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Research Article

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A New Correlation for the Estimation of Gas Breakthrough Time for Horizontal Well in Saturated Oil Reservoirs

Usiayo Victor Afoke[1], Baridor Samuel Odagme[2], Osuman Lawrence Osazuwa[3]

[1]Petroleum and Gas Engineering Department, University of Port Harcourt, Port Harcourt, Nigeria
[2]Petroleum and Gas Engineering Department, University of Port Harcourt, Port Harcourt, Nigeria
[3]Ciscon Nigeria Limited, KM 14 PH/Aba Road, Port Harcourt, Rivers State, Nigeria

Abstract The fact that most wells are produced with a constant oil flow rate with constant gas-oil ratio (GOR) before gas or/and water breakthrough is conventional. However, Gas coning in Production wells may reduce the oil production. From operational and economic point of view, this occurrence is not good for several reasons: the gas price is much lower than the oil price, the affected wells may be abandoned early, and the gas handling capacity is often a problem. Therefore, there is the need to produce such wells before gas or/and water breakthrough for an extended period of time. In this work, a simple equation that relates gas breakthrough time with oil flow rate in Horizontal wells was developed based on Papatzacos equation and the dimensionless variables were derived. Sensitivity analysis was carried out in order to see how other parameters affect the breakthrough time, to enable operators handle the gas coning problem effectively. The results showed that, increase in oil flow rate reduces breakthrough time, hence accelerates the rate of coning in horizontal wells. Also, the sensitivity analysis also indicated that gas breakthrough time increases with increasing oil column thickness and porosity.

Keywords Breakthrough Time, Saturated Oil Reservoir, Coning, Simulation, Horizontal Well.

Introduction

One major aim of using the horizontal well technology is to enhance oil recovery from water or gas-cap drive reservoirs. The advantage of horizontal wells over the conventional vertical well, is its ability of producing oil at a longer time to breakthrough and at the same pressure drawdown at a particular rate of production. Correlations that are used in predicting the way the coning behaviours in are horizontal wells are found in various literatures. In 1991, Joshi gave a thorough treatment of coning problems encountered in horizontal wells. Coning issues in vertical and horizontal wells involves calculating the following parameters: critical flow rate determination, predicting breakthrough time, wells performance calculations after breakthrough [1].

A well is usually produced with a constant oil rate with constant gas-oil ratio (GOR) during the subcritical phase, i.e. before gas breakthrough. The presence of gas coning in production wells may reduce the oil production. The decline in the oil rate will be followed by an increase in the well head pressure. From an economical and operational point of view, this condition may be undesirable for several reasons; the gas price is much lower than the oil price, the affected well may be abandoned early, and the gas handling capacity often is a constraint. Therefore, there is an incentive to produce such wells in their subcritical phase for an extended period of time [2]. Coning is used to describe the process underlying the upward movement of water or the flow of gas downward into the well perforations. Petroleum reservoirs most times have a gas cap or an aquifer in situations like these, they are construed to a quick water/gas flowing into the well perforations due to pressure drawdown in the well direction. Before the well starts production, the reservoirs usually have known Gas-Oil Contacts (GOC) and Water-Oil Contacts (WOC). As soon as the well production starts, the known contacts that was previously defined, becomes deformed from is level or plane shape to form a cone in vertical wells or a crest in horizontal wells.

Pressure drawdown is one of the main causes of coning. Vertical wells experiences an enormous pressure drawdown around the region of the wellbore, which causes coning. Thus coning can be removed or reduced by reducing the pressure around the wellbore region. For the pressure to be reduced there must also be a simultaneous reduction of oil production rate, which is usually not economically feasible or viable. Horizontal well helps in cone reduction and maintaining the rate of oil production.

Most times critical production rates are very low, and because of economic benefits, wells are produced at rates above critical rate. This leads to the simultaneous production of water/gas and oil. Correlations in horizontal wells were developed by Papatzacos et al [3] for breakthrough time with a dimensionless oil rate. Yang et al [4] developed theirs with cumulative oil production, while Ozkan et al [5] correlation for breakthrough time was developed with relation to sweep efficiency. However, a direct relationship was not established between breakthrough time of gas/water and oil flow rate. In this study that relationship was established.

