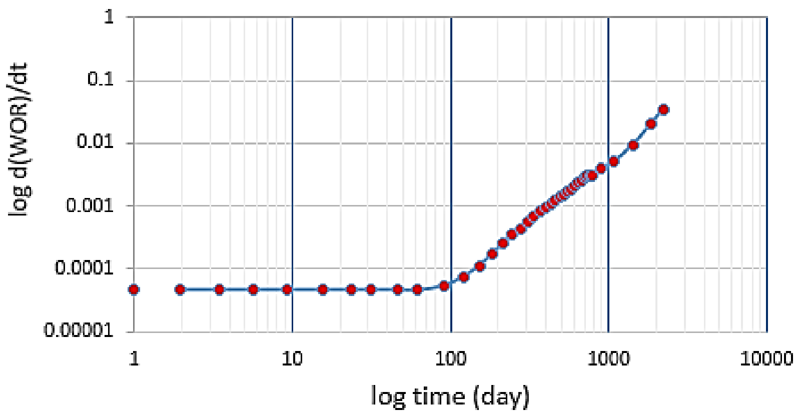

Fig. 17. Derived from Chan plot for model (X axis represents the logarithm of time and log d(WOR)/dt on the Y axis represents the logarithm of the ratio of water to oil Vs. Time on X axis)

The canals quickly supply water to the production well, preventing the oil from being swept away by the water and leaving the oil inside the pores. To observe the flow of channeling in the model, it is possible to realize the channeling of fluid flow in the model with the help of fluid flow and fluid saturation. Fig. 18 shows the water saturation of the model that the water flow chooses the fastest path for the flow and the other areas of the model remain intact, and the water saturation has increased in the same direction as the water flow.

