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PREDICTING POST BREAKTHROUGH PERFORMANCE OF WATER AND GAS CONING

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ABSTRACT

Water coning is a serious issue for the oil and gas industry. This poses a big concern regarding the costs that to be incurred for separation and equipment capacity. Coning is the production of an unwanted phase with a desired phase. Over the years, many techniques and control methods has been birthed, however, the issue of coning can only be mitigated and not completely discharged. Reservoir and production engineers need to understand the basic framework; the parameters that greatly influence coning and how effective manipulation of it can deal with it. With the introduction of horizontal wells, the production rate is two to four times that of vertical wells, and coning is reduced and the breakthrough time is increased. Numerous papers has been written regarding to coning and vertical wells, only a few emphasize on horizontal wells and simultaneous water coning and gas coning. The objective of this research is to study the post breakthrough performance in simultaneous coning and a black oil simulator was use for the research. Sensitivity analysis was carried out on: the production rate of oil (qt), horizontal permeability, vertical permeability, perforation length, the height above perforation, extent of reservoir area and the formation porosity. A generalized correlation was developed for predicting coning behavior using non-linear analysis.

Key words: Gas-and-Water Coning, Vertical wells, Post Breakthrough Performance, Breakthrough time, Black oil simulator, Horizontal wells.

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1. INTRODUCTION

Coning according to (Ahmed 2006) can be determined when there is interaction of three forces being the capillary, gravity forces and viscous. In producing wells viscous forces result from pressure gradients, gravity force due to density differences and capillary forces have been found to have negligible effects on coning problems. A cone eventually breaks into the perforation interval when the viscous force exceeds the gravity force. It is termed coning when water is involved and termed cusping when gas is produced as the unwanted phase. However, for the purpose of this research, coning will represent both water and gas situations. In the recovery of hydrocarbons, coning cannot be completely excluded. However, it can be mitigated by increasing time before undesired phase breakthroughs. In petroleum industry, production of water and gas production are the typical problems of serious concern in the industry (Inikori 2002). Many gas and oil reservoirs are water driven with the rest driven by gas or rock-and liquid expansion. Although water/ gas provides a drive energy to produce the oil and/ or gas reservoir, it can cause production-associated problems in the wellbore. Therefore, in a bid to mitigate water and gas coning, the cycle of coning; before and after inception should be studied and carefully categorized. The objective of this research is to apply Addington and Yang method in a like manner for predicting post breakthrough performance which is indicated by GOR and WOR in the horizontal wells because of simultaneous gas and water coning.

Correlations will be formulated to predict breakthrough time, critical production rate, WOR and GOR. The method used in this study is the construction of a reservoir model using a 3D simulator (ECLIPSE 2010.1) and perform a broad parameter study using reservoir simulation. After creating a box model, the reservoir petrophysical parameters are then factored in, that will describe the reservoir, which will amount to base case scenario. The resulting correlations will be obtained by conducting regression analysis for GOR and WOR and the well placement length. An extensive sensitivity analysis was performed to conclude on the fluid and reservoir properties with greatest influence by changing the reservoir and offtake rate parameters individually.

Numerical correlations were developed for both horizontal and vertical wells by Yang and Wattenbarger (1991). The correlation developed was centered on regression analysis and basic flow equations using the data from numerical simulations, which follows Addington's gas coning approach. In calculating breakthrough time, a tank reservoir assumption was made. The average oil column height beneath perforation, h_{bp}, is related to the cumulative oil production (Np) linearly. At breakthrough the oil cumulative production can be evaluated from breakthrough height h_{wb}, for both horizontal and vertical wells.

average Oil column height beneath perforation h_{bp}

$$h_{wb} = h - \frac{(N_p)_{BT}}{A\emptyset(1 - S_{wc} - S_{or})} - h_{ap} - h_p \qquad [1]$$

Cumulative Oil production at breakthrough, $(N_p)_{BT}$

$$(N_p)_{BT} = A\emptyset(1 - S_{wc} - S_{or})(h - h_{wb} - h_{ap} - h_p) \qquad [2]$$

Time to breakthrough, t_{BT}:

$$t_{BT} = \frac{(N_p)_{BT}}{q_t} \qquad [3]$$

2. POST BREAKTHROUGH PERFORMANCE

In the oil and gas industry, owing to period of lease and economic investments, production of wells are above the critical oil rate as it may be low and unfeasible to satisfy the proposed payback period stipulated. Thus, predicting the production performance of the reservoir as a function of time is of critical essence. Evaluation can then be performed usually by basing the production performance on the gas cut and water cut of a reservoir having a gas cap drive and water drive respectively. As regarding post breakthrough performance, many have addressed this issue. Diverse authors have addressed the aspect of the (WOR) water-oil-ratio after breakthrough has occurred in a vertical well. Bournazel and Jeanson (1971) developed a strategy for WOR, combining experimental correlations with the use of dimensionless numbers and a simple analytical method. Assuming that water is isolated from the oil, the oil-water level rises and remains at a certain interval just above the perforation level.

Consequently, WOR can be predicted by computing the perforation length interval in the water. (Byrne and Morse 1971, Blades and Stright, 1975) explored the impacts of several well and reservoir parameters on water-oil-ratio (WOR) performance utilizing numerical simulation. Yet, a general predictive strategy was not developed.

Olabode et. al (2018a) designed an experiment from oil rim uncertainties using a wider variety of reservoir parameters to develop a response surface model under concurrent production to estimate oil and gas recovery before coning. Chapplelear and Hirasaki (1976) built up a hypothetical model which can be introduced into a finite-difference reservoir simulator. The model existed for oil-water coning in an incompletely perforated well. The resultant coning model which is expressed as equation, shows the relationship between the (h) average oil column thickness, water cut, f_w, and (q_t) total rate.

Kuo and Desbrisay (1983) used material balance to forecast the increase in the oil-water contact of a homogenous reservoir. The sensitivity of water coning performance to various reservoir parameters was conducted, with numerical simulation. The results were correlated to the following dimensionless parameters; $(f_w)_D$ Dimensionless water cut, t_{DBT} Dimensionless breakthrough time, (WC)limit dimensionless limiting water cut.

Lee and Tung (1990) demonstrated the average cone formation speed as the inverse of the time it takes to water breakthrough. The water breakthrough time correlations were initially created in view of three significant controlling parameters: q (flow rate), (density difference) C and (mobility ratio) m. At that point, the impact of (h) aquifer thickness, and perforation interval were combined with the correlations. A single practical form with three coefficients and an independent adjustable time was formulated to show the performance of water cut. There are three coefficients reliant on the controlling parameters. In a bid to study and decipher the challenges of water coning assuming a strong aquifer, Kabir et al. (2000) studied the effect various parameters have on water coning from a single well model developed. Olabode et al. (2018b) did a simulation study to investigate alternative completions techniques, utilizing single or dual lateral and cone inversion strategies was also investigated. They also studied the effect of a grid refinement, drainage area size and anisotropy. They also observed that k_v/k_h ratio is a parameter that is critical in coning appraisal. Olabode et al. (2018) also verified that increasing horizontal well length can not only improved gas productivity but also prolong condensate formation when compared to vertical wells. Permadi, and Jayadi (2010) examined the impact of the forces of interaction on reservoir production performance of a horizontal well whose primary drive was water drive from an aquifer. In their study, they a model built for simulating production performance of the well. The result analysis showed a robust connection existing between the forces of interaction and well production, and production performance of a reservoir rise as the ratio of gravity and viscous forces rise for all the cases examined. Mjaavatten (2006) studied coning and established a mathematical model capable of predicting the rate dependent GOR and the performance of coning. The model developed is based on based on a simplified depiction of the interaction between the reservoir and the well and a dynamic model which forms the basis for the defining the reservoir behavior. The model has been used in validating oil wells on the Troll field and the results was good and encouraging.

