A Simulation Study to Investigate Water Coning

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Abstract— ***Water coning is a usual problem that is faced by petroleum engineers in reservoirs having an aquifer, particularly at the bottom. The critical rate is the subject discussed mostly in the studies on water coning. This paper presents a simulation study using petrel and eclipse software to investigate water coning. Some variables have been taken to investigate their effect on the repression that occurs in oil reservoirs and the effect of changing their amounts on the production of oil and water and to choose the optimal amount of each variable. The variables was perforation interval, oil viscosity, permeability ratio and aquifer size. The highest oil recovery for each case has been found .the highest oil recovery in the perforation case was found in the top perforation. The highest oil recovery for oil viscosity was found for the lowest viscosity. The highest oil recovery for permeability ratio was found for the lowest vertical permeability. And for the last case the highest oil recovery was found in the lowest aquifer size.***

Keywords— ***coning, critical production, perforation, oil viscosity, breakthrough time.***

I. INTRODUCTION

Coning is a term used to describe the mechanism underlying the upward movement of water and/or the down movement of gas into the perforations of a producing well. Coning can seriously impact the well productivity and influence the degree of depletion and the overall recovery efficiency of the oil reservoirs. The specific problems of water and gas coning are listed below.

- Costly added water and gas handling
- Reduced efficiency of the depletion mechanism
- The water is often corrosive and its disposal costly
- The afflicted well may be abandoned early
- Loss of the total field overall recovery

The fluid interface deforms from its initial shape into a cone shape and that is why this phenomenon is referred to coning depicted in Fig.1 there are three essential forces controlling the mechanism of water coning which include capillary, gravity, and viscous forces. At initial reservoir conditions, the gravity force is dominant and once the wells start to flow the pressure drawdown increases and viscous force arises to be part of the controlling mechanisms [1].

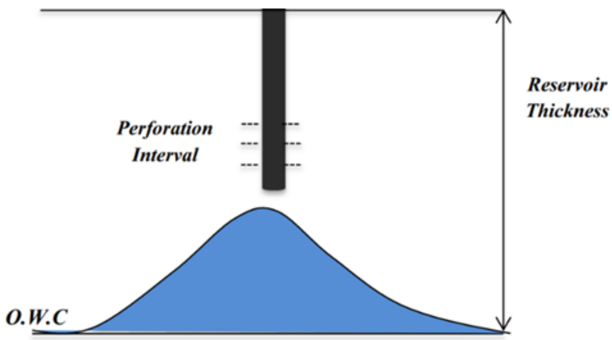

Fig 1. Initial Shape of Coning[3]

Gravity forces are directed in the vertical direction and arise from fluid density differences. The term viscous forces refers to the pressure gradients associated fluid flow through the reservoir as described by Darcy's Law. Therefore, at any given time, there is a balance between gravitational and viscous forces at points on and away from the well completion interval. When the dynamic (viscous) forces at the wellbore exceed gravitational forces, a "cone" will ultimately break into the well. There are two important terms that must be known to understand coning, and these terms are critical production and breakthrough time

A. *Critical Production*

Critical rate Qoc is defined as the maximum allowable oil flow rate that can be imposed on the well to avoid a cone breakthrough. There are several empirical correlations that are commonly used to predict the oil critical rate, including the correlations

- Meyer-Garder
- Chierici-Ciucci
- Hoyland-Papatzacos-Skjaeveland
- Chaney et al
- Chaperson
- Schols

However, this analysis states nothing directly about the time it takes the Water cone to rise to the initial breakthrough position. Nevertheless, a lot of critical rate correlations have been developed in the literature for vertical wells.

B. Breakthrough Time

Breakthrough time is the time it takes for the water to reach the wellbore under the prevailing production rate regime. This marks the end of the production of clean oil from the well. Practically, producing oil within or below the critical rate is not economical, due to economic necessity. Therefore, operating companies often produce at a rate higher than the critical coning rate. A stable cone exists for a limited period. Once the production rate exceeds the critical rate, the water cone moves toward the well and subsequently breaks into the wellbore. At this production stage, knowing the breakthrough time helps to improve well management and extend well life without water production [2].