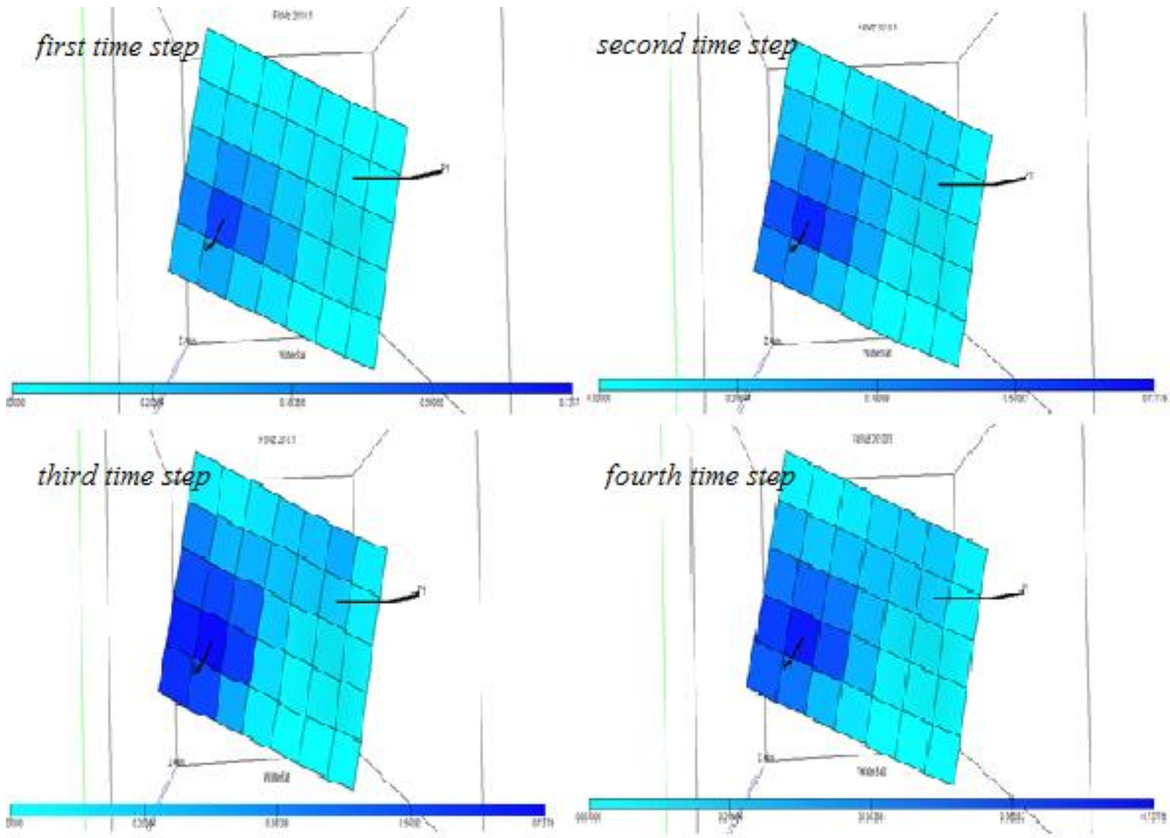

Fig. 18. Changes in water saturation in the different time steps from the injection well to production well (X axis represents the water saturation alteration)

Fig. 19 shows the oil saturation in the model that the oil saturation has only decreased in the direction of water flow, and other areas remain intact.

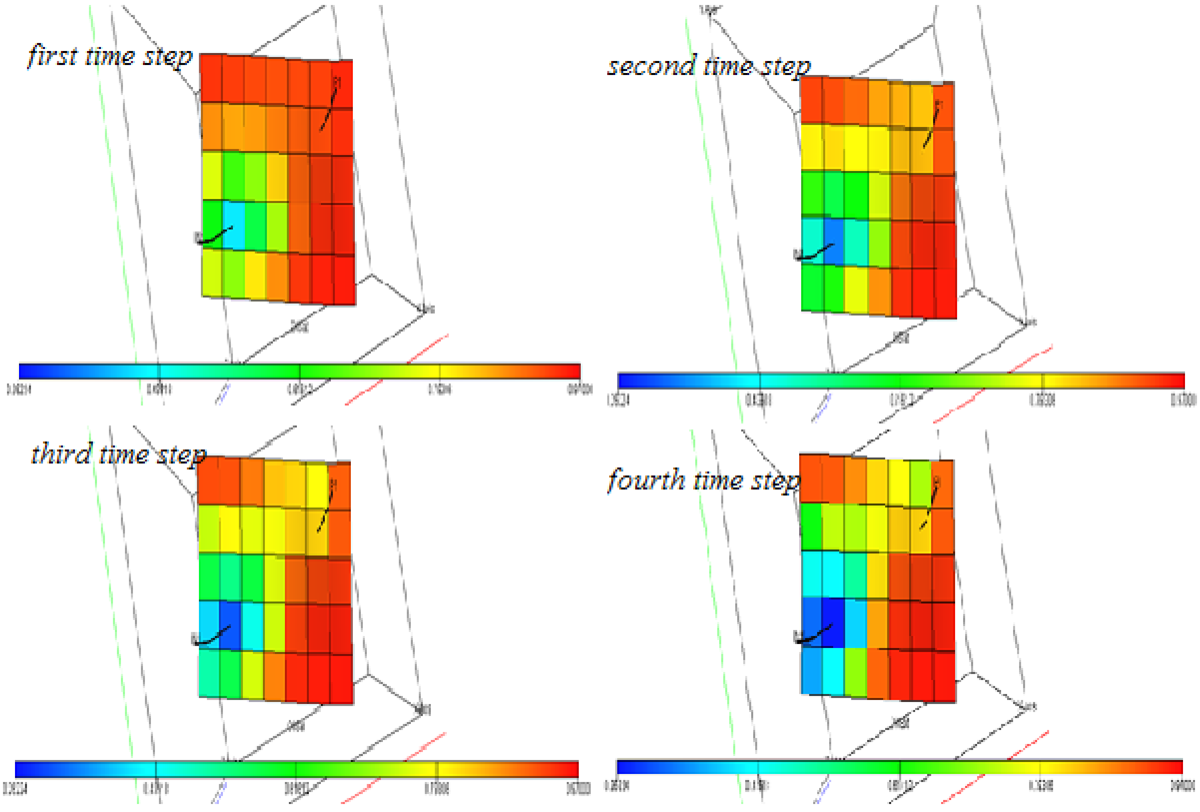

Fig. 19. Changes in oil saturation in the different time step from injection well to production well (X axis represents the oil saturation alteration)