Methodology

A single horizontal well reservoir model was built with ECLIPSE 100. The model consists of 1620 grids (20x9x9). The reservoir fluid consists of live oil (with dissolved gas), dry gas (no vaporized oil) and water PVT functions.

Scope of Simulation

Different values of Oil flow rate was entered in ECLIPSE 100 in order to see the gas breakthrough in terms of increase in Gas-Oil-Ratio, GOR. Nineteen different Oil flow rate were used to obtain 19 different time of gas breakthrough in the ECLIPSE run.

The Relationship between the Oil Flow Rate and Time of Breakthrough

From Papatzacos' equation,

We have:

$$t_{BT} = \frac{22758.528 h\phi\mu_o (t_D)_{Bt}}{kv(\rho o - \rho g)} \tag{1}$$

Making $(tD)_{Bt}$, the subject of the formula, equation (1) becomes

$$Bt = \frac{Kv(\rho_o - \rho_g)t_{BT}}{22758.528 h\phi\mu_o} \tag{2}$$

Also recall that,

$$(tD)_{Bt} = \frac{1}{6q_D} \tag{3}$$

Make $\frac{1}{(tD)Bt}$ the subject of the formula in equation (2) and equation (3)

$$\frac{1}{(t_D)_{Bt}} = \frac{22758.528 h\phi\mu_o}{kv(\rho o - \rho g)t_{BT}} \tag{4}$$

$$\frac{1}{(t_D)_{Bt}} = 6q_D$$

Equating equation (4) to equation (5)

$$6qD = \frac{22758.528 h\phi\mu_o}{kv(\rho o - \rho g)t_{BT}}$$

Hence,

$$qD = \frac{22758.528 h\phi\mu_o}{6kv(\rho o - \rho g)t_{BT}} \tag{6}$$

Also, recall Papatzacos' dimensionless flow rate to be,

$$qD = \frac{20333.88 q_o\mu_o\beta_o}{Lh\sqrt{kvkh}(\rho_o - \rho g)} \tag{7}$$

Hence, equating equation (6) - (7) and make t_{BT} the subject of the formula.

Gives:

$$\frac{22758.528h\phi\mu_o}{6kv\,(\rho o-\rho g)t_{BT}}=\frac{20333.88q_o\mu_o\beta_o}{Lh\sqrt{kvkh}(\rho_o-\rho g)}$$

$$t_{BT}=\frac{0.1865Lh^2\phi\,\sqrt{kvkh}}{q_o\beta_o kv} \quad (8)$$

Equation (8) is the new model for estimating breakthrough time for a horizontal Well in saturated oil reservoirs.

Validation of Model

Field data was used to validate the model. Figure 3 validate the equation and shows the trend between the derived equation and that of ECLIPSE 100. The model was compared with predictions from ECLIPSE 100 Model for water breakthrough and very good results were obtained (figure 1-5) This graph also confirms the relationship between the oil production rate and the time for gas breakthrough to occur (**figure 7-12).**

