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Numerical simulation on the effects of fracture parameters on oil and water production in unconsolidated reservoirs

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ABSTRACT: Oil production in unconsolidated reservoirs such as sandstone can be really challenging because of solids coming from the formation. In order to solve problems caused by produced solids, frac-packing is one of the methods used. It aims to maintain or increase production and control produced solids. This research focuses on the hydraulic fracturing part of that method. A numerical model is created using CMG-2015 with data from a given field to analyze the effects of some factors on oil production. Two cases are considered in this research, the first one is a one-layer case and the second one is a two layers case. Water is injected into the reservoirs in both cases. The results reveal that formation damage by its degree (Ks/K) and size can significantly decrease oil production and fracturing treatment can help recover the oil production to almost the initial value. After bypassing the damaged area, keeping increasing fracture half-length and conductivity is not important because there is no significant effect on the production. The results also show that for double layers case, the best way to increase oil production is to fracture the low permeability layer and maintain or leave the formation damage that will naturally happen.

KEYWORDS: Formation damage, Water Injection, Hydraulic Fracturing, Fracture parameters, Sensitivity Analysis.

1 INTRODUCTION

Although 60% of the world's oil and gas reserves are in carbonated reservoirs, 90% of oil and gas producing wells are drilled in silicates reservoirs and most of the recent discoveries have been in unconsolidated sandy soils formations unconsolidated or in weakly consolidated and cemented sandstones (Shetland Islands, U.K; Gulf of Mexico, offshore Angola and Brazil) [1]. In unconsolidated reservoirs, several methods can be employed to recover the maximum of the Original Oil In Place [2]. Between them we can have water injection which can help maintain the initial reservoir pressure and the hydraulic fracturing which can help bypass the formation damage zone that may occur after a certain time of production and finally recover the production [3].

Research into the effects of fracture length and conductivity in well productivity for unconventional reservoirs, many scenarios were executed with various fracture half- lengths and conductivities. CfD of 1, 2, 3, 5, and 10 and half-lengths of 300, 500, 700, 900, and 1000 ft were considered, and a fixed fracture width of 0.05 ft was used [4]. The outcomes showed that optimal half-length is from 700 to 900 ft to have good production; half-length less than 700 ft could provoke production limit, and a half-length greater than 900 ft could cause high water production. CfD different from 1.0 to 2.0 could cause massive water production. The above fracture parameters can increase the recovery factor from 0.82% to more than 3.0% with a gas production rate of 0.3*106 ft^3/day, while a cumulative gas can be increased to 0.52 MMM ft^3 with 21000 bbl of produced water [5].

To keep going, we have research on Frac-packing Shallow Unconsolidated Reservoirs Onshore Trinidad [6]. Almost all of Trinidad's onshore hydrocarbons production is mature. Hydrocarbons reserves were produced by primary methods, with EOR methods contributing to nearly half of the total production. With the natural decline in the production, it is normal to find ways to increase the production; frac-packing is presented as one appropriate method to reach this goal [7]. Also, frac-pack has an advantage over gravel pack when it comes to reducing and keeping the skin low after the treatment. Results obtained from the treatment show a growth of more than 200% on the production rate compared to the pre-fracture one [6]. The results also showed an increase in reserves of 8- 35% per well due to a prolonged life of the reservoir.

Another work is presented here about an approach to getting effective parameters monitoring the efficiency of multistage fractured horizontal wells in low permeability reservoirs employing the Response Surface Methodology (RSM) technique. This research was focused on improving fracture parameters in Multi-Stage Fractured Horizontal Well (MSFHW) [8]. Homogeneous and heterogeneous area reservoir models with a range of 0.5 and 5 mD as permeability were used; approximately 2400 cases were studied through simulation. The RSM was then used to separate the outcomes got from different fracture parameters [9]. The best fracture parameters were also given by doing an economic study and calculating NPVs matching different fracture plans. The following conclusions were obtained from this research:

- Cases with the permeability of 5 mD, the main parameters increasing the productivity are fracture conductivity and the number of fracture stages. The more the permeability decreases (for instance, 0.5 mD, the dominant parameter controlling the well efficiency is the fracture number.
- In low permeability formation, to get higher productions, it was essential to increase Fracture. But it should be stated that if the fracture conductivity is small, it is a profitable technique to maintain the fracture length shorter to reduce costs. Taking into count reservoir heterogeneity, mostly the organization of formation permeability in the SRV, revealed an essential role in defining the best fracture design. For the low permeability heterogeneous area model, the fracture length had a considerable encouraging result on the productivity than fracture conductivity. In contrast, the dominant factor in homogeneous reservoirs over the former one was the last parameter.
- The economic investigation of the fracturing treatment had a critical role in planning the ideal fracture parameters. Precisely, the choice of maximum half-length and the number of fracture stages significantly depend on the operation's productivity [10].

Recent research on Frac-Packing completion has been conducted; the research discussed the criteria for selecting wells to be frac-and-packed [3]. It was shown how a systematic study of the inflow performance could be used to assess the potential of frac-and-packed wells, to identify the controlling factors, and to optimize design parameters. It was also shown that fracture conductivity is often the key to successful treatment [7], [11]. That conductivity depends largely on proppant size; formation permeability damage around the created fracture has less effect [1].

More than 60% of the total world's reserves of oil and gas are classified in poorly or weakly consolidated reservoirs [12]. These types of rocks are relatively young in geologic age, and are unconsolidated due natural processes have not cemented the rock particles together by mineral deposition [1], [13]. Because of that, reservoirs located on different regions have as a main feature the sanding offset [14]. This is particularly significant in cases that have a high change of in-situ stresses i.e., Offshore Wells, high production rates, collapse of hole cavities, and presence of water in the formation [15]. Field operations showed in the report indicate volumetric concentration of sand in oil pipe systems can varies from 1% to 40% [16]. Sand production may lead to the erosion of downhole and surface equipment, could be creating severe safety problems including loss of well control, and production shut-in [17]. and the production of sand can be restricting the quantity of production of the formation to the wellbore, doing not possible the recovery of the hydrocarbons [18].

By seeing and analyzing the above work and other papers, we can notice that the use of hydraulic Fracturing in unconsolidated formations as a way to bypass the formation damage is not really developed like hydraulic fracturing in unconventional reservoirs. Especially when it comes to the effects of fracture parameters on the production. This research studied different scenarios and sensitivity analysis of some fracture parameters was conducted to investigate their impacts on the reservoir productivity and finally determine the fracture half-length and conductivity to use in unconsolidated reservoirs.

2 MATERIALS AND METHODS

A model was built using CMG-2015 [19], [20]. We used data from a given field with large remaining oil reserves in some sections of the main oil field. The production is low, and hydraulic Fracturing is urgently needed to improve production [21].