II. CONING IN VERTICAL WELLS

In bottom-water drive reservoir, during the production of oil and gas, the flow of oil from the reservoir to the well introduces an upward dynamic force upon the fluids. This dynamic (viscous) force due to wellbore pressure drawdown causes the bottom water to rise to a certain point at which the dynamic force is balanced by the height of the water beneath that point. Then, as the distance from the wellbore increases the pressure drawdown and the upward viscous force caused by it decreases. This development causes the water-oil contact (WOC) below the oil completion interval to rise toward the perforation; as depicted in Fig 2. At low production rate, a stable cone is experienced as the dynamic force offset the gravity contrast between the oil and water phase. This implies that the upward dynamic force is sufficiently balanced by the weight of water beneath the cone. However, when the production rate increases, the cone height above the water oil contact (WOC) also increases. Over time, the gravity contrast between the water and oil cannot offset their mobility differences, then, the water cone becomes unstable and rises towards the well completion interval. Thus, the breakthrough (i.e., water enters the well perforation interval) occurs when the cone shaped profile becomes unstable due to the high-pressure drawdown around the wellbore [3].

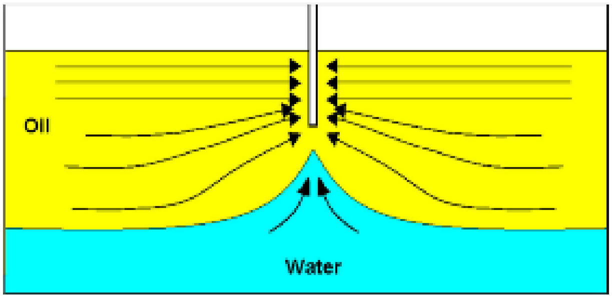

Fig 2. Coning in Vertical Wells [3]

III. PARAMETERS INVESTIGATED

In this paper, we study the effect of a group of variables that directly or indirectly affect to the coning in vertical wells. The parameters that have been studied:

A. Perforation Interval

Perforating is a process used to establish a flow path between the near reservoir and the wellbore. It normally involves initiating a hole from the wellbore through the casing and any cement sheath into the producing zone. The perforation area plays an important role in coning. The farther the perforation is from the water-oil contact, the less the effect of the water coning.

B. Oil Viscocity

The viscosity of oil is directly effect on oil flow and its movement towards the perforation in the wells the lower the viscosity of oil, the faster it will move and the easier it will flow towards the well bore. And decrease water flow.

C. Permeability Ratio

The ratio of vertical and horizontal permeability is important when reservoir anisotropy (Kv/Kh) and heterogeneity cannot be neglected. Therefore, an accurate knowledge of vertical and lateral permeability distribution is essential for better reservoir characterization.

D. Aquifer Size

The size of the aquifer is one of the most important factors affecting the coning problem, as it is responsible for the driving force for the movement of oil. And also for providing the reservoir with sufficient pressure to compensate for the shortage in the oil production process.

IV. SCOPE OF WORK

To study and simulate the problem of coning in vertical wells, we must create a reservoir model verify the impact of the parameters that were previously determined on coning in this well.

Table 1. Reservoir Data

Reservoir Data	
Pay zone thickness, h (ft)	100
Horizontal permeability, kh (md)	100
Vertical permeability, kv (md)	10
Drainage radius, re (ft)	1000
Wellbore radius, rw (ft)	0.25
Formation porosity, φ	0.2
Average reservoir pressure, P	3769
Oil production rate, q	1000
Density of water, ρw	62.4
Density of oil, ρo	43.67
Oil viscosity, μo (cp)	0.7
Water viscosity, μw (cp)	1
Oil formation volume factor, Bo	1.1

Reservoir Data	
Water formation volume factor, Bw	1
end-point oil relative permeability (kro)	0.72
end-point water relative permeability (krw)	0.4
Connate water saturation, Swc	0.25
API	26

Table 2. API classification

Oil class	***API***
Light	API > 31
Medium	22 < API > 31
Heavy	10 < API < 22
Extra-heavy	API < 10

Table 3. Vertical Permeability KV

Vertical permeability KV
10
30
100

V. METHODOLOGY

This paper simulate the performance of a two phase system that is water, oil in the producing reservoir in order to investigate the deferent production rates. This research used existing commercial numerical simulator (Eclipse 100) and a Cartesian grid model to study the effect of water and gas coning on vertical producer well. Through the development of a set of strategic plans of the type of depletion strategy that simulate production for a period of 20 years, starting from 2022 to 2044. And taking a set of cases for each variable to be studied and comparing the results of the cases with each other.

