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Research Article

Oil Recovery Enhancement in Thin Oil Rim Reservoirs with a Large Gas Cap and Aquifer using Perforation Completion Optimization

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Abstract The importance of designing a horizontal well completion for the purpose of optimizing production can never be overemphasized. In thin oil columns wherethe problem of gas and water coning is predominant, it is important to optimize the perforation length so as to get as much oil as possible from the thin oil rim reservoirprior to the onset of water and gas coning. It is very critical to know exactly how much of the horizontal length should be perforated. In this study, the effect of perforation lengthsand densitieson oil production is from a thin oil rim reservoir wereanalyzed.The results show that horizontal well performance is directly affected by the distribution/location and length of the perforated intervals i.e. the higher the length of fraction perforated the less dependent is the production on the distribution,the more uniform the distribution of the perforations along the entire length of the reservoir, the lower the gas oil ratio(GOR) The same fraction length uniformly perforated across the entire length of the well yields a higher production when compared to when perforated length is concentrated at the heelor toe.

Keywords horizontal wells, completions, thin oil rim, perforations, optimization.

Introduction

Technically, the objective of the horizontal well is the exposure of the formation to production which in turn increases production as compared to the use of a vertical well through the same formation. Because more formation is exposed, the pressure drop from the formation into the wellbore is significantly less than in a vertical well. This is even true where the producing rates in the horizontal well are much greater than in a vertical well. The significant of this is less tendency for water or gas coning and less tendency to produce sand, while producing the well at higher rates.

In many cases, increasing production cannot by itself economically justify the cost of a horizontal well, but the added benefits of preventing coning and reducing sand production are of significant cost benefit.

The production rate of oil or other fluids from a reservoir is controlled by pressure gradients between the reservoir and the borehole. With conventional wells, it is broadly recognized that most of the reservoir pressure decline occurs close to the well. In order to achieve greater production rate, it is necessary to decrease the resistance to flow within the reservoir, particularly in the near wellbore region.There has been an increase in the use of horizontal wells in the last two decades. Popa and Simion [1].The most popular completion designs for horizontal well are : Cased cemented and perforated, liner with external casing packet,slotted, perforated or prepacked liner in an open hole and open hole completions. The disadvantage of using open holes or slotted liners is the inability for operators to perform a thorough diagnostic or remedial work, in many cases, horizontal wells in which open hole completion was employed are now experiencing production problems as a result of poor completion control especially in thin oil rim reservoirs where gas and water coning problems are prevalent,Goode and Wilkinson [2]. Many authors have researched on the effect of perforation density on oil production. Suzuki et al [3] examined the effects of perforations on multiphase flow in horizontal wells by using a flow test unit specifically designed for this purpose and simulating its effects on the perforations in the laboratory.

Spreux et al [4], Reiss[5],have both presented completion technologies in their work.Perforation is one of the methods of completing a well. The completion performance depends generally on the length of perforation and its distribution along the horizontal well. Theoretically, the same perforated length should lead to the same productivity index, this has been disproved by field experience where it is observed that horizontal well performance is dependent on the location of these perforated sections, Abdullah et al [6].Goode and Wilkinson [2] presented an analytical solution for the performance of partially completed horizontal well, main limitation of their model was that they did not consider the gas and water coning effect.A perforation scheme must be well planned so that the frictional pressure losses within the perforation section of the well will be minimized. The knowledge of how much the horizontal well should be perforated along with the perforation density is very critical. Ultimately, perforation completion optimization in horizontal wells goes a long way to reduce the problem synonymous to thin oil rim reservoir i.e. gas and water coning thereby minimizing the investment cost in return.A typical Horizontal well is shown in Fig 1.