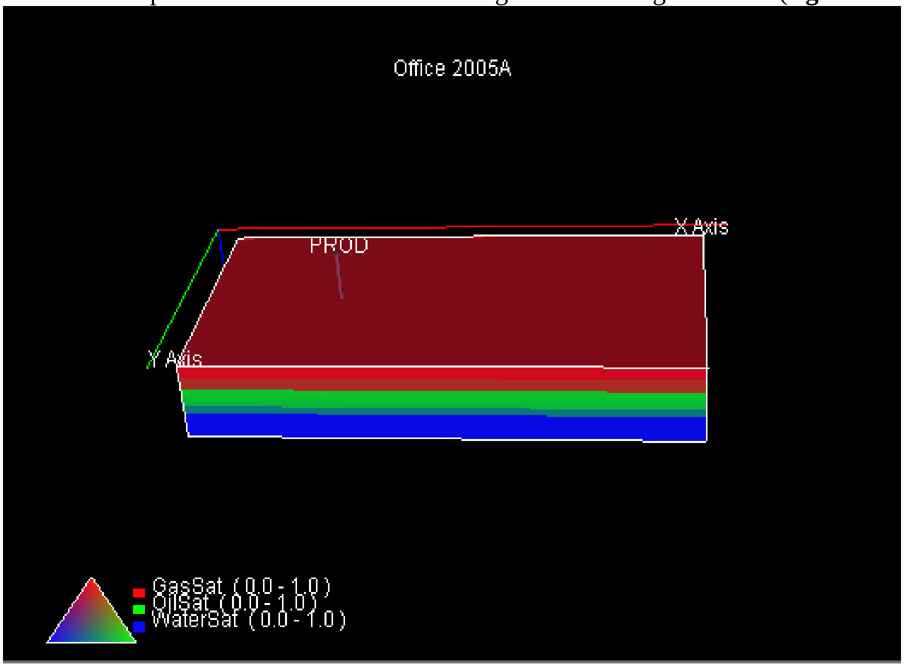

Figure 1: Eclipse 100 Reservoir Model

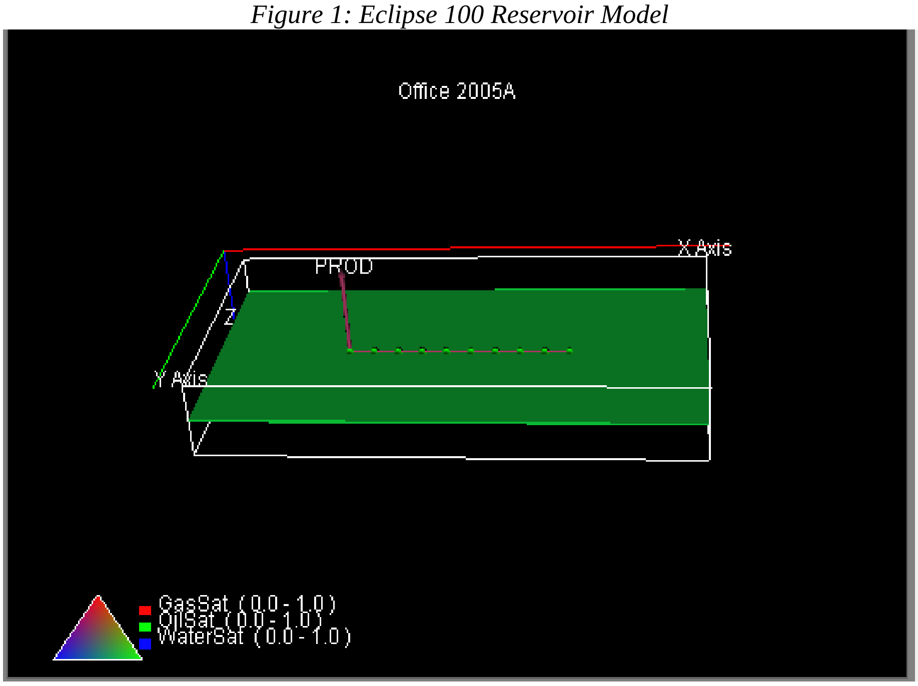

Figure 2: Horizontal Well Completions for the Simulation Model

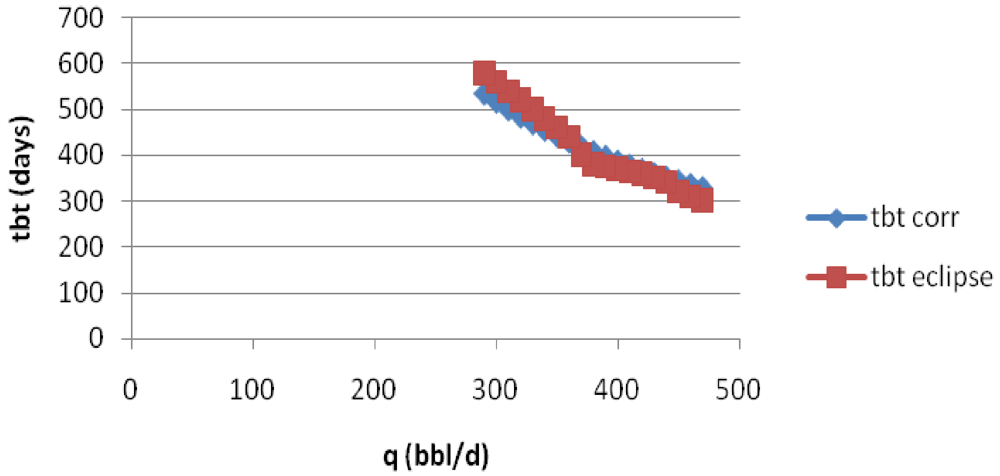

Figure 3: Comparisons of the new correlation with and Eclipse Result

