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Intelligent Well Completions as a Production Optimization Strategy for Oil Rim Reservoirs

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Abstract

Water and gas coning and breakthrough are the most common of the numerous difficulties faced in the development of oil rim reservoirs. Water and gas breakthrough are caused mostly by the heel-toe effect and differences in reservoir permeability. This paper demonstrates the value of Inflow Control Devices (ICDs) in reducing the heel-toe problem encountered during production from an oil rim reservoir. The reservoir was modelled using the Multi-segment well model in Schlumberger ECLIPSE reservoir simulator. Two case situations were simulated to evaluate the performance of the Inflow Control Devices: A traditional horizontal well completed without Inflow Control Device and a horizontal well completed with Inflow Control Device. The simulation results revealed that in the absence of Inflow Control Devices, the Production Logging Test (PLT) plot suggested that only around 15% of the well length was contributing to flow. The heel-toe impact caused early water and gas coning, as well as a low oil recovery of 21%. The use of Inflow Control Devices resulted in more uniform fluid inflow (100%) over the entire length of the well, a one-year delay in water and gas breakthrough, an improvement in well operational life, and an increase in oil recovery of 22% (which is reflected in a cumulative oil production of about 3.65 MMSTB).

1.0 Introduction

Horizontal wells have proven to be efficient in the development of oil rim reservoirs in terms of increased well production, greater drainage area, better sweep efficiency and increased well-reservoir interaction [1]. However, they also offer new difficulties in terms of drilling and completion due to the increasing duration and difficulty of the well's exposure to the reservoir and premature water and/or gas breakthrough [2].

The premature water or gas breakthrough in horizontal wells is mainly due to frictional pressure losses along the completion (the "heel-toe effect") and reservoir permeability heterogeneity. They are also as a result of variations in the distance between the wellbore and fluid contacts e.g. due to multiple fluid contacts, an inclined wellbore, a tilted oil-water contact, etc. and variations in reservoir pressure in different regions of the reservoir penetrated by the wellbore [2, 3].

The "heel-toe effect" refers to the difference in real inflow rate between the well's heel and toe caused by frictional pressure drop along the completion (Figure 1). As a consequence, drawdown stresses at the heel are considerably greater than at the toe. When the frictional pressure drop is comparable to well drawdown, the effect becomes important. The "heel-toe" effect is more severe in reservoirs with high permeability or where a narrow diameter flow conduit is used when producing at high flow speeds, resulting in considerable frictional pressure decrease along the conduit's length [4, 5].

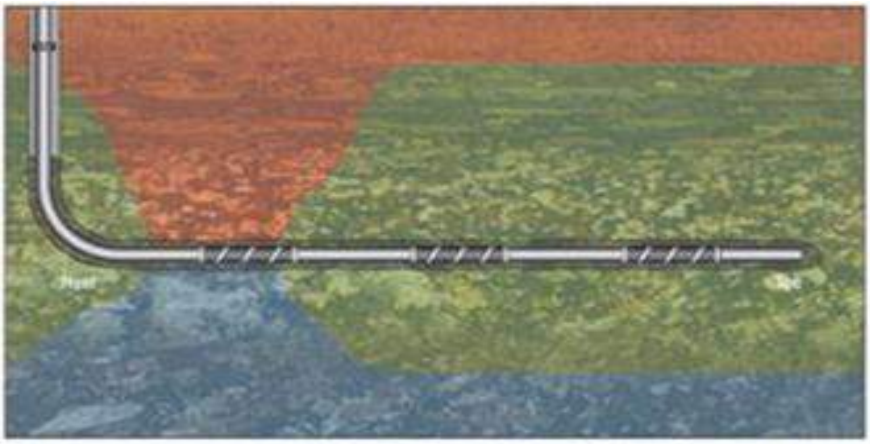

Figure 1. Water coning due to heel-toe effect [10]

This condition can result in an early end to the well's productive existence and significant reserves remaining unrecovered in the well's lower portion. The heel-toe effect can be mitigated by raising the diameter of the wellbore conduit or by using shorter laterals, but such options are not necessarily affordable or realistic [6].
The development rate at the heel of a long horizontal well is usually higher than the rate at the toe. As a consequence of the imbalanced production profile, early water or gas breakthrough into the wellbore at the heel is possible. When coning occurs, well production can suffer as a result of the toe's reduced flow contribution [7].
The most recent completion strategy by production and completions engineers is to design wells (Intelligent Wells) that are outfitted with devices that allow remote monitoring, control, and transmission of data from multiple zones, thus providing capabilities to maximize performance, enhance reservoir management, and minimize intervention costs [8]. These are unconventional wells equipped with downhole instrumentation (sensors, valves, and inflow control devices) on the production tubing. Such wells provide continuous in-situ monitoring of fluid flow rates and pressures, as well as periodic adjustment of downhole valves. Due to their ability to track and regulate flow rate and pressure, intelligent wells may be useful for regulating the coning or cusping of water and gas.