A. STATIC MODEL

We have built a model for a single layer of the reservoir, where it is located at a depth of 13,120 feet, the thickness of the pay zone is 100 feet, and aquafer is located at a depth of 13,220 feet. The area of the reservoir was 2000 * 2000 F^2

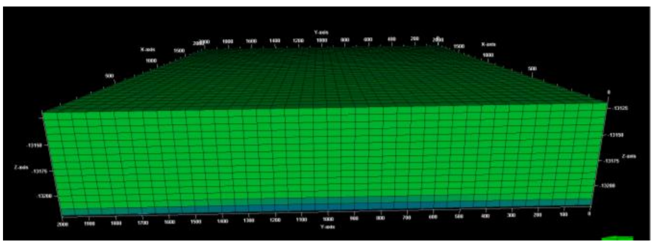

Fig 3.static model

B. DYNAMIC MODEL

The data has been used Table 1 and entered into the Petrel software and has been simulated and prepared to study the effect of changing the variables .the base case was taken is the perforation was done 20 feet from the center of the production area, API 26 and the reservoir was under saturation, the drive mechanism of the reservoir was water drive, the thickness of the aquifer was 50 feet. Four cases were taken to investigate;

1) Perforation Interval

Three cases were taken in which the perforation site was changed in pay zone, the result was compared between the three sites on each of case.

- First case was at the top of the productive layer, where 20 feet were perforated at the top of the layer far from the water layer,
- Second case, the perforation site was taken in the center of the producing layer.
- Third case the perforation site was changed to the bottom of the producing layer and at an extension of 20 feet.

2) Oil Viscosity

The second parameter whose effect was studied the viscosity of the oil. And the extent of its effect on coning by taking into consideration the different reservoirs that differ in the quality of the oil depending on the API values. Four cases have been taken that share the reservoir shape, production rate, location of the well and the perforation interval at the center of the well, but the viscosity of oil was changed in each of the cases as shown in Table 4.

Table 4. API Range

Oil API
45
35
25
15

3) Permeability Ratio

- The third case was the permeability ratio. Changing the value of the vertical permeability on the funnel was studied by providing channels for the passage of liquid.
- Due to its contribution to the movement of water up the layer towards the perforation site.in this case, a vertical well was perforated in the center of the producing layer, a constant flow rate and horizontal permeability values were maintained.
- Five cases of vertical permeability were taken showed in Table 3.

4) Aquifer size

The fourth case was taken the aquifer size. The thickness of the aquifer has been changed. It took it into consideration the size of Aquifer with the size of the productive zone. An increase in its volume is shown by an increase in the amount of water produced on the surface and a decrease in breakthrough time. Four thickness values were taken as shown in the Table 5.

Table 5. Aquifer thickness Range

Aquifer thickness
50
100
150
200

VI. Results and Discussion

The factors have been identified due to their importance to production and the possibility of knowing the economic return of this process and predicting any possible damage in the production process. These factors are oil recovery, reservoir pressure, oil production, water production and water cut, the values of each of these factors will be taken for each case of changing parameters.

A. Perforation interval

1) Oil recovry and pressure

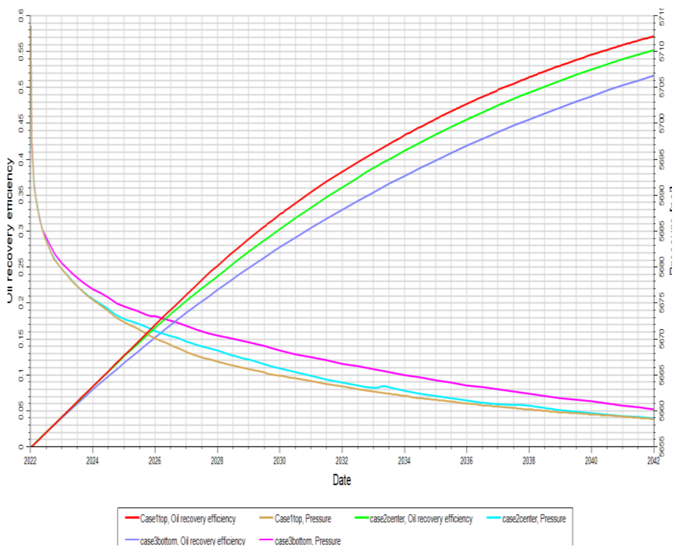

Fig 4. Oil Recovery, Reservoir Pressure vs Time (case A)