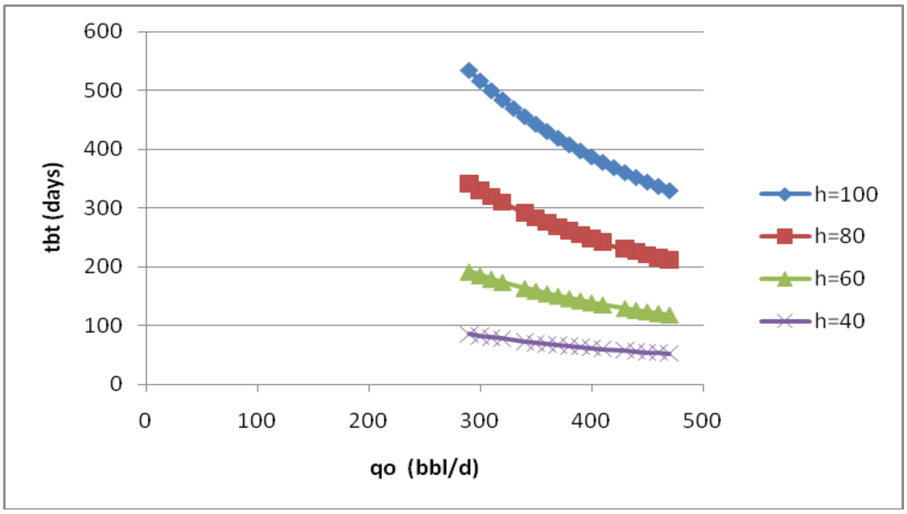

Figure 4: Effect of Production Rate on Breakthrough Time at varying Reservoir Thicknesses

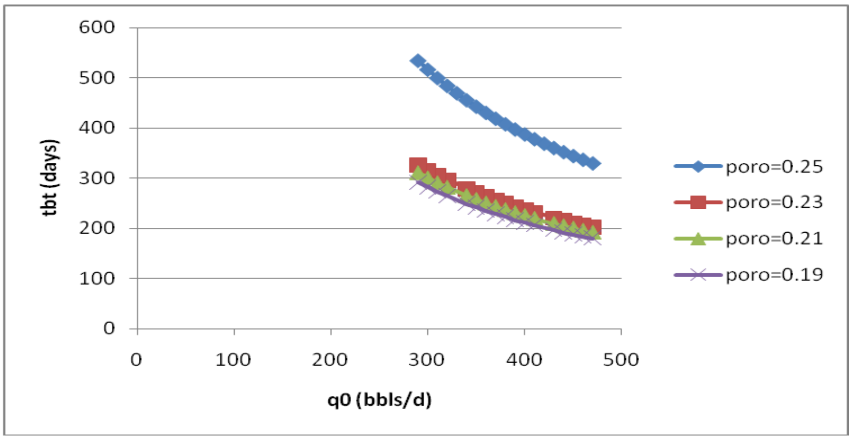

Figure 5: Effect of Production Rate of Breakthrough Time at varying Reservoir Porosities