3. METHODOLOGY

3.1. Simulation with ECLIPSE 2010

A commercial (3D) three phase black oil simulator, ECLIPSE 2010 was used to simulate gas and water coning in a horizontal well that is placed in an oil zone between an aquifer and a gas cap. The model having a horizontal well is placed in a box model having an oil zone between the overlying a gas cap and underlying aquifer and assumes:

i. There is no flow across the outer boundary
ii. Capillary pressure is negligible
iii. Frictional losses in the horizontal wellbore is negligible.

3.2. Reservoir Model

The model imitates oil reservoir, 150` by 150 by 50 thick. The fluid in the reservoir consists of gas, oil and aquifer. The reservoir model was subdivided into 8 X 8 X 10 grid blocks. In the z- direction, finer grid spacing was used for simulating water and gas coning into the horizontal well. The reservoir is produced from a horizontal well which is placed at the reservoir center and perforated along the center of the horizontal well length.

There are 640 cells in the model, Fig 1 and Fig 2 displays the initial condition of the three-dimensional model. Datum depth is given as 6500ft, the pressure at datum depth given as 3200 psi, the gas oil contact was at 6750ft, water oil contact as 7000ft.

3.3. Plot of WOR against h_{bp}

A plot of water-oil-ratio (WOR) against h_{bp} was made on a Cartesian graph and examined. Thus, showing the relationship between the two parameters, as shown in fig. 4 below. Upon oil production, the WOR is initially at zero. Consequently, as production continues, the oil column decreases and the aquifer in a piston-like displacement manner moves upwards to occupy the vacuum created by the produced oil, thereby reducing the height of oil column beneath perforation, h_{bp}. Eventually at some point, there was water breakthrough in the well (WOR $\neq 0$), the height of oil column below perforation, $h_{bp,}$ at this point is termed height of oil column below perforation at breakthrough, h_{bb}.

3.4. Plot of GOR against h_{ap}

Following the approach for the (WOR) water-oil-ratio, the GOR was plotted against the h_{ap} on a Cartesian graph and observations were made. This is shown in fig.5 Subsequently, the GOR is zero (GOR=0) upon initial oil production. However, as production continues the gas cap in a piston-like displacement pushes down on the oil and moves in to occupy the space supposedly left empty by the produced oil, thus reducing the height of the oil column above the perforation, h_{ap}. At some point, there was gas breakthrough in the well (GOR $\neq 0$), the height of oil column above perforation, $h_{ap,}$ at this point is termed height of oil column above perforation at breakthrough, h_{ab}.

3.5. Parameter Sensitivity Analysis

Various reservoir and fluid parameters was investigated extensively by carrying out sensitivity analysis to ascertain the parameters that have the greatest influence on coning behaviour in horizontal wells. The base case data is varied. The parameters are varied and estimated by 28 simulation runs during parameter sensitivity analysis. The sensitivity of each well parameter to coning behavior was studied independently such that only one parameter s varied per time.The specific interest is to understand how the varying well parameters affects (h_{bb}) oil column height beneath perforations at breakthrough and (h_{ab}) oil column height above the perforations at breakthrough. Taken into consideration is the time of breakthrough of water and gas into the well.

3.6. Model Development

Following sensitivity analysis on the parameters, which have the greatest effect on simultaneous gas coning and water coning. In a bid to predict the post breakthrough performance of the horizontal wells, general correlations are derived for the (a) simultaneous water and gas breakthrough time (b) WOR and GOR after breakthrough has occurred

- The height of the oil column above the perforation at breakthrough, h_{ab}. (GOR≠0)
- The height of the oil column above the perforation at breakthrough, h_{bb}. (WOR≠0)
- The slope of h_{bp} against WOR after breakthrough has happened. The slope varies with each of the well parameters considered by the parameter sensitivity analysis.
- The slope of GOR against h_{ap} after breakthrough has occurred. The slope differs with each of the parameters of the well-considered by the sensitivity analysis.

Upon determining the (m) slope and the oil column height above and below the perforation at breakthrough (h_{ab} and h_{bb}), an equation for the GOR and WOR after breakthrough can be derived by using the general equation of a straight line.

Generally, the basic equation of a straight line:

$$y = mx + c \qquad [5]$$

Where slope, m is given by:

$$m = \frac{y - y_1}{x - x_1} \qquad [6]$$

Where (x_1,y_1) are points on a straight line.

In this case, (x_1,y_1) is the point where the breakthrough occurs, i.e (0,h_{bb}). The equation for the straight line written in terms of WOR and hbp is given as;

$$WOR = -m\left(h_{bp} - h_{bb}\right) \quad \text{for } (h_{bp} < h_{bb}) \qquad [7]$$

This equation applies only to post breakthrough performance of the well. Thus, before the occurrence of breakthrough, GOR and WOR is taken to be zero. Before the eventual breakthrough of gas and water into the well, the GOR and WOR is given as thus:

$$WOR = 0\ for\ \left(h_{bp} > h_{bb}\right) \qquad [8]$$

3.7. Generalized correlations

Generalized correlations are established from the result of sensitivity analysis in order to determine the breakthrough time and breakthrough height. The collected data from the simulation runs was subjected to a non-linear regression analysis using SPSS 17 to develop correlations for optimum horizontal well location with respect to (WOC and GOC) and breakthrough time.

3.8. Non-Linear Regression using SPSS 17

Regression is a process of determining a line or curve that represents best the general trend of a data set [7]. Non-linear regression is a technique that involves finding the non-linear model of the relationship between the set of independent variables and dependent variable. Non-linear regression can estimate models having an arbitrary connection between dependent and independent variables. This is realized using an iterative estimation algorithm. Non-linear regression involves setting up a model equation that includes all the independent variables and dependent variable. The model equation also includes the unknown parameters known as the nonlinear regression parameters, these unknown parameters are the parts of the model that the non-linear regression procedure estimates. The non-linear regression analysis was performed with SPSS 17. SPSS 17 is a comprehensive system for analyzing data. SPSS statistics can take data from almost any file and generate tabulated reports, charts, and plots of distributions and trends, descriptive analysis and complex statistical analysis.

4. RESULT AND DISCUSSION

4.1. Sensitivity Analysis Results

A sensitivity analysis was done on the parameters which was used for developing generalized predictive correlations to calculate the breakthrough time (Tbg), the height of oil column below and above perforations at breakthrough (h_{ab} and h_{bb}) and the GOR and WOR after breakthrough. The breakthrough time is the time the other phases apart from oil eventually break s into the well. The height of oil column above and below the perforation gives a suggestion of the original oil recovered before coning eventually sets in. The lower the height of this column, ultimately will result in more oil production before the simultaneous production of gas and water sets in. with the slope of GOR and WOR curves acting as a measure of post breakthrough performance.In conducting the sensitivity analysis on the parameters, a base case scenario is initially assumed, and the following simulation runs was conducted by changing the base case data scenario. Seven parameters were varied keeping one constant to arrive at 32 simulation runs for a horizontal well. The analysis is a function of the following parameters: vertical permeability, porosity, horizontal permeability, length of perforation, oil flow rate, height above the perforation, height below perforation and the areal extent of the reservoir. The results of the sensitivity analysis are shown in the Table 1:

4.2. Oil Production Rate Effect

The oil production rate was varied starting from a base case of 1500 to 5500 stb/day (1500, 2500, 3000, 4000, 5500) resulting in five simulation runs. Table 1 and fig. 6 shows increases in the rate of oil production results at an increase in the simultaneous coning rate of gas and water into the horizontal well. This relationship is seen in graph showing the variations of oil production rate to breakthrough time.