The target study area is a structural layered oil and gas reservoir with substantial vertical heterogeneity and significant differences in the degree of recovery between layers; Long-term production has caused heavy pollution (formation damage), low production, and low efficiency near the well [22], [23]. It is urgent to reform the layer-by-layer Fracturing to eliminate damage and restore production capacity.

In this simulation, we have different cases:

- One-layer case where we have formation damage around the producer wells,
- Then we will have the two layers case (the top layer has high permeability compared to the bottom one) with damage around the producers.

CMG-2015 is used to build the reservoir model and do sensitivity analysis on different parameters to optimize the Hydraulic Fracturing operation.

2.1 Single-layer

A reservoir grid cartesian block was created with dimensions 140 × 70 × 1 in the I J K directions. The grid size is 5m × 5m, and the longitudinal thickness is 2.5m. The well pattern is a row well pattern, with a well spacing of 350m between producers and injectors, well spacing between producers is 175m, and a well spacing of 175m exists between injectors. The simulated production time is 10 years.

Table 1. Reservoir properties

Parameters	Values
Grid block	140 x 70 x 1
Reservoir temperature	60ºC
Initial reservoir pressure	17700 kPa
Permeability	292 mD
Porosity	27.8%
Bottomhole pressure of producers	13700 kPa
Production rate	8m^3/day
Reservoir depth	1715 m
Layer	1
Thickness	2.5 m
Water saturation	28.6%
Initial oil saturation	61.7%

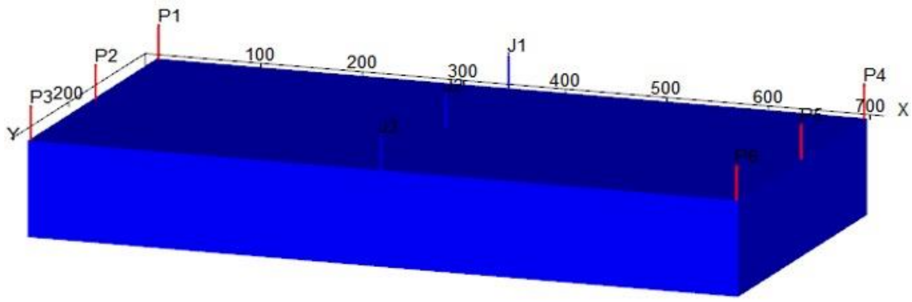


Fig. 1. Model representation

In order to maintain the initial reservoir pressure and help to better sweep the oil in the reservoir, it is essential to execute the water injection [9], [24]. In this model, we have 3 injectors and 6 producers. The surface water rates are respectively 2m^3/day, 4m^3/day, and 2m^3/day for J1, J2, and J3. The upper limit of bottom flow pressure of all water injection well is 28300 kPa.

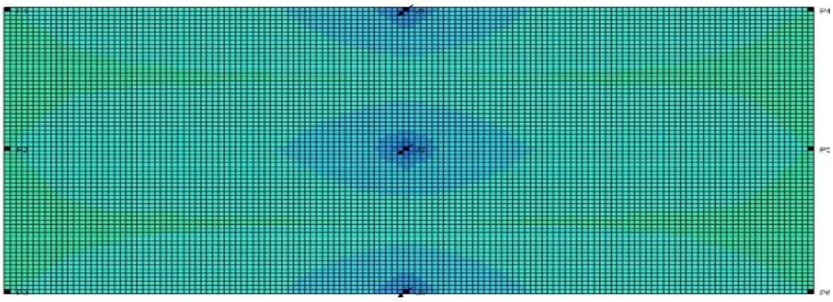


Fig. 2. Water distribution

Hydraulic Fracturing is a technique used to increase the permeability around the damaged zone [1], [25]. Hydraulic fractures also increase the area of diffusion for the injected water in the reservoir [3], [26]. The table and Figure show the hydraulic fracture parameters used in designing the hydraulic Fractures.

Table 2. Fracture parameters

Parameters	Values
Half-length	4.78 m (1grid) more behind the damaged area
Fracture width	0.05 m
Fracture conductivity	2000 mD*m

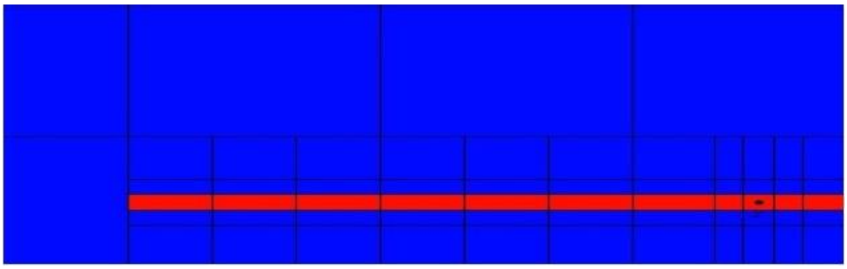


Fig. 3. Fracture representation

2.2 DOUBLE-LAYERS

A reservoir grid cartesian block was created with dimensions 140 × 70 × 1 in the I J K directions. The grid size is 5m × 5m, and the longitudinal thickness is 2.5m. The well pattern is a row well pattern, with a well spacing of 350m between producers and injectors, well spacing between producers is 175m, and a well spacing of 175m exists between injectors. The simulated production time is 10 years.

Table 3. Reservoir properties

Parameters	Values
Grid block	140 x 70 x 3
Reservoir temperature	60°C
Initial reservoir pressure	17700 kPa
Permeability	150 mD (bottom layer), 1186 mD (top layer)
Porosity	29.7% (top layer), 26.3% (bottom layer)
Bottomhole pressure of producers	13700 kPa
Production rate	8m^3/day
Reservoir depth	1673 m
Layer	3
Thickness	2.5 m (top one), 0.5 m (middle one), 9 m (top one)
Water saturation	43.2% (top layer), 34.3% (bottom layer)
Initial oil saturation	56.8% (top layer), 65.7% (bottom layer)

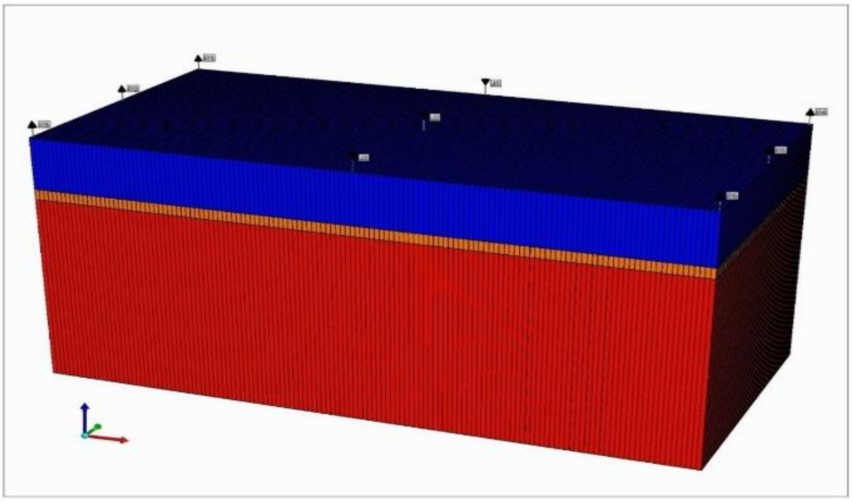


Fig. 4. Model representation

The surface water rates are respectively 9.2m^3/day, 18.4m^3/day, and 9.2m^3/day for J1, J2, and J3, and the injection pressure is 28300 kPa.

