Investigating the Mechanism of Water Inflow in Gas Wells in Fractured Gas Reservoirs and Designing a Controlling Method

Masoud Nasiri, and Iman Jafari

***Abstract*---**In most of oil and gas reservoirs, after a period of production, due to the imbalance between gravitational, viscous and capillary forces, the water in aquifer and the gas in gas cap will moved to the wellbore and will produced with oil. Water production is one of the most important problems in oil and gas industry. The produced water contains salt, chemical materials, metallic compounds and contaminated with hydrocarbon compounds which has detrimental effects on environment. Study of produced water in an Iranian gas reservoir revealed that this wastewater is one of the most important environmental consequences in the region that was contaminated seawater and soil. There are numerous ways of management of unwanted water production. In this study, measures for prevention of water coning in vertical wells had been studied and solutions to minimize water production is provided. Finally, the reservoir under study had been simulated using Eclipse 300 software. It is concluded that to control and remove the harmful effects of water production in the region, it is essential taking into account environmental consideration, purchase and design new equipment, using production rates less than critical rate, well plugging and using horizontal wells for environmental cleanup projects.

Keywords: Coning, Environmental Problems, Controlling Methods, Vertical Wells, Simulation.

I. Introduction

Coning occurs in oil and gas reservoirs with water drive and gas cap drive mechanisms. In this phenomenon, water and gas flows into the wellbore from below and above of the perforations and causes several problems in wellbore and surface facilities. Before starting production, the reservoir fluids are under equilibrium condition. But with starting the production, a non-uniform pressure gradient will be created. With increasing fluid velocity and decreasing reservoir energy, the distribution of WOC and GOC in oil reservoirs and GWC in gas reservoirs will change, so water and gas can flow toward perforation interval. The time that it will take for water to reach the producing interval of the well is called breakthrough time. The subcritical time is the time at which the cone hasn't reach the producing interval. The time at which the cone reaches the well is called critical time, and when it surrounds the wellbore is called supercritical time.

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The distribution of fluids around the wellbore is influenced by the following factors[1]

1- capillary forces
2- buoyancy forces
3- gravity forces

In the coning phenomenon the upward dynamic forces which is created by pressure drop around the wellbore, causes water to rise to a height that is equal to water gravity. By moving from the well in a radial direction, because of reduction of upward dynamic forces, the height of equilibrium point between these forces and water gravity will decrease. Therefore the locus of equilibrium point will create a cone in the water oil contact level. As long as water is stationary below the contact level, oil will flow above the water. By increasing production rate, the height of cone above the original WOC, will increase and continues until at a specific rate the water cone become unstable and water will be produced [2].

The changes in gas/oil-water contact profiles as a result of drawdown pressures during production is called conning. Coning occurs in vertical or slightly deviated wells and is affected by the characteristics of the fluids involved and the ratio of horizontal to vertical permeability.

If the wellbore pressure is higher than the gravitational forces resulting from the density difference between gas and water, then water coning occurs. Equation 1 shows the basic correlation between pressure in the wellbore and at the well area for coning [3].

$$\bar{P} - P_{well} = \text{٠.٤٣٣}(\gamma_w - \gamma_g)h_{g-w} \quad (1)$$

Where P is average reservoir pressure (psi), P_{well} is the flowing bottom hole pressure (psi), γ_w is water specific gravity, γ_g is gas specific gravity, and h_{g-w} is the vertical distance from the bottom of the well's completion to the gas/water contact (ft).

One of the first studies on coning phenomenon is a study done in 1935 by Muskat and Wyckoffhk. For the first time they demonstrated clearly and analytically that coning phenomenon occurs at high pressure drops. In this study because of difficulties in simultaneous calculation of pressure distribution and cone shape, it was assumed that pressure distribution in a real cone system is like a system without cone. Besides they assumed that oil is flowing in a sand bed between two impermeable boundaries, and there is a partially penetrated well in this sand bed [4].