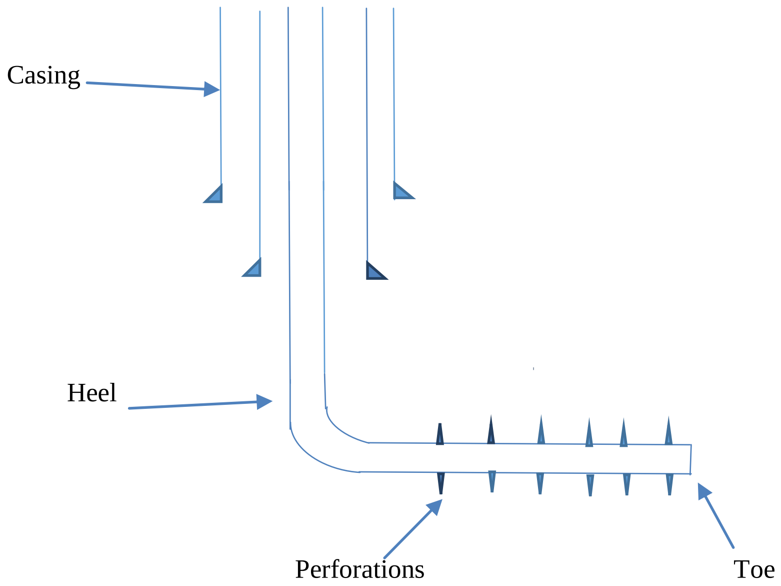


Figure 1: A typical horizontal well showing completion perforations

Case Study

The case study used here is a reservoirX in the Soku field in the Niger Delta region of Nigeria, Soku field is situated in OML-23 , 40km Southwest of PortHarcourt along the coastal swamp of the Niger-Delta, some 40km north of the present day coastline. Production commenced from this field in 1971, its.

The Properties of Reservoir X are as follows;

Permeability range 392-989 mD

Porosity range 24- 35%

Anistrotopy(kv/kh) 0.05-0.15

Gas Cap 200-400ft

Oil Rim Height 72ft

Viscosity 1.17-0.89cp

Aerial extent is 3 km^2

Methodology

A simulation model has been developed/adapted to assess the impact of perforation density/distribution on oil recovery. For simplicity sake, an average properties of this reservoir is used to build this reservoir model using ECLIPSE 100

The geometry of the model has been fixed at 4674ftx 2296ftx 617ft in the X and Y directions.The Structure of this model is a simple 3D box with uniform properties. Grid dimension of 57x28x20 in the XYZ direction.In this model, a horizontal oil production well is placed centrally within the oil rim section to allow for proper drainage of the oil within the oil rim. The model is based on a rectangular drainage area. Table 1 below shows the average reservoir parameters used for the model. The position of the horizontal well in the model is shown in figure 2.

Table 1: Average Reservoir Parameters

Reservoir Parameter	**Value**
Oil Rim Thickness, ft	72
Permeability, mD	700
kv/kh(permeability anisotropy)	0.1
m-factor(dimensionless)	5.8
Porosity(dimensionless)	0.25
Viscosity, cP	1.03

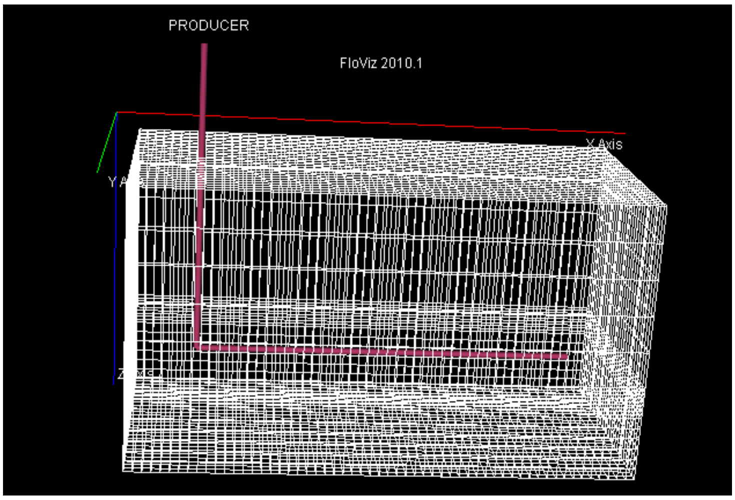


Figure 2: Reservoir model showing the horizontal well

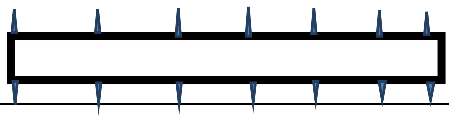
The Constraints applied to this reservoir model are