This increase in oil rate is inversely proportional to the breakthrough time, indicative of the fact that increasing the production rate will result in an earlier breakthrough time and coning occurring.

However, the overall oil recovery increases with flow rate, the quantity of oil produced before the simultaneous production of the three reservoir fluids is affected by the oil column height below and above perforations at breakthrough (h_{ab} and h_{bb}). Consequently, as production rate is increased, a smaller amount quantity of "water free" oil and "gas free" oil will be produced before eventual simultaneous coning into the well despite oil recovery increase with flow rate. This again supports the fact that increasing the oil production rate will increase the rate of simultaneous coning into the well. The effect of oil flow rate on the slope of the WOR- h_{bp} curve is minimal after xxx STB/D. This indicates that variations in flow rate only affect the time at which water coning begins, once water breaks into the well, subsequent changes in oil flow rate has minimal effect on GOR and WOR.

4.3. Horizontal Permeability Effect

The horizontal permeability base case scenario was varied from 1000mD to 5000mD to setup five different simulation runs. Table 1 and fig. 8 indicates a proportionally inverse relationship between horizontal permeability and simultaneous coning. Looking at the plot, increasing the horizontal permeability will reduce the time to coning, as shown in the breakthrough time and WOR-h_{bp} slope curve after breakthrough. Table 1 and fig. 9 show that the breakthrough time increases with the horizontal permeability of the reservoir. In addition to this, slope of the WOR-h_{bp} curve decreases with attendant increases in the horizontal permeability. This is indicative of the fact that, the WOR of the well decreases with the horizontal permeability. As stated earlier, the oil column height above and below the perforations at breakthrough (h_{ap} and h_{bp}) as an indirect relationship with the oil produced before water production commences. The h_{bh} decreases with an increase in the horizontal permeability. This shows that a higher quantity of “gas free” oil and “water free” oil can be produced but results with increases in horizontal permeability. The relationship between the horizontal permeability and the water coning behaviour in a horizontal well is less significant as the horizontal permeability increases.

4.4. Vertical Permeability Effect

The effect of vertical permeability on simultaneous coning is less significant in horizontal wells. Table 1 and fig. 10 indicate that increases in vertical permeability could causes slight delay in coning occurring. The vertical permeability effect was studied by varying the vertical permeability from the base case of 100mD to 500mD. Increases in the vertical permeability results in a corresponding increase in the time of breakthrough of water and gas into the well. The oil column height below and above the perforation at breakthrough is reduced because of increasing vertical permeability. Indicative of the fact that a larger volume of oil is produced before coning sets in.

4.5. Porosity Effect

Porosity effect is illustrated by varying the base case of 0.1 to 0.3. It is seen that porosity affects the parameters in various ways making it a bit complex. Table 1 and fig. 13 shows that increase in porosity of the formation have a large effect on the breakthrough time in the well. Resulting in delayed coning into the well with increases in porosity. However, the WOR increases with the porosity of the formation once water breaks into the well and because of the slight increase in the slope of the WOR-hap curve with the porosity of the formation. This effect reduces with increasing porosity values.

4.6. Height above Perforation Effect

Varying the height above the perforation form the base case from 60ft to 88ft for four simulations run. A higher height above the perforations implies that the well is completed closer to the WOC and vice versa. Table 1 and fig. 14 shows that increases in height above perforation speeds up the onset of coning by reducing the breakthrough time. However, the height of oil column below the perforations at breakthrough decreases with the height above perforation. This indicates the production of a higher “water free” oil and “gas free” oil, before the onset of coning for wells completed further away from the WOC. After breakthrough, there is a notable reduction in the slope of the WOR-hap curve with the height above the perforations decreases the WOR after breakthrough.

4.7. Length of Perforation Effect

The horizontal well length was examined by varying the perforation length of the well from the initial base case of 1000ft to 3000ft. At breakthrough the length of perforations only slightly affects the breakthrough time and the oil column height below the perforations. In other, words the length of perforations has only a slight effect on the determination of the onset of coning. Details of the effect length of perforation on coning behaviour are shown in table 1 and fig. 16. However, after water breaks into the horizontal well the length of perforation has a significant impact on the WOR. After breakthrough increase in the length of perforation causes reductions in the slope of the WOR-hap curve. As a result, longer perforations in horizontal wells bring about reductions in the WOR after breakthrough and thus improve the post breakthrough performance of the horizontal well.

4.8. Areal extent of reservoir

The areal extent as studied in the analysis was varied from 30 acres to 190 acres. It indicated that holding other parameters constant and increasing acres will delay the onset of coning into the well. The reservoir fluid and property data and geometry is shown in appendix A.

5. (BASE CASE SCENARIO) CASE STUDY

Post Breakthrough Performance Prediction

The post breakthrough performance of horizontal wells was predicted using the generalized correlations. The effectiveness of the correlations is study in the base by the reservoir simulation. This shows that the prediction using generalized correlation for post breakthrough performance is as good as the one obtained using ECLIPSE simulator. The variation may be said to be a result of the complex nature of simultaneous coning.

Several factors affecting coning were not factored in this work and as such contributes to the disparity in predictions with simulator. These include:

- Drainage radius of reservoir
- Effect of pressure on coning
- Density difference

Table 2 shows that generalized correlation gives almost the same result as the simulator.

6. CONCLUSIONS

Despite the use of horizontal wells, the production of an unwanted phase can greatly affect productivity at large. In horizontal wells increase in flow rate accelerates the rate of coning and high horizontal permeability delays coning. Vertical permeability has little effect on coning behavior before breakthrough. However once breakthrough occurs, water-oil-ratio (WOR) rises with vertical permeability. Porosity has no or little influence on post breakthrough performance. However, increase in porosity delays coning and increase in height above perforation (wells completed closer to WOC) accelerates water coning rate. The Increases in perforation length delays time to breakthrough. A set of correlations to predict time of breakthrough and post breakthrough performance was proposed. A design of experiment can be made on all contributing factors to coning instead of running individual sensitivity analysis on factors as described by Olabode et al. (2018a).