Sobocinski and Cornelius found a correlation to predict the water cone behavior in a static WOC level condition to dynamic condition and the transition between these two. Guo and Lee also by considering the effect of well penetration on its productivity index, developed a graphical analysis for physical process of coning. In addition, these two researchers came up with an analytical method for calculation of the maximum critical rate with the best well penetration index in an isotropic oil interval [5].

Guo et.al. suggested a method for calculation of WOC position in a anisotropic reservoir, in which the WOC position is a function of critical rate and wellbore location [6].

The problem of water production in oil and gas fields had been one of the greatest problems with a lot of cost and environmental problems. The cost resulting from corrosion, reduction of production or deduction of refining costs, all are due to salt water production that must be properly managed in order to solve this problem. Coning reasons and water production from wells are directly related to mechanical or reservoir problems.

Contamination of underground water in contact with oil and cause environmental problems, that most of them are known today.Perhaps many others would later be known. When crude oil and water get the surface, lighter parts of it that are highly toxic, such as benzene and toluene vapors pollute the air, but heavier compounds remains in environment for a long period, so land, water, soil, seas, oceans and coasts of them will gone contaminated.The marine organisms are damaged and destroyed, so even though oil and resulting compounds which are necessary for life but its production and transfer that polluted the environment damage the human beings and the other planet lives.[7].

There are a lot of developed technology to identify the entrance of water, and prevention of its production. Nevertheless, before any preemptive action, entrance of water should be recognized. When problem is diagnosed, defining an accurate choice to control is important. The water flows in two ways. In first case, water flows separately, this type of water production is considered in oil and gas production. The water production control in this reservoir led to an increase in hydrocarbon and recovery rate. In these kinds of water production, water control should be considered in the first step. In second type, water is produced with oil in a short period of time after flooding. Water production decrease of this type, led to decline in oil production [8].

There are several cases to manage unintended water production. In this study the proceedings before drilling is studied to prevent coning of water in vertical wells in one of the Iranian gas reservoirs and in order to prevent water production, guidelines had been developed.

II. Building Model

One of the main parts of the simulation is network design and geometry of the reservoir. For example, the XY view of the designed network for simulation of desired reservoir is given in Figure 1.

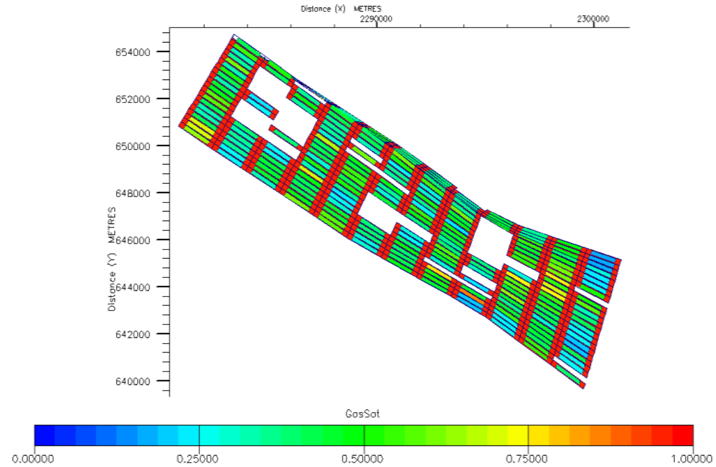

Fig. 1: XY view of the designed network

This model is Cartesian, single well and compositional and is divided into 12 columns, 24 rows and 50 layers, which consists of 14400 grid block. Because water coning occurs only in the perforated area of a well and below that, only blocks around the well is used, Therefore, in order to simulate the phenomenon there was no need to have all reservoir blocks, and only the lower part of the well (1) in reservoir A that water coning has occurred in the area is investigated as a sector.

