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

Iman Jafari[1], **Arezoo Rezaei**[2]

1-Department of petroleum engineering, science and research branch, Islamic azad university, Tehran, Iran
2-Department of Chemical Engineering, Young Researchers Society, Shahid Bahonar University of Kerman, Kerman, Iran

Fax:09390329075- Iman jafari Email: jafari3760@gmail.com

Abstract:

Water inflow may cease production of gas wells, leaving a significant amount of gas in the reservoir. Conventional technologies of gas well dewatering remove water from inside the wellbore without controlling water at its source. This paper addresses mechanisms of water inflow to gas wells in fractured reservoirs and a new completion method to control it. In a vertical oil well, the water cone top is horizontal, but in a gas well, the gas/water interface tends to bend downwards. It could be economically possible to produce gas-water systems without water breakthrough. Non-Darcy flow effect (NDFE), vertical permeability, fracture characteristics, aquifer size, density of well perforation, and flow behind casing increase water coning/inflow to wells in gas reservoirs with bottom water.

In this paper Downhole Water Sink (DWS) installation in gas wells includes dual completion with an isolating packer and gravity gas-water separation at the bottom completion is studied for removing the water coning problem of a well in Reservoir A in Iran. According to the results of this study, the best DWS completion design should comprise a short top completion penetrating 20% - 40% of the gas zone, a long bottom completion penetrating the remaining gas zone, and vigorous pumping of water at the bottom completion. Being as close as practically possible the two completions are only separated by a packer. To Sum, it can be mentioned that DWS extends the well life longer and could be a proper solution for the well studied in this work.

KEYWORDS:

WaterConning, Gas Wells, Fracture Reservoirs, DWS.

1. Introduction

Water production is one of the main common problems of critical concern in the oil and gas industry. Many gas reservoirs are water driven. Water supplies an extra mechanism to produce the gas reservoir, but it can create production problems in the wellbore. Water influx can occur via several mechanisms (flow through fractures, channeling, or coning), and the water may approach from several directions (from below, from the sides, or from above). These water production problems are more critical in low productivity gas wells.

Forty percent of world gas reserves are placed in Middle East region and about forty percent of these reserves in this region are located in Iran. The production rate from oil and gas wells in Middle East region is declining. This reduction may threat the wells with more water production problems.

In this work it is intended to deal with water conning problems. It is well known that water coning occurs in oil and gas reservoirs, with the water drive mechanism, when the well is produced above the critical rate. Water coning is responsible for the early water breakthrough into the wellbore. Water coning has been studied extensively for oil reservoirs. However, only a few studies of water coning in gas wells have been reported in the literature. In most of the investigations it is believed that water coning are the same phenomenon in gas and oil wells, and correlations developed for oil-water system could be used for gas-water systems.

It is a common practice in oil industry to perforate vertical wells as far above the oil water contact (OWC) as possible and producing the wells at or below the critical oil rate. Similarly, wells are often perforated low in the oil column away from the gas-oil contact (GOC) in gas-oil reservoirs mixed in that limited perforations may increase the pressure gradient (the drawdown) near the well, which can exacerbate coning. There has also been success in reducing coning with polymers and gels (Speight et al., 2003). Pumping units, liquid diverters, gas lifts, soap injections, flow controllers, swabbing, coiled tubing/nitrogen, venting, plunger lift, and one small concentric tubing string are among different well dewatering technologies that have been used to control water loading problem in gas wells. The common point in all these methods is that they would reduce liquid-loading without controlling water inflow. A more recent and novel approach is to use downhole water-sink technology (DWS) where water is produced separately from the oil using dual packers (Reynolds et al., 2003).

The purpose of this work is to evaluate the performance of the DWS in one of the Iranian fractured reservoirs gas wells. But prior to this, the most effectual parameters influencing the water influx in a gas well in this reservoir are studied. Eclipse 100 is used to study water coning mechanisms and DWS evaluation in gas reservoirs. Conceptual analyses are performed with the numerical simulation results from the analysis of mechanisms affecting water coning/production in gas wells.

2. BACKGROUND

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 (MIGUEL A., 2003).

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

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).

The maximum rate at which oil/gas is produced without production of water is defined as Critical rate (Joshi, 1991). The critical rate for oil-water systems has been discussed for several authors developing different correlations to calculate that rate. Based on our knowledge, for gas-water system, however, no correlation has been published calculating critical rate, yet.