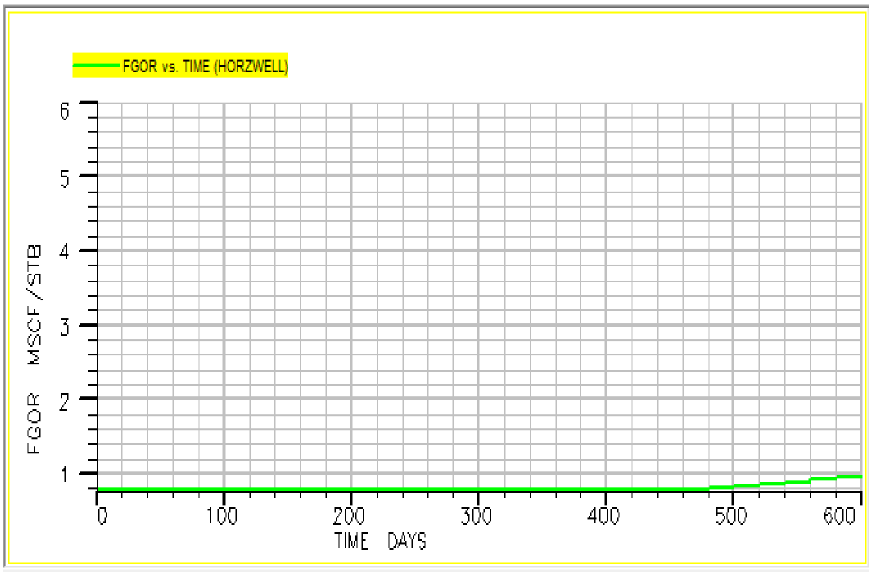

Figure 6: Simulation of Flow Rate 340 Bbl/D on Eclipse 10

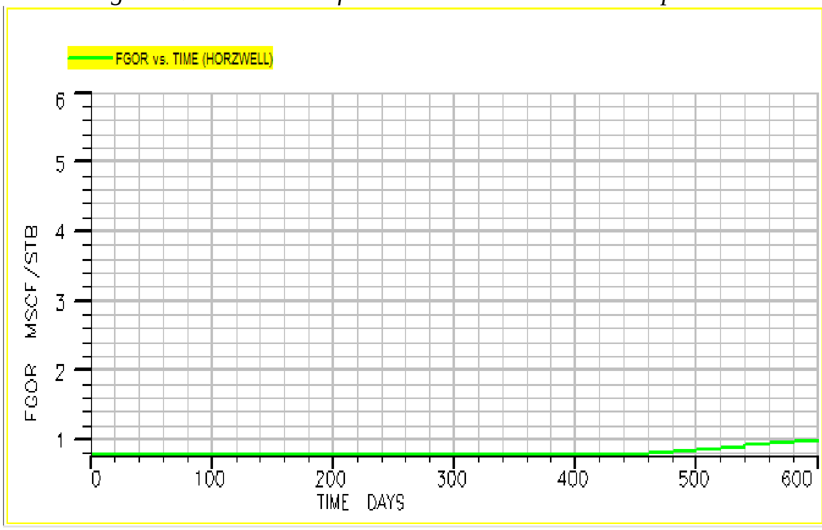

Figure 7: Simulation of Flow Rate 350 Bbl/D on Eclipse 100

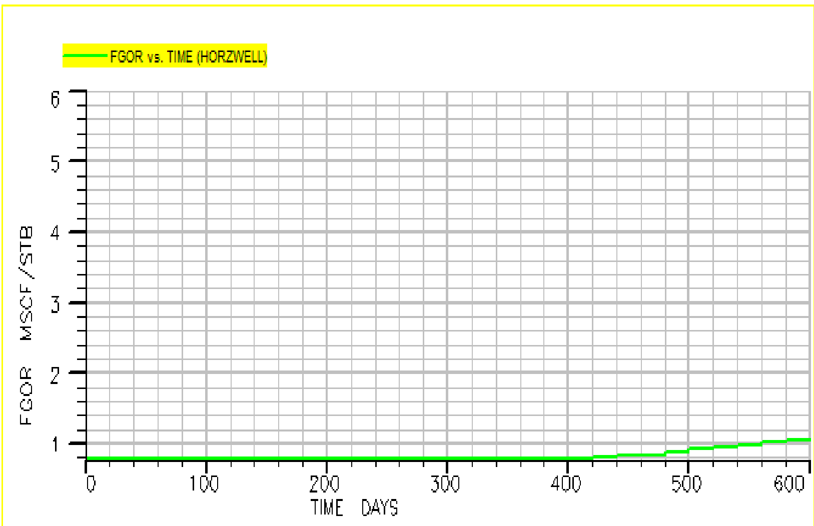

Figure 8: Simulation of Flow Rate 370 Bbl/D on Eclipse 100

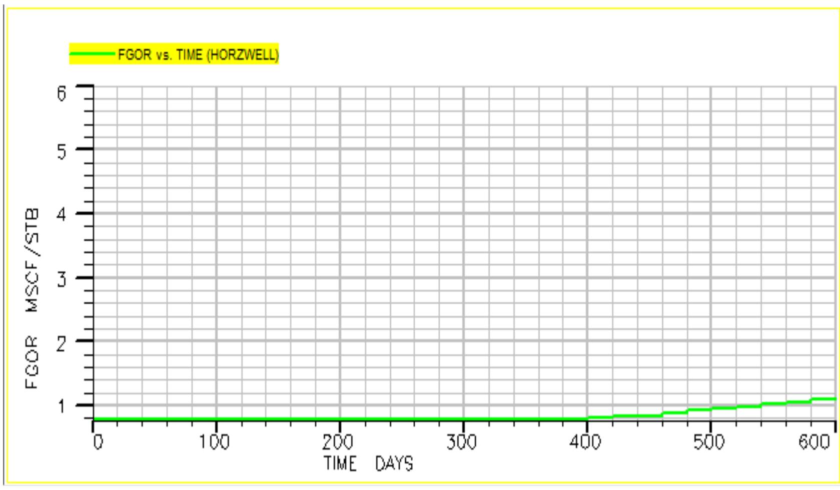

Figure 9: Simulation of Flow Rate 380 Bbl/D on Eclipse 100

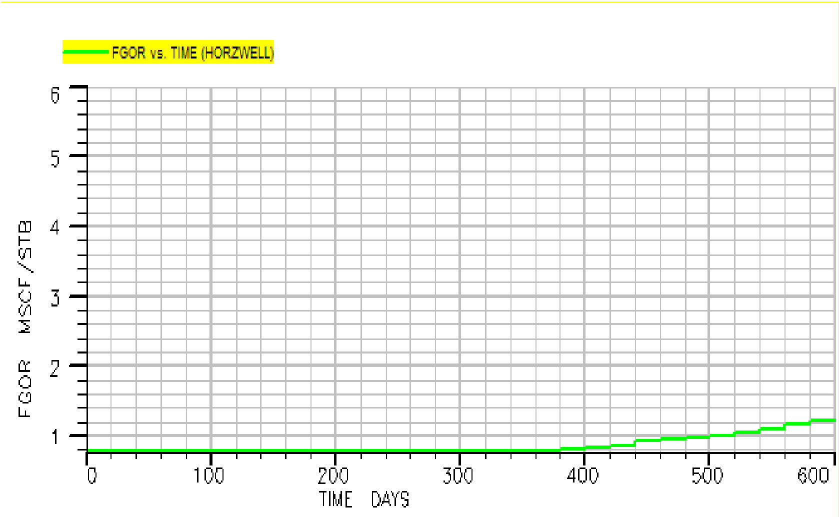

Figure 10: Simulation of Flow Rate 400 Bbl/D on Eclipse 100

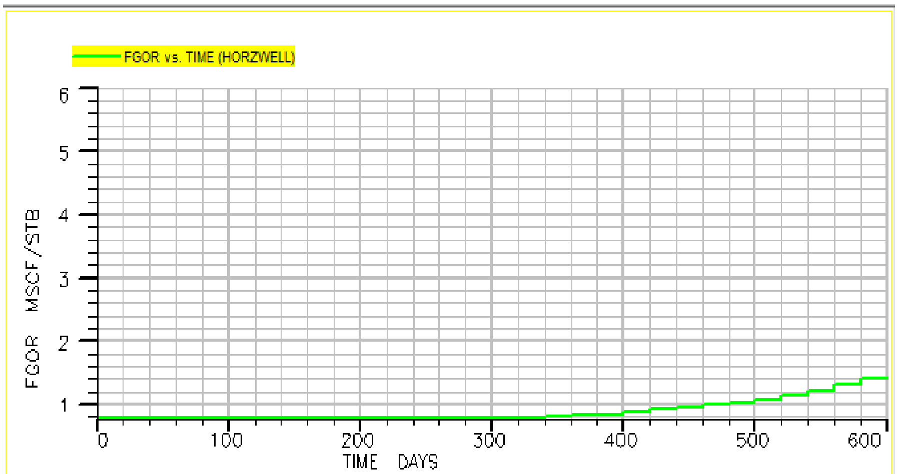

Figure 11: Simulation of Flow Rate 420 Bbl/D on Eclipse 100

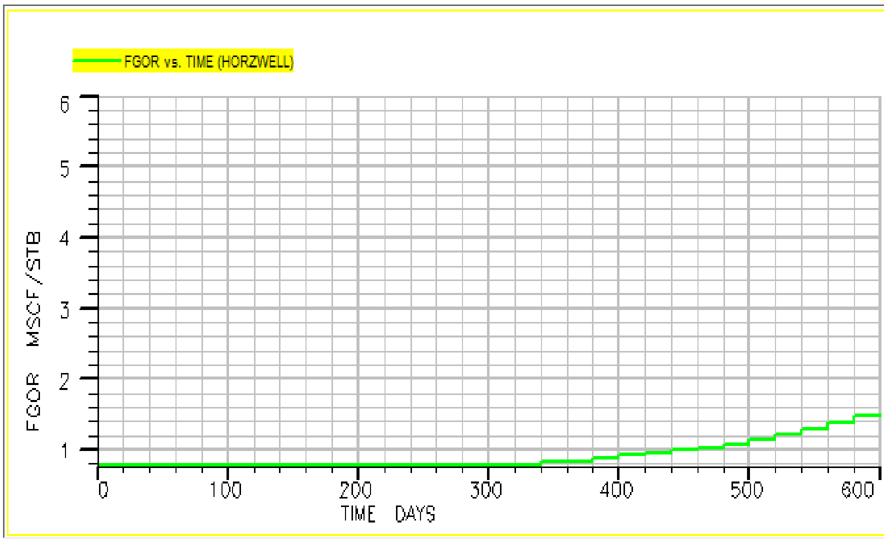

Figure 12: Simulation of Flow Rate 430 Bbl/D on Eclipse 100

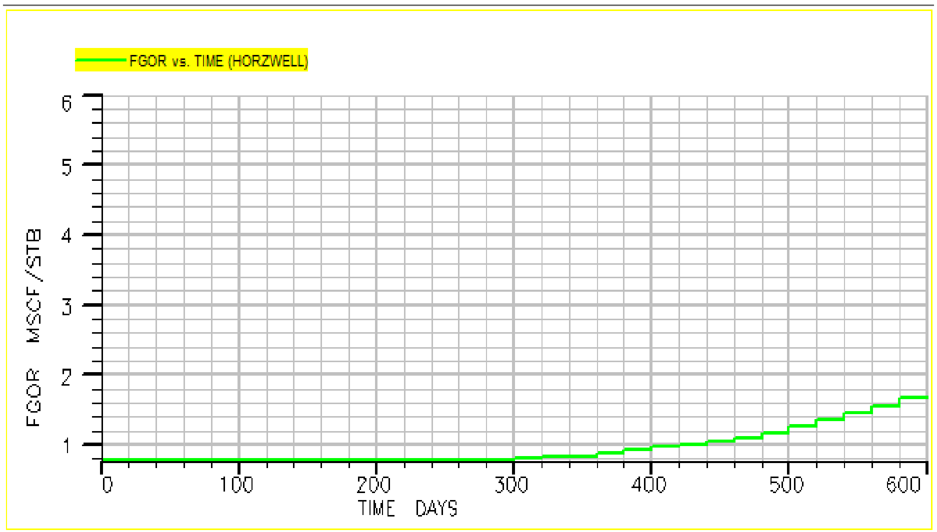

Figure 13: Simulation of Flow Rate 450 Bbl/D on Eclipse 100

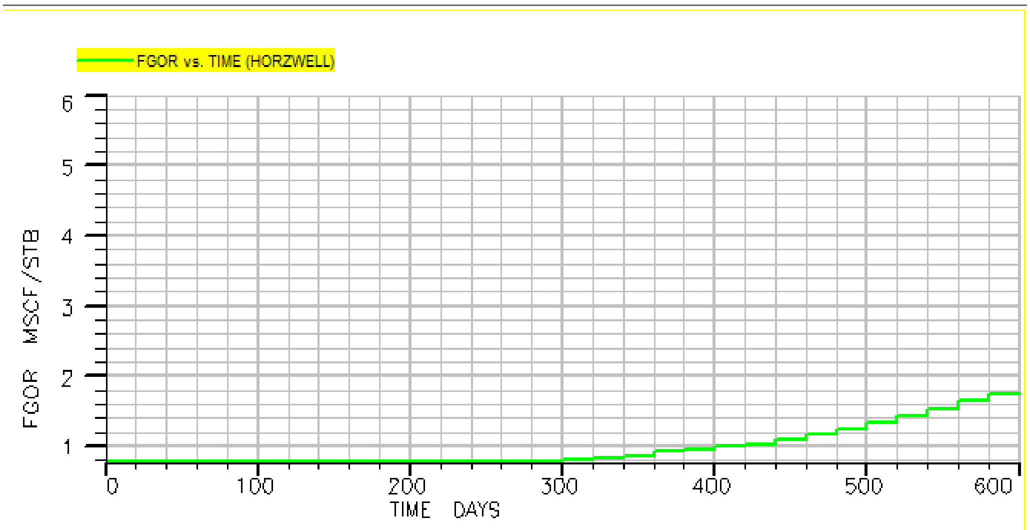

Figure 14: Simulation of Flow Rate 460 Bbl/D on Eclipse 100

Sensitivity Analysis