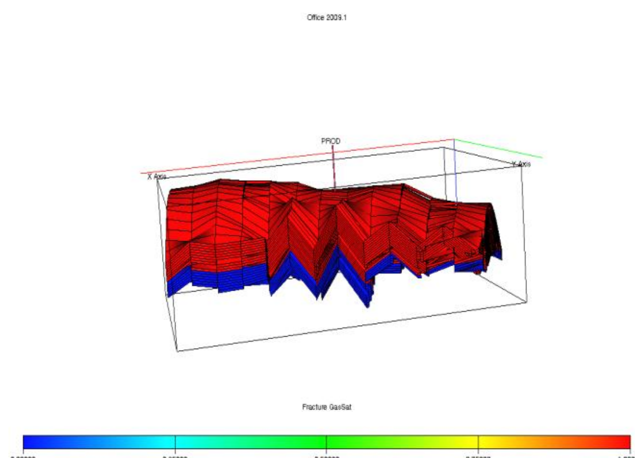

Fig. 2: 3-D view of the studied sector

For better investigation of this phenomenon around the wells, LGR has been used. The following figure shows the schematics of LGR used around the well. Because the pressure gradient around the well is very high, therefore it is necessary to consider the grid blocks smaller in that area.

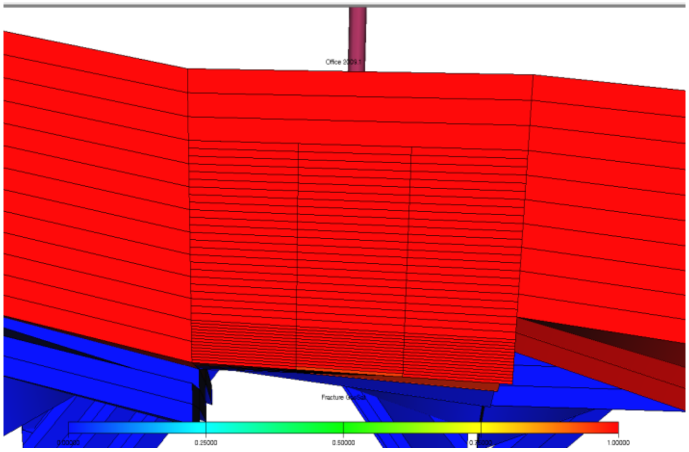

Fig. 3: schematics of LGR used around the well

PVT tests at reservoir and surface conditions are done at the time of sampling. Therefore using the reservoir fluid properties simulator, these properties are calculated at different temperatures and pressures for reservoir gas and water.

Software used for thermodynamic modeling of the reservoir gas is PVTi. The equation of state used is Peng Robinson (3-Parameter) and Lohrenz-Bray-Clark correlation is used for viscosity prediction.

III. THE PROCEEDING BEFORE DRILLING WELLS FOR WATER CONING PREVENTION

3.1. Contacts

Completion of wells near water-oil contact and perforating the top of water - gas contact or water-oil, caused production of unintended water coning. Wells completion in layers that their water saturation is higher than interstitial water saturation, caused unintended water production. Sometimes impermeable dams like (anhydride and shales), separate the hydrocarbon layers from the layers with high water saturation. Figure 4 indicates water production percentage of well 1 in which there are two or three wells. According to the chart, it is clear that when the number of wells increases, as a result of coning reinforcement water cut increases in well 1.

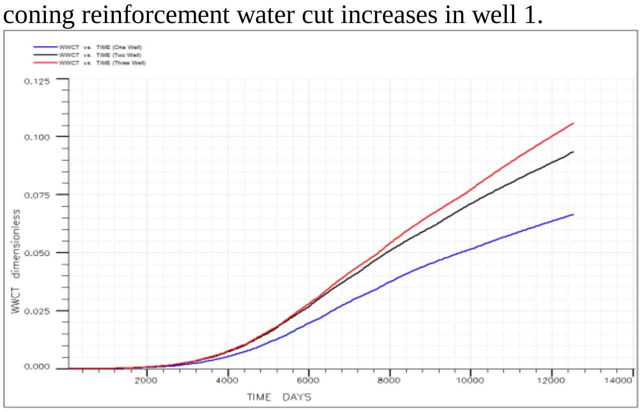

Fig. :4 water cut Comparison for one, two and three wells.