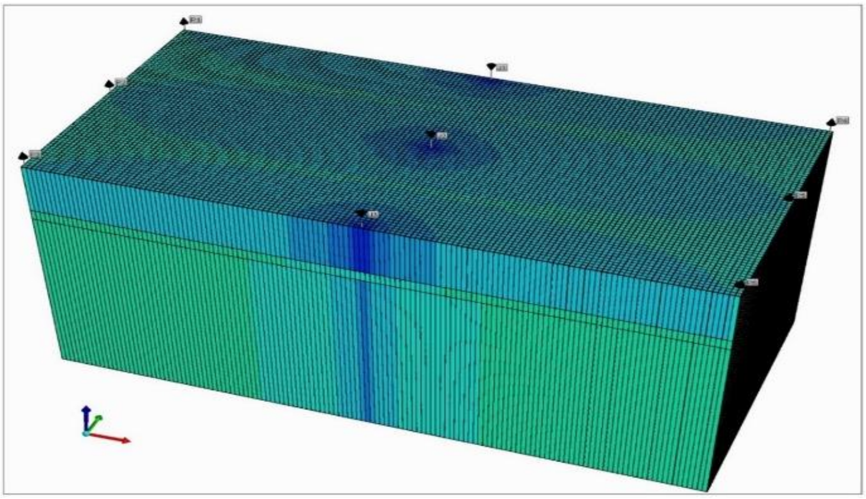


Fig. 5. Water distribution

The coming table depicts the hydraulic fracture parameters used in designing the Hydraulic Fractures.

Table 4. Fracture parameters

Parameters	Values
Half-length	25 m
Fracture width	0.04 m
Fracture conductivity	2000 mD*m

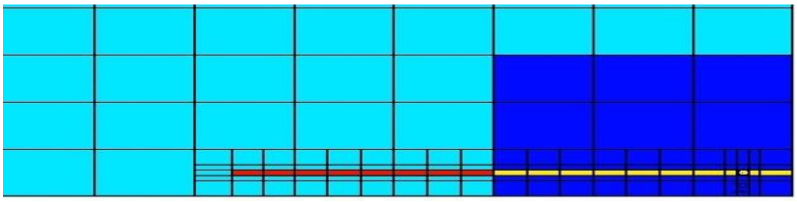


Fig. 6. Fracture representation

3 RESULTS AND DISCUSSION

3.1 SINGLE-LAYER

3.1.1 EFFECT OF FORMATION DAMAGE DEGREE (KS/K)

In unconsolidated formations, we will have solid particles coming from the reservoir to well perforations after a particular production time. That can cause formation damage and reduce production [1], [27]. The damage degree is given by Ks/K, with K (primary permeability of the reservoir); Ks (damaged zone permeability) [20], [28]. To illustrate the effects of the formation damage, we will consider the damage degrees of 0.01, 0.2, and 0.5.

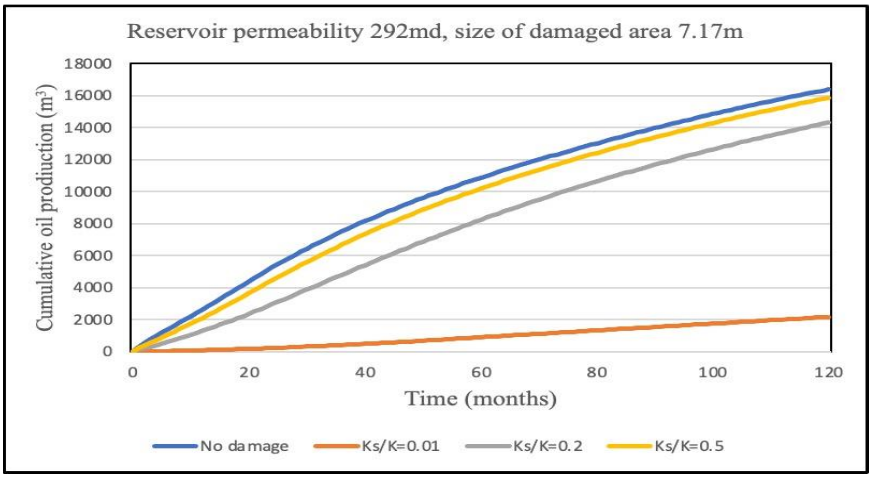


Fig. 7. Effect of formation damage on cumulative oil production

By seeing the above results, we notice that the smaller the damage degree (Ks/K) is, the more the oil production is being reduced. For example, when we have a damage degree of Ks/K=50% (0.5), the cumulative oil production is 15873m^3 or 96.8% which is close to the case without formation damage (16394m^3 or 100%), but when we have Ks/K of 1% (0.01), the cumulative oil production is only 2182m^3 or 13.3%.

To sum up, we can say that the injected water is not sweeping oil perfectly from the reservoir to the well because of the reduced permeability caused by the damage.

3.1.2 EFFECT OF THE SIZE OF DAMAGED AREA

Here we have a damage degree of 10% or Ks/K=0.1. The sizes of damaged areas are 2.39m, 7.17m, 26.29m, and 31.07m. The following picture shows the effects of different damaged sizes on production.

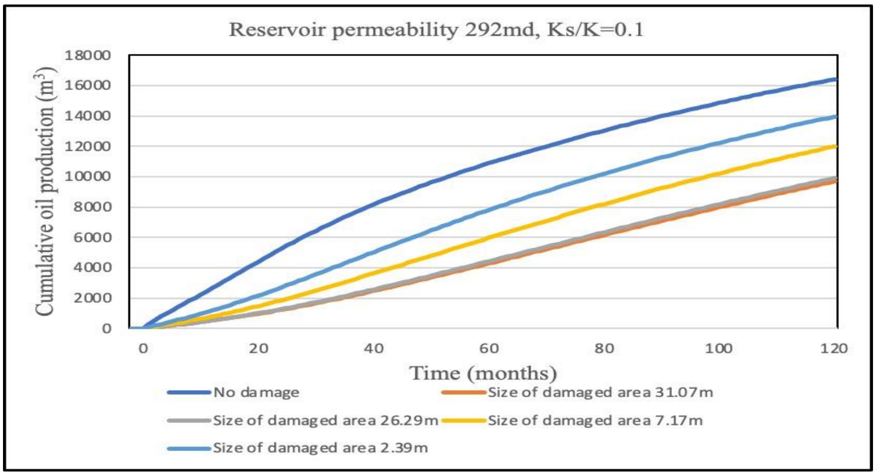


Fig. 8. Effect of the sizes of damaged area on cumulative oil production

For a fixed damage degree of 10% (Ks/K=0.1), we can observe that the larger the damaged area, the low the oil production. We have cumulative oil productions of 16394m^3 (100%), 9900m^3 (60.38%) and 13948m^3 (85.07%) for no damage case, damaged size of 31.07m and for damaged size of 2.39m respectively.