The sensitivity analysis showed that with increasing production rate, breakthrough time decreases (Figure 3, 4 and 5). Oil column thickness and porosity has a direct influence on breakthrough time. Figure 4 and Figure 5 shows that breakthrough time increases with increasing oil column thickness and porosity. As the oil column is depleted it takes a shorter time for the gas to breakthrough.

Results and Discussion

Equation 8 was used to estimate the breakthrough time **(Table 1)** and also ECLIPSE 100 was used to estimate the breakthrough time as shown in the APPENDIX. A production rate of 290 bbls/d to 470 bbls/d was used whereby the percentage relative error in both methods, ranges from -9 % to 8 %. From the results obtained from both methods it shows that, as the oil production rate increases, the breakthrough time decreases. That is to say as you increase the rate of production, it will take a shorter time for gas to breakthrough and vice versa. Figure 3 validate the equation given the trend between the derived equation and that of ECLIPSE.

Table 1: Estimation of Breakthrough Time for Flow Rate from 290 - 470 bbl/d**.**

qo (bbl/d)	tbt corr	tbt ecclipse	Error %
470	329	300	-9.691364
460	336	310	-8.460606
450	344	320	-7.406128
440	352	340	-3.385577
430	360	350	-2.767325
420	368	360	-2.29155
410	377	365	-3.351035
400	387	370	-4.503259
390	397	375	-5.753726
380	407	380	-7.108604
370	418	400	-4.503259
360	430	440	2.358066
350	442	460	3.934892
340	455	480	5.229887
330	469	500	6.263743
320	483	520	7.05239
310	499	540	7.607632
300	516	560	7.937605
290	533	580	8.047073

Conclusion

1. A correlation for the estimation of gas breakthrough time in horizontal wells in an oil reservoir saturated with gas cap for well producing at critical rates developed.
2. The breakthrough time correlation was successfully applied in solving problems of both water and gas coning issues.
3. The applicability, simplicity and accuracy of the correlations have been demonstrated using ECLIPSE 100.
4. The results should that increase in oil flow rate reduces breakthrough time, and accelerates the rate of coning in horizontal wells.