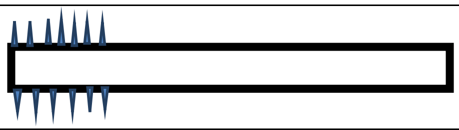
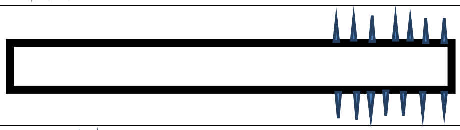
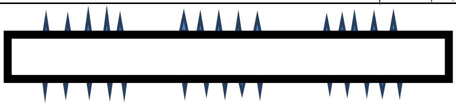
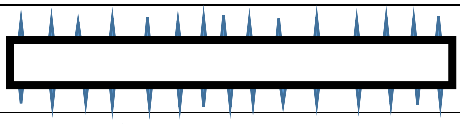
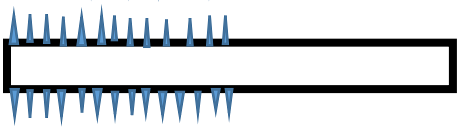
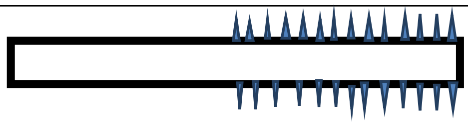
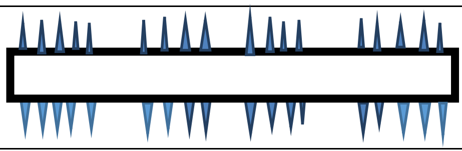
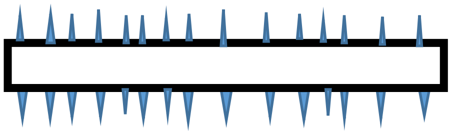
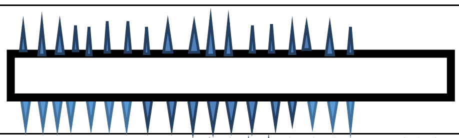
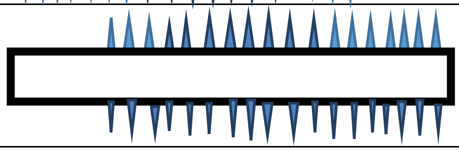
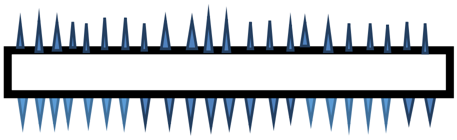
- Initial production rate of 2000stb/day
- Minimum BHP of 1000psi
- Maximum allowable water cut of 90%
- Simulation time of 192months (16 years)

A sensitivity analysis is carried out for various cases of perforation density to determine the optimum perforation density by simulating the twelve different scenarios using Eclipse 100.

In this study, 12 perforation schemes are shown in the Table 2 below:

Table 2: Perforation Schemes used in the Sensitivity Analysis

Case	**Diagram**	**Description**
1		20% perforation density uniformly distributed along the entire length of the horizontal length

2		20% perforated uniformly from the heel to the toe
3		20% perforated uniformly from the toe to the heel
4		50% perforation density distributed at 3 open intervals along the entire well length
5		50% perforation density uniformly distributed along the entire length of the horizontal length
6		50% perforated uniformly from the heel to the toe
7		50% perforated uniformly from the toe to the heel
8		80% perforation density distributed at 3 open intervals along the entire well length
9		80% perforation density uniformly distributed along the entire length of the horizontal length
10		80% perforated uniformly from the heel to the toe
11		80% perforated uniformly from the toe to the heel
12		100% perforation density uniformly distributed along the entire length of the horizontal length

Results and Discussion

Simulation of the twelve different perforation schemes was done and the resulting cumulative oil production, GOR and water cut was recorded and analyzed.