To conclude, we can say here that, the size of the damaged area is really important and the more it is large the low the oil production will be, because the injected water will struggle to cross that large damaged zone and the water will not sweep oil properly.

3.1.3 EFFECT OF HYDRAULIC FRACTURING ON FORMATION DAMAGE DEGREE

This part will study the effects hydraulic Fracturing can have on a damaged zone. One of the hydraulic fracturing goals is to bypass the damaged area and increase pro-duction. The template about the Fracture characteristics is given previously; the size of the damaged area considered in this part is 7.17m. We have a half-length of 11.95m for medium and high permeability cases. We will consider different damaged degrees to see the effects of hydraulic Fracturing on the damage degree.

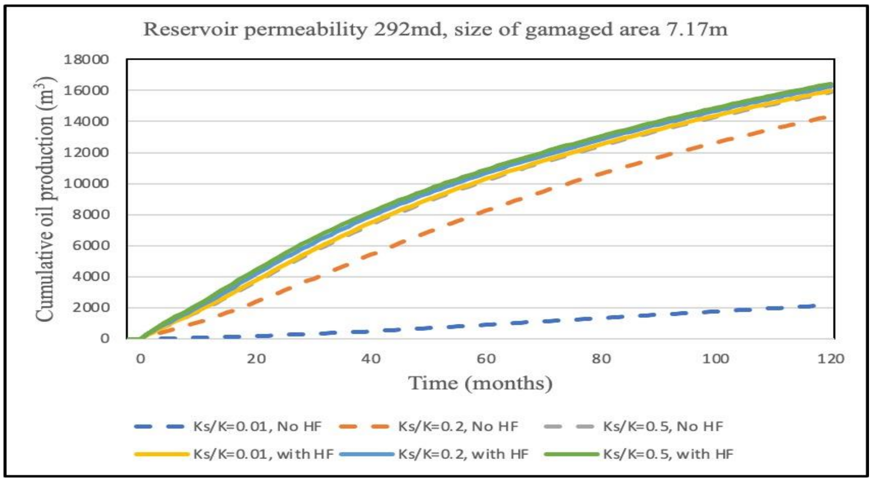


Fig. 9. Effect of hydraulic fracturing on the damage degree (cumulative oil production)

We can notice and see from the results that hydraulic Fracturing has a substantial positive effect on oil production; for instance, when we have a damage degree of 1% (Ks/K=0.01) without hydraulic Fracturing, the cumulative oil production is 2182m^3 or 13.3% of the initial production, but when we add hydraulic Fracturing, the cumulative oil production is being multiplied by more than seven 15989m^3 or 97.5% which almost equal the case without damage 16394m^3 or 100%. The same effect is observed for the daily oil production rate.

Hydraulic Fracturing is more efficient in the cases where we have a minor damage degree or high formation damage around the wellbore. From that we can see the how effective hydraulic fracturing is in these unconsolidated formations because it helps to almost recover the initial production.

3.1.4 EFFECT OF HYDRAULIC FRACTURING ON THE SIZE OF DAMAGED DEGREE

Concerning the effects of hydraulic Fracturing on the size of the damaged area, we will consider the same fracture parameters. The fracture half-length is going 4.78m (which is the size of one a grid) behind the damaged area. For instance, if the size of the damaged area is 7.17m, the half-length will be 7.17m + 4.78m which is equal to 11.95m. We will also have a fixed damage degree of Ks/K=0.1.

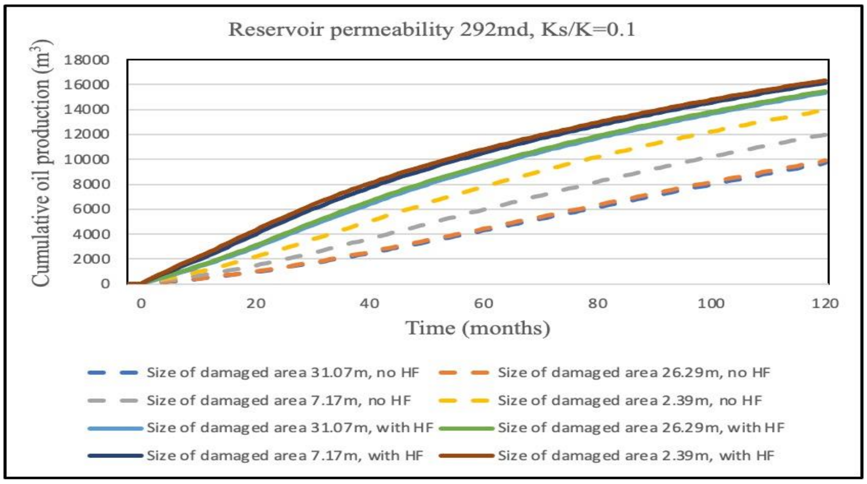


Fig. 10. Effect of hydraulic fracturing on the size of damaged area (cumulative oil production)

The results show that hydraulic Fracturing also positively affects oil production in this section. We can observe how oil production increases for all the hydraulic fracturing cases. For example, we can check the case of 31.07m with and without hydraulic Fracturing. For the case without HF, the cumulative oil production is 9690.5m^3 or 59.1% of the initial production (without damage) but when we put HF, the cumulative oil is going up to 15266m^3 or 93.11% of the initial production. The more the damaged area is large, the more efficient Hydraulic Fracturing is.

We can conclude by saying that HF is increasing the oil production in all the cases where we have damage but it is more effective in the cases where the damaged area is large.

3.1.5 EFFECT OF FRACTURE HALF-LENGTH

The fracturing treatment extension from the well to the producing reservoir can be determined by Hydraulic Fracture half-length [29]. In other words, it is the size (length) of the hydraulic Fracture starting from the well and going into the formation [3].