1.1 Inflow Control Devices (ICD)

An Inflow Control Device (ICD) is a device that is mounted as part of the sand face completion hardware to limit fluid movement from the annulus into the wellbore. This limitation can take the form of channels or nozzles but the purpose is to stabilize the horizontal well's inflow profile and mitigate annular flow at the expense of a small additional pressure drop [9].
Inflow control devices (ICDs) are installed in each screen joint to match the production influx profile over the entire lateral length and allow for permeability heterogeneity. They have been used in conjunction with swellable packers to facilitate uniform flow across the reservoir. According to Ellis, et al. [10], ICDs produce higher drawdown pressures and hence higher flow speeds along the borehole sections that are more prone to flow by restraining, or normalizing flow through high-rate sections. This corrects irregular flow created by heel-toe effect and heterogeneous permeability.
In their work [11], it was observed that extensive flow-loop tests and subsequent field experience have shown that ICDs have the ability to prolong well life by stretching the plateau time, mitigating water and gas coning, minimizing annular flow, and increasing recovery.
The use of ICDs not only increases production, but it has also been shown to be cost effective. In their study [12], it was stated that the completion of two horizontal wells with ICDs in a field

offshore Malaysia raised the asset valuation by an estimated 100,000 bbl while the total project expense was 15% less than it would have been using conventional well construction methods. They also noted that, in addition to improving drainage quality, ICDs will increase accumulated oil recovery and provide the industry with reasonably cheap, low-risk components for technology-driven strategies.

It was reported by [13], that the use of ICD in a thin oil column reservoir in the Troll oil field resulted in a rise in oil output of 200,000 Sm^3 (1.26 MMbbl) in 17 years. The gas breakthrough was postponed by about 100 days. They discovered a link between GOR behaviour and ICD coverage. The longer the ICD, the more smoothly the well will be controlled in terms of GOR power.

Owing to the fact that the oil reservoir is spread out in thin layers with limited initial mobile thickness and the existence of a massive overlaying gas cap and differing intensity of underlying water, field exploration teams are often faced with many difficulties in the management of thin oil columns. Thus, this paper investigates the early water and gas breakthrough caused by the heel-toe impact and reservoir heterogeneity associated with generating oil rim reservoirs with traditional horizontal wells in the Niger Delta.

2. Methodology

The Schlumberger ECLIPSE dynamic reservoir simulator was used in the dynamic simulation analysis to model the deployment of Inflow Control Devices in a horizontal well situated in a heterogeneous reservoir.

The Multi-segment well model was used in ECLIPSE to model the Inflow Control Devices. The system is specifically built for horizontal and multi-lateral wells which give a clear explanation of fluid flow in the well bore. The model is very effective and precise and it provides an excellent estimate of wellbore friction, cross flow, pressure drop, and multiphase fluid flow in the wellbore [14, 15]. Figure 2 shows the precise definition of the fluid flow conditions inside the well as obtained by splitting the well bore into a variety of one-dimensional parts, each with its own collection of independent variables to define the fluid conditions. The annulus space is represented as segments that are linked to grid cells that represent the reservoir.

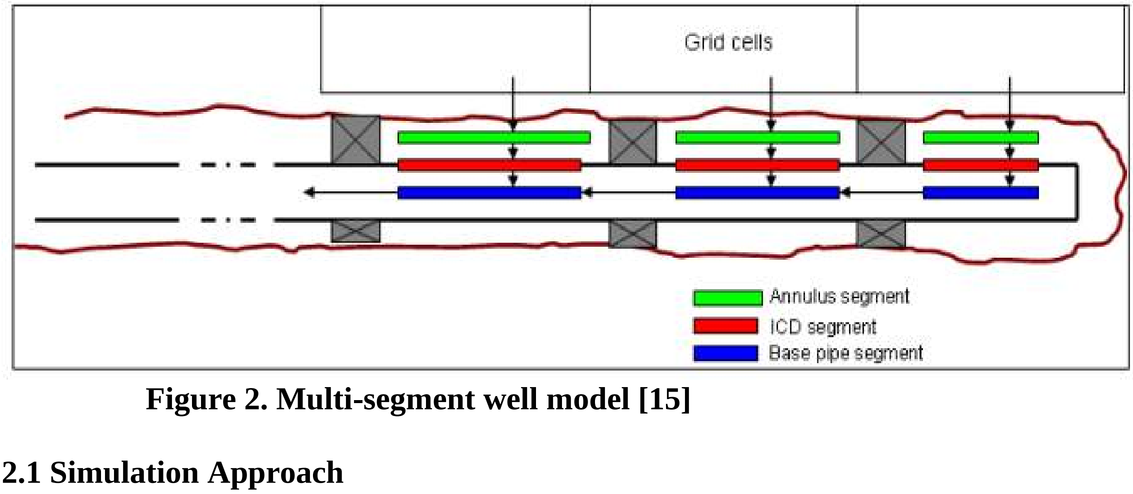

Figure 2. Multi-segment well model [15]

2.1 Simulation Approach

The simulation approach is to simulate a Base case (oil production without Inflow Control Devices i.e. using conventional completions strategy) and a Test case (oil production with Inflow Control Devices). In both cases, the well was positioned within the model's oil rim section at 75 percent stand-off from the water-oil-contact while honouring the following system constraints:

- Maximum liquid flow rate of 2500 STB/day

- Minimum oil production rate of 100 STB/day
- Maximum allowable water cut of 90%
- Minimum bottom hole pressure of 1500 psi
- Simulation time of 30 years

Using Eclipse's multi-segment model, the well is split into twenty-five (25) segments. Using the WSEGTABL keyword, the pressure drop through each section of the entire well duration was correctly applied from the VFP table. To see the “heel-toe” reaction naturally, the pressure reduction must be properly modelled. The combined effect of frictional and hydrostatic pressure losses along a representative length of tubing is described in VFP tables. ECLIPSE interpolates a pressure drop from a table; it scales the pressure drop in proportion to the length or depth span of the fragment. The hydrostatic pressure drop is proportional to the depth span, while the frictional pressure drop is proportional to the volume. Since the well is horizontal, the segments were scaled by length.
In addition, a production logging test (PLT) survey was also carried out to analyze the inflow profile along the length of the well without Inflow Control Devices using the WRFTPLT keyword. The PLT survey enabled understanding of the contribution and performance of each segment along the well length.
The case study for this work is a reservoir in the Niger Delta with a thickness of 30ft and a horizontal well length of 4250ft completed in the oil column. The reservoir's porosity and permeability ranges from 0.0857 to 0.4000 and 0.16 to 2644 mD respectively with a vertical-to-horizontal permeability ratio (k_v/k_h) of 0.01. Reservoir fluid properties are shown in Table 1