- Fig 4 shows the relationship of reservoir pressure and oil recovery with time through the curves, the highest oil recovery was reached when the perforation is at the top of the layer.
- And the lowest oil recovery when perforation is at the bottom of the layer. And that is because the perforation is far from the water area in the first case so oil production is higher and free of water for a higher period than the rest of the cases, so higher oil is produced and a high yield is obtained.
- As for the reservoir pressure, it can be seen that there is a significant drop in pressure in the case of perforation at the top. Due to the difficulty of compensating the pressure drained from the oil production process due to the distance of the water layer.
- In the case of perforation at the bottom of the layer, we notice that the pressure does not decrease significantly, due to the presence of compensation by the high-impact of aquifer.

2) Oil production and water cut

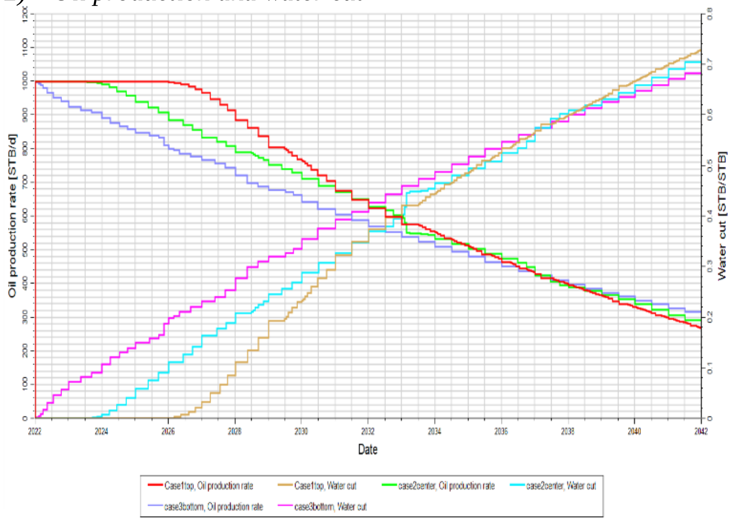

Fig 5.Oil Production and Water Cut vs Time (case A)

- In Fig 5 the water cut factor, we notice an increase in water production in the case of perforation at the bottom of the layer, as it is close to the water layer. And also a decrease in the time of water cut penetration into the well, and this is a problem in the production process.
- And vice versa in the case of perforation at the top of the layer, the water cut decreases and the time of water penetration into the well increases, but in the case of perforation at the top, we notice there is an increase in water production after a period that exceeded the water output from the perforation at the bottom, due to the possibility of the presence of a drive mechanism other than the water drive, which is solution gas.
- As for the oil production factor, the perforation at the top of the layer is the highest in terms of oil production.
- And we notice a decrease in its production after a long period, due to the period that the water takes until it reaches the perforation area, and in the rest of the cases when the perforation is at the bottom or in the center of the layer, the drop is Water production is faster due to the speed of water reaching the perforation area due to its proximity to the aquifer.

B. *Oil viscocity*

1) *Oil recovry and pressure*

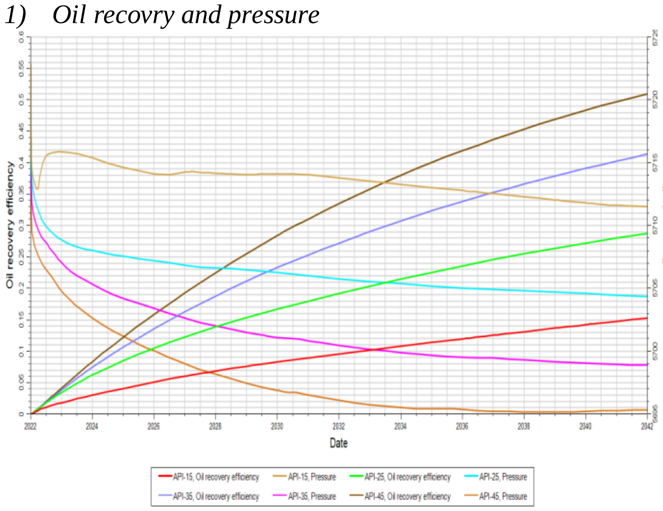

Fig 6. Oil Recovery, Reservoir Pressure vs Time (case B)

