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A SIMULATION STUDY OF WATER INVASION IN THE FRACTURED GAS RESERVOIR BY USING A FULLY IMPLICIT COMPOSITIONAL SIMULATOR

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Abstract

Water coning is a complicated process which relies on a set number of parameters which are production rate, perforation interval, mobility ratio, capillary pressure, etc. Its production can mainly influence the efficiency of a well and the reservoir. In fractured reservoirs, the process is more complicated because of high fracture permeability. With this compliance in mind, water coning phenomenon in the fractured gas reservoir was investigated by simulating a reservoir using ECLIPSE-300 Compositional Simulator. A sensitivity analysis of different parameters including permeability and porosity of fracture and matrix was conducted to better describe and understand the mechanism of water coning in the studied gas reservoir. Results of the present work showed that vertical and horizontal permeability of the fracture, horizontal permeability of the matrix, the porosity of the fracture and the matrix have a significant effect on the time between water breakthrough and its production, which leads to better understa nding of the coning phenomenon.

***Keywords**: Water conning; Gas reservoir; Simulation; Eclipse-300; Sensitivity analysis.*

1. Introduction

Water production from oil wells is a natural process in oil reservoirs [1-3]. This is referred to one some indexes including; an increase of oil-water contact (WOC), water coning in addition to water fingering. Production of oil from a well completed in oil layer surrounded by water may result in the oil/water interface to change into a bell shape [4-5]. This change is namely water coning [6-8]. On the other hand, coincide production of oil and water from the well due to the difference between viscous and gravitational forces is usually called water coning. Water coning process is a complicated problem in the oil industry [9-13]. This phenomenon is more complicated in fractured reservoirs [9]. In another word, this process in fractured reservoirs usually leads to the massive production of water which can damage a well or drastically its production efficiency [14]. Three parameters are important in the investigation of water conning phenomenon namely: critical rate, the breakthrough time and water cut performance after breakthrough [3-6, 15-18]. The critical rate is usually defined as the maximum possible oil flow rate which can be produced from the well to prevent a cone breakthrough [19]. In fractured reservoirs, the critical rate is effected by additional parameters including fracture storativity (ω) and fracture transmissivity (λ) [1]. According to the rates, a cone with high velocity can be presented in the fracture while cone with low velocity is developed in the matrix. The position of these cones relative to each other is dependent on the rate and reservoir properties [21]. It is important to note that the main factor in evaluating water coning is the ration of permeability in the vertical and horizontal directions, kv/kh [14]. High value of vertical permeability in fractures are connected to increase the rate of the coning phenomenon leading to a decrease in the critical rates and more fast breakthrough times. Moreover, the channels of fluid flow within the fractures usually occured in fractured reservoirs is expected to influence wells [21]. In this study, the water coning behavior of a gas reservoir is investigated and the main parameters are influencing on this phenomenon were determined by applying a sensitivity analysis to obtained results.

2. Mathematical model

There are different mathematical models utilized in various circumstances in the Eclipse-300. The mathematical model of simulation is as below:

For the water and gas phases [22]:

$$\nabla\left[\frac{KK_{rw}}{B_w\mu_w}\nabla(p_w-\rho_w gD)\right]_f+q_w+\tau_{mfw}=\frac{\partial}{\partial t}\left(\frac{\varphi S_w}{B_w}\right)_f \tag{1}$$

$$\nabla\left[\frac{KK_{rg}}{B_g\mu_g}\nabla(p_g-\rho_g gD)\right]_f+q_g+\tau_{mfg}=\frac{\partial}{\partial t}\left(\frac{\varphi S_g}{B_g}\right)_f \tag{2}$$