So, in case of break and loss of dams, fluid could be moved to inside wells [9].

3.2. wells distance

If coning occurs nearby wells, in any way based on the size of limited area water would be produced. According to such experience, if wells be nearby reservoir settle in situation which their cones don't contact each other or in other words cones couldn't be able to strengthen each other, the petroleum pool has more efficiency. Thus, knowing the water coning position in wells in terms of horizontal and vertical length is very important, hence the calculations are designed for this purpose [10].

Where H is high water column in coning phenomenon, x horizontal distance from the well and t_A ، t_B ، t_C و t_D are constants.

$$
\begin{aligned}
H &= A\left[B[C]+D\right]Ln[F] \\
A &= \frac{q\mu}{2\Pi^3 kg\Delta\rho} \\
B &= \frac{2}{t_A t_C - t_a - t_C + 1} \\
C &= \left[\frac{1}{3}\sqrt{-t_E}^{\,3} + \left(1-t_A-t_C\right)\sqrt{-t_E}\right] \\
D &= Tan^{-1}\left(\frac{-2\sqrt{-t_E}}{t_E+1}\right) \\
F &= \frac{\left(t-t_A\right)\left(1-t_E\right)}{\left(1-t_E\right)\left(1-t_A\right)}
\end{aligned}
\tag{2}
$$

IV. WATER CONING CONTROLLING METHOD IN VERTICAL WELLS AFTER DRILLING

4.1. Well plug

$$
\begin{aligned}
X &= H - Ln\left(\frac{\sqrt{t}-1}{\sqrt{t}+1}\right)\left(\frac{1}{t-t_A} - \frac{1}{t-t_E}\right)dt \\
H &= \int_{\infty}^{t} \frac{q\mu}{2\pi^2 kg\Delta\rho}\left[\frac{2}{t_A t_C - t_A - t_c - 1}\left(\frac{-1}{3}\sqrt{t^3} - \left(1-t_A-t_C\right)\sqrt{t}\right)\right]
\end{aligned}
\tag{3}
$$

The primary goal of all well repairing operation includes care, control and repairing wells to keep well in ideal situation of production. to repair this wells if wells be open, the end of wells will be blocked with cement (Plug Back) or by running liner pipeline the water invaded parts are separated, and then higher distances with gas will be perforated. If wells are completed in cased hole, lower perforation which produced water will be blocked and casing will be perforated in higher points and wells are completed. In this way, it is possible to have more or less water production, but after a while contact with progress of water–gas, as before there will be the previous problem again [11].

In this way, the software designed in manner that if amount of water cut reach to 0.001, water production is continued. Figures 5 & 6indicate water cut and cumulative gas production and production in normal situation.

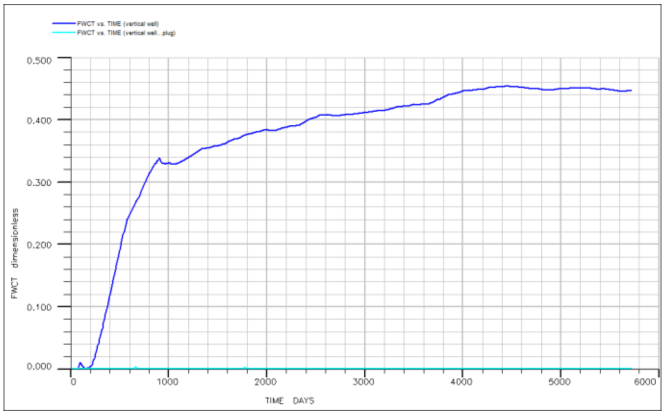

Fig. 5: water cut comparison for ordinary production and plugging the bottom of well.