2) *Oil Production and Water Cut*

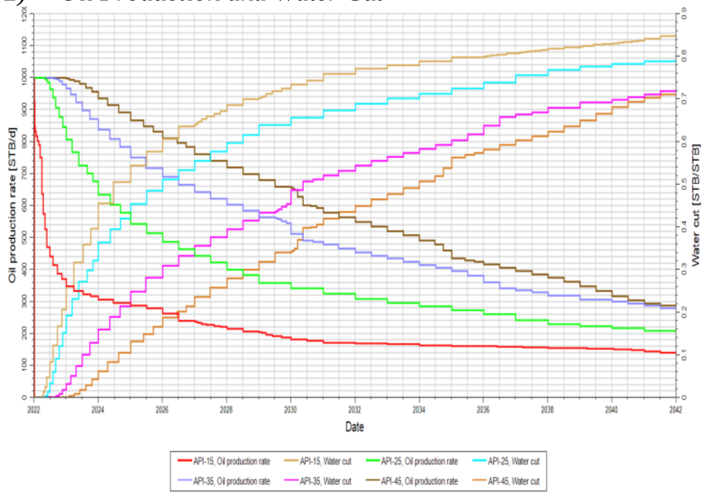

Fig 7.Oil Production and Water Cut vs Time (case B)

- In Fig 5 the case of more than one viscosity value (different API), a significant decrease in pressure is observed at high API, i.e. when light oil.

- This is due to the high depletion of oil and the easy movement of oil towards the well. Also, the loss of pressure is not compensated by the production of water, due to the difficulty of ascending the water to the perforation area, as it takes time for the water to rise and compensate for the loss of pressure.

- In the case of heavy oil, the pressure does not drop in an inkling manner due to the lack of oil flow from the reservoir due to its high viscosity and the difficulty of its movement towards perforation.

- As for the value of Water Cut, it can be observed that its highest values are in the case of heavy oil.

- And that is because the movement of the oil is less due to its high viscosity, so it causes water to slip and move it towards the perforation quickly due to the difference in viscosity and density between water and oil.

- Also heavy oil has a short breakthrough time. Where it is noted that the water penetration of the well occurs in the first moments of production, unlike light oil, where the breakthrough time is much greater due to the oil flowing earlier than the water flow.

- Fig 7 shows through the curves in the table, it was noted that the highest values of oil recovery were at API 45.

- Due to the high production of oil for ease of movement due to its low viscosity. Its high viscosity and its inability to move towards the well easily, the oil recovery values are low because the oil remains inside the layer and cannot be used on the surface.

- And in the case of observing the curves of the oil flow rate, we can find average values that are high at the beginning. And then start to decline as a result of the rise of water production with oil, but the important thing is the decrease in oil production in the low API values.

- And this is due to the high viscosity of oil that reduces Its movement is towards the perforation area, as it shows the production of this heavy oil after a period of starting production, but its flow rate is less than the rest of the cases.

C. Permeability ratio

1) Oil recovery and pressure

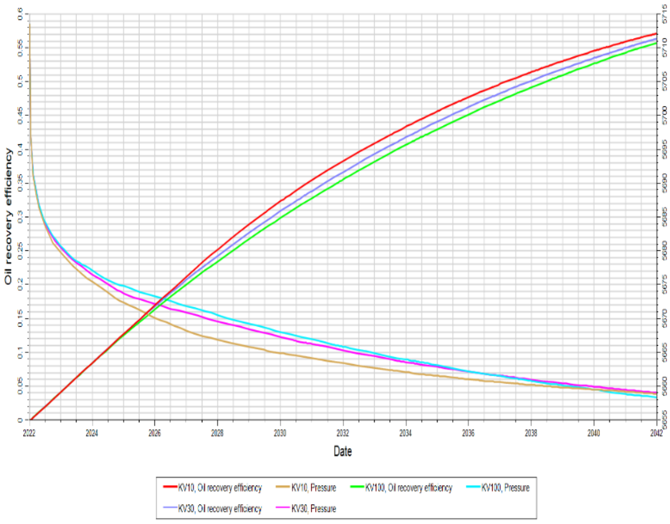

Fig 8. Oil Recovery, Reservoir Pressure vs Time (case C)