Table 1: Fluid properties

Property	**Oil**	**Water**	**Gas**
Density (lb/ft^3)	55.53	63.03	0.05
Initial viscosity (cp)	2	0.43	0.02

Table 2: Orifice ICD data

WSEGVALV				
PROD1_HI	3	0.65	0.02	50
PROD1_HI	4	0.65	0.02	50
PROD1_HI	5	0.65	0.08	50
PROD1_HI	6	0.65	0.16	50
PROD1_HI	7	0.65	0.24	50
PROD1_HI	8	0.65	0.24	50
PROD1_HI	9	0.65	0.08	50
PROD1_HI	10	0.65	0.24	50
PROD1_HI	11	0.65	0.08	50
PROD1_HI	12	0.65	0.08	50
PROD1_HI	13	0.65	0.08	50
PROD1_HI	14	0.65	0.08	50
PROD1_HI	15	0.65	0.32	50
PROD1_HI	16	0.65	0.32	50
PROD1_HI	17	0.65	0.32	50
PROD1_HI	18	0.65	0.32	50
PROD1_HI	19	0.65	0.32	50

PROD1_HI	20	0.65	0.32	50
PROD1_HI	21	0.65	0.24	50
PROD1_HI	22	0.65	0.24	50
PROD1_HI	23	0.65	0.24	50
PROD1_HI	24	0.65	0.24	50
PROD1_HI	25	0.65	0.24	50
PROD1_HI	26	0.65	0.24	50
PROD1_HI	27	0.65	0.24	50

3. Results and Discussion

The reservoir features a gas cap as well as a strong aquifer with a bottom water drive system. This study employs a three-dimensional (3-D) reservoir model with the oil column thickness of the oil-rim model approximately 30 feet. The model is divided into 140 X 49 X 130 grid blocks, each with dimensions of approximately 165ft X 165ft X 1.65ft in the x, y, and z directions respectively (Figure 3).

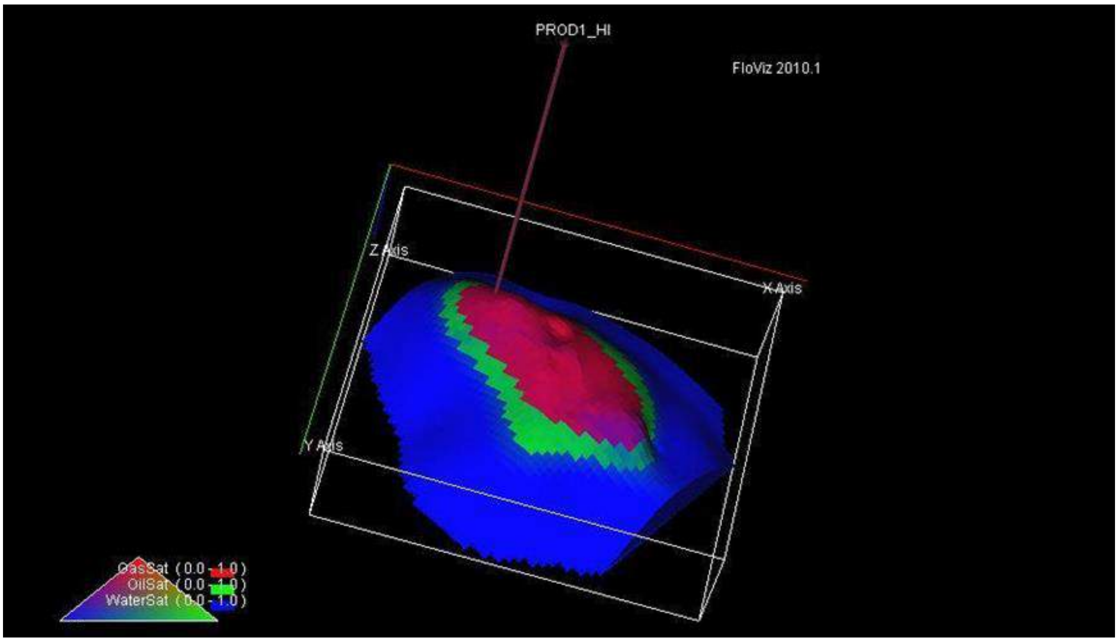

Figure 3. Reservoir model showing the oil rim

The heel toe-effect has been verified as predicted from the PLT survey. The PLT plots (Figures 4, 5, & 6), shows that over 85% of the well in the direction of the toe does not contribute to the production. Therefore, as a result, orifice ICDs is mounted along the entire length of the well using the WSEGVALV keyword and data from Table 2.

On the basis of the PLT survey, ICDs with smaller limitation have been put in the direction of the heel and a bigger limitation has been placed at the tip of the well. This is done to equalize flow in the wellbore, increasing flow contribution from the toe.