In which K depicts absolute permeability; K_{rw} and K_{rg} stand relative permeability; B_w and B_g denote the formation volume factor; μ_w and μ_g indicate viscosity values; p_w and p_g depict pressure; ρ_w and ρ_g show the density of water and gas; g denotes the acceleration constant; D is depth; ∇ is gradient vector; q_w and q_g denote flow rates of water and gas, respectively; τ_{mfw} and τ_{mfg} are transfer equations from matrix and fracture, given by [22]:

$$-\tau_{mfw}=\frac{\partial}{\partial t}\left(\frac{\varphi S_w}{B_w}\right)_m \tag{3}$$

$$-\tau_{mfg}=\frac{\partial}{\partial t}\left(\frac{\varphi S_g}{B_g}\right)_m \tag{4}$$

In which φ *show the effective porosity of the reservoir;* S_w *and* S_g *denote the saturation of water and gas; subscripts "f" and "m" are stand for fracture and matrix.*

3. Reservoir model description

ECLIPSE-300 Simulator is utilized in the present study to investigate water coning in fractured gas reservoir. The model is dual porosity dual permeability. A Cartesian model is used in present work. The model has 50 layers in the vertical-direction, and 12, 24 grids in the x-direction and y-direction, the XY view of the model is depicted in Figure 1.

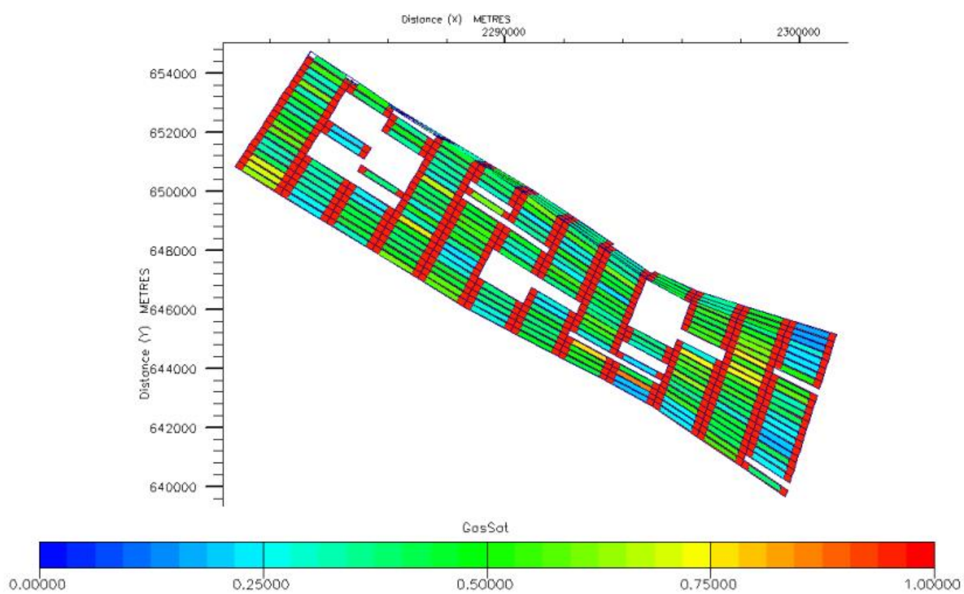

Figure 1. The XY view of the model

Since the conning phenomenon is occurred in the perforated interval of a well and below it, it is not required to have all grids of the model, and only the grids which are around the production well are required. In order to have a better simulation of conning phenomenon near the production well, an LGR is applied to the grids near the production well which is shown in Figure 2.