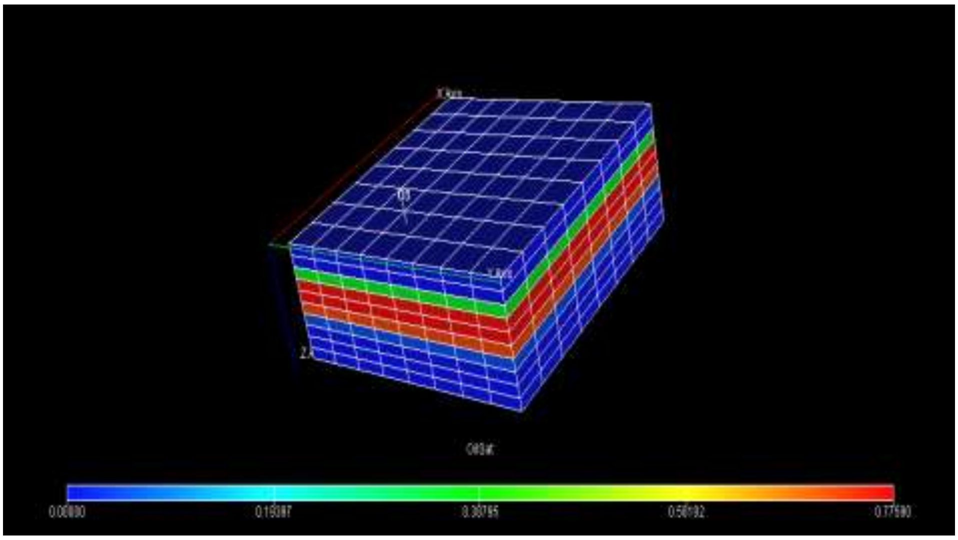

Figure 1 (initial Oil saturations) Initial conditions of the box model

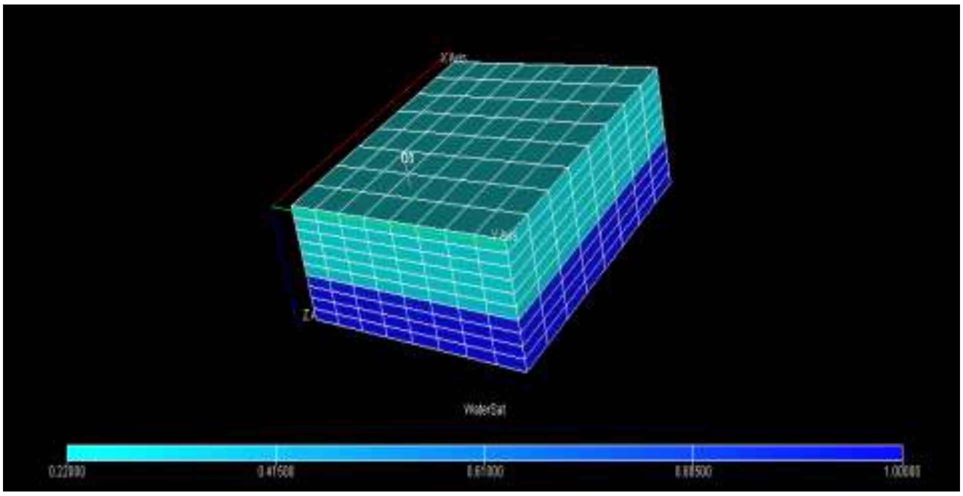

Figure 2 (Initial water saturation) Initial conditions of the box model

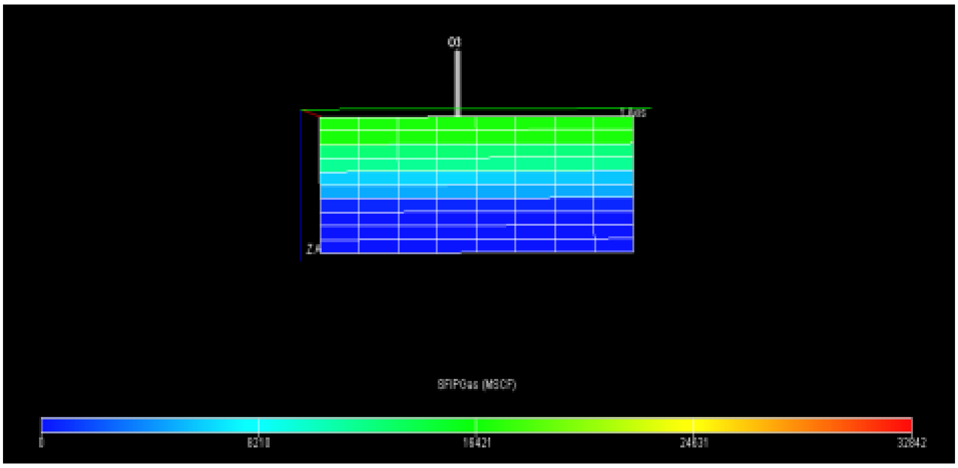

Figure 3 Animation showing water and gas movement due to coning

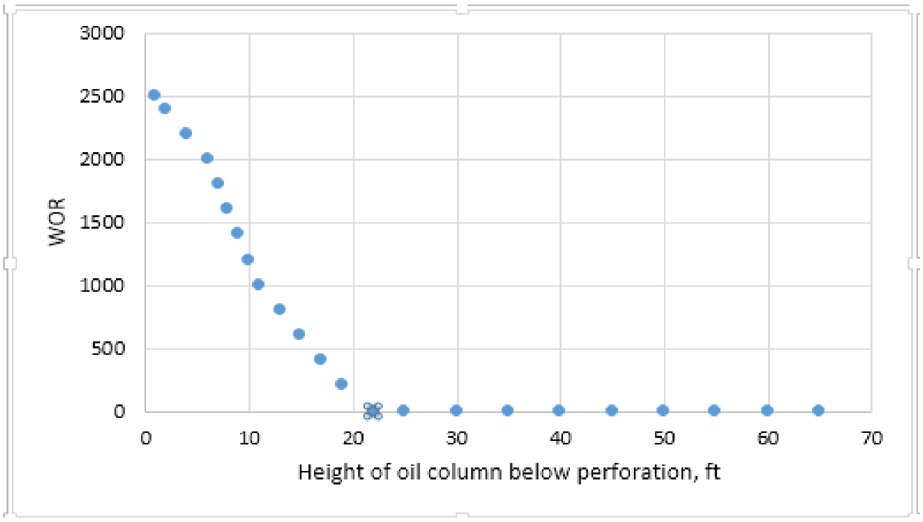

Figure 4 WOR vs Hbp for the base case scenario

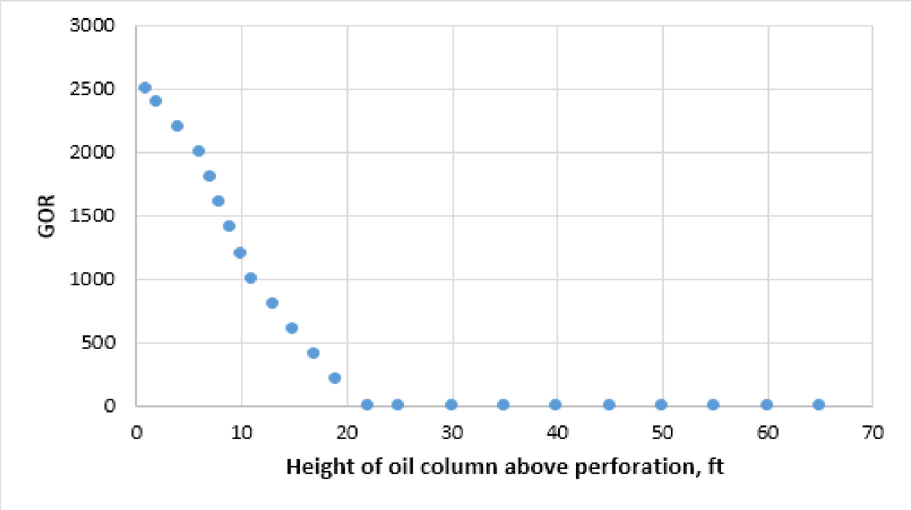

Figure 5 GOR vs Hap for the base case scenario

Table 1 Different breakthrough time correlations

S/N	Q(stb/d)	Kh(mD)	Kv(mD)	poro	hap (ft)	Lp (ft)	Acres (acres)	hbg (ft)	tbg (years)
Base	1500	4000	200	0.176	60	1000	120	27.32	9.02
1	2000							39.5	3.22
2	2500							45.32	1.97
3	3500							49.2	1.54
4	5000							57.98	0.75
5		1000						37.27	6.92
6		2500						31.52	7.04
7		4000						26.33	7.98
