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Optimization of Oil Rim Development by Improved Well Design

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Abstract The goal of an oil field development project is to accelerate the hydrocarbon production and maximize recovery at the lowest cost. Optimizing the production of oil from thin oil rims reservoirs poses a major challenge in the oil and gas industry as a result of the coning tendencies which in turn limits the ultimate recovery from the reservoir. Successful oil rim development requires careful management of a wide range of subsurface uncertainties and generally lengthy study efforts are needed to assess technical and economic feasibility. Optimal well design is very important so as to get as much oil from the thin oil rim reservoir as possible. Reduced oil or gas production and increased operating expenses all lead to reduced revenues. In this study a comparison will be made between vertical and horizontal well to ascertain the design that produces results in higher oil recovery and lower water and gas coning. The results show that advantages of reduced water coning into the well bore for the horizontal well in comparison to the vertical well is time dependent and the cumulative oil produced in the use of the horizontal well is far higher than oil produced using the vertical well.

Keywords Oil rim, Horizontal Well, Vertical Well, Oil recovery, Optimizing, Well Design

Introduction

An Oil rim reservoir is a reservoir with small oil columns enveloped between a large gas cap and a water zone at the base. Most oil rim reservoirs are overlain by massive gas cap and pose serious operational and economic challenges using existing conventional methods of optimizing reservoir development. The presence of a wide range of uncertainty, the peculiar complexity in the distribution of the resident fluids and geological strata geometry, have made efficient development and production of thin oil column a difficult task. The rims are thin with huge gas column on top and are generally considered marginally economic for development by many operators. Oil rim production can suffer from low oil recovery due to water coning and gas coning. Gas cap oil re-saturation is also a major cause of low oil recovery in oil rim reservoirs, this occurs when an oil column is displaced upwards during production from gas cap under an active water drive, in this case a zone of residual oil is left behind the advancing water leading to loss of mobile oil and trapping of gas.

The main development problem with the use of vertical wells in gas cap reservoirs underlain with thin oil rim is gas and water coning. Horizontal well technology has proved more efficient, when compared with vertical wells, for recovery of oil from reservoirs with gas cap. When horizontal wells are used to develop oil rim reservoirs, research has shown that the rate of rise of gas-oil ratio and water ratio is lower; the overlaying gas and bottom water would breakthrough into the well at much later time. Horizontal wells have the advantage of reducing pressure depression around the well resulting from a smaller flow rate per unit length of the well for a given production rate.

Increased production rate is due to the fact that a horizontal wellbore exposes more formation to production than does 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,while still providing total flows which are economical. Because horizontal drilling allows a large portion of wellbore to remain in a single zone of interest, a greater area of pay zone can be exposed. Therefore, horizontal drilling may be defined as implementation of a horizontal wellbore designed to take optimum advantage of the three dimensional geometry of a reservoir. Recently, horizontal drilling has been applied to oil and gas reservoirs to provide economic production of marginal reserves. In many specialized applications, substantial productivity gains have resulted from the use of this rapidly developing technique.

Several authors have proposed horizontal well technology as a solution for reservoir development with water coning issues. 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.

Generally development of oil rims requires understanding the complex interplay of the subsurface uncertainties in order to determine technical feasibility, economic attractiveness of the optimal strategy of producing the reservoirs. There are many technical and non-technical challenges associated with optimal development of the rims.

Review of Existing methods of production from Oil Rim reservoirs

Muskat and Wyckoff (1935) also pointed out that it is impossible to eliminate bottom water when producing thin oil zone unless the production is reduced economically low values. The results they got indicated that water free oil production rate could be maintained for a short-penetrated well, and this rate decreased with increasing well penetration [1].

The conventional approach involves the use of all horizontal wells, all vertical wells, combination of vertical and horizontal wells and use of water injector and oil producer horizontal wells. A review of some Niger delta reservoirs indicates the most of the reservoirs are less than 80ft thick and therefore vulnerable to coning problem [2]. Yang et al., (2013) in their development strategy research on a narrow oil rim with a weak edge aquifer in Bohai bay in China concluded that optimal well design, with respect to the orientation, vertical location, trajectory, production rate and length of horizontal wells, is critical for the attainment of significant economic benefit especially for offshore project. During pressure depletion using conventional method, the gas cap would expand to provide energy support [3]. Keng et al, (2012) in their study of a thin oil rim reservoir located in the Selgi field in Malaysia proposed the placement of a system of water injectors at the selected sector periphery and at gas oil contact (WOC) for pressure support and at the gas oil contact (GOC) to prevent losses due to gas cap oil [4].