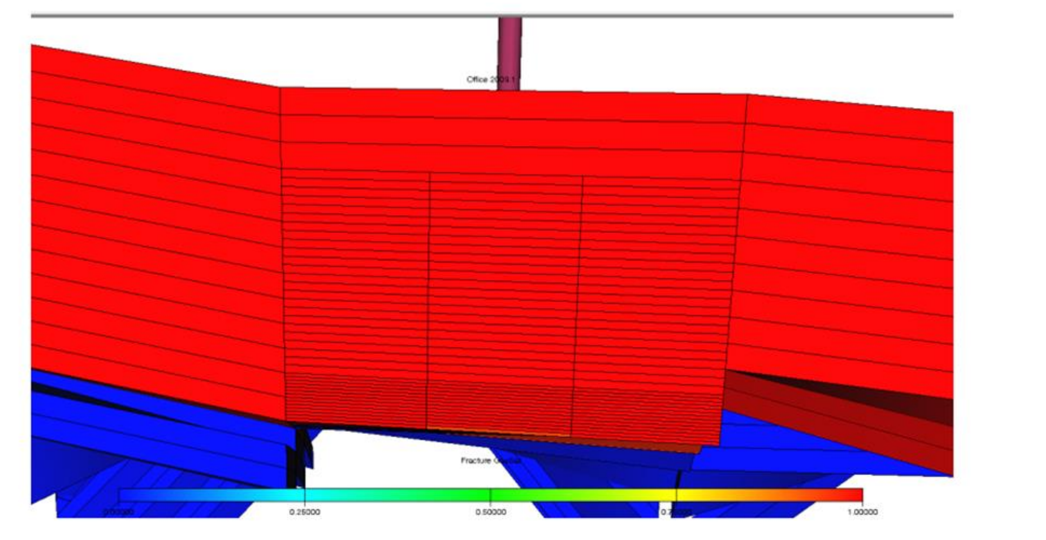

Figure 2. The LGR view applied to the perforated layers of the production well

Table 1 through 5 shows the properties of the rock and fluid utilized in the model. The formation volume factor, compressibility and viscosity of formation water at a pressure of 161.3 bar are 1.009317 rm^3/sm^3, 4.2878e-05 bar^{-1}, and 0.4562 cP, respectively. The formation rock compressibility factor was 4.45e-05 bar^{-1}, and reservoir temperature was 61.33°C. The PVTi software is utilized to describe the phase behavior of the reservoir fluid. The 3 parameter Peng-Robinson equation of state and Lohrenz-Bray-Clark viscosity model is used to simulate the phase behavior of reservoir fluid. The reservoir fluid composition data is depicted in Table 5.

Table 1. The water relative permeability and water-gas capillary pressure of matrix

S_w	K_{rw}	P_{cgw}	S_w	K_{rw}	P_{cgw}
0	0	13.79	0.6	0.415	1.38
0.1	0.006	5.16	0.7	0.56	1.11
0.2	0.033	3.69	0.8	0.72	0.83
0.3	0.117	2.8	0.9	0.86	0.34
0.4	0.193	2.07	1	1	0
0.5	0.3	1.72			

Table 2. The water relative permeability and water-gas capillary pressure of fracture

S_w	K_{rw}	P_{cgw}
0	0	0
0.5	0.5	0
1	1	0

Table 3. The gas relative permeability and water-gas capillary pressure of matrix

S_g	K_{rg}	P_{cgw}	S_g	K_{rg}	P_{cgw}
0	0	0	0.6	0.092	0
0.1	0.004	0	0.7	0.24	0
0.2	0.007	0	0.8	0.5	0
0.3	0.008	0	0.9	0.76	0
0.4	0.016	0	1	1	0
0.5	0.03	0			

Table 4. The gas relative permeability and water-gas capillary pressure of fracture

S_w	K_{rw}	P_{cgw}
0	0	0
0.5	0.5	0
1	1	0

Table 5. The composition of reservoir fluid

Component	Mole fraction	Component	Mole fraction
N_2	0.35	C_{4+}	0.0079
C_1	0.8883	C_6	0.0016
C_{3+}	0.529	C_{7+}	0.00310205
C_3	0.106	C_{12+}	0.0005795

4. Results and discussion

As mentioned before, several factors were utilized for the sensitivity analysis namely; anisotropy ratio (kv/kh), permeability and porosity of the fracture and porosity, permeability and porosity of matrix. The outcomes of this simulation are described as below:z

4.1. Anisotropy ratio

Figure 3 through 4 and Table 6 depicts the impact of anisotropy ratio in comparison to the base model. Figure 3 shows the impact of this ratio of various conditions on the water cut. The outcomes reveal that the increase in this ratio will increase the water cut. In another word, the coning process will be more severe with high vertical permeability (Kv) values. This due to the fact that coning is a cause of the movement of water in the vertical direction due to pressure drawdown in the wellbore.