Fig 3 below is a plot of the Cumulative oil production for the different perforation Cases for the 16years. It is observed that case 5 which is the 50% perforation density distributed at 3 open intervals along the entire well length has the highest cumulative oil production at the end of the 16 years of simulation.

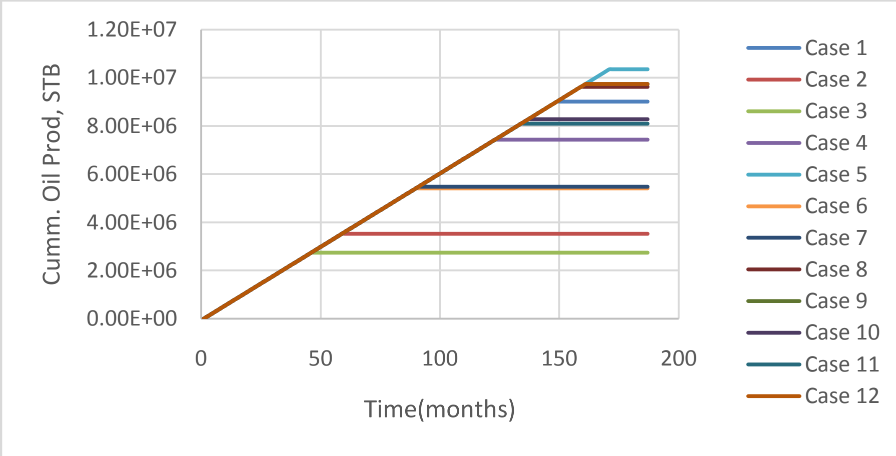


Figure 3: Cumulative oil production for the different perforation Cases for the 16years

Case 3 has the least cumulative oil produced. For all the cases the trend is very similar i.e. there is increase in production until at a particular stage the trend becomes constant, at this stage the constraint of the water cut begins to take effect. Once the water cut is 0.9 the production automatically stops and the trend becomes horizontal meaning the cumulative oil production is constant with no increase. The cumulative production for each of the cases at the end of the 16 year run can be represented by the bar chart below in fig 4.

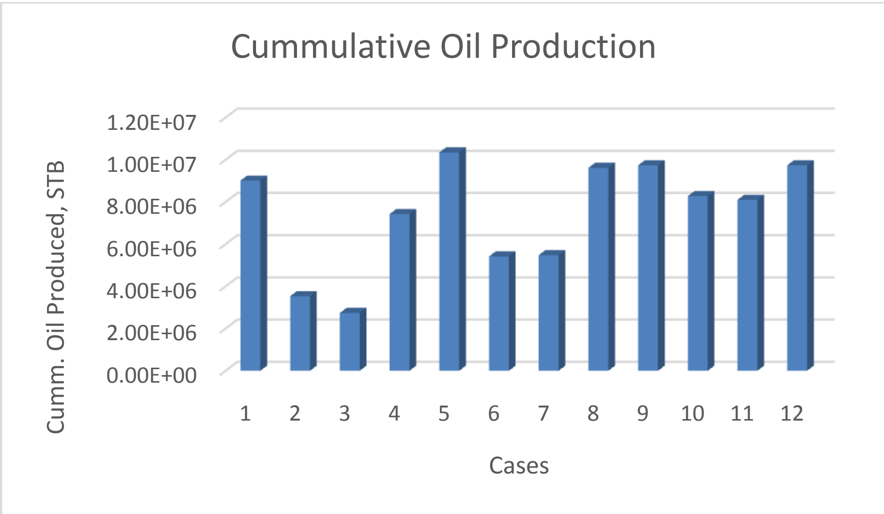


Figure 4: Cumulative oil production for the different perforation Cases at the end of the Simulation run