8		5000						22.21	8.92
9			100					30.28	8.33
10			200					26.55	9.35
11			400					24.32	9.56
12			500					21.98	9.98
13				0.1				27.89	5.76
14				0.176				26.82	11.78
15				0.2				25.32	12.76
16				0.3				24.52	18.45
17					60			21.99	6.89
18					67			18.77	5.09
19					78			14.55	4.52
20					88			12.22	1.98
21						1000		20.83	10.26
22						1500		19.11	10.99
23						2500		14.21	11.31
24						3000		13.28	12.01
25							30	34.32	1.34
26							80	26.62	4.53
27							120	25.43	7.89
28							190	24.87	15.89

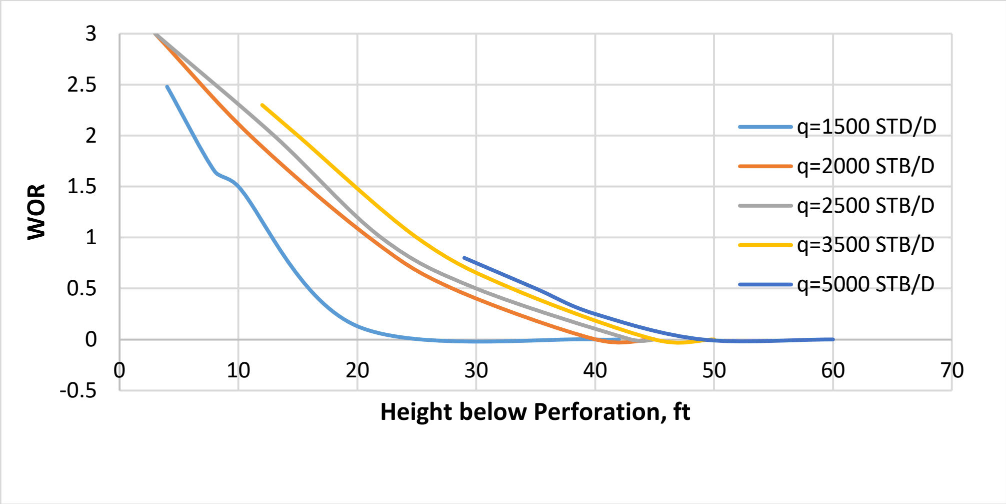

Figure 6 Effect of production rate on breakthrough height and WOR after breakthrough

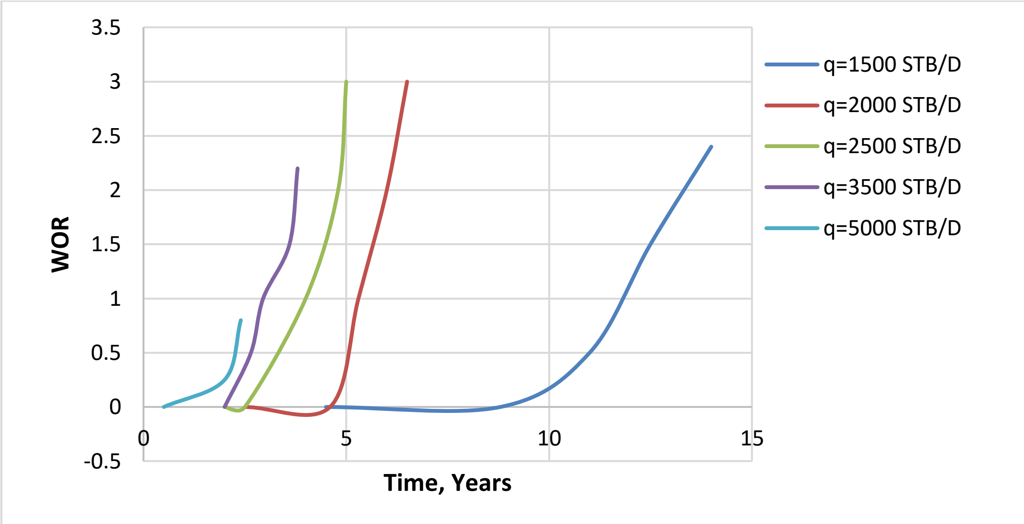

Figure 7 Effect of production rate on breakthrough time

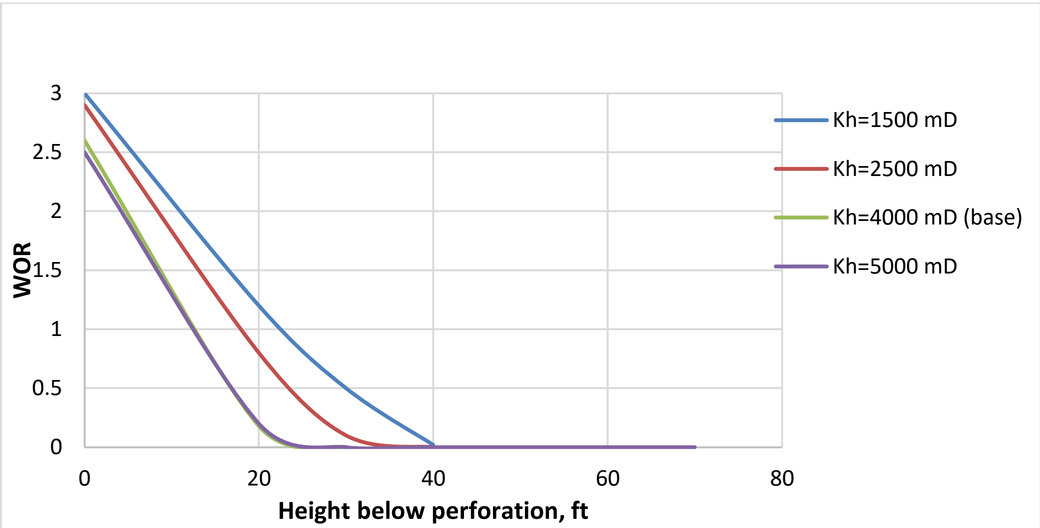

Figure 8 Effect of Horizontal permeability on breakthrough Height and WOR after breakthrough