Gas injection technique was initiated for a narrow oil rim in the Mereenie field in Australia [5]. This technique is not a new concept in the targeted field or elsewhere in the world. However, the incremental oil recovery recorded in a narrow oil rim has not been recorded in the petroleum literature as at that time. The method provides direct displacement as well as pressure maintenance. It helps targeting multiple layers in a single well and reduces the sensitivity of the rim to distance from the fluid contact unlike primary recovery. However, the concept is not applicable to all cases of oil rims. It can only be used in fields with narrow oil rim, low permeability rock and weak aquifer support.

Zakirov and Zakirov(1996) in their research presented the use of a pseudo-horizontal well as an alternative to horizontal and vertical well, they showed in their work that this type of well combines the advantages of the horizontal and vertical well. In this work a layered reservoir was used to show the advantage over the horizontal and vertical wells. Although similar to slanted wells, pseudo-horizontal wells are characterized by a smaller slope to the horizon. They came to the conclusion that the pseudo-horizontal wells are attractive in the case of layered reservoirs since they jointly accumulate the advantages of a horizontal and vertical well, however the use of this well is only limited to layered heterogeneous reservoirs [6].

Bourenane et al (2004) did a study in the HassiR'mel oil rim in Algeria on the optimization of perforated completions for horizontal well in thin oil rims, this was achieved by the performance of a parametric study which involved the analyses of the effect of most relevant reservoir parameters on horizontal well performance. The limitation of this work was that it ignored reservoir homogeneity by assuming homogeneous reservoir, secondly, it ignored the effects of water and gas coning which is a major factor affecting production from thin oil rim reservoirs [7].

Uwaga et al 2006 investigated the feasibility of intermittent production of the gas cap with continuous oil production from an oil rim reservoir in the Niger Delta by assessing the impact of as offtake rate, offtake frequency and period to sustain each cycle on oil recovery, they concluded that the proposed development strategy (is feasible if reservoir and fluid uncertainties are properly managed. However, the optimization of the frequency and cycle time for the swing option was not considered [8].

Onyeukwu et al., (2012) investigated the technical feasibility of gas and/or water injection in an oil rim under various subsurface uncertainties. The development concept involves completion of horizontal gas injector well in the gas cap while the horizontal oil producer was completed in the rim. Alternatively, another dedicated horizontal water injector well was completed in the aquifer leg while the horizontal oil producer was completed in the rim. The result shows that simultaneous gas and water injection could increase recovery factors [9]. This observation is similar to the result of Kabir et al, (1998) except that more recovery was gotten using water injection in cases where weak aquifer support is predominant [5]. The limitation of their founding is the consideration of only technical oil and gas recovery in their analysis. Beyond consideration of only oil recovery versus sub-surface uncertainties, the final investment decision will largely be based on many considerations the chief of which is the economic viability of the project.

Problem Statement

Several strategies have been used for effective and efficient development of oil rim overlain by large gas cap. Since the awareness of the problem of coning in both vertical and horizontal wells, a lot of efforts has been made to control it. Coning problem in oil rim reservoirs is very sensitive when the oil rim is sandwiched between a gas cap and bottom water, Coning is a problem because the second phase must be handled at the surface in addition to the desired hydrocarbon phase, and the production rate of the hydrocarbon flow is usually dramatically reduced after the cone breaks through into the producing well. Produced water must also be disposed of. Gas produced from coning in an oil well may have a market, but also may not. In any event, production of gas in an oil well after the cone breaks through can rapidly deplete reservoir pressure and, for that reason, may force shut in of the oil well.

Methodology

Simulation used in the evaluation of multiple design objectives and constraint functions can take hours or even days to complete using full field simulation, hence the use of a surrogate model that mimics the behavior of the full field model. In addition to this, surrogate models are computationally cheaper as evaluation tools. Cartesian and corner point reservoir grids are commonly used in industry for simplicity sake.

In this work ECLIPSE 100 black oil Simulator will be used to run the two simulation scenarios. Simulation is done using a horizontal well and the cumulative oil produced, gas rate and Cumulative water produced is recorded, same is done for the vertical well using the same model. The results are compared and analysed. A model with uniform properties will be used to run the simulations. A generic simulation model is developed and its parameters are briefly described below.