Craft and Hawking method (1959), Chaperon method (1986), Schols method (1972), and Hoyland, Papatzacos and Skjaeveland method (1986) are imperical and analytical methods for calculating the value of critical rate. These methods are not accurate but a proper result will be obtained if a suitable method is selected based on the field conditions.

Meyer, and Garder (1954), and Schols (1972) presented two well known correlations for critical rate of oil-water system. They made some corrections to Darcy's equation and used approximately the same parameters in their study. Trimble and De Rose (1976) modified Mustak-Wyckoff (1935) theory for critical rates in oil wells to calculate critical rate for gas wells. Their equation could give an approximate idea about the gas critical rate for quick field calculations (Miguel A., 2003).

In this part we are going to compare water coning in gas-water and oil-water systems. Analytical and numerical models are used to identify possible differences and similarities between both systems.

3.THE MAIN PARAMETERS INFLUENCING BOTTOM WATER INFLOW TO GAS WELLS

3.1 Effect of Vertical Permeability

Formerly, Beattle and Roberts (1996) reported that high vertical permeability should generate early water production in gas reservoirs with bottom water-drive. Vertical permeability accelerates water coning because high vertical permeability would reduce the time needed for a water cone to stabilize. To investigate this, a numerical simulation is made with Eclipse software. (Miguel A., 2003)

Horizontal permeability is set at 10 md, and four different values of vertical permeability, 1, 4, 7, and 10 md, were considered (Permeability anisotropy, kv/kh, equal to 0.1, 0.4, 0.7, and 1 respectively). The wells are produced at constant tubing head pressure of 600 psia (maximum gas rate).

The initial water-gas contact was at 6000 ft. The top of the cone for kv/kh equal to 0.1, 0.4, 0.7, and 1 is at 6080 ft, 6038 ft, 6025 ft, and 6021 ft respectively after 760 days of production. For kv/kh equal to 0.1, and 0.4 the water cone is still below the completion and there is no water production.

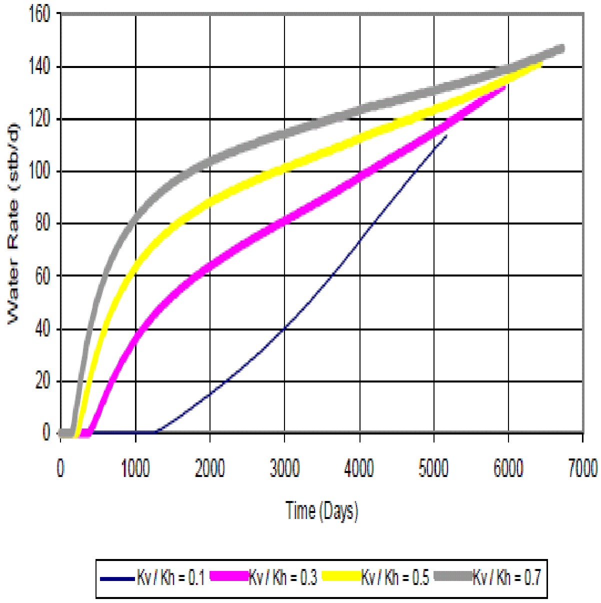


Figure 1. Water rate versus time for different values of permeability anisotropy.

Figure 1 shows water rate versus time for the four different values of vertical permeability. This figure shows that water breakthrough time and water rate increase with permeability anisotropy. The shortest water breakthrough time and highest water rate is for kv/kh equal to 0.7. The longest water breakthrough and lowest water rate time is for kv/kh equal to 0.1.

3.2 Aquifer Size Effects

Textbook models of water inflow for material balance computations assume that the amount of water encroachment into the reservoir is related to the aquifer size (Craft & Hawkins, 1991). Vertical and horizontal permeability are set at 10 and 1 md respectively (kv/kh equal to 0.1). The aquifer is represented by setting porosity to 10 (a highly fictitious value for porosity), for the outermost gridblocks and the thickness of the lowermost gridblocks are varied from 100 to 800 ft to adjust aquifer volume. The results of eclipse software are shown in Figures 2-a,b,c, and d. According to this figure, the initial water-gas contact was at 5100 ft. The top of the cone for *VAD* equal to 346, 519, 864, and 1383 is at 5046 ft, 5040 ft, 5034 ft, and 5030 ft respectively; after 760 days of production. Figure 2, consequently, shows that water coning increases with the aquifer size.