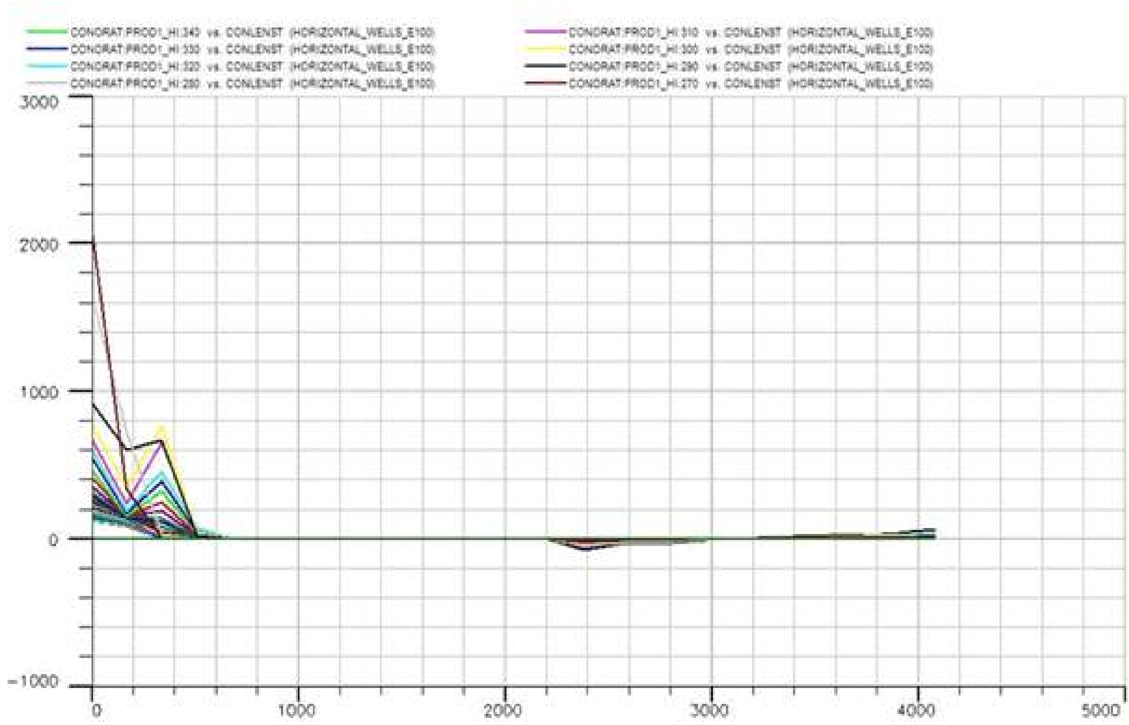

Figure 4. Oil inflow profile along the well length without ICDs

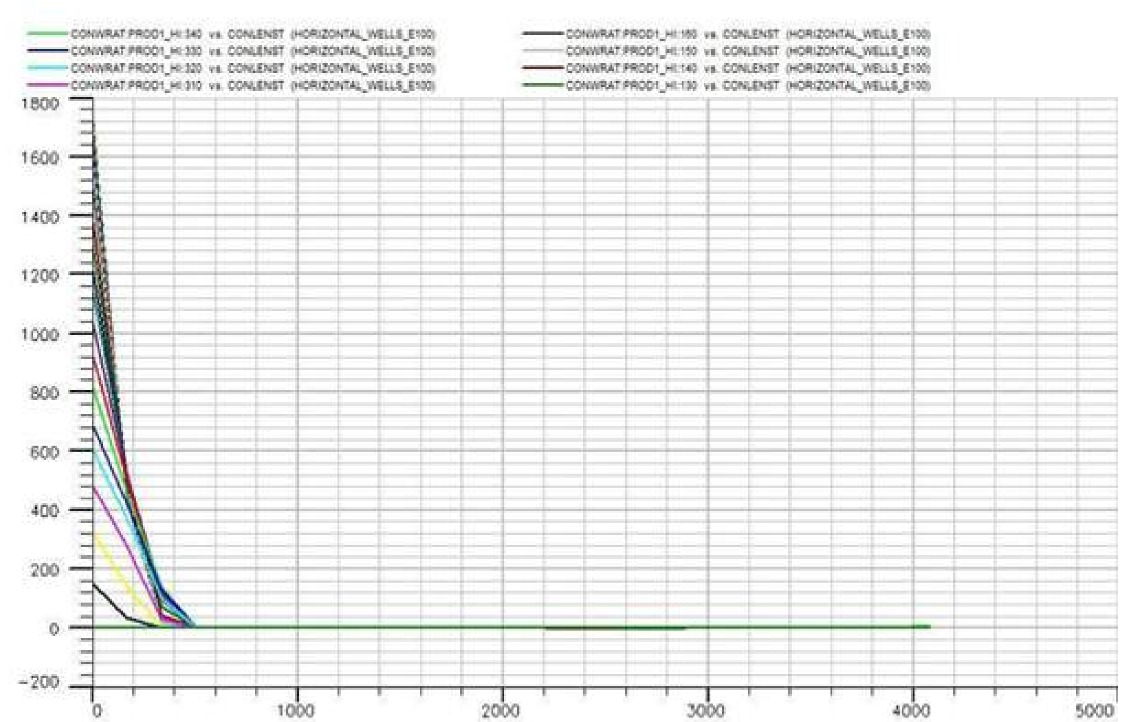

Figure 5. Water inflow profile along the well length without ICDs

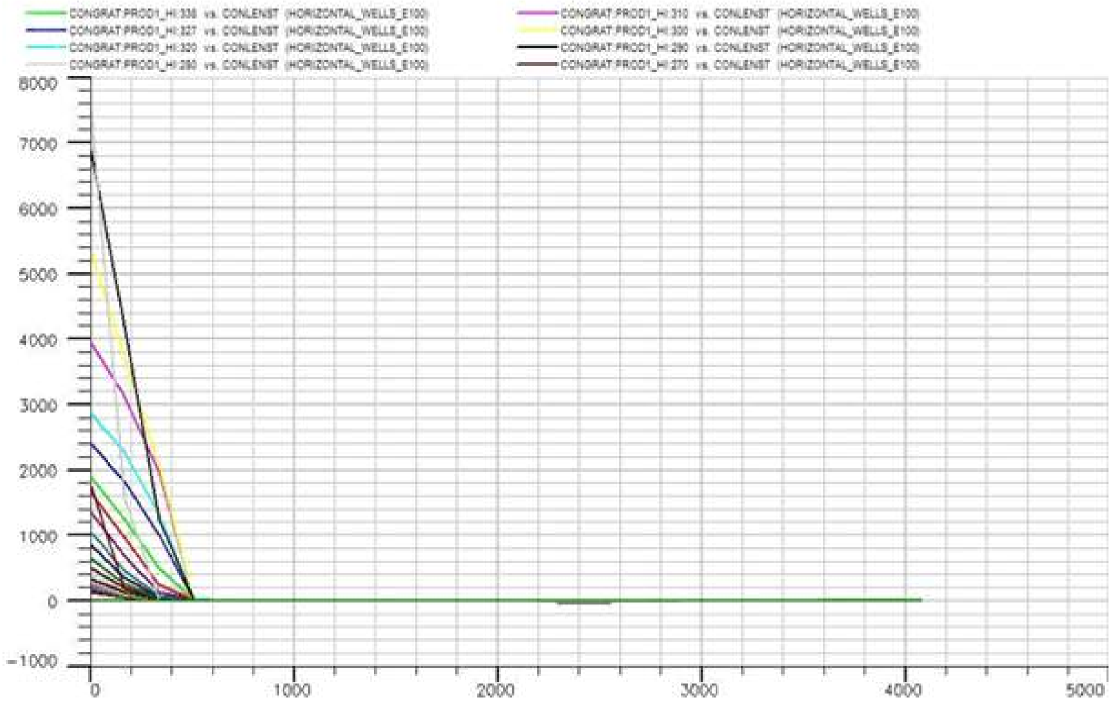

Figure 6. Gas inflow profile along the well length without ICDs

The main issue with the base case was the early water and gas breakthrough at the well's heel, which ultimately hampered flow from the well's toe. Figures 7 & 8 show how ICDs mounted along the entire length of the well with different constriction sizes slowed the water and gas breakthrough.