Model Geometry and Structure of Grid

The geometry of the model used has been fixed at 57 X 28X24in the XYZ directions. The Grid is sufficiently sized in order to avoid any boundary or edge effect impacting on the recovery process.

Reservoir Properties

The reservoir properties used throughout the model are constant; the model has no faults or shale barriers. Its uniformity is ensured so as to allow focus on the underlying physics of the oil rim movement. The Properties are shown in Table 1 Below

Table 1: Reservoir Parameters

Reservoir Parameter	Value
Permeability, mD	678
Viscosity, cp	1.05
Anistrotopy (kv/kh)	0.15
m-factor	5
Porosity, %	20
Oil Rim Thickness, m	19.2

Initialization

The initialization assumed in this simulation process is Hydrostatic

Model Constraints

The Constraints applied to this model are shown below;

- Initial production rate of 400m^3/day
- Minimum BHP of 103bar
- Maximum allowable water cut of 80%
- Simulation time of 30 years

Well Description

Horizontal Well

The Horizontal Well is placed centrally within the Oil Rim section of the model. The vertical section of the horizontal well spans from layer 8 to 52 of the X-axis, layer 14 of the Y-axis and the horizontal section runs through layer 11 of the Z-axis. A picture of the model with the horizontal well placed centrally in the oil rim is shown in figure 1

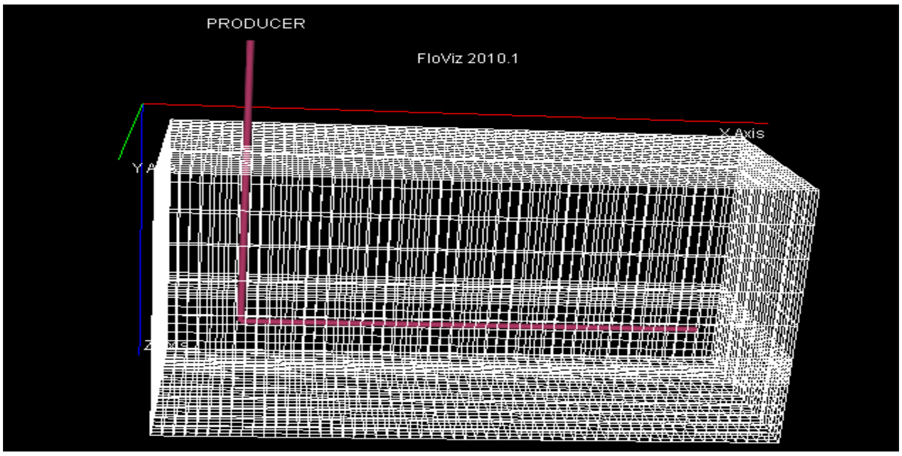

Figure 1: Reservoir Model Showing the Placement of the Horizontal Well

Vertical Well Description

The Vertical Well is placed centrally within the reservoir model at the grid block 8,4 on the X-Y axis and completed on layer 8 to 12 on the Z-axis. This is to allow for proper drainage. Figure 2 shows the model with the vertical well placed centrally in the model.