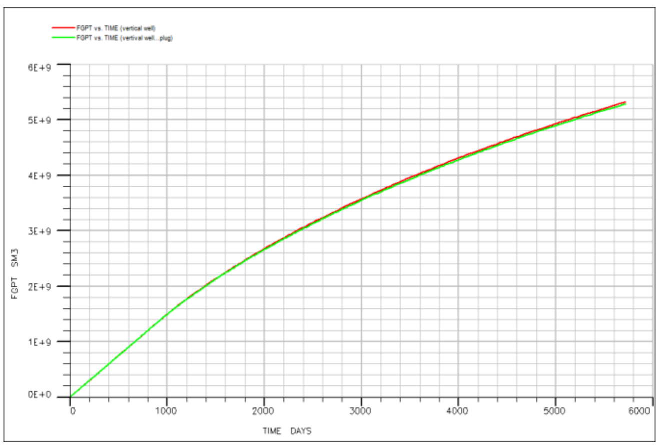

Fig. 6: cumulative gas production Comparison in normal situation and plugging the bottom of well.

Clearly if plugging the bottom of well is used, in addition to energy conservation, environmental effects do not occur. The main goal of coning control methods at well is to minimize water cut, flow and final production, also maximize flow rate and final gas production. So in this way we have been able to minimize the amount of water cut and cumulative gas production with almost normal production.

4.2. Producing less than critical flow rate in vertical wells

One of the best ways to prevent coning phenomenon in wells is definition of critical flow rate. Production below critical flow rate conditions results in stability of water cone. Pressure gradient of production under critical flow rate is less than pressure gradient between water and gas gravity. Therefore cannot be overcomed and horizontally move to top of water-gas contact. But according to economic and political reasons, production in rates lower than the Critical flow rate would not be possible, because under these conditions production rate will be much less than the normal situation and cumulative production will be too low .Hence Critical flow rate only theoretically has been accepted. Figures (7) and (8) indicate water cut and cumulative gas production under critical flow rate in this way and normal situation.

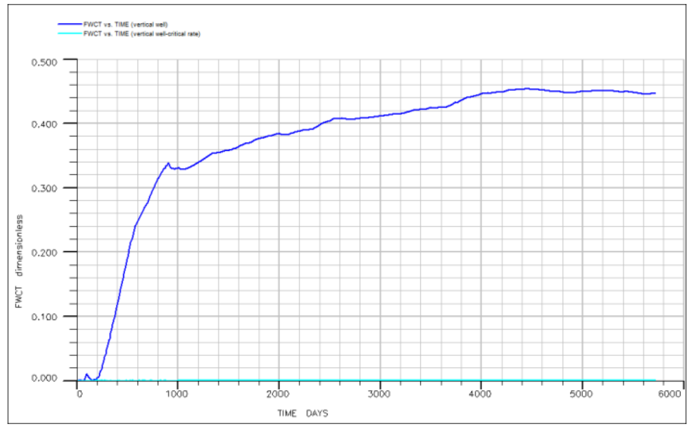

Fig. 7 Comparison of water cut for normal production and production under Critical flow rate.

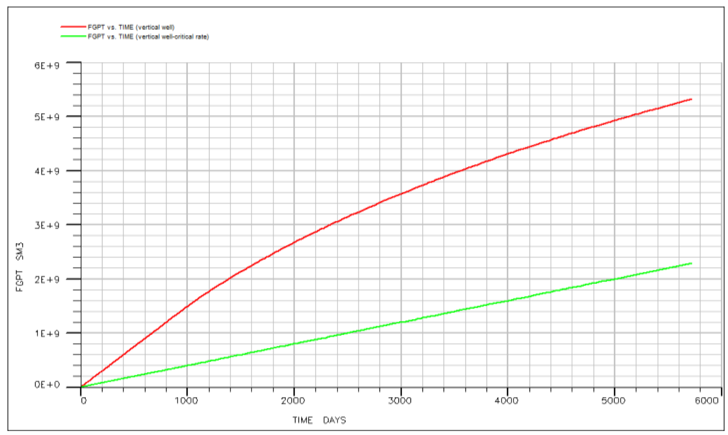

Fig. 8 Comparison of cumulative gas production for normal production and critical flow rate production.