Figure 2 shows that water rate increase with aquifer size. Water breakthrough time, however, is not affected by aquifer size.

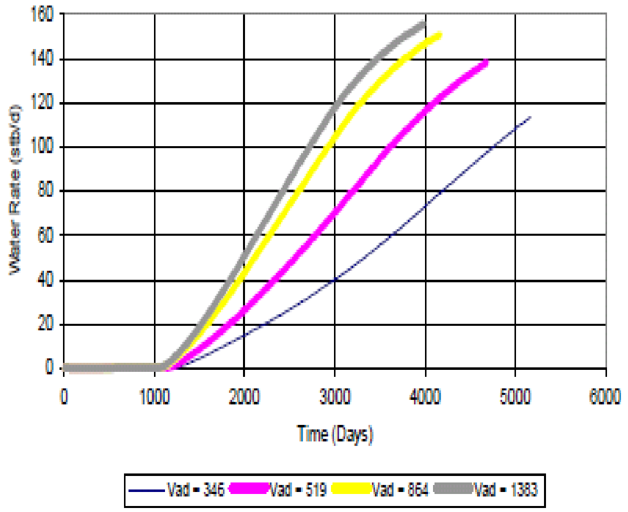


Figure 2. *Water rate versus time for different values of aquifer size.*

Figures 1 and 2 show that vertical permeability is more important than aquifer size in controlling the water breakthrough time. Both aquifer size and vertical permeability, however, play an important role in increasing water rate.

From this study, one could conclude that aquifer size increases water coning/production in gas wells without affecting water breakthrough time. The higher the size of the aquifer is, the higher the water coning/production of the well.

3.3 Non-Darcy Flow Effects

Non-Darcy flow generates an extra pressure drop around the well bore that could intensify water coning. Non-Darcy flow happens at high flow velocity, which is a characteristic of gas converging near the well perforations.

The effect of Non-Darcy flow in water production is studied in this section. According to previous computation procedure presented by (Miguel A., 2003) the following steps have to be done,

1. Assume constant value for the pressure the drawdown at 100 psia, 300 psia, 500 psia, 1000 psia, and 1500 psia.

2. Calculate gas and water production rates for the initial condition using Equations 4.2 and 4.5, respectively.

3. Compute the rates for water and gas for several intermediate steps of gas recovery 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 95%. (Note that the fraction of initial gas zone invaded by water represents the gas recovery factor.)

The above procedure was repeated for three different scenarios. The scenarios were:

without Non-Darcy and skin effects, including only skin effect, and including both skin and Non-Darcy effects. The results of the study are shown in Figures 3 to 5.

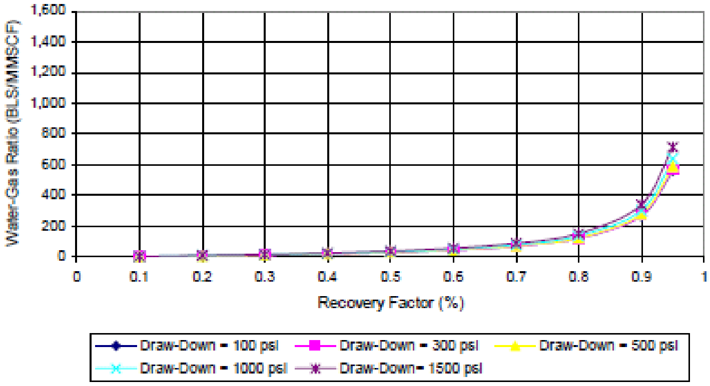


Figure 3. *Water-Gas ratio versus gas recovery factor for total penetration of gas column without skin and Non-Darcy effect.*

Figure 3 demonstrates the “delayed” effect of water in a gas well completed in the gas zone when Non-Darcy and skin are ignored. Not only does the problem occur after 750% of gas recovered but also Water-Gas ratio (WGR) is independent of pressure drawdown and production rates.

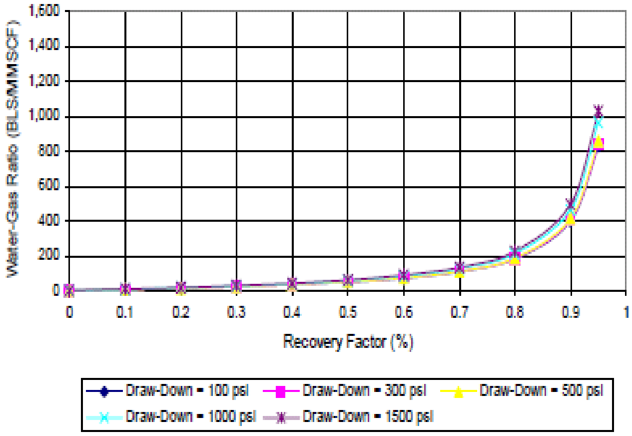


Figure 4. *Water-Gas ratios versus gas recovery factor for total penetration of gas*

Figure 4 indicates that mechanical skin alone slightly increases WGR.