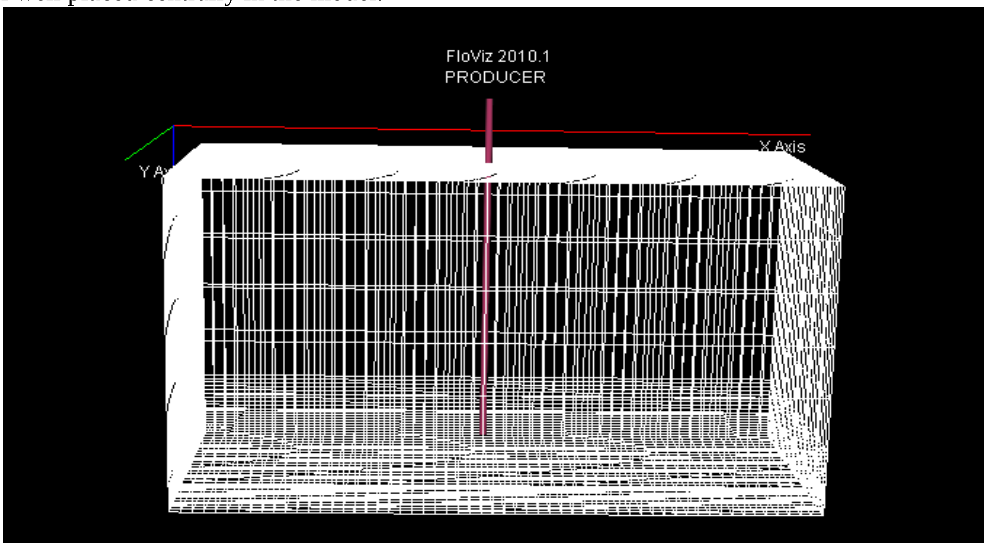

Figure 2: Reservoir Model Showing the Placement of the Vertical Well

Results/Discussions

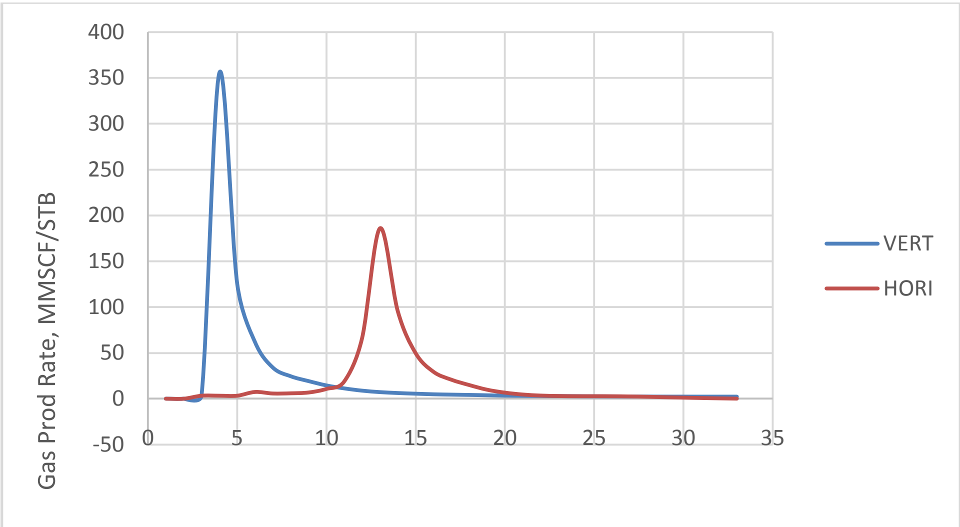

Figure 3: Gas Production rate for 30years of simulation.

It is delay gas coning as much as possible so as the optimize the oil production. In Figure 3 above it is shown that at the 3rd year for the vertical well, the gas starts coning into the well bore at a high rate and it peaks at the 4th year before it starts to decline, while for the horizontal well the starts to cone into the well bore at the 5th year and it peaks at the 13th year with about 185MMSCF/STB which is very little compared to the peak gas production rate of 355 MMSCF/STB the vertical well. The horizontal well produces gas compared to the vertical well for the entire 30 years of simulation.