To study the effects of the fracture half-length (X_f) [25], we have different scenarios:

3.1.5.1 DAMAGE DEGREE OF 1% (K_S/K=0.01) IN A DAMAGED AREA OF 11.95M

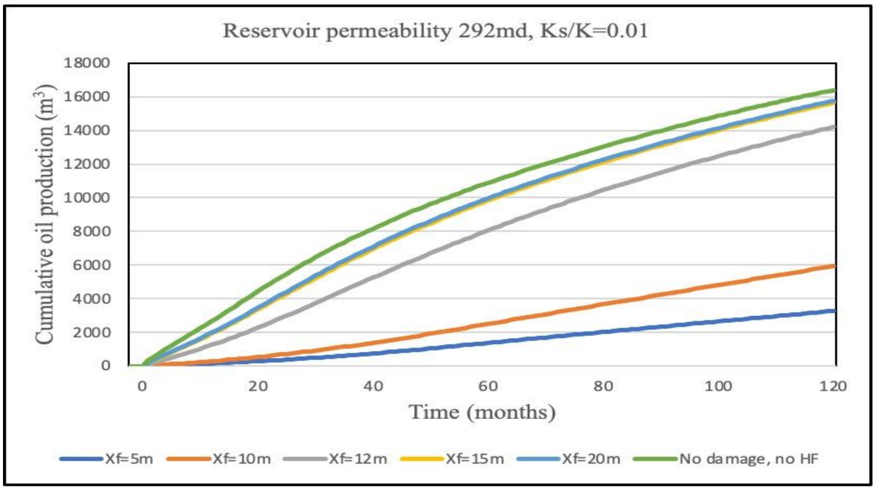


Fig. 11. Effect of half-length on cumulative oil production

3.1.5.2 DAMAGE DEGREE OF 1% (K_S/K=0.01) IN A DAMAGED AREA OF 31.07M

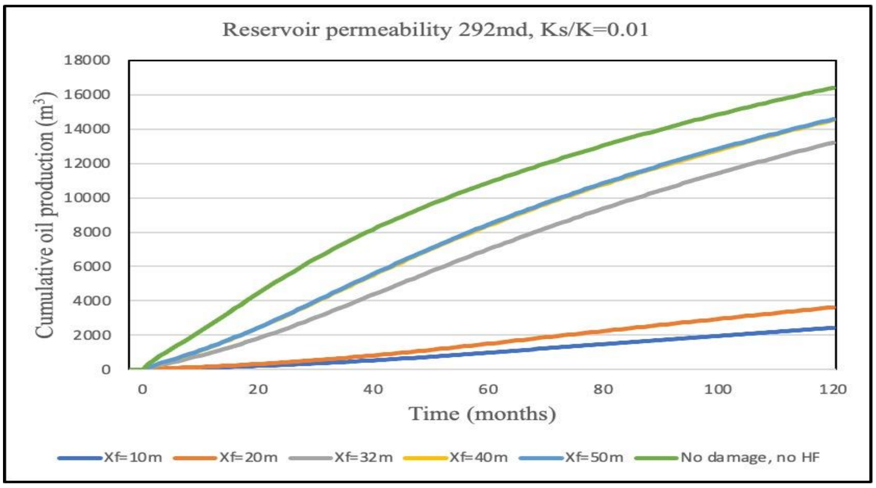


Fig. 12. Effect of half-length on cumulative oil production

3.1.5.3 DAMAGE DEGREE OF 10% (KS/K=0.1) IN A DAMAGED AREA OF 11.95M

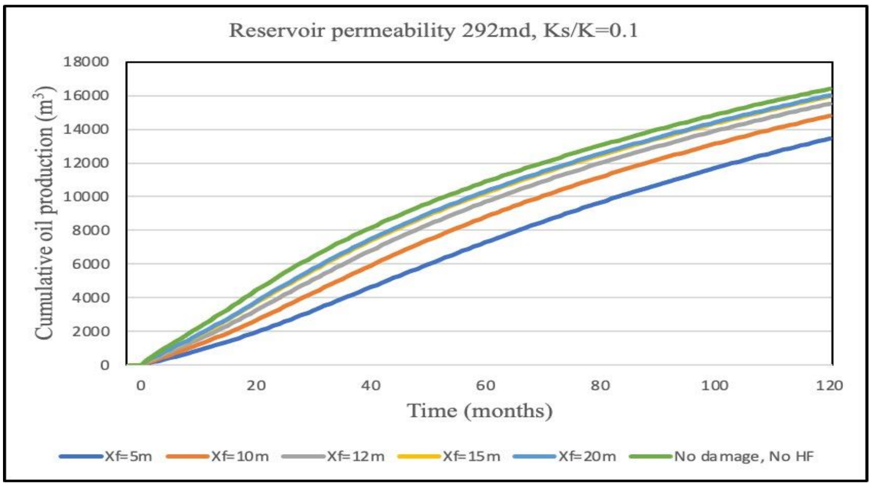


Fig. 13. Effect of half-length on cumulative oil production

3.1.5.4 DAMAGE DEGREE OF 10% (KS/K=0.1) IN A DAMAGED AREA OF 31.07M

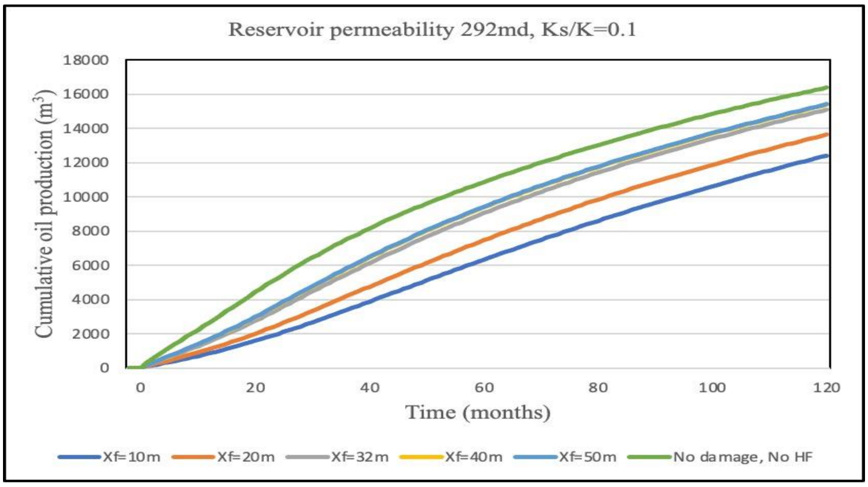


Fig. 14. Effect of half-length on cumulative oil production

The effect of the half-length is depicted in the previous figures [9]. We can observe that the longer the half-length, the higher the production. To better illustrate the effect of the half-length on the production let us see the cumulative oil production where we have a damage degree of 1% (Ks/K=0.01) in a damaged area of 31.07m. The cumulative oil productions are as follow: 16394m^3 or 100% for the no damage case, 14582m^3 or 88.94% for the half-length of 50m, 14358m^3 or 87.58% for the half-length of 40m, 13218m^3 or 80.62% for the half-length of 32m and finally, 3631m^3 or 22.14% for the half-length of 20m. For the half-length inside the damaged area (20m), the oil production is really low and far from the initial production (22.14%), but as soon we bypass the damaged area (32m) the oil production can be recovered to 80.62%. Even if we bypass the damaged area, there is still a need to keep increasing the half-length to 40m to recover more than 87% of the initial production but there is no need to go higher than 40m for the half-length because there is no significant effect on the oil production and to keep increasing the half-length can lead to additional costs. The goal here is to recover the production to the case's value without damage or even more than that.