Gel Treatment

It was modeled a gel treatment to heal the water channels, which were producing high water cuts. The POLYMER keyword is used in the Eclipse simulation model; the properties of the gel are according to the following Tables 3 and 4.

Table 3. Polymer Adsorption in the rock as function of concentration

Polymer Concentration (lb/stb)	Concentration of Polymer Absorbed by the Rock (lb/lb)
0	0
7.01	0
8.011	0.000005
40	0.0000051

Table 4. Change in polymer viscosity as function of concentration

Polymer Concentration (lb/stb)	Rate of Viscosity Change (cps)
0	1 1

40	1.00001 1.00001

A flow resistance factor (RRF) of 10,000, was applied, to create high resistance to (against) water flow. The Fig. 20 shows the injection of the gel and illustrate the gel propagation in the reservoir (blue is zero gel concentration, and red maximum gel concentration 50 lb/STB). The gel injection was initiated in the model, at 410 days when the reservoir started water production; the injection gel rate is 3500 (lb/day) diluted in the injection water, Fig. 21.

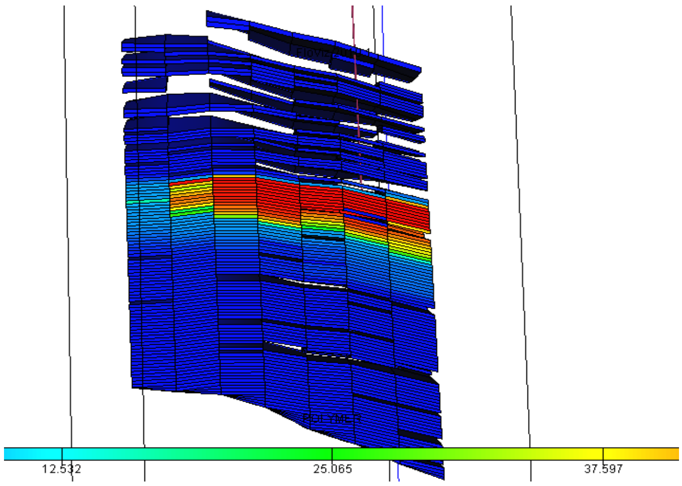

Fig. 20. Injection Gel, blocking the cells in the direction of injection wells

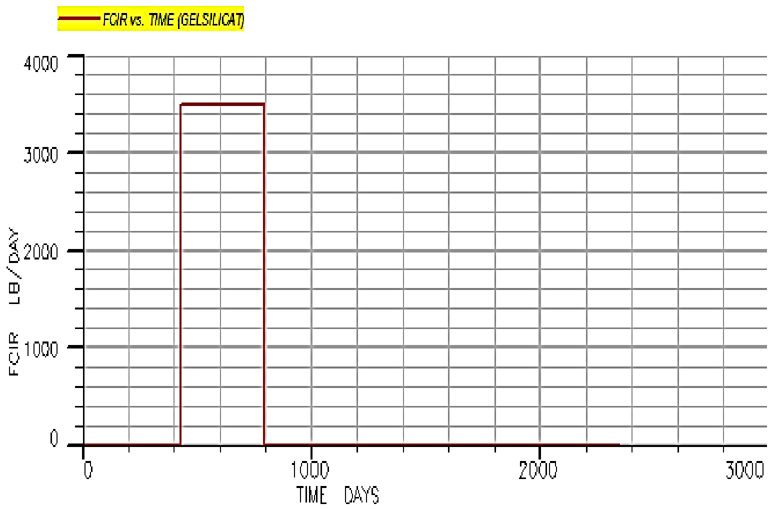

Fig. 21. Injectable Polymer Rate (FCIR on the Y axis represents the mass of polymer produced Vs. Time on X axis)