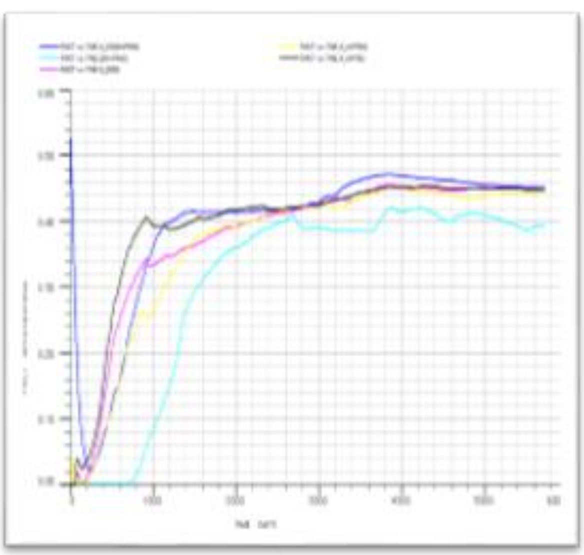

Figure 3. Effect of reservoir anisotropy on water conning

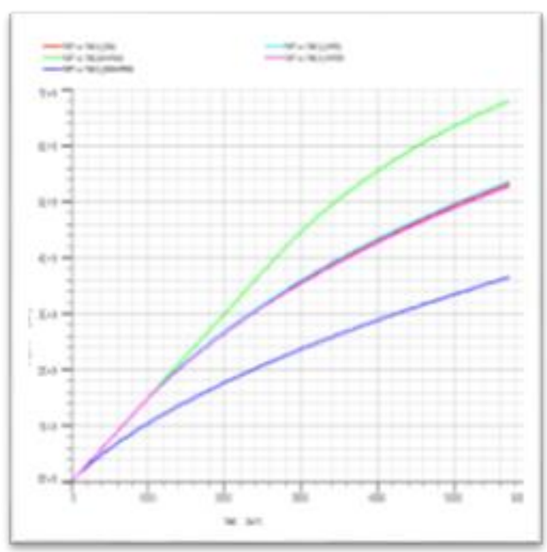

Figure 4. Effect of reservoir anisotropy on cumulative gas production

Table 6. Comparison between results of different horizontal and vertical fracture permeability

No	Work over type	Breakthrough time (day)	Fwct (15 years)	FGPT (SM^3)
1	0.5 Kh	5	0.46	3.65×10^6
2	2 Kh	808	0.40	6.79×10^9
3	0.5 Kv	254	0.44	5.27×10^9
4	2 Kv	76	0.44	5.35×10^9

According to Table 6, change in this ratio due to the change in the vertical permeability (Kv) enhances the movement of water in the vertical direction and leads to a decrease in the breakthrough time.

4.2. Fracture permeability

One of the most prominent factors in conning is fracture permeability. This is because the movement of the cone in the fracture is faster than that of the matrix. Figure 5 depicts the sensitivity analysis of various values of fracture permeability and the base model. Figure 5 shows the water cut from the various conditions in comparison with the base model. The outcomes show that the fracture permeability has an important influence on the break through time from the coning investigation. Results reveal that an increase in the fracture permeability increases the breakthrough time. In addition, the water cut and cumulative gas production of the reservoir with an increase in fracture permeability will remain constant.