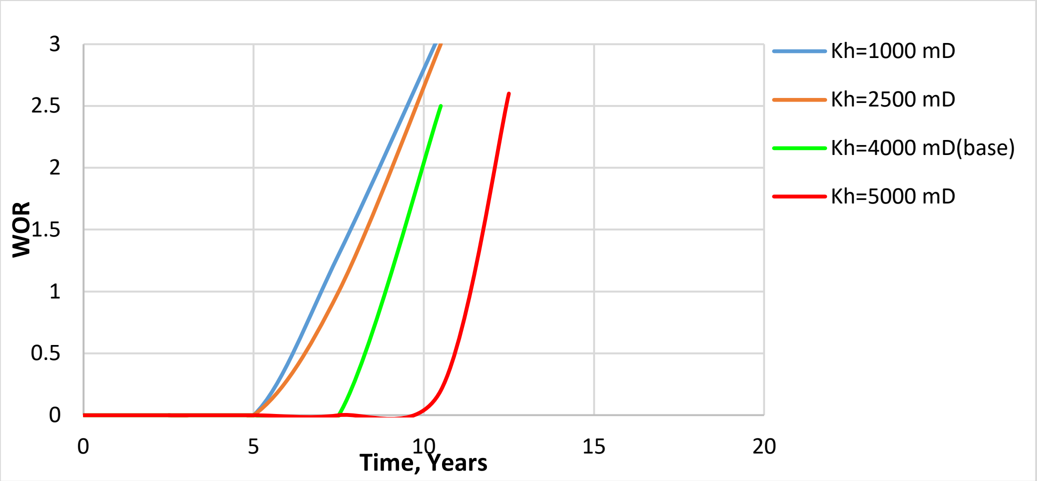

Figure 9 Effect of horizontal permeability on breakthrough time

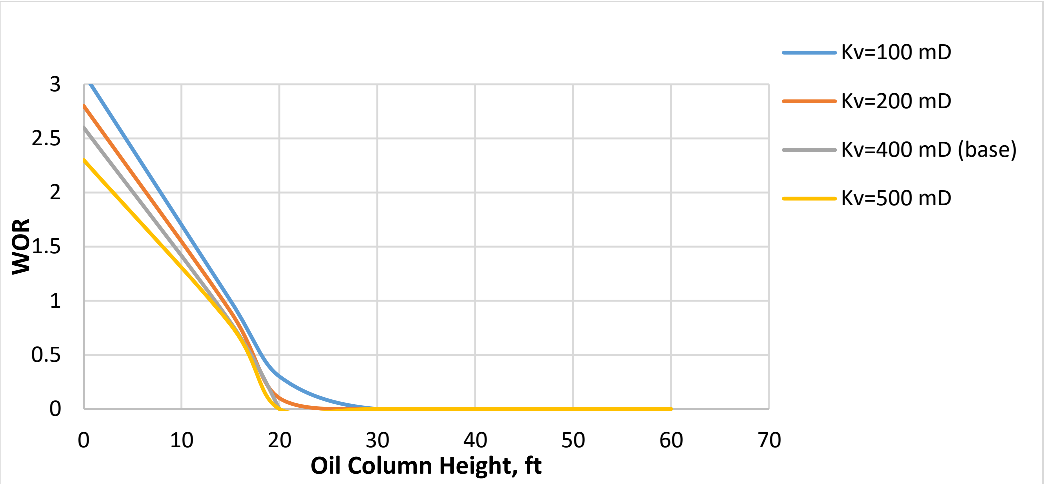

Figure 10 Effect of vertical permeability on breakthrough height and WOR after breakthrough