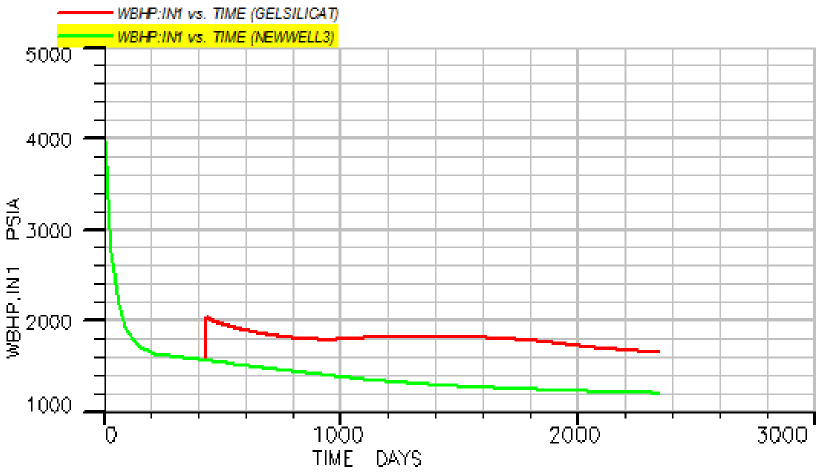

Fig. 22. Bottom hole pressure for injection well (WBHP on the Y axis represents the bottom pressure of the well)

The bottom hole pressure in the injector well before and after injection of gel, Fig. 22, showed increases from 1600 to 2000 Psi.

The water cut in the producer well was substantially reduced. That's why if on the 500th day of production, the injected gel reduces the water production; on the 1400th day of production, the water cut is 45%, and the gross water cut reduced is 30%, Fig. 23.

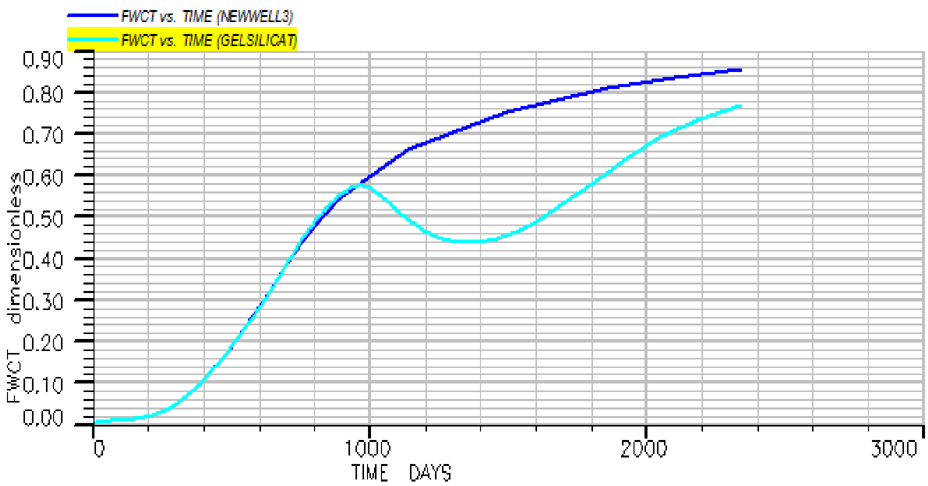

Fig. 23. Percentage of water produced before and after gel injection (The FWCT on the Y axis represents the produced water)

The reason for the decrease in oil before gel injection is the increase in water cut, which is rapidly transferred to the production well by the channels in the reservoir layers.