Clearly, if Critical flow rate procedure is used to produce, there will not be water cut. In this way, according to political and economic reasons, production lower than Critical flow rate would not be possible, because under these conditions well production is much less than the normal situation and cumulative production would be too low. However, water cut is zero and there is no effect on the environment.

4.3. horizontal drilling

Longer time for breakthrough time in the horizontal wells is one of its advantages. through simulation vertical to horizontal well, breakthrough time increased , water cut reduced and cumulative production increased. Note that horizontal well l places carefully selected, wrong choice make deteriorating situation compared to current state. Figures (9) and (10) show water cut, cumulative gas production and production in normal situation.Clearly if horizontal well is used, less water cut occurred in comparison with vertical wells, but cumulative production will be reduced. The following table shows the passed time, percentage of water cut and cumulative gas production for different ways of coning prevention in vertical well.

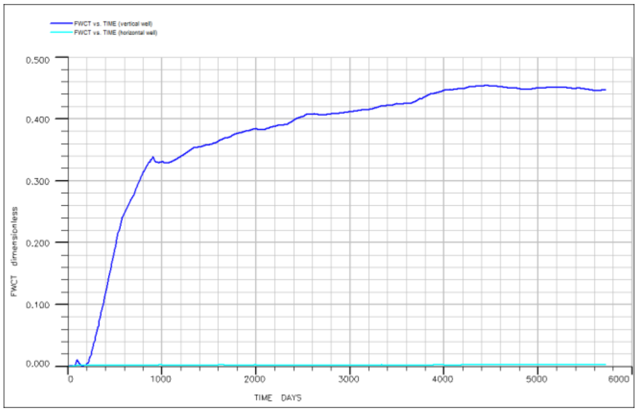

Fig. 9: water cut comparison for ordinary production and horizontal well.

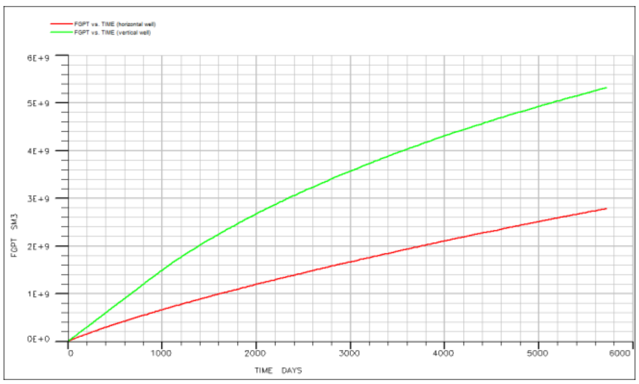

Fig. 10: cumulative gas production comparison for ordinary and horizontal well.

Table 1- comparision of different coning prevention methods in vertical wells				
Row	Prevention method type	Breakthrough time(*day*)	Water cut (15 years)	Cumulative gas production (SM^3)
1	Without prevention method (vertical well)	230	0.45	$5.3181\text{x}10^9$
2	Well plug	----	0.0000	$5.2842\text{x}10^9$
3	Critical rate	----	0.0000	$2.2892\text{x}10^9$
4	Horizontal well	3596	0.00225	$2.9724\text{x}10^9$

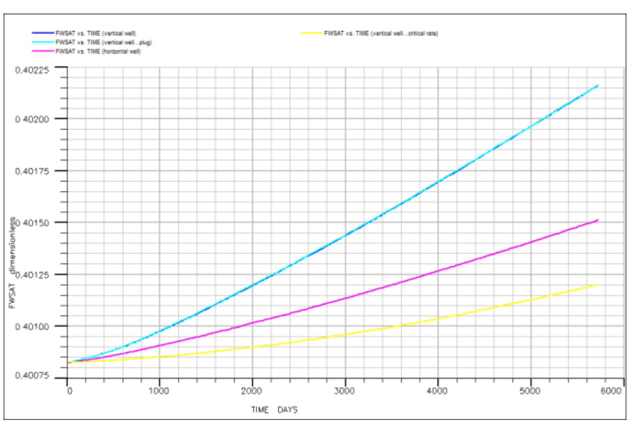

Fig. 11: saturation comparison in last block in which wells is completed for procedures of coning prevention in vertical well.