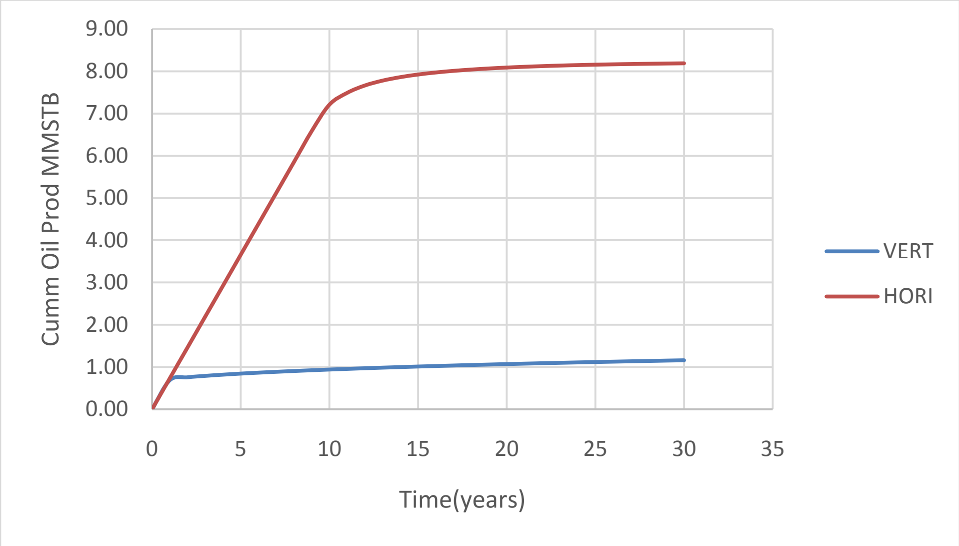

Figure 4: Cumulative Oil Production for 30years of Simulation

Figure 4 shows the comparison of the cumulative oil produced from the vertical and horizontal well. It is observed that for the first year the cumulative oil produced is the same for both the horizontal and the vertical well, after the first year the trend changes, the horizontal well cumulative production overtakes that of the vertical well right till the very end. Increase in cumulative production is constant with respect to time for the first 10years of producing with the horizontal well, the increase becomes very minimal at the beginning of the 15th year right till the end of the simulation run. For the horizontal well, the increase of the cumulative oil production with respect to time becomes very low compared to the horizontal well after the 4th year. The disparity between the two well designs is quite high, so it implies that the advantage as regards to oil production in an oil rim reservoir is very high compared to the use of a vertical well.

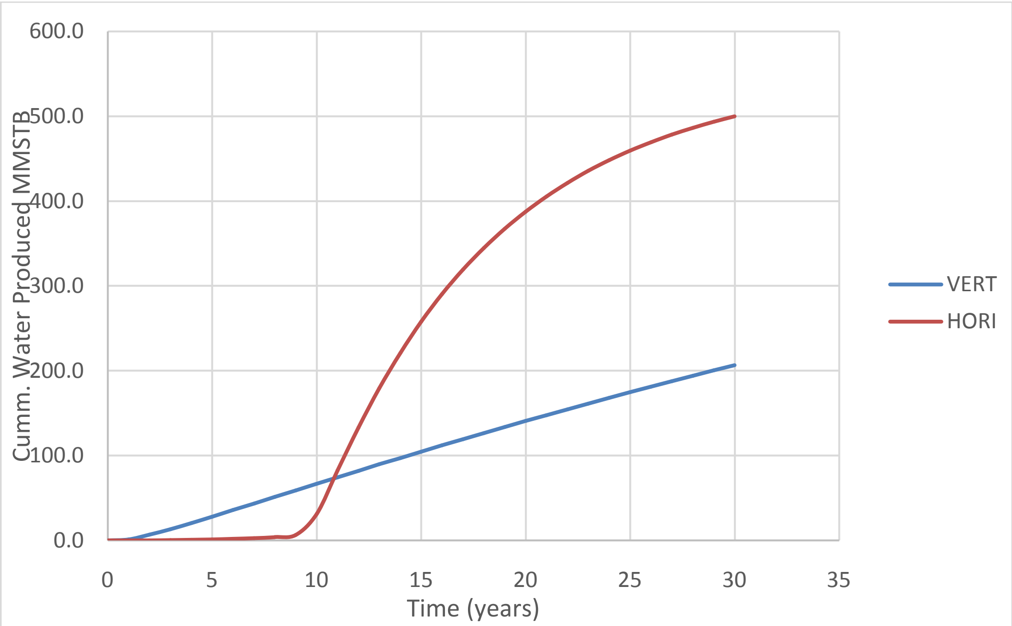

Figure 5: Cumulative Water Production for 30 years of simulation

It is observed that for the first 11years of simulation, the cumulative oil produced by the vertical well exceeds that of the horizontal well but shortly after the 11^{th} year the trend is reversed and the cumulative water produced by the horizontal well becomes much higher than that of the vertical well. This shows that advantage or using a horizontal well over a vertical well is time dependent. Meaning ideally the simulation shouldn't run for more than 10 years to take advantage of the low water production rate.

Conclusions

After careful analysis of the results, the following conclusions were made;

- Advantages of reduced water coning into the well bore for the horizontal well in comparison to the vertical well is time dependent.
- The cumulative oil produced in the use of the horizontal well is far higher than oil produced using the vertical well.
- Gas production rate is higher for the vertical well than the horizontal well
- The higher the exposure of the drainage area to the well completion the lower the GOR
- For thin oil rim reservoirs, productivity is highly dependent on well design.

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