The amount of oil in place in the model was decreased before the gel injection and after the injection of the gel. Because the gel is injected into the pores and canals of the water transducer and prevents the flow of water in these channels, then the water is forced to pass through other finer pores and undisturbed areas, which will sweep the oil into untapped areas, which results in a reduction in water production and an increase in oil production and a reduction in the amount of oil left underground.

In the case of gel injection, the field oil in place (FOIP) after 2300 days of production decreases from 300000 barrels for the water injection case to 280000 barrels that mean 20,000 barrels of oil incremental production, Fig. 24.

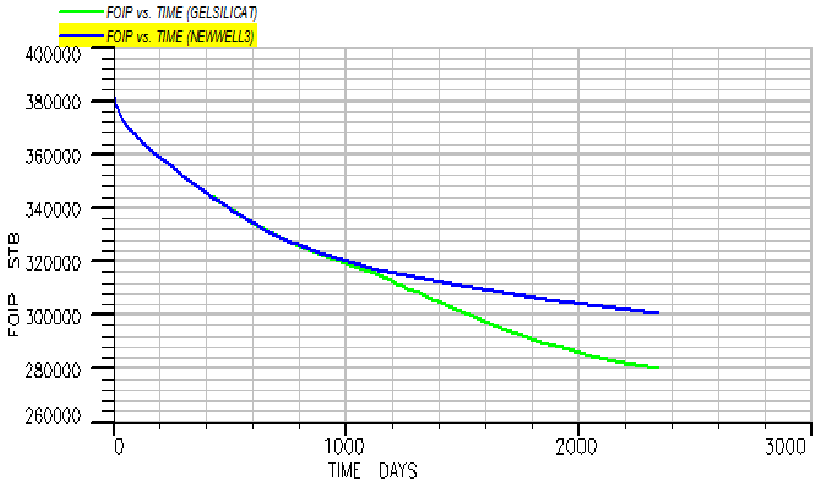

Fig 24. Indicator of the amount of oil in place before and after gel injection (The FOIP on the Y axis represents the amount of oil in place)

Additionally, and more importantly, the oil production rate will increase by 5% after 2300 days of production, Fig. 25.

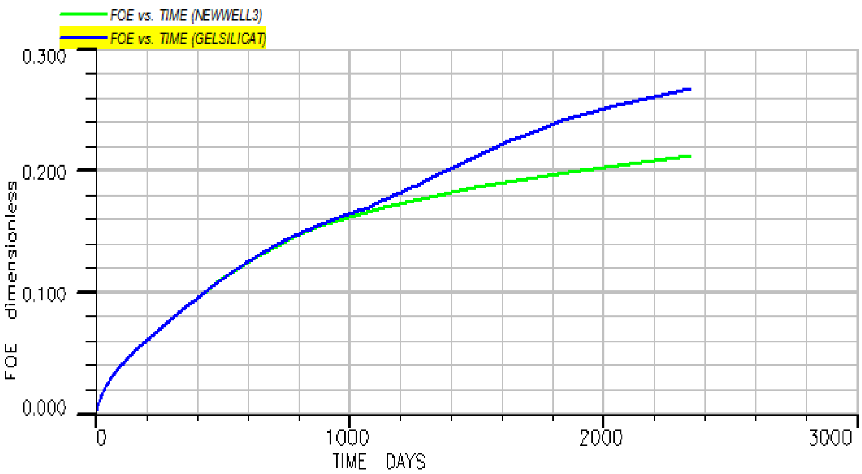

Fig. 25. Efficiency of oil produced before and after gel injection (FOE on the Y axis represents the efficiency of oil production)

Comparing the water produced in the cases of water injection and the gel injection, Fig. 26, it shows 94,000 barrels of producing water for the water injection and 72,000 barrels of water for the gel injection that means a total of 22,000 barrels of water production has been reduced.