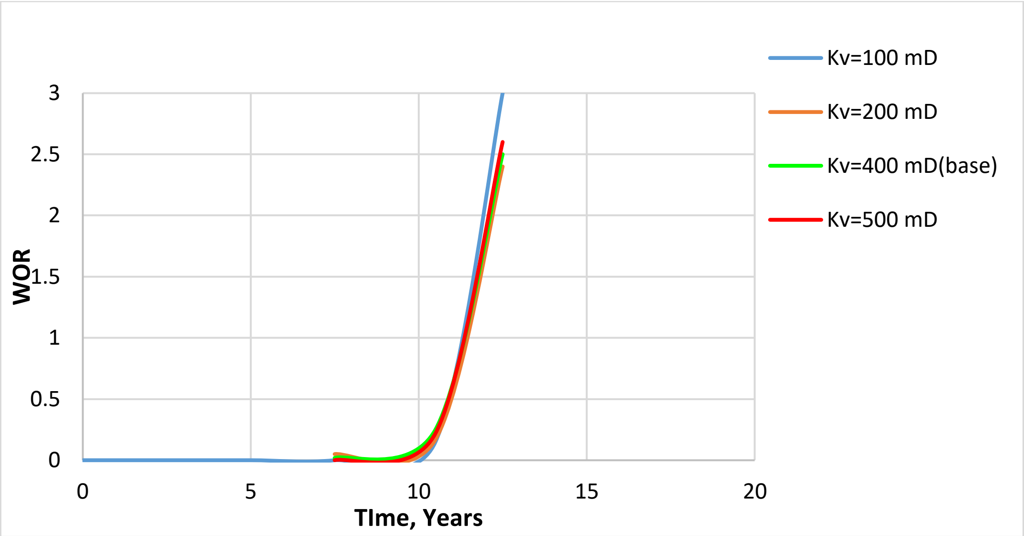

Figure 11 Effect of vertical permeability on breakthrough time

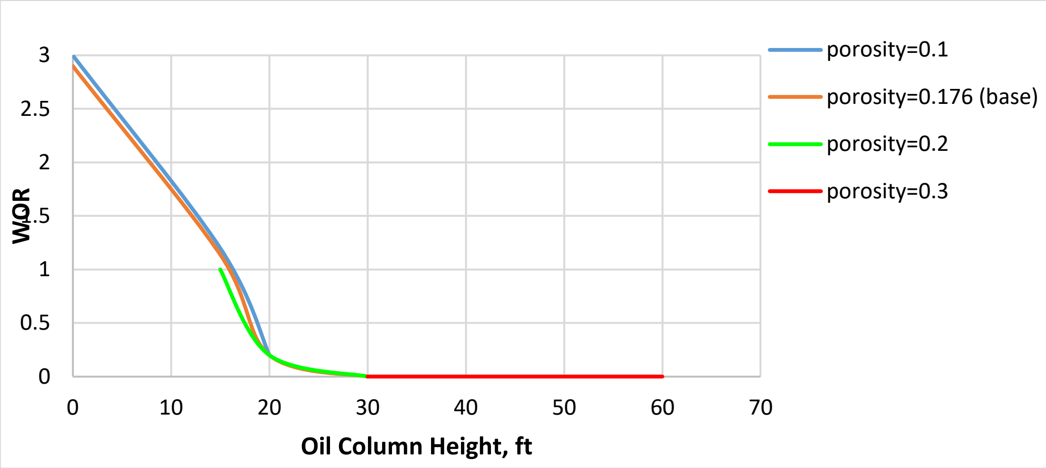

Figure 12 Effect of porosity on breakthrough height and WOR after breakthrough

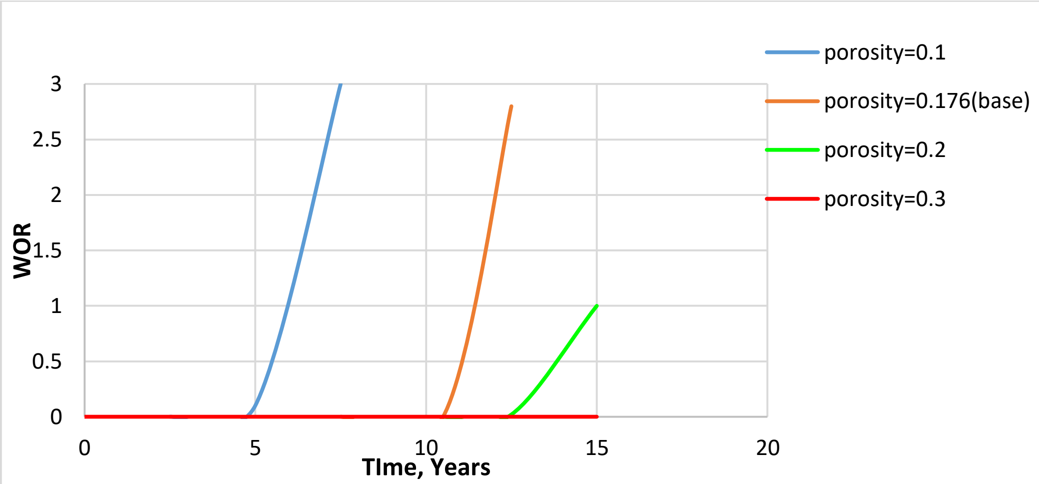

Figure 13 Effect of porosity on Breakthrough time

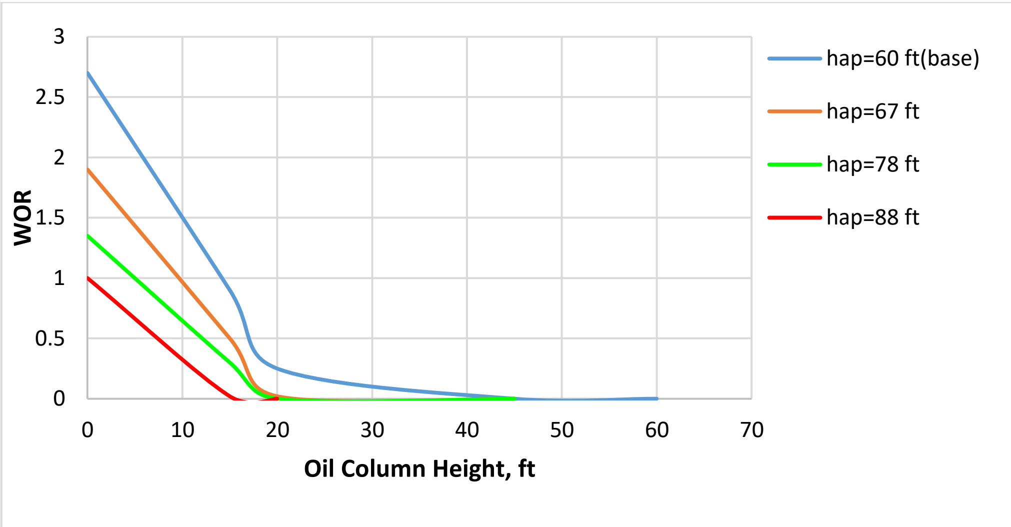

Figure 14 Effect of Oil column height above perforations on breakthrough height and WOR after breakthrough

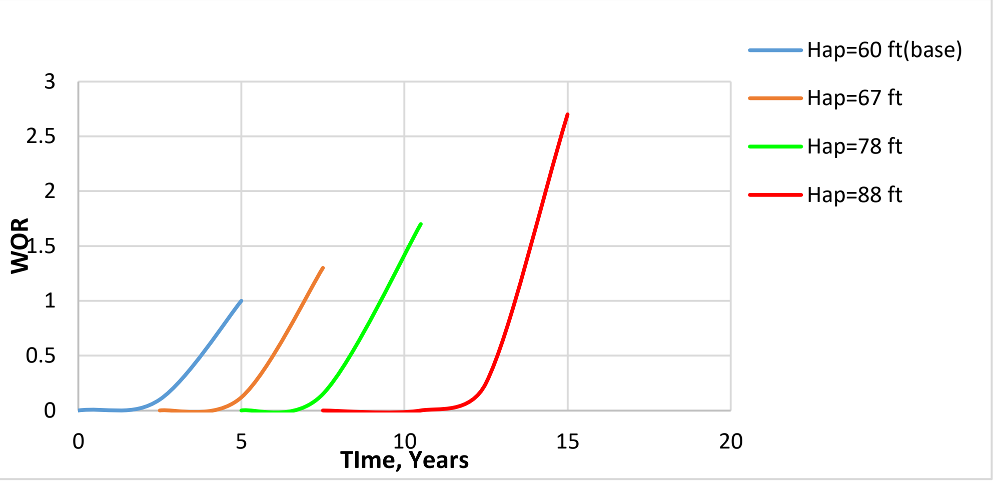

Figure 15 Effect of oil column height above perforations on breakthrough time

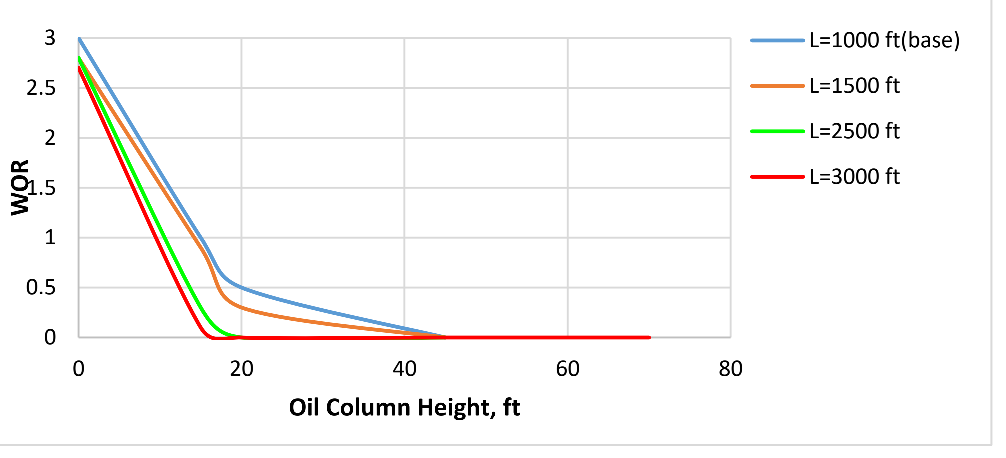

Figure 16 Effect of perforation length on breakthrough height and WOR after breakthrough