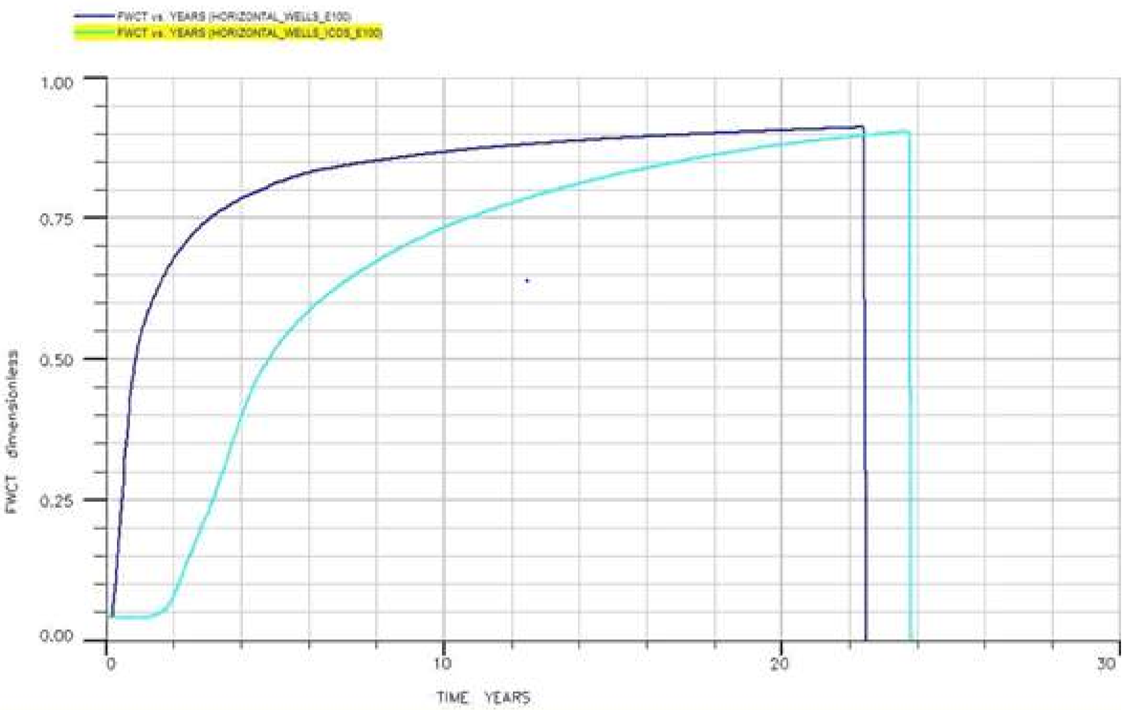

Figure 7. Water Cut

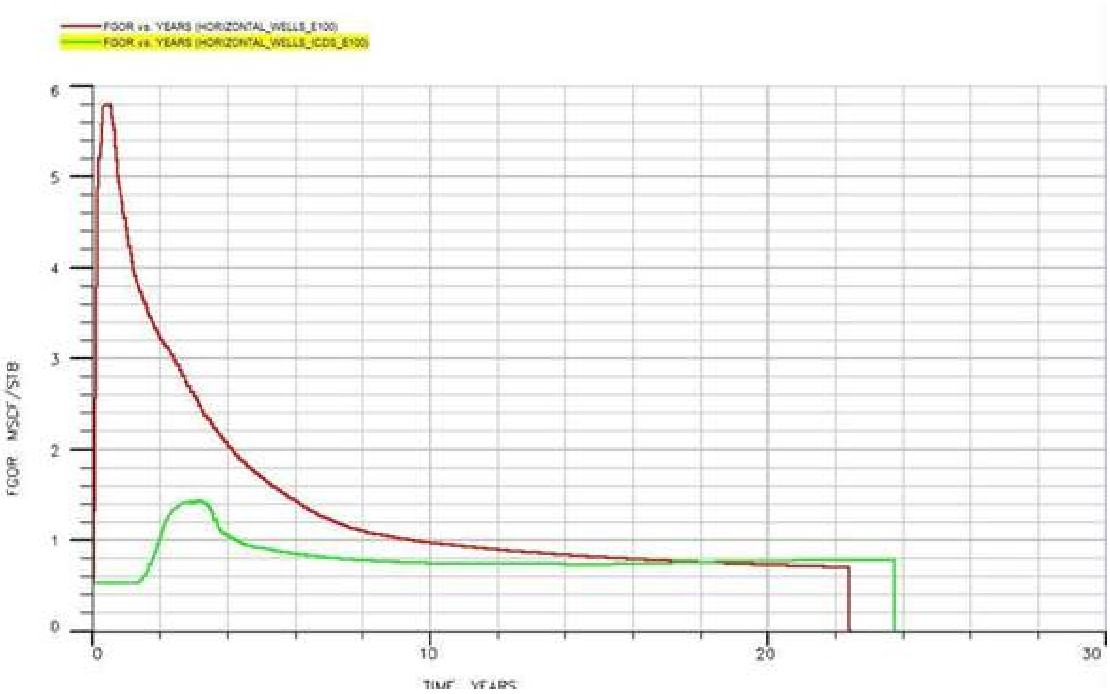

Figure 8. Gas-Oil Ratios

In addition to delaying water and gas breakthrough, ICDs also aid in the even distribution of flow along the length of the well. In contrast to the base case, the PLT survey on the well after the ICDs were deployed found that the whole length of the well was contributing to flow, and the flow was even across the well length (Figures 9, 10, & 11).