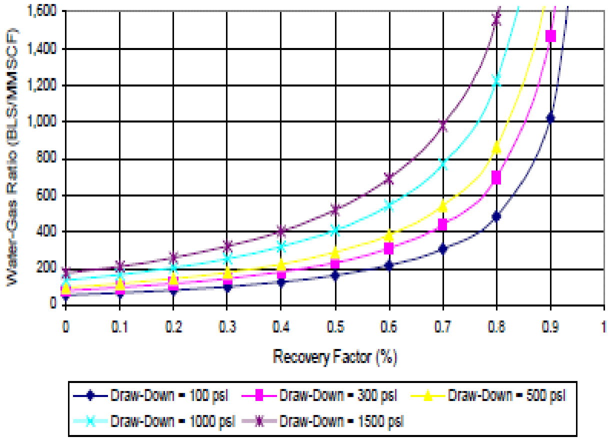


Figure 5. *Water-Gas ratio versus gas recovery factor for total penetration of gas and water columns, skin and Non-Darcy effect included.*

Figure 5 indicates that combined effects of skin and Non-Darcy flow would strongly increase water production in gas wells. Also, WGR increases with increasing pressure drawdown.

3.4 DESIGN AND PRODUCTION OF DWS GAS WELL

How to produce DWS wells in low productivity gas reservoirs with bottom water? In this part we are going to deal with this question. The operational principle is maximum final gas recovery. Six factors control DWS operation: water rate from the bottom completion; top completion length; bottom completion length; distance between the bottom and the top completion; bottomhole flowing pressure at the bottom completion, and time to install DWS in gas wells (Miguel A., 2003).

The evaluation is done for a low productivity gas reservoir with reservoir pressure: 1500 psia; depth: 5000 ft; and for two different permeabilities: 1 and 10 md. The well (top completion) is produced at a constant tubing head pressure, 300 psia. The bottom completion is produced even at constant water rate or constant Bottom Hole Pressure (BHP). The gas-water contact is located at 5100 ft.

Figures 6 and 7 show the results for the top completion length evaluation. Four different top completion lengths were evaluated (40%, 60%, 80%, and 100% penetration of the gas zone) for permeability 1 md. Five different top completion lengths were evaluated (20%, 40%, 60%, 80%, and 100% penetration of the gas zone) for permeability 10 md. Bottom completion is located at the top of the aquifer (at 6100 ft) penetrating 20 ft of the water zone. The bottom completion length (20 ft) was constant for each case. Constant water-drainage rate from the bottom completion was used.

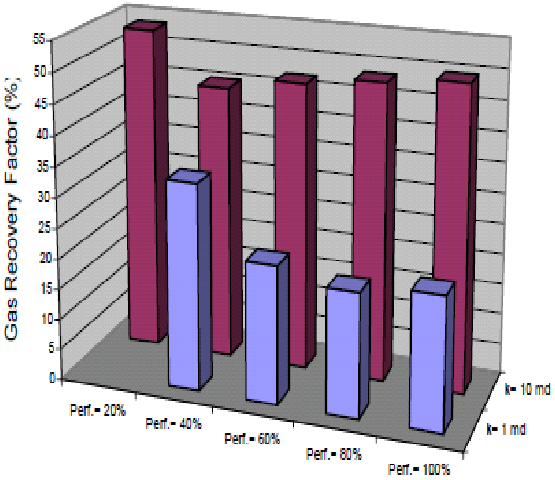
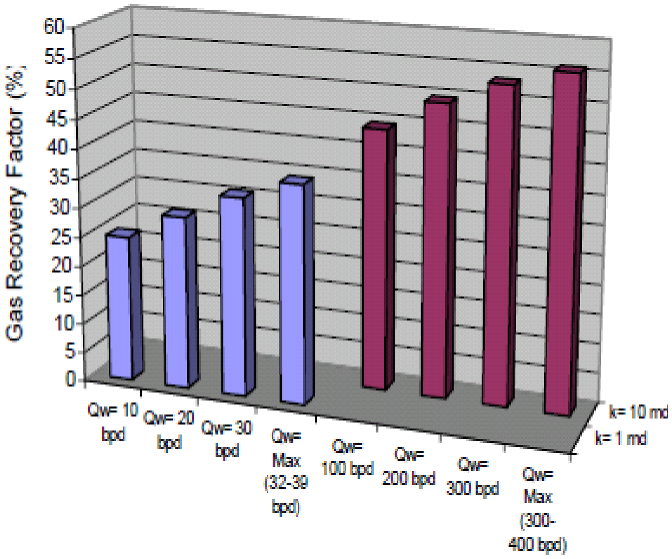