As it is clear based on figure when well production is less than critical flow rate, water-gas contact remains constant or slightly move upwards. So water saturation during production period has minimal changes. But as well production continues, in normal or plug situation, pressure gradient between reservoir and wells increases and gas-water contact moving upward and saturation of block is extremely high.

Figures (12) and (13) shows water cut and cumulative gas production for all different ways of coning prevention methods in vertical well and production in normal situation.

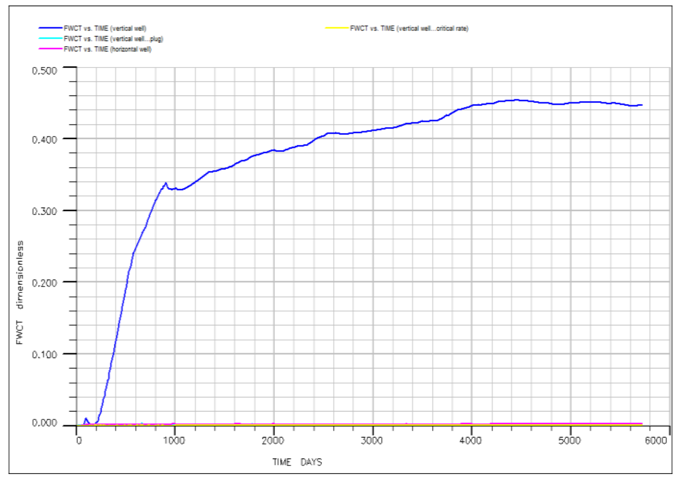

Fig. 12: Water cut Comparison for ways of coning prevention in vertical well.

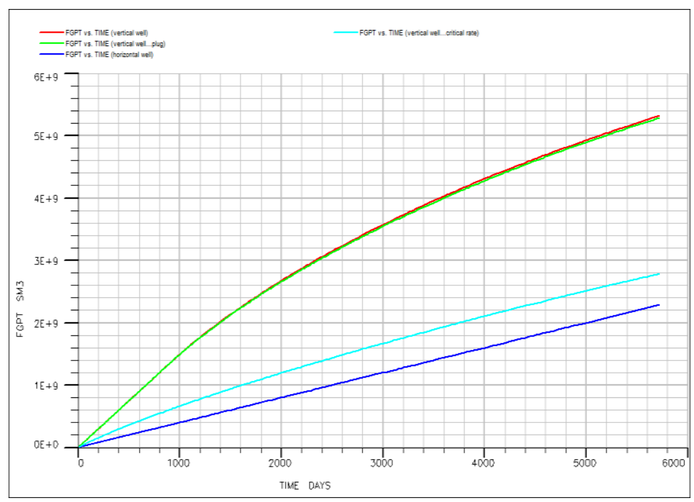

Fig. 13: Comparison of cumulative gas production for different coning prevention methods in vertical well.

V. CONCLUSION

1- It seems that flow rate has effect on water production, thus the easiest way to reduce coning phenomenon is lowering flow rate. Keep in mind that in many cases, flow rate reduction is economically unprofitable, therefore, it is not the final solution

2- Try to prevent coning phenomena, otherwise prevention methods have very little effect.

3- In this reservoir, vertical well plugging is the best method in terms of cost and technology, but the coning problem still remains.

4- Instead of using equipment of level separation, the separation method inside wells are used. These tools allow the water to stay in wells, while preserving reservoir energy, cost of surface corrosion is reduced.

5- Before any preventive proceeding to prevent coning phenomenon and water production, the problem and arrival of water should be recognized. After diagnosis, it is difficult to define various strategies and more accurate choice to control the problem.

6- Pumping water into the aquifer of a gas reservoir, in addition to being able to dispose waste production can be a significant help to increase gas production from that reservoir, and make profitability. This harmful water is considered as a valuable source for productivity and efficiency.

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