2) Water cut and oil production

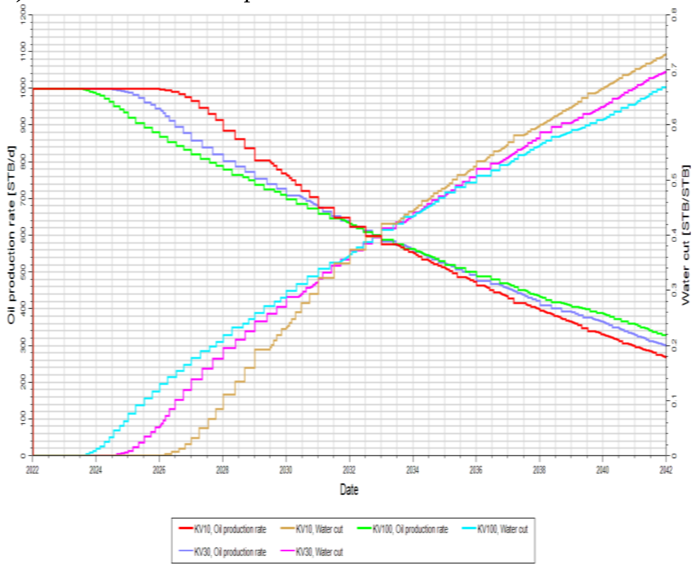

Fig 9. Oil Production and Water Cut vs Time (case C)

- Fig 8 show that the highest values of oil recovery are at the lowest value of the vertical permeability.

- The reason is due to the superiority of the horizontal permeability over the vertical, which causes a greater movement of oil towards the exploration area and reduces the value of water production and its rise by the production of the perforation area Increases oil production from the reservoir.

- As for the reservoir pressure, it decreases in all cases of permeability, but its drop is higher than the lowest vertical permeability.

- And this is due to the high droplet production and at the same time the water cannot rise quickly and compensate for the pressure, due to the low value of the vertical permeability, however, in the case the pressure drop is very small.

- Due to the water compensating for the decrease in pressure and the ease of movement of water due to the availability of channels for water flow towards the perforation area.

- In Fig 9 we notice the value of the break through time at its highest value when the vertical permeability is low.

- Because the water needs more time to move to the perforation area and start producing water due to the lack of channels that facilitate the passage of water.

- As for the case of high permeability, the break through time is very little, because the water rises easily after a very short period of time by producing the perforation area.

- In the case of the oil flow rate, it is related to the water penetration and its rise to the perforation area.

- We note a correlation between the decrease in the production of the tunnel with the production of water, as the production of water and its rise to the perforation affects the lowering of the values of the oil produced on the surface. In such cases, it is Low vertical permeability values are the best and preferred choice in the oil production process.

D. Thickness of Aquifer

1) Oil recovry and pressure

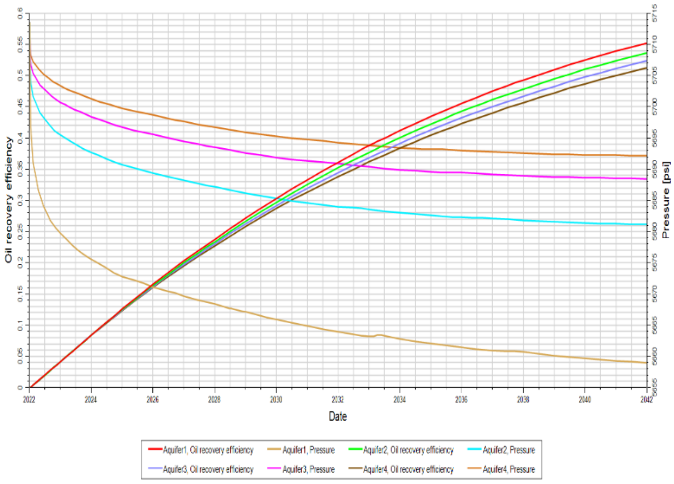

Fig 10. Oil Recovery, Reservoir Pressure vs Time (case D)

- Fig10. Show the higher the thickness of the layer, the less pressure drop in the reservoir.
- Due to the availability of a greater driving force from the aqueous layer to the oil area, which leads to compensating the lost pressure.
- On the other hand, the small thickness of the water layer affects little to compensate for the lost pressure.
- For oil recovery, it is possible through the curves to observe its highest value, which is at the lowest thickness of the water layer.
- Due to the fact that in the case of increasing the thickness of the aqueous layer leads to an increase in the amount of water entering the Bay Zone.