To summarize, we can say that it is important to bypass the damaged area to significantly increase the production but after a certain value of the half-length, there is no need to keep increasing the half-length to avoid additional costs.

3.1.6 EFFECT OF DIMENSIONLESS FRACTURE CONDUCTIVITY (C_{FD})

To show the effects of C_{fD}, it is essential to remind that [13]:

$$C_{fD} = K_f * W / K * X_f \quad (1)$$

The damage degree is 10% (Ks/K=0.1). The damaged area is 16.73m, the half-length is 21.51m.

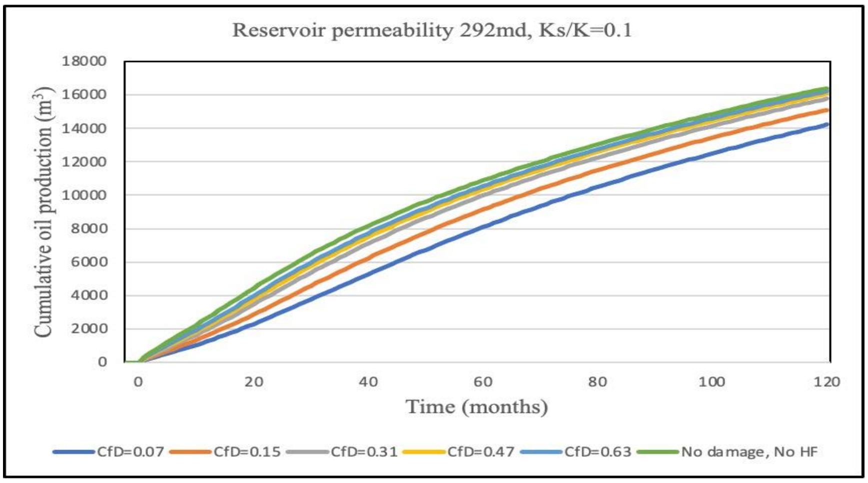


Fig. 15. Effect of C_{fD} on cumulative oil production

The conductivity is also a key parameter of hydraulic Fracturing [25]. From our simulation, we can see that it is affecting production. The more it gets big, the more the production increases, but there is no prominent effect after a specific value. For a fixed damaged area of 16.73m with a damage degree of Ks/K=0.1 and a half-length of 21.51m we have the following cumulative oil production: 16394 m^3 or 100% for the no damage case, 16213m^3 or 98.89% for the CfD of 0.63, 16059m^3 or 97.95% for the CfD of 0.43 and, finally, 14213m^3 or 86.69% for the CfD of 0.07.

3.2 DOUBLE LAYERS

3.2.1 DAMAGE AND HYDRAULIC FRACTURING FROM THE BEGINNING (2010)

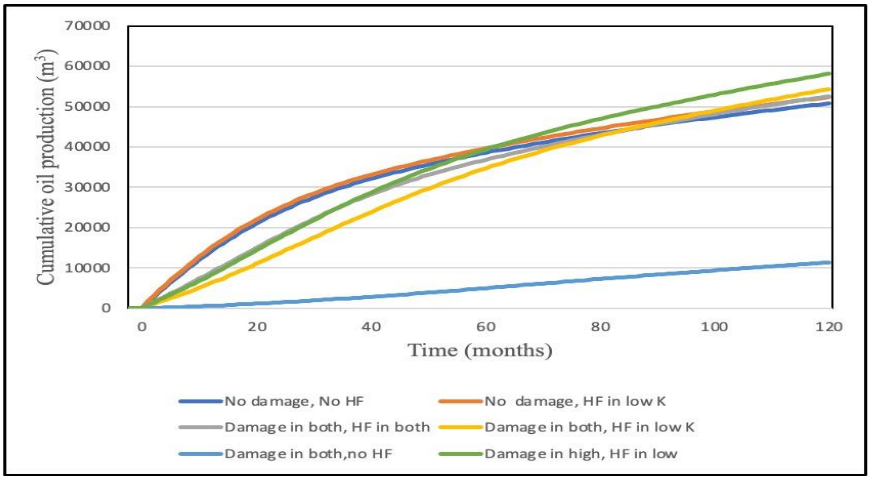


Fig. 16. Effect of different scenarios on cumulative oil production

3.2.2 DAMAGE AND HYDRAULIC FRACTURING AFTER TWO YEARS (2012)

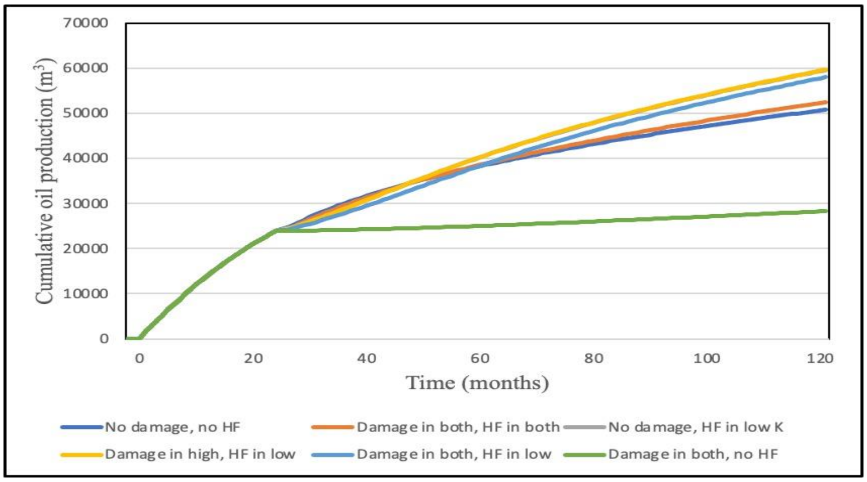


Fig. 17. Effect of different scenarios on cumulative oil production

From the previous one-layer cases, we learned that hydraulic Fracturing could help recover the initial oil production in the damaged zone. We also learned that after we bypass the damaged area, there is no need to increase the half-length and the conductivity. The purpose of the double layers cases was to find a way to balance production in the two layers and increase oil production, knowing that the water injected is going more in the top layer because of its high permeability, and it is difficult to sweep oil in the bottom layer.

Some simulations were run with damage and hydraulic Fracturing around the producers from the beginning of the simulation time (2010). Others were run with damage and hydraulic Fracturing around the producers after two years (2012).