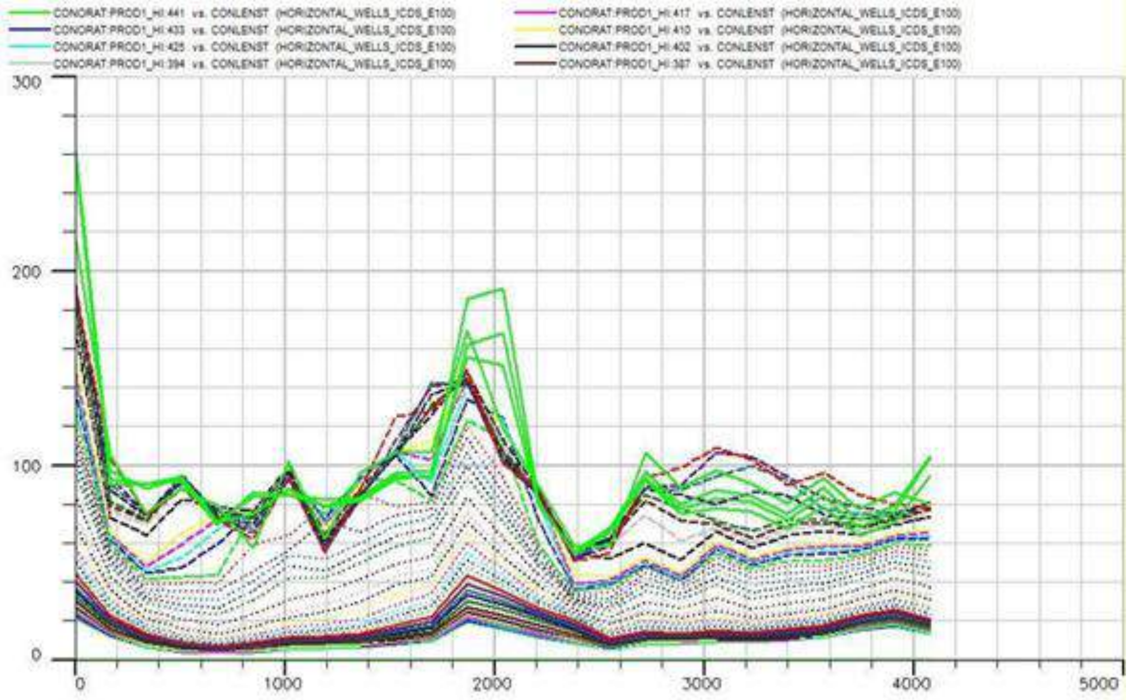

Figure 9. Oil inflow profile along the well length with ICDs

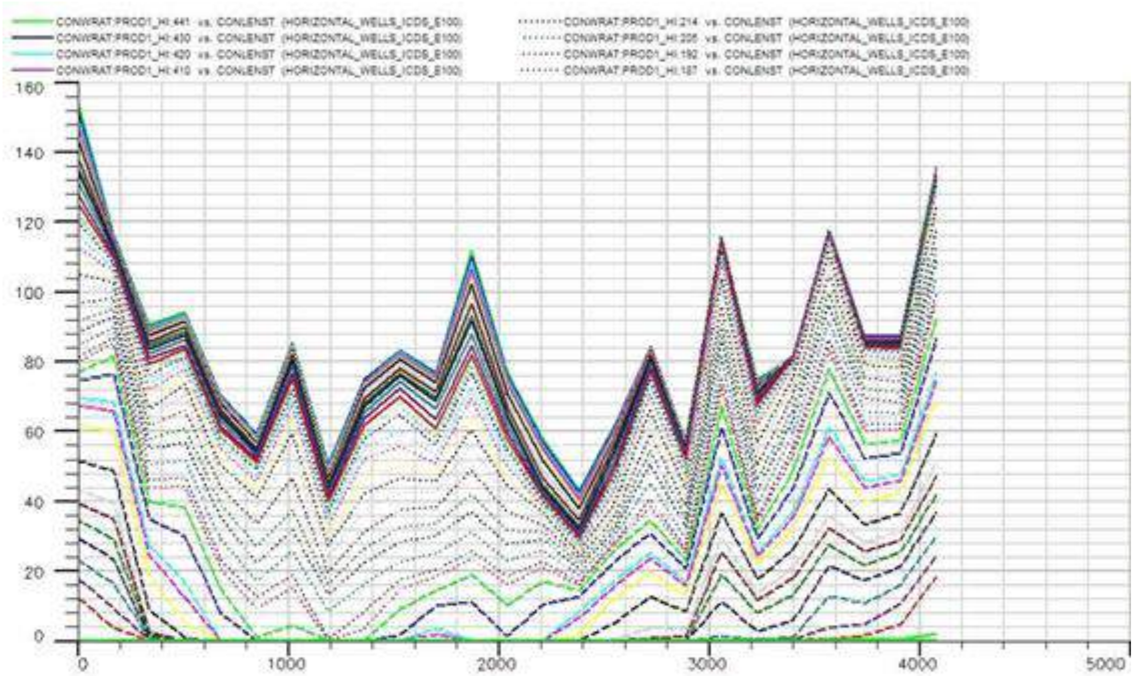

Figure 10. Water inflow profile along the well length with ICDs

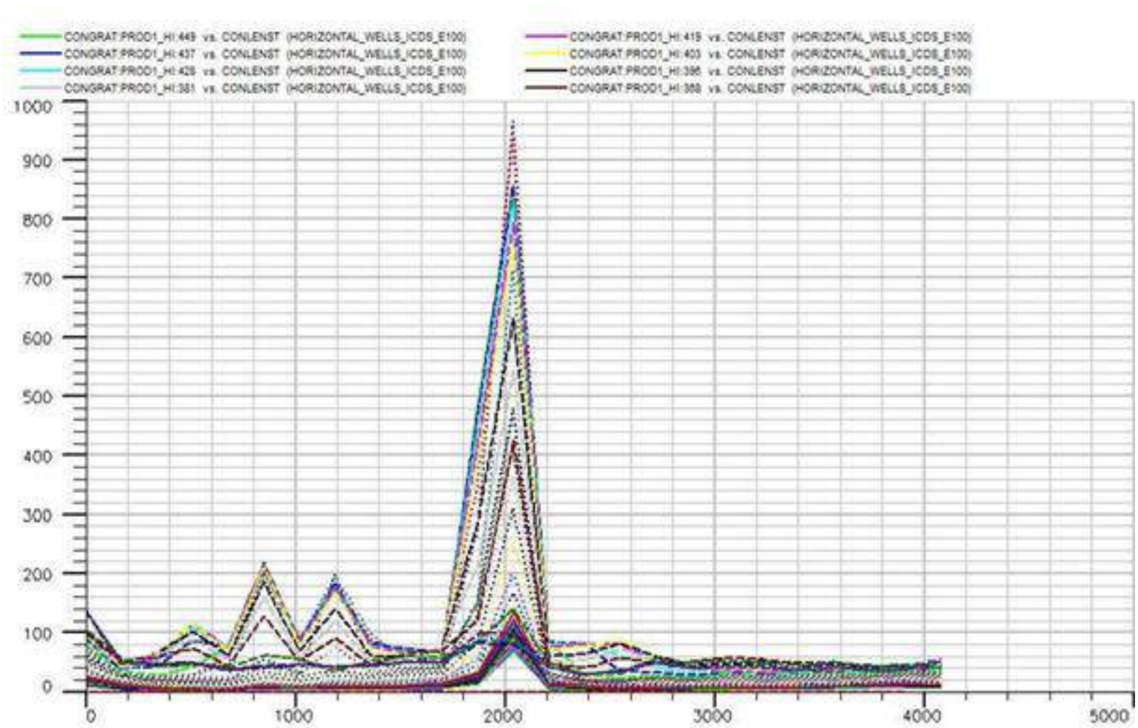

Figure 11. Gas inflow profile along the well length with ICDs

The use of ICDs resulted in a substantial rise in total oil output over the base case, an additional 22% of oil was recovered from the reservoir and the well's life was also prolonged by almost a year. The combined oil output and recovery component for the ICD case (blue) and the base case (no ICD) (green) are displayed in Figures 12 & 13. Oil recovery was lower in the base case due to the heel-toe impact, which restricted the usable span of the length, as seen in the PLT plots.