5. The sensitivity analysis showed that breakthrough time increases with increasing oil column thickness and porosity.

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Appendix

Reservoir Description

- Horizontal Permeability, Kh=100 mD
- Vertical Permeability, Kv =100 mD
- Porosity, Φ=25 %
- Gas Cap Formation Thickness, =hg=100 ft
- Oil Formation Thickness, h=100 ft
- Water formation Thickness, hw=50 ft
- Gas-Oil Contact, GOC=7100 ft
- Oil-Water-Contact OWC=7200 ft
- Datum Depth, D=7150 ft
- Top =7000 ft
- Reservoir Pressure, P=3814 psia
- Oil formation Volume Factor, Bo=1.447 rb/stb
- Oil Viscosity, µo=0.691 cp
- API=35°API
- Gas Formation Volume Factor, Bg=0.8900 rb/stb
- Gas Viscosity, µw=0.01870 cp
- Gas Specific Gravity, (S.G)gas=0.75
- Gas-Oil-Ratio, GOR=0.77
- Water Formation Volume Factor, Bw=1.02310 rb/stb
- Water Viscosity, µw=0.94 cp
- Water Compressibility, Cw=3.1E-06 Psi-1
- Water Specific Gravity, (S.G)water=1.00960
- Length of Well, L=480 ft