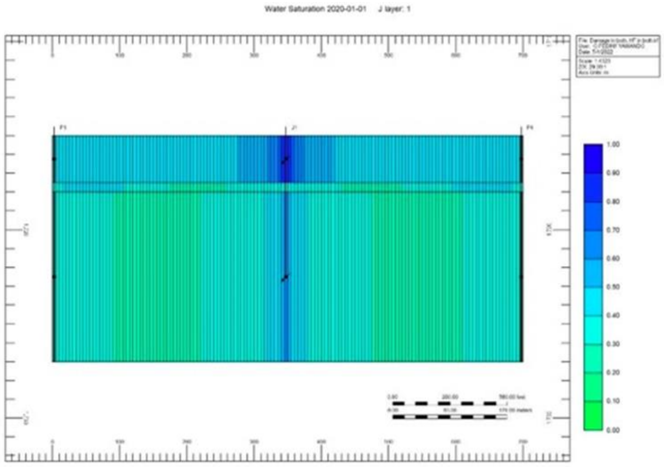
The purpose here was to see the best scenario that could give the higher oil production. The damage degree was 1% or Ks/K=0.01, which means that for the top layer (K=1186mD), the permeability of the damaged area is 11.86mD, and for the bottom layer (K=150mD), the permeability of the damaged area is 1.5mD.

The size of the damaged area in all the cases is 12.5m, and the fracture half-length was 25m (it bypasses the damaged area).

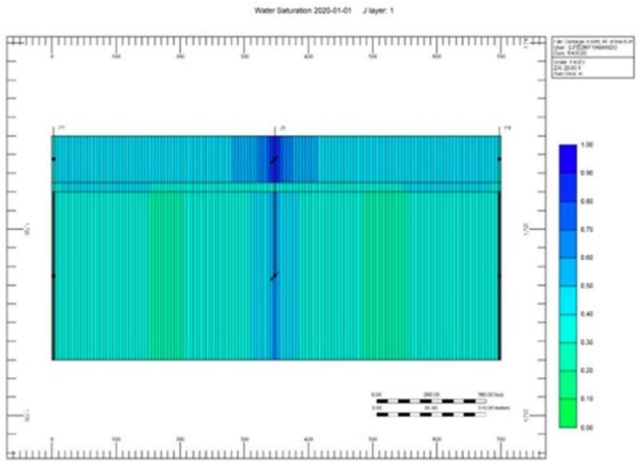
We found that the best scenario that gives the best results is to damage the top layer, which has a high permeability value, and then fracture the bottom layer, which has a low permeability value (after two years).

To give numbers, we can check our results graphs and notice that for the cases where we damage and fracture from the beginning (2010), the best scenario is when we damage the top layer and create hydraulic Fracture, the low one, the cumulative oil is 58149m^3. When we see the cases where we damage and fracture after two years (2012), the best scenario is still the one we damage the top layer (with high permeability value) and fracture the low one; the cumulative oil production is 59684m^3.

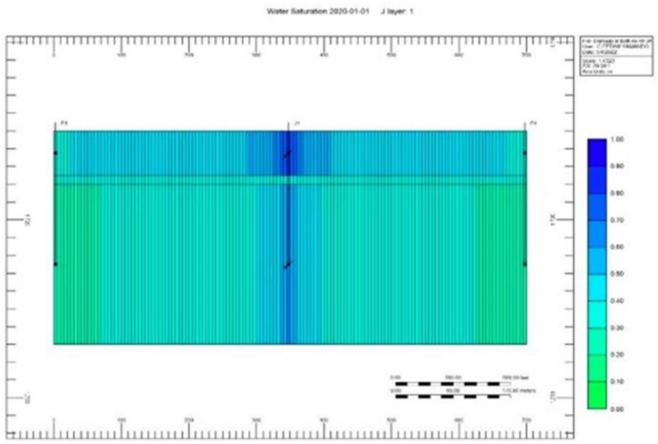
To better understand the above numbers or results, we can check the following figures that depict the water injection distribution in the reservoirs for different cases.



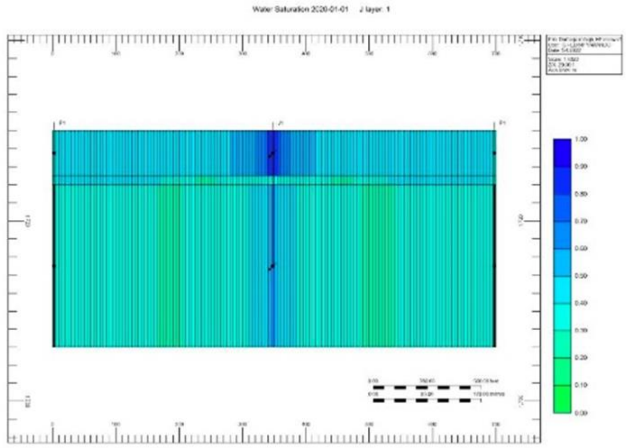
(a) damage and HF in both layers



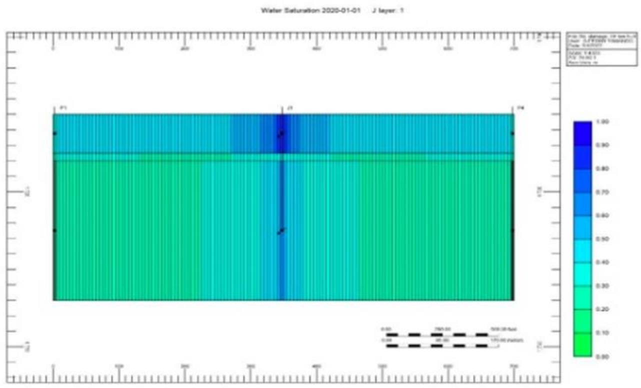
(b) damage in both layers and HF in the low K