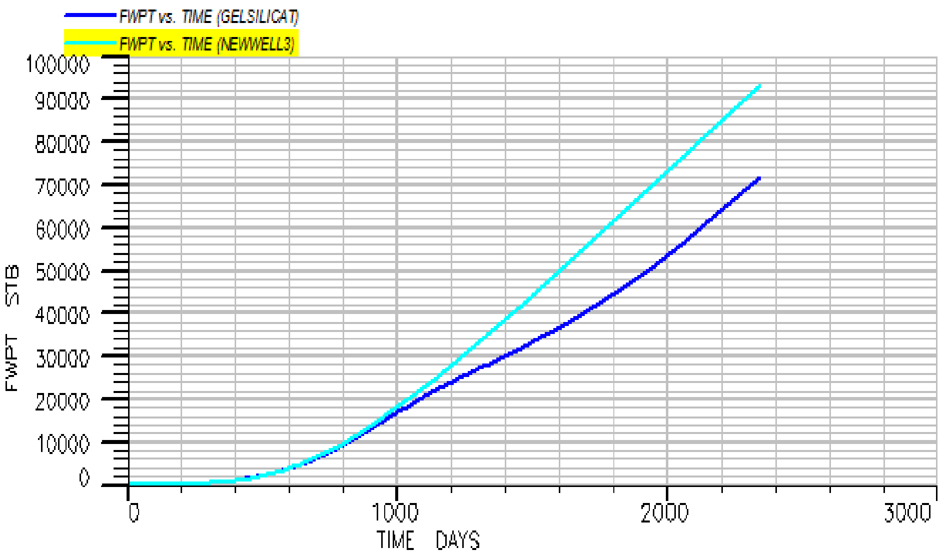

Fig. 26. Compare the water produced before and after gel injection (FWPT on the Y axis represents the rate of produced water)

The pressure variation, Fig. 27, shows that with increasing fluid production, pore pressure decreases, with the injection of gel, the pressure graph has increased. The gel is placed inside the pore instead of water, and it prevents the pore pressure drop and reservoir. The Simulation results of gel injection on the oil production efficiency and Reduction of water production for gel injection are according to Tables 5 and 6.

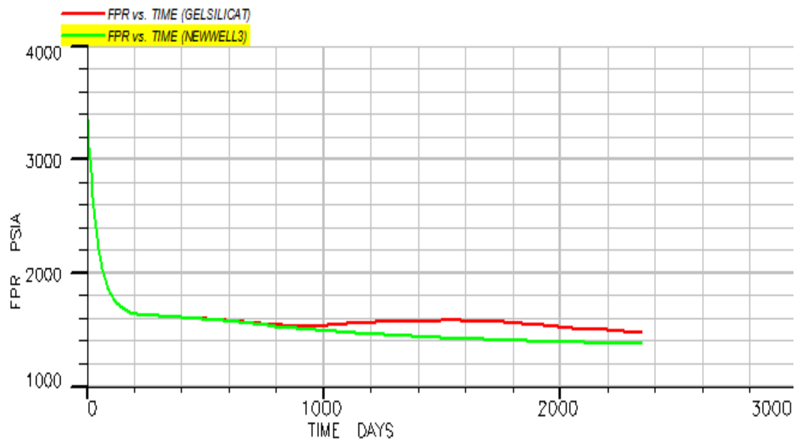

Fig. 27. Chart of reservoir pressure changes before and after gel injection (The FPR on the Y axis represents the reservoir pressure)

Table 5. Simulation results of gel injection on oil production efficiency

Well	**Injected volume of gel (bbl.)**	**Oil in situ (bbl.)**	**Oil cumulative production (bbl.)**	**Oil Recovery%**
New well	-------	300000	80000	21%
Gel Injector	25550	280000	100000	27%
Incremental produced oil	20000		6%	

Table 6. Reduction of water production for gel injection

Well	**Injected volume of gel (bbl.)**	**Produced Water (bbl.)**	
		Water Injection	**Gel Injection**
Gel Injector	25550	94000	72000

Reduction in produced water	22000

Gel Injection with different concentrations

The gel was injected at various concentrations of 10, 20, 50, and 100 (lb/STB).Comparing the efficiency of oil production for these concentrations, it can be seen that increasing the concentration of injected polymer also increases the oil production efficiency, Fig. 28, maximum concentration was 100 (lb/STB).