Table 3: Cumulative oil production for the cases analyzed

Case	Perforation density (%)	Cumulative Oil Production(MMSTB)
1	20 alt	9.0
2	20 openheel	3.5
3	20 opentoe	2.7
4	50	7.4
5	50 alt	10.3
6	50 openheel	5.4
7	50 opentoe	5.5
8	80	9.6
9	80 alt	9.7
10	80 openheel	8.3
11	80 opentoe	8.1
12	100 open	9.7

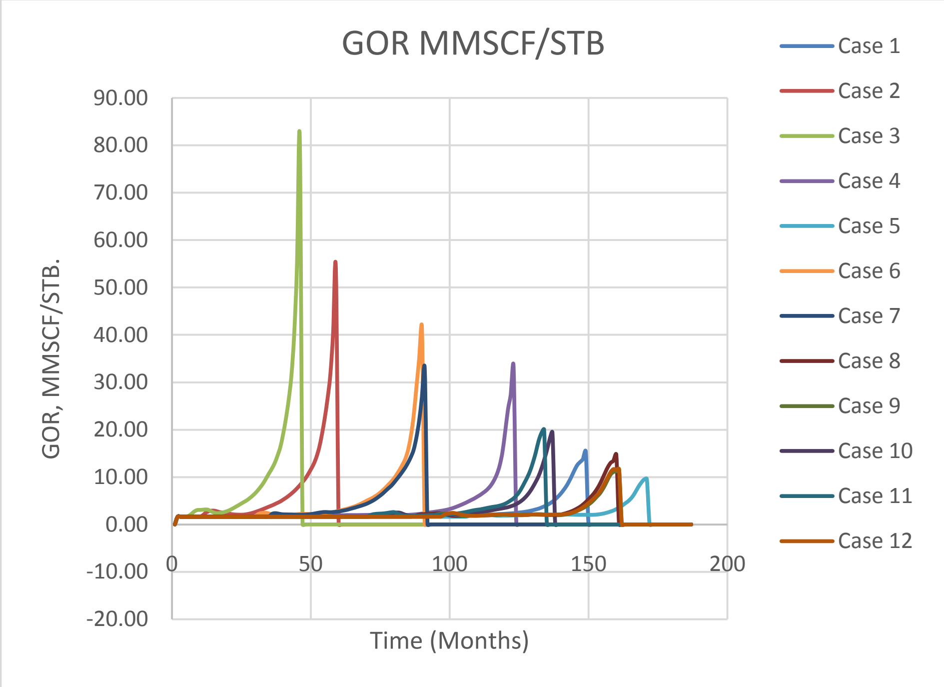


Figure 5: GOR for the different perforation schemes for 192months (16years)

In Fig 5 above case 5 has the lowest GOR in comparison to the other cases, case 3 has the highest GOR, and for the same perforation density the uniform distribution across the entire length of the well has the lowest GOR.

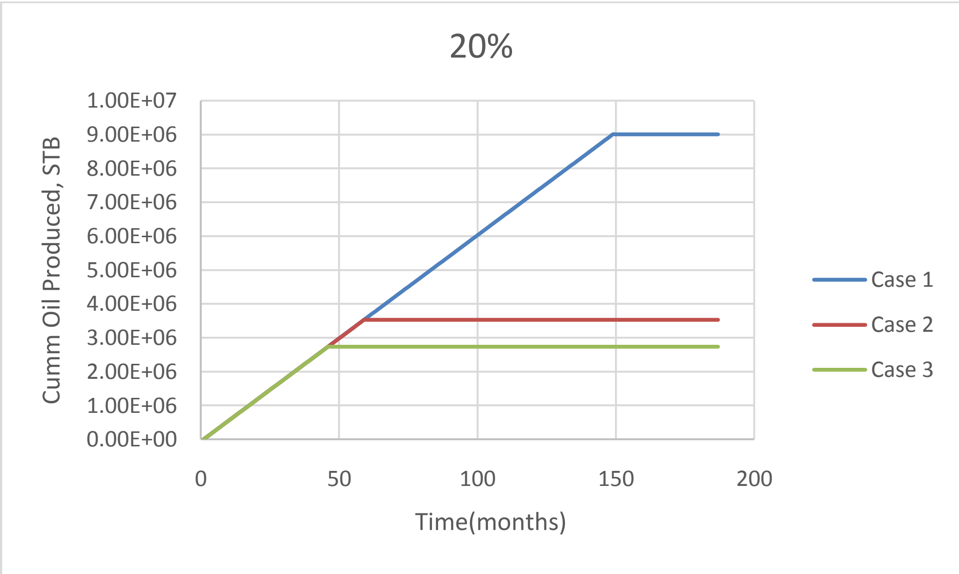


Figure 6: Graph showing the comparison of the 3 different perforation scheme with a perforation density of 20%