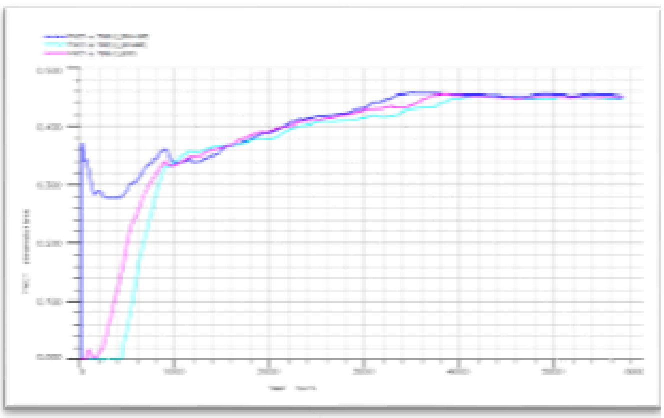

Figure 5. effect of horizontal fracture permeability variation on water cut

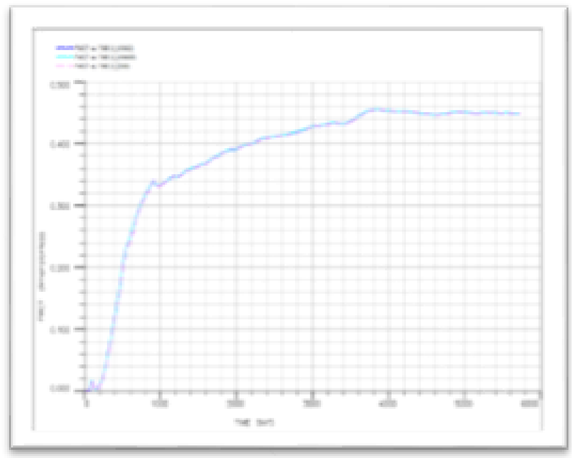

Figure 6. effect of vertical fracture permeability variation on water cut

Table 7. Comparison between results of different horizontal fracture permeability

No	Work over type	Breakthrough time (day)	Fwct (15 years)	FGPT (SM^3)
1	1.5 Kh	230	0.45	5.31×10^9
2	0.5 Kh	14	0.45	5.30×10^9
3	2 Kh	4449	0.44	5.32×10^9

The influence of variation of vertical permeability of fracture on breakthrough time, water cut, and cumulative gas production is depicted in Figure 6 and Table 8. Results show that the variation of vertical fracture permeability has no significant effect on water cut and cumulative gas production of the reservoir and these parameters remain nearly constant for all cases.

Table 8. Comparison between results of different vertical fracture permeability

No	Work Over Type	Breakthrough Time (day)	Fwct (15 years)	FGPT (SM^3)
1	1.5 Kv	230	0.45	5.31×10^9
2	0.5 Kv	230	0.45	5.31×10^9
3	2 Kv	230	0.45	5.31×10^9

4.3. Fracture porosity

Figure 7 shows the outcomes of the sensitivity analysis of fracture porosity in the model. The various conditions of fracture porosity are put into comparison with the base model. Figure 7 shows the water cut from various conditions of fracture porosity in comparison with the base model. According to these results, in can be concluded that the water cut is almost constant in various cases. But there was an increase in breakthrough time with an increase in fracture porosity. Hence, the increased fracture porosity leads to fast movement of gas from the matrix into the fracture. Hence, cone in the fracture and movement of water by gas will lead to high breakthrough time. Table 9 also shows that the increase in the fracture porosity will increase the cumulative gas production from the reservoir.

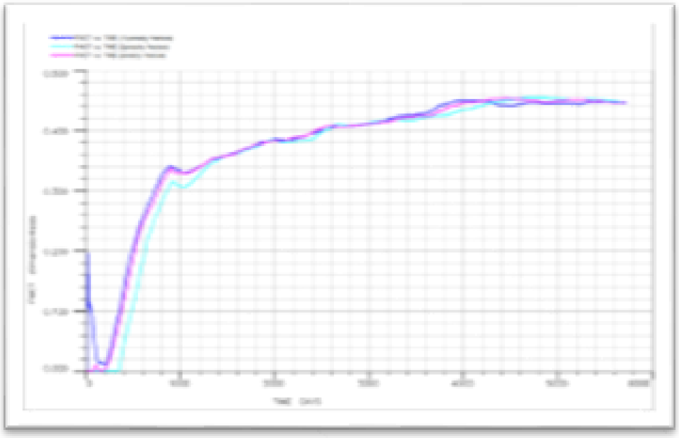

Figure 7. Effect of fracture porosity variation on water cut

Table 9. Comparison between results of different fracture porosity values

No	Work over type	Breakthroug time (day)	Fwct (15 years)	FGPT (SM^3)
1	φ_f	230	.45	$5.3181x10^9$
2	$.5\varphi_f$	7	.44	$5.2983x10^9$
3	$2\varphi_f$	352	.45	$5.3438x10^9$