(c) damage in both layers and no HF



(d) damage in high K and HF in the low K

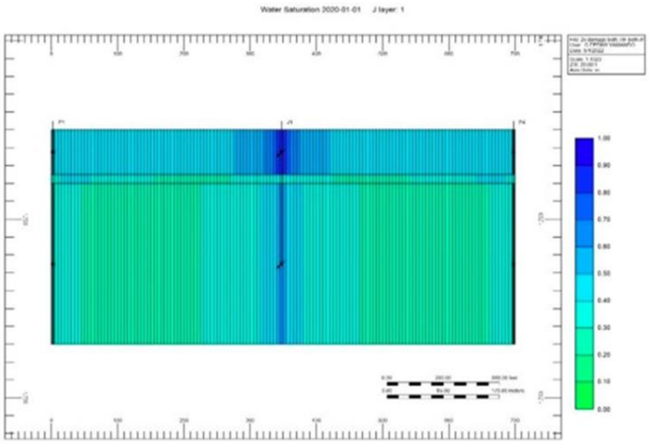


(e) No damage and HF in the low K

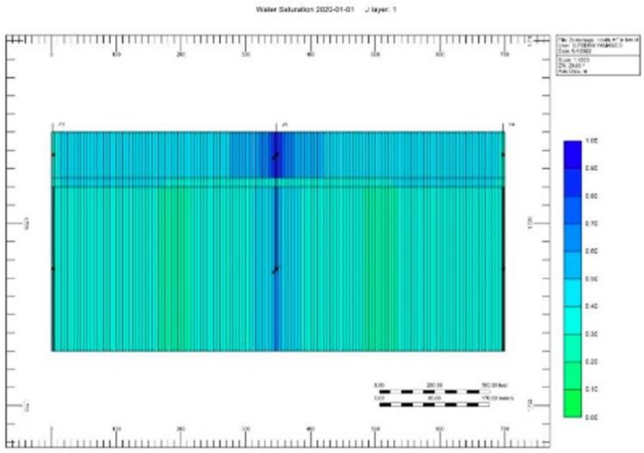
Fig. 18. Water distribution 2010

The above pictures give more details about the fluid's production for the cases with damage and hydraulic fracturing since the beginning of the simulation time (2010). We can see that water is being more displayed in the reservoir for the case where we have damage in the high permeability layer and HF in the low permeability one. That is because, the reduction of the permeability caused by the formation damage around the wellbores in the high permeability layer leads to a fluid flow resistance, so the injected water is facing difficulties to flow in that high permeability layer. That flow resistance in the high permeability layer generates an important flow of the injected water in the low permeability layer. A considerable amount of the injected water will go to the low permeability layer to better sweep oil.

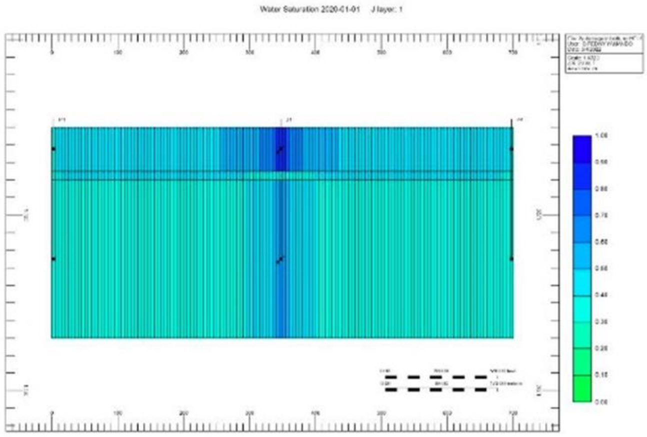
We can conclude from the above pictures that, to have a better water distribution in the two layers, it is necessary to have formation damage in the high permeability layer (which will naturally occur because of the impurity of the injected water and also after a long production time) and hydraulic fracture the low permeability one



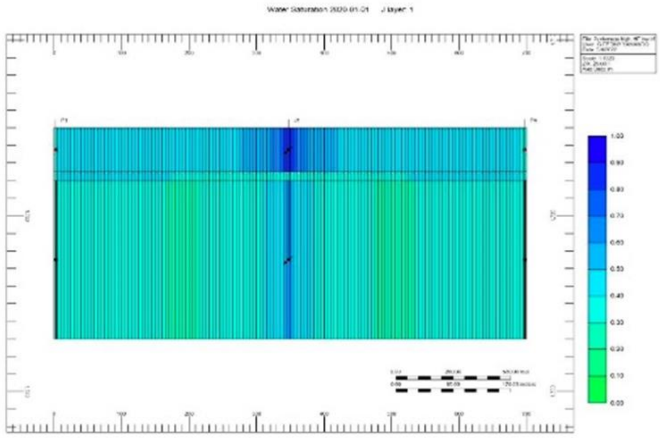
(a) damage and HF in both layers



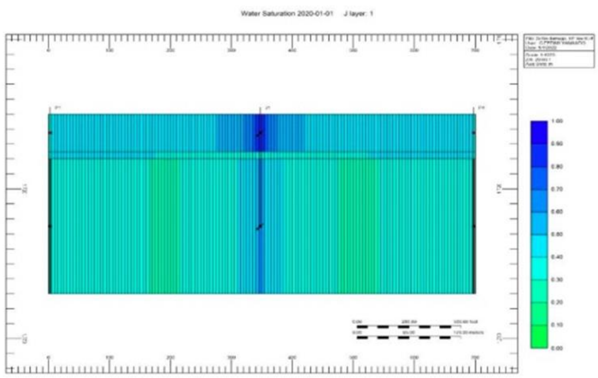
(b) damage in both layers and HF in the low K



(c) damage in both layers and no HF



(d) damage in high K and HF in the low K



(e) No damage and HF in the low K

Fig. 19. Water distribution 2012

The previous pictures explain the water distribution in the two layers after two years of the simulation time (2012), that means that, we have formation damage and hydraulic fracture in wells after two years of production. From the above, we can notice that, the injected water is more being expanded in the cases where we have: damage in both layers and hydraulic fractures in the low permeability layer, damage in high permeability and hydraulic fractures in the low permeability, and, finally, no damage in the two layers and hydraulic fractures in the low permeability layer. The more the injected water faces flow resistance in the high permeability layer, the more it will go to the low permeability one. We can conclude that, it is necessary to treat the low permeability layer by hydraulic fracturing to recover more oil located there.

4 CONCLUSIONS AND RECOMMENDATIONS

The main purpose of this research was to study the effects of fracture parameters on oil and water production and find a way to balance the water injected in the two layers with different permeabilities then increase the production through numerical simulation.

This research was subdivided into two sections to reach the main target (the single and the double layers). The purpose of the single-layer case was to show the effects of formation damage (by changing the damage degree), size of formation area (with a fixed damage degree), hydraulic Fracturing on formation damage and its size then finally, the effects of fracture parameters (the hydraulic fracture conductivity and the half-length) on oil production. The purpose of the double layers cases was to find the perfect scenario that could balance the fluids production between the two layers and also help recover the maximum quantity of oil in the low permeability layer.

The conclusions and recommendations are given as follows:

1. The formation damage has a significant effect on production. The more serious the damage (low Ks/K), the more the production will be reduced.
2. The size of the damaged area is also an essential factor that can affect production. For a given formation damage (fixed Ks/K), the larger the damaged area is, the lower the production will be.
3. Hydraulic Fracturing has shown that it can help recover the production despite the formation damage and its size. Hydraulic Fracturing is more efficient or gives better results when we have severe formation damage in a large area.
4. The hydraulic Fracture parameters like the Fracture conductivity and half-length have a significant role in hydraulic fracturing efficiency. For the hydraulic fracture half-length, it is necessary to bypass the damaged area to increase the production, but after a specific value (behind the formation damage area), there is no need to keep expanding the half-length because the production will no longer go up; the same conclusion is made for the fracture conductivity.
5. For the double layer's cases, it is vital to treat bottom layer (with a low value of permeability) by hydraulic fracturing and keep the damage in the top layer (with high-value permeability). By considering those aspects we will balance the injected water into both layers and finally increase production. It is necessary to specify that the damage here will occur after a long time of production (due to impurity of the injected water and the fluids flow from the reservoir to the well.

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