Figure 6 indicates that for the first 48month, the recovery is the same for all the 3 types of perforation densities, the trend changes after the 36th month where the case3 (20% open from toe) has the lowest oil recovery, case 1 and 2 arethe same and slightly higher. In the 60thmonth, case 1 which is the evenly distributed perforations along the entire length of the well has the highest oil recoveryhas the highest cumulative production of the three cases

The results of the sensitivity analysis show that for the 20% perforation density the even distribution along the entire length of the horizontal length gives the highest cumulative oil recovery

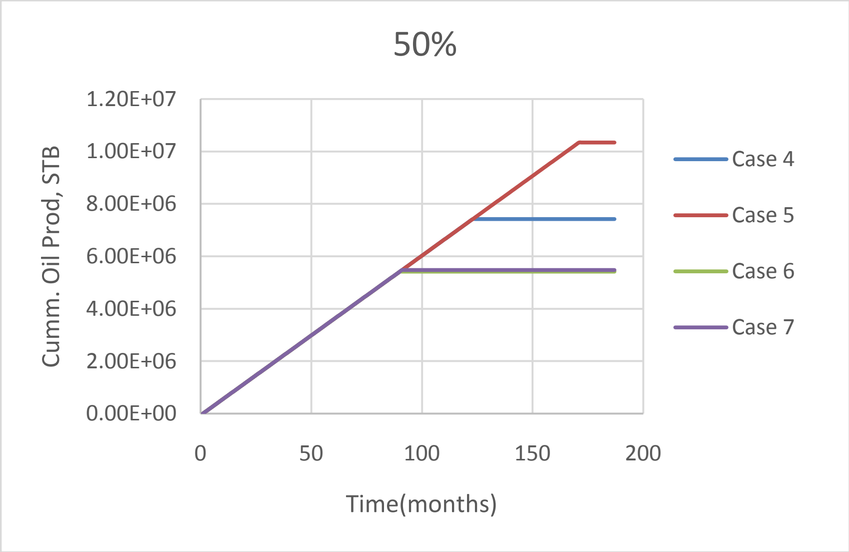


Figure 7: Graph showing the comparism of the 4 different perforation scheme with a perforation density of 50%

Figure 7 indicates that for the first 76months the recovery is the same for all the 3 types of perforation densities(Cases), the trend changes after 76months where the case 6 and7 has the lowest oil recovery and this trend continues till the end of the production year, case 4 and 5 slightly higher with same production until about the 11th year wherethere is an increase in production in case 4 right till the very end.The results of the sensitivity analysis show that for the 50% perforation density the even distribution along the entire length of the horizontal length gives the highest cumulative oil recovery

