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Improving Gas Recovery of Water Drive Gas Reservoir

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ABSTRACT

A gas reservoir with bottom water drive has lower recovery factor compared to depletion drive gas reservoir. Along with the increase in gas demand and the majority of gas reservoirs are water-drive, a method that are still being developed to increase the recovey factor in water-drive gas reservoir is co-production method. This method reducing water influx by planned water production. In this study, a conceptual model of gas reservoir with depletion-drive and water-drive is build and being analyzed. Co-production technique is applied by adding one water production well to the water-drive gas reservoir. The recovery factor is being analyzed through some production scenarios. Sensitivity analysis are being done with parameters including: reservoir permeability, permeability anisotropy, aquifer volume, flow rate of water production, gas tubing head pressure, and gas well perforation interval Furthermore, experimental design, response surface methodology, and monte-carlo simulation is used to analyze the influencing parameters of gas recovery factor. It is found from this study that co production increased gas recovery factor by 28% from water drive gas reservoir, with water production rate is the most influencing parameter. From the result of this study, it can be inferred that it is possible to improving the recovery factor from water drive gas reservoir. With the increasing demand of gas energy, this method is possible to applied.

Keywords: co-production, improve gas recovery, gas reservoir, reservoir simulation

I. INTRODUCTION

Based on the driving mechanism, gas reservoirs can be classified into two groups, namely water-drive and depletion-drive (Ikoku, 1992). In terms of recovery factor, abbreviated as RF, there is a significant difference. Where, RF of depletion-drive gas reservoir ranges from 80-90% while in water-drive gas reservoir it is only around 35-75% (Ikoku, 1992). Conventional production in a water-drive gas reservoir terminates when the producing wells load up with water, leaving high-pressure bypassed gas in the watered-out areas and in the gas cap up dip of the watered-out wells (Arcaro & Bassiouni, 1987). In a water-drive gas reservoir, the reservoir pressure is maintained by the encroaching water. The stronger the water drive, the higher the reservoir pressure remains. Because residual gas saturation is independent of pressure, larger amounts of gas (residual gas) are trapped at the higher pressure than if a lower stabilization pressure could be reached (Craft et al., 1991). Experimental study by Geffen et al., 1952 indicating that the residual gas saturation can vary from 16 to 50%, depending on the rock type. If the aquifer is strong enough, residual gas saturation can be trapped permanently at high pressures. That is, about 30% of the pore volume invaded by water contains high pressure immobile gas. The abandon gas saturation in a water-drive gas reservoir is usually much greater than that of a depletion-drive. Thus, higher abandon pressure will usually result in lower recovery in water-drive gas reservoirs. This is the background for conducting various studies to be able to increase the recovery factor in water-drive gas reservoirs, or what is then known as improve gas recovery.

An existing technique that would benefit recovery in strong water-drive gas reservoirs is the accelerated blowdown method (Brinkman, 1981; Chesney et al., 1982; Lutes et al., 1977). In essence, the concept is to out- run the water influx by producing gas at accelerated rates. Reservoir pressure is reduced before the aquifer can respond fully. Usefulness of the process, however, is limited in many cases. Deliverability controls because of sales contracts or production facilities may disallow high pro- duction rates (Agarwal et al., 1965).

Another improve gas recovery technique is the co-production process, as the downdip wells begin to water out, they are converted to high-rate water producers, while the updip gas wells maintain gas production. The coproduction process enhances recovery in three ways: (1) production of water lowers reservoir pressure, and more gas is produced because of expansion; (2) water production slows the advance of the water front; and (3) previously immobile gas in the swept zone might become mobile again as the pressure is lowered. The process is applicable in all moderate-to-active water-drive gas reservoirs. Reservoirs not yet watered out, however, present the greatest economic potential (Arcaro & Bassiouni, 1987).

The coproduction process is defined as the simultaneous production of gas and water. Initial attempts of enhanced gas recovery by coproduction focused on the depressurization