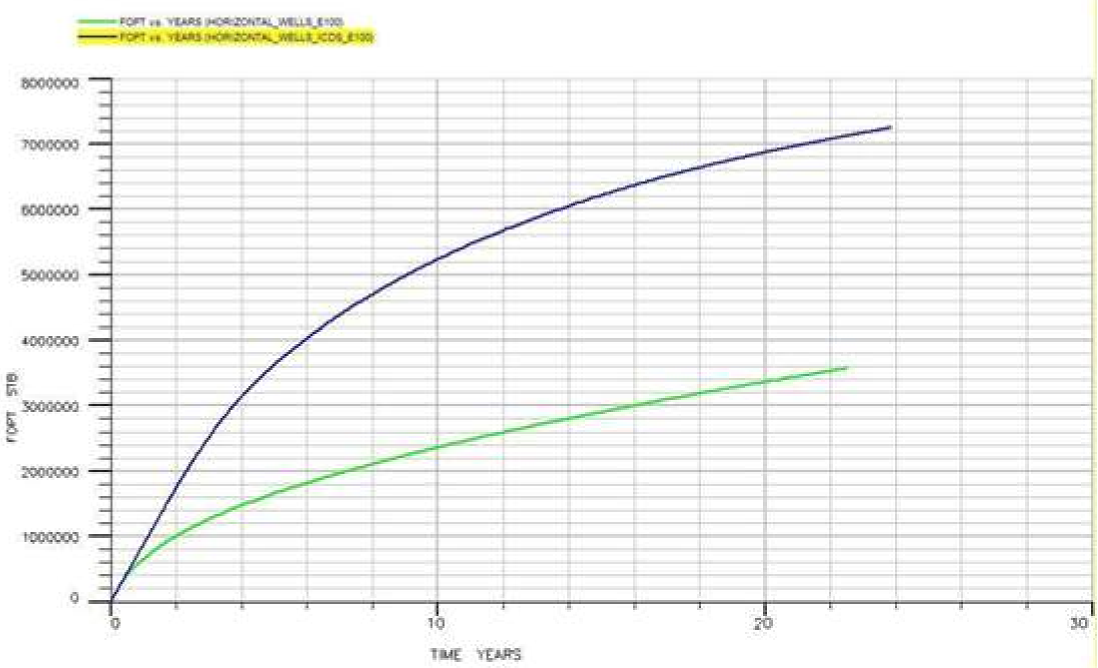

Figure 12. Cumulative oil production

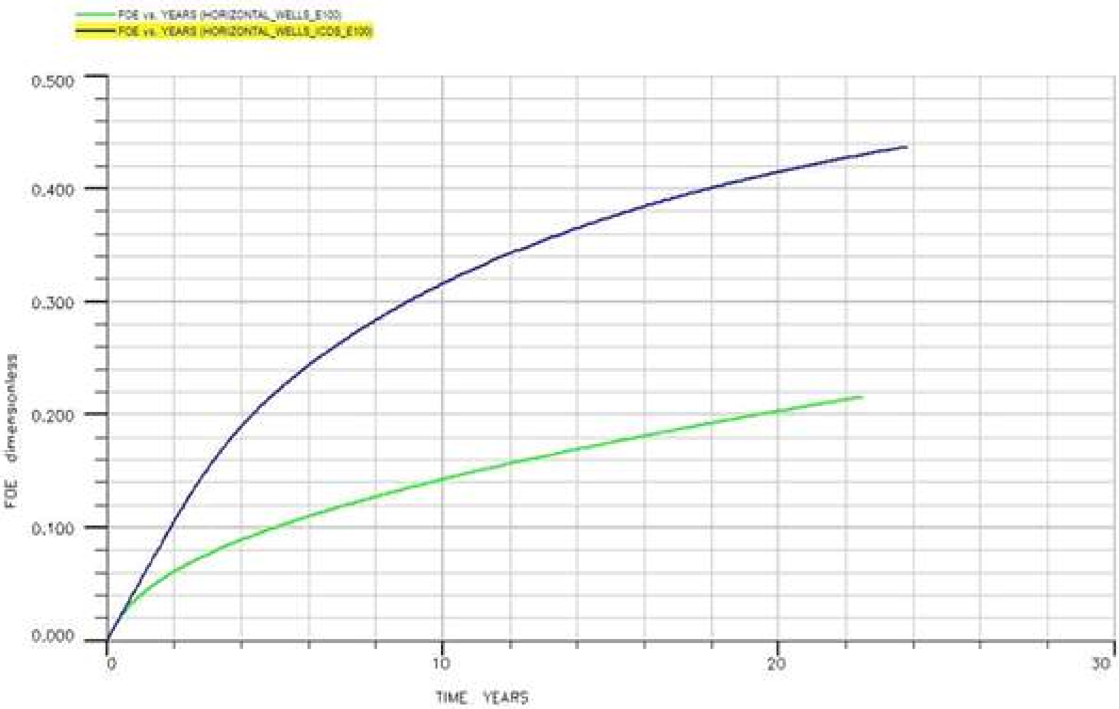

Figure 13. Recovery factor

4.0 Conclusion

This study investigated the challenges of oil rim reservoirs, reiterated their development strategies and establishes understanding of factors that control recovery in oil rim reservoirs by carrying out flow simulations to predict and compare the performance of oil rim reservoirs under conventional horizontal wells completions strategy and horizontal wells completed with Inflow Control Devices. The model deployed in this paper is similar to the approach of [15] and those illustrated using published Troll oil field data [13].

The simulation results show that installing Inflow Control Devices improves the well influx profile in the reservoir and extends well life by preventing water and gas breakthrough. This result is consistent with those of the different uncertainty realization models for decision analysis [8] as well as the results of numerical simulations performed in commercial well modelling software [9].

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