The reason for injecting gels with concentrations of 10, 20, 50 and 100 is to increase the concentration of the gel step by step to show The higher the concentration of the gel, the greater its effectiveness due to the large channels in the reservoir.

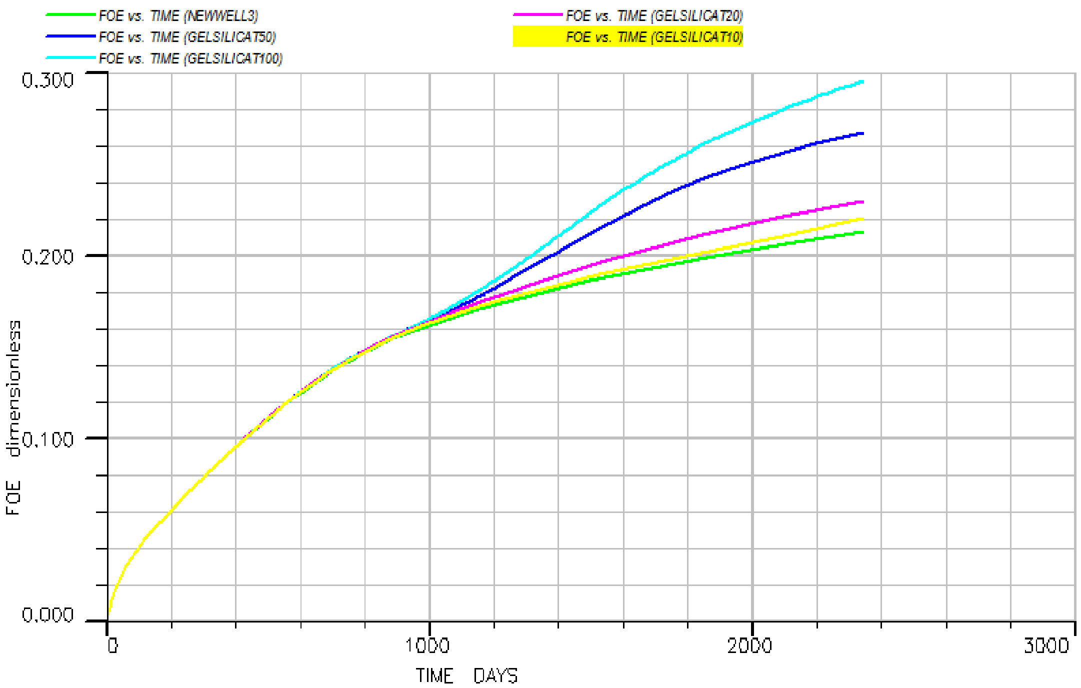

Fig. 28. Diagram of oil production efficiency for different concentrations (FOE on the Y axis represents the efficiency of oil production)

The predicted water production rate is different for different gel concentrations. By increasing the concentration of injectable polymer, the resistance of the gel to flow is increased, and as a result, the water production rate decreases Fig. 29. The Effect of Different Concentrations on Water Cut and Production Efficiency is shown in Table 7.