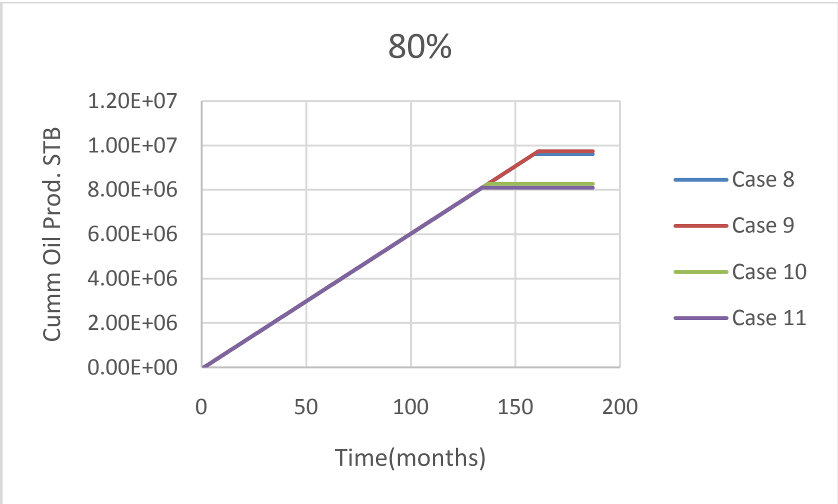


Figure 8: Graph showing the comparison of the 4 different perforation scheme with a perforation density of 80%

Figure 8 indicates that for the first 144month, the oil recovery is the same for all the perforation densities Cases, the trend changes immediately after where cases 8 and 9 have about the same productionthe case 10 and 11 have the lowest oil recovery and this trend continues till the end of the production.The results of the sensitivity analysis show that80% perforation density uniformly distributed along the entire length of the horizontal length gives the highest cumulative oil recovery followed very closely by case 9.

Fig9 below indicates that water cut for case 5 reaches the 0.9 almost at the end of the simulation, meaning production goes on for the longest period compared to the other cases.

From all the results it is observed that case 5 is the optimum perforation scheme since it has highest oil production, lowest GOR and most desirable water cut profile as compared to all the other cases. \

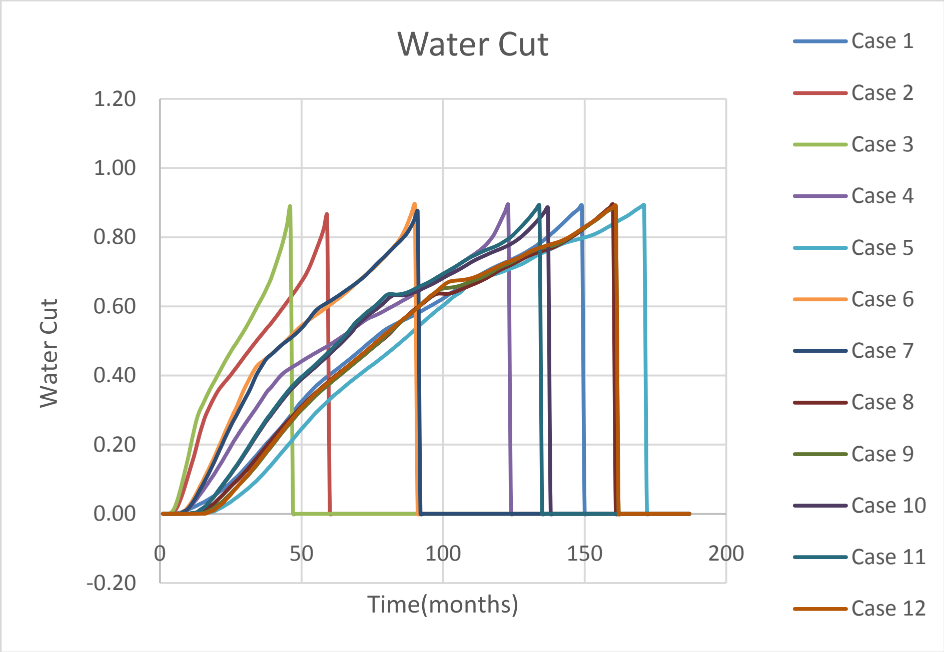


Figure 9: Water-cut for the 12 different perforation scenarios for 192months (16yrs)

Conclusions

- Horizontal well performance is directly affected by the distribution/location and length of the perforated intervals.
- The same fraction length uniformly perforated across the entire length of the well yields higher oil production when compared to when perforated length is concentrated at the toe or heel.
- Production of oil is slightly higher for the same perforation length concentrated at the heel than at the toe.
- The higher the length of fraction perforated the less dependent is the production on the distribution.
- The more uniform the distribution of the perforations along the entire length of the reservoir, the lower the gas oil ratio (GOR).

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