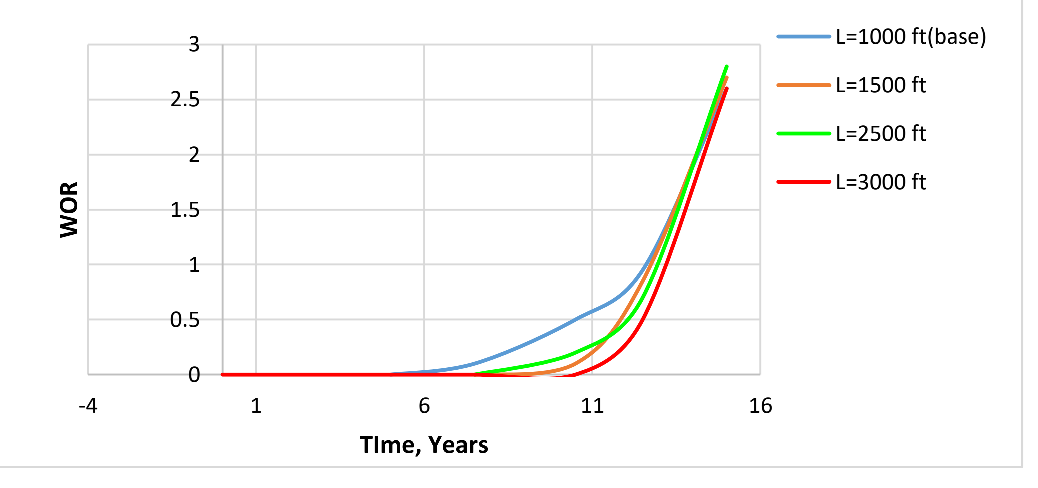

Figure 17 Effect of Perforation Length on breakthrough time

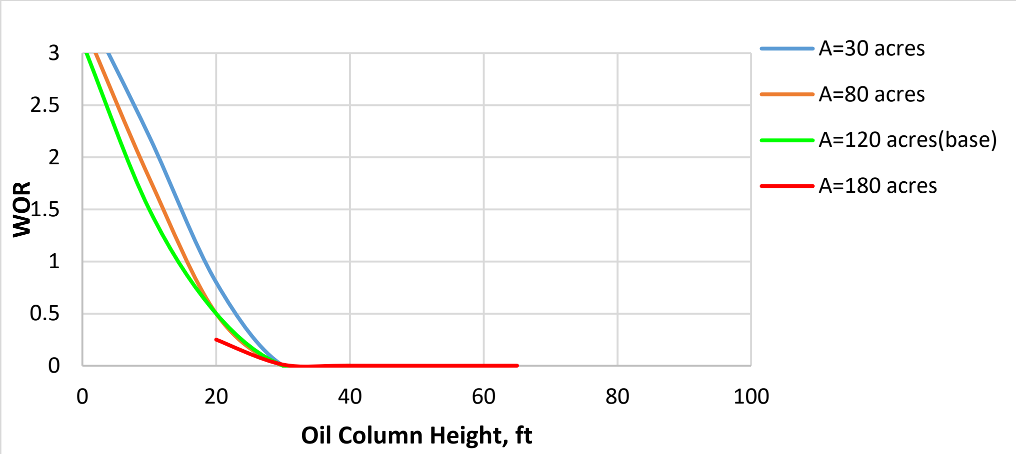

Figure 18 Effect of area on breakthrough height and WOR after breakthrough

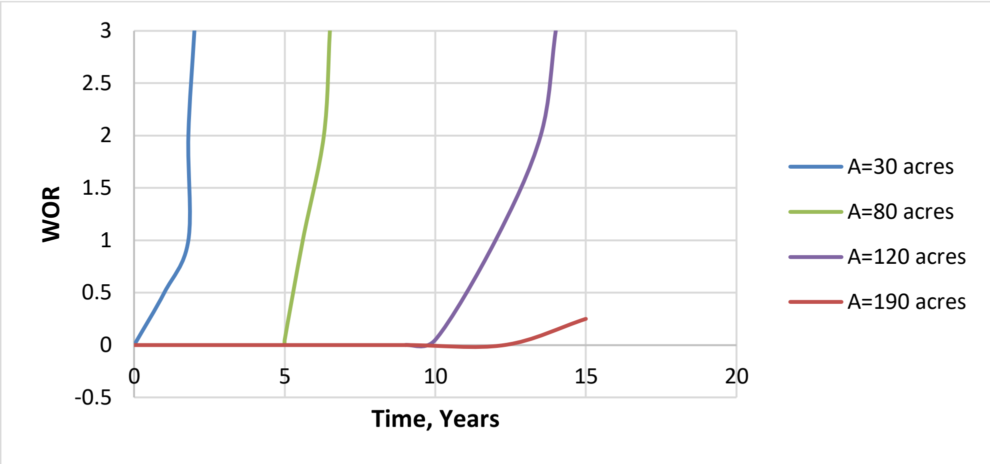

Figure 19 Effect of area on breakthrough time

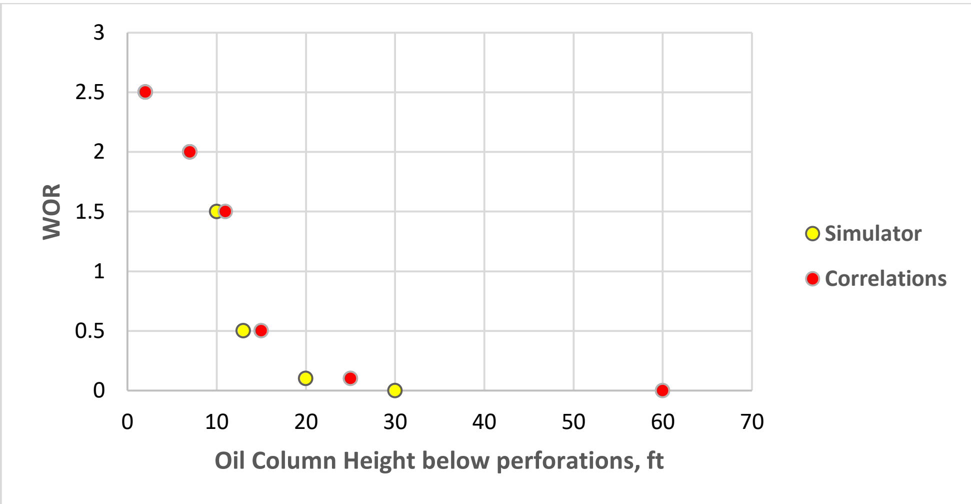

Figure 20 Comparison between correlation and simulator.

Table 2 Different breakthrough time correlations

Predicting Breakthrough Time

Method	Breakthrough Time (Years)
Wagenhofer (1994)	10.2
ECLIPSE	9.84
Generalized correlation	9.02

APPENDIX A: RESERVOIR AND FLUID PROPERTIES

Reservoir Fluid Data

Table A1 Reservoir Fluid Data

Gas surface density	0.04104 lbm/cu.ft
Oil surface density	56.85 lbm/cu.ft
Water surface density	65.55 lbm/cu.ft
Water viscosity (Vw)	0.5 cp
Water FVF (Bw)	1.0 rb/stb
Water Compressilbility (C)	3E-6 psi^{-1}

Table A2 Endpoints of relative permeability curves with corresponding mobility ratios

Mow	Krw	Kro	Mog	Kro	Krg
1	0.19375	1	25	0.26414	1
2	0.3875	1	50	0.52825	1
3	0.58125	1	75	0.79243	1
8	1	0.64514	146.7	1	0.64613
10	1	0.51631	183.38	1	0.51641

Pressurization (PVT) data

Table A3 Presuurization (PVT) data

Pressure (psia)	B_g(rb/Mscf)	μ_g (cP)	R_s (Mscf/stb)	B_o (rb/stb)	$\mu_{o\ (cP)}$
14.7	208.974	0.01280	0.0012250	1.04	18.57
500	5.86600	0.01320	0.0602210	1.07	8.285
1000	2.81000	0.01390	0.1285700	1.10	5.5052
1500	1.85300	0.01490	0.2000000	1.132	3.617
2000	1.33400	0.01610	0.2744000	1.16	2.821
2500	1.06400	0.01750	0.2503000	1.19	2.318
3500	0.78600	0.02050	0.5000000	1.25	1.722
4500	0.65200	0.02350	0.7000000	1.31	1.380
5000	0.60900	0.02500	0.8000000	1.345	1.259

Reservoir Data

Table A4 Reservoir Data

Length	1200 ft
Width	1200 ft
Thickness	500 ft
Depth of reservoir	6500 ft
Datum Depth	6500 ft
GOC Depth	6750 ft
WOC Depth	7000 ft
Thickness of aquifer	150 ft
Thickness of gas cap	180 ft
Rock compressibility	4.0E-6 psi^{-1}
Initial Datum Pressure	3200 psi
Oil thickness zone	170 ft
Length of perforation	1000 ft
Average porosity	17.6%
Average horizontal permeability	4000mD
Average vertical permeability	200 mD

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