2) Oil production and water cut

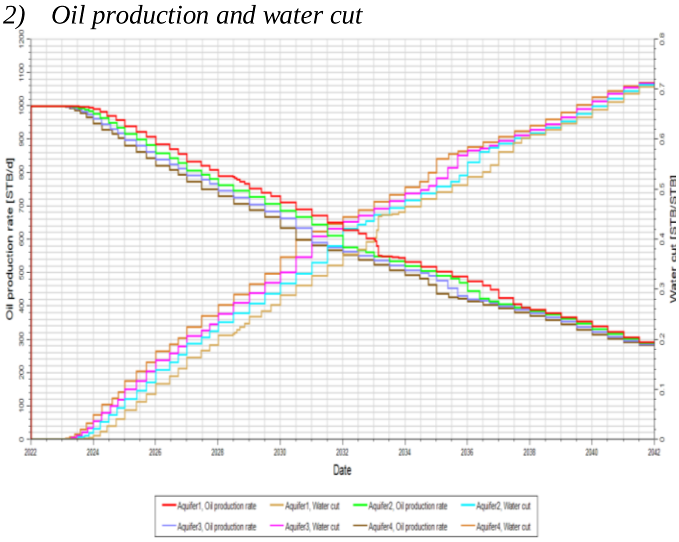

Fig 11. Oil Production and Water Cut vs Time (case D)

- In Fig 11. production of water, its highest value at the higher thickness of the aquifer
- Due to the speed and quantity of water ascending to the exploration area due to the large force provided by the aquarium, and also the large amount of
- The faster the penetration of water into the penetration area.
- In Fig 11. We notice a correlation between a decrease in oil production and an increase in water production.
- As the large thickness of the layer for the coiffure provides greater pressure compensation.
- But at the same time leads to a decrease in oil production and an increase in water production.

VII. Conclusion

In these paper of this simulation study sensitivity analysis was carried out. These parameters include permeability ratio (kv/kh), perforation interval (hp), oil viscosity (u) and Aquifer thickness. By varying this parameters during simulation, the following conclusion can be drawn from this simulation;

- When the perforation is in a location close to the water-oil contact area, Increases the chance of coning in wells, and reduce the breakthrough time of water into the perforation area .Where the best option in most cases is a perforation in the center of the layer.
- When the viscosity of the oil is low, the chance of coning in the well is reduced and reduce the production of water from the well
- Decreasing the value of vertical permeability reduces the chances of coning and increases oil production and oil recovery.
- Increasing the thickness of the aquifer increases the chances of coning and increases water production and reduces oil production at the same time.
- Investigation of the effective parameters is necessary to understand the mechanism of water coning in naturally fractured reservoirs. Simulation of this phenomenon helps to optimize the conditions in which the breakthrough time of water cone is delayed.

VIII. Recommendations for futer work

Based on the results obtained from the model, the following recommendations prefer to work on it;

- It is recommended that this work to be taken further by studying water coning in a horizontal well.
- It is recommended that this work to be further researched by considering a saturated reservoir (Oil-Water-Gas system).
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REFERENCES

[1] Ahmed, T. H. (2000). Reservoir Engineering Handbook. Houston, Tex, Gulf Pub. Co. pp 570-622.

[2] Hoyland, L. A., P. Papatzacos, et al. (1989). "Critical Rate for Water Coning: Correlation and Analytical Solution."

[3] Abbas, H. H., and Bass, D. M. (1988). The Critical Production Rate in Water-coning System. Paper presented at the SPE Permian Basin Oil and Gas Recovery conference. Midland, Texas, pp. 351-360.

[4] Beattie DR, Roberts BE (1996) Water coning in naturally fractured gas reservoirs. Society of Petroleum Engineers Paper, SPE 35643

[5] Al-Afaleg NI, Ershaghi I (1993) Coning phenomena in naturally fractured reservoirs. Society of Petroleum Engineers Paper, SPE 26083