4.4. Matrix porosity

According to the results of this case which are presented in Figure 8 through 9 and Table 10, it was observed that with an increase in matrix porosity, the amount of breakthrough time and cumulative gas production would increase. In addition, the value of water cut decreases with the increase in matrix porosity.

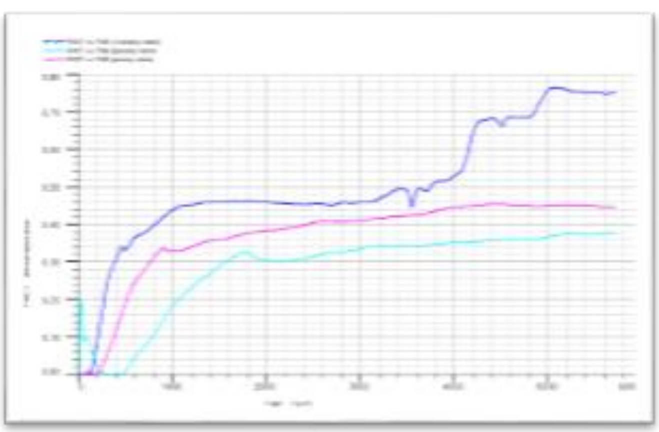

Figure 8. Effect of matrix porosity variation on water cut

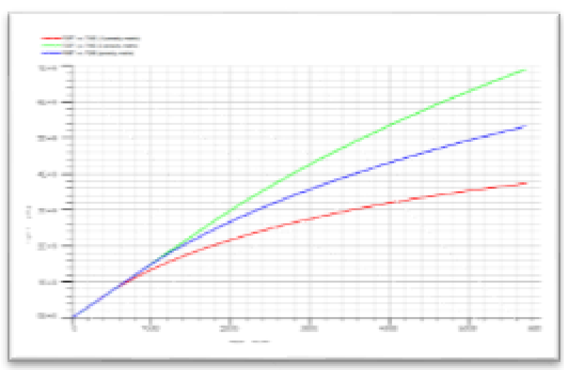

Figure 9. Effect of matrix porosity variation on cumulative gas production

Table 10. Comparison between results of different matrix porosity values

No	Work over type	Breakthroug time (day)	Fwct (15 years)	FGPT (SM^3)
1	φ_f	230	.45	5.3181x10^9
2	$.5\varphi_f$	147	.76	6.2886x10^9
3	$2\varphi_f$	518	.37	3.7257x10^9

5. Conclusion

Water coning phenomenon is very important in the oil industry. This process is more complicated in the fractured reservoirs. In present work, a sensitivity analysis was done to evaluate the dependency of several factors to the coning phenomenon in a fractured reservoir. The production rate of the reservoir has the most impact on the conning behavior. The breakthrough time decreases with an increase in production rate. The most effective way of reducing the conning of the studied fractured gas reservoir in reducing the production rate. The sensitivity of breakthrough time to fracture porosity is higher than the matrix porosity. Conversely, the sensitivity of water cut after breakthrough time to fracture porosity is lower than the matrix porosity. Among different types of reservoir permeability, the breakthrough time is most sensitive to vertical fracture permeability compared to matrix horizontal permeability. In addition, the water cut is most sensitive to fracture horizontal permeability, while vertical matrix permeability has no effect on water cut. Increase in fracture porosity increases the water breakthrough time. This is due to the fact that with an increase in the fracture porosity, the width of fractures will increase which will result in better distribution of fluids within the reservoir and decrease in flow velocity of fluids. This will reduce the arrival time of reservoir fluids to the production interval.

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