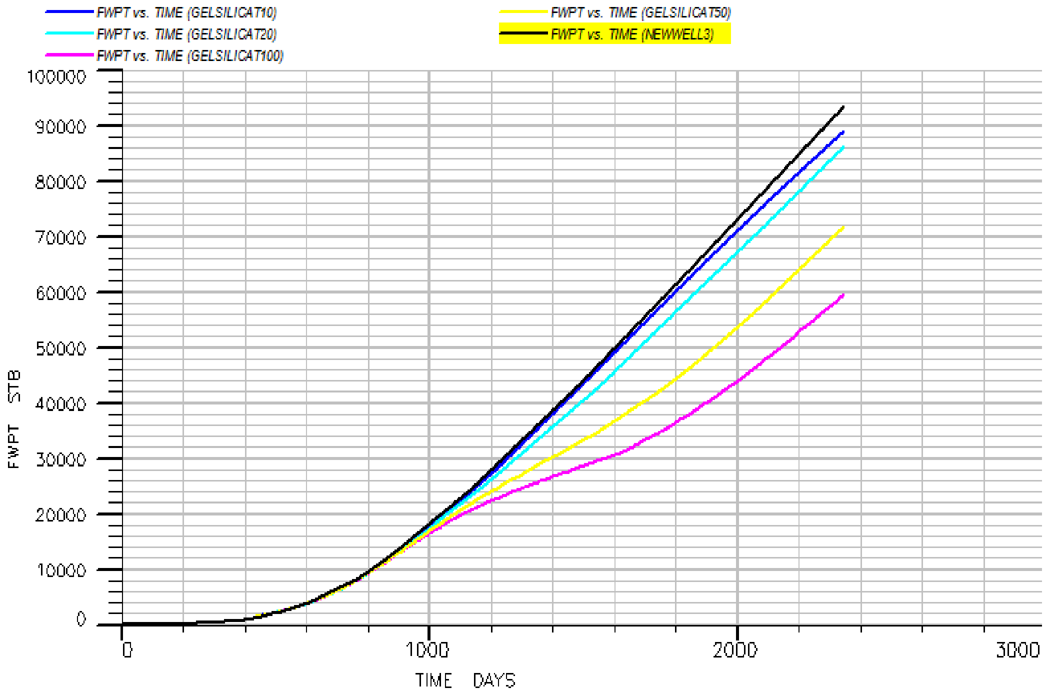

Fig. 29. Water Percentage Graph for Different Concentrations (The FWPT on the Y axis represents the total rate of produced water)

Table. 7 Effect of Different Concentrations on Water Cut and Production Efficiency

Well and gel concentration	Injected volume of gel (bbl)	Produced water (bbl)		Oil recovery factor (%)
		Before Injection Gel	After Injection Gel	
NEW WELL	-------	94000	-------	21%
Gel inj 10 (lb/stb)	25550	94000	89000	22%
Gel inj 20 (lb/stb)	25550	94000	86000	23%
Gel inj 50 (lb/stb)	25550	94000	72000	27%
Gel inj 100 (lb/stb)	25550	94000	60000	29%

Conclusion

By history matching and changing parameters of reservoir properties, including relative permeability, we achieved a representative model of the reservoir.

The model made according to the fluid production rate charts has a high water production compared to oil.

Oil production is done in the model, but then the production of water breaks down rapidly. As water production increases, oil production decreases, and the fluid outflow rate is higher than the oil outflow rate.

The problem of water production, according to Chan's diagnostic diagram, is related to canalization. Because the ratio of water to oil and its derivative has increased rapidly.

According to Chan's diagnostic chart, the problem of water production is related to channeling. Because the ratio of water to oil and its derivative has increased rapidly.

Depending on the model's fluid saturation and flow direction, the percentage of water saturation in the direction of flow increases and oil saturation remains constant in other areas. This is the reason why there is a channel.

Gel injection reduces water production and increases oil production. By injecting the gel, the amount of oil in place dropped from 300,000 barrels to 280,000 barrels after 2,300 days of production. That means 20,000 barrels of incremental oil are predicted to be produced.

After 1400 days, the percentage of water production has dropped by 30%.

By increasing gel concentration, the rate of water production decreases, and oil production efficiency increases.

From different gel concentrations modeled, the gel concentration of 100 (lb/STB) showed the best results.

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