Figure 6. *Gas recovery for different perforation lengths.*

The highest gas recovery for both permeability values happens for the shortest top completion length (Figures 6). This means that the benefit of DWS is reduced for longer top completion. The longer the top completion is, the closer to the gas-water contact is the completion. Then for long completions, water inflows the top completion early. Water rate at the top completion is higher for longer completion, also. Therefore, higher water-drained rates from the bottom completion are needed to maintain the top completion water free. In this case, however, to evaluate the effect of the top completion length alone, the water-drainage rate is constant. The benefit of the highest gas recovery for the shortest top completion length is more evident for permeability 1 md than 10 md (Figure 6). This is because of the higher gas mobility related to water. Low permeability delay vertical water movement to the top completion allowing longer water free production of the top completion.

3.5 Effect of Water-drainage Rate from the Bottom Completion

Four different water-drainage rates were used to evaluate its effects on gas recovery and production time. Three of them were constant all the time, and the other one was varied to always produce at maximum water rate from the bottom completion. Location (at the top of the water zone: 6100 ft), and length (20 ft) for the bottom completion is constant for all the cases (1 and 10 md). For permeability 1 md, top completion length was constant penetrating 40% of the gas zone, and the water rates were: 10 bpd, 20 bpd and 30 bpd. For permeability 10 md, top completion length was constant penetrating 20% of the gas zone, and the water rates were: 100 bpd, 200 bpd and 300 bpd.



Figurer7. *Gas recovery Factor for different water drainage rates*

Gas recovery increases with water-drained rate. The maximum recovery occurs at the maximum water-drainage rate (Figure 7). The effect of water drained in gas recovery follows the same pattern on both permeabilities.

3.6Effect of Separation between the Two Completions

Four (for permeability 1md) and five (for permeability 10 md) different separation distances between the two completions were evaluated. The top completion length was constant, perforating 40% (permeability 1 md) and 20% (permeability 10 md) of the gas zone. Top and bottom completion produced gas from day one. The waterdrainage rate was constant (15 bpd for permeability 1 md and 150 bpd for permeability 10 md). Figures 8 shows the results for the evaluation of separation distance between the two completions.

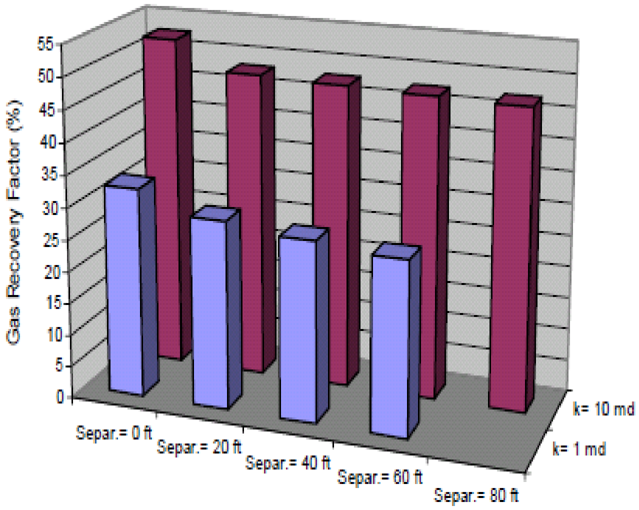


Figure 8. *Gas recovery for different separations between the completions.*

Gas recovery reduces with the separation between the two completions (Figure 8). The highest recovery occurs when the two completions are one after the other. Both permeabilities values (1 md and 10 md) show the same pattern. Reducing separation between the completions increases gas recovery because the inverse gas-cone to the bottom completion is more efficient.

3.7Effect of Bottom Completion Length

Four (for permeability 1md) and five (for permeability 10 md) different lengths for the bottom completion were evaluated. The top completion length was constant, perforating 40% (permeability 1 md) and 20% (permeability 10 md) of the gas zone. The bottom completion starts at the end of the top completion. Top and bottom completion begins producing gas from day one. The water-drainage rate was constant

(15 bpd for permeability 1 md and 150 bpd for permeability 10 md) once the bottom completion started producing water. Figure 9 shows the results for the bottom completion length evaluation.

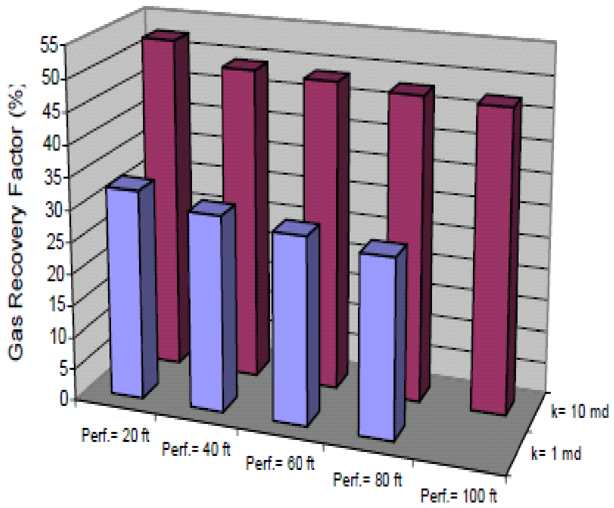


Figure 9. *Gas recovery Factor for different bottom completion lengths.*

The highest recovery happens at the shortest bottom completion length. The longest production time occurs at the shortest completion, also. Long bottom completion moves the perforation loser to the gas-water contact, increasing water rate and accelerating the well water load-up. Water inflows the well early.

4.CONCLUSIONS

According to this paper the following conclusions are drawn,

1. Vertical permeability increases water coning/production in gas wells. The higher the vertical permeability is, the higher the water coning/production of the well.

2. It does not make much difference how much of the well completion is covered by water as long as the completion is in contact with water.

3. Non-Darcy and distributed mechanical skin increase water gas ratio (WGR) by reducing gas production rate and increasing water inflow, and the two effects accelerate water breakthrough to gas well.

4. DWS delays water loading longer when short top completion are used.

5. The more water is removed from the top completion, the higher and faster/longer the gas recovery.

6. DWS extends the well life longer when the two completions are together, also Delaying water inflows to the top completion retards well liquid loading.

5.REFERENCES

1-Beattle, D.R. and Roberts, B.E., 1996, “Water Coning in Naturally Fractured Gas Reservoirs,” Paper SPE 35643, *Gas Technology Conference*, Calgary, Alberta,Canada, 28 April – 1

2-Chaperon, I., 1986, “Theoretical Study of Coning Toward Horizontal and Vertical Wells in Anisotropic Formations: Subcritical and Critical Rates,” paper SPE 15377, *SPE Annual Technical Conference and Exhibition*, New Orleans, Oct. 5-8.Craft and Hawking

3-Hoyland, L.A., Papatzacos, P., and Skjaeveland, S.M., 1989, “Critical Rate for Water Coning: Correlation and Analytical Solution,” *SPE Reservoir Engineering*, p459-502, November 1989.

4-Joshi, S.D., 1991, “Horizontal Well Technology,” *PennWell Books*, Tulsa, Oklahoma, p251-267.

5-Meyer, H.I. and Garder, A.O., 1954, “Mechanics of Two Immiscible Fluids in Porous Media,”

6-Journal of Applied Physics, (November 1954) **25**, No. 11, 1400.Hoyland, Papatzacos and

7-Miguel A., 2003, “Mechanisms and Control Of Water Inflow To Wells In Gas Reservoirs With Bottom-Water Drive”, Ph.D. Thesis, Louisiana State University, Agricultural and Mechanical College.

8-Reynolds P. R., 2003, “Produced Water and Associated Issues”, Oklahama Geological Open File Report.

9-Schols, R.S., 1972, “An Empirical Formula for the Critical Oil Production Rate,” *Erdoel Erdgas, Z,* Vol 88, No 1, p6-11, January 1972.

10-Speight R. S., Lane R.H., Sydansk, R. D., 2003, “ A Strategy for attacking Excess Water Production”, SPE Production and Facilities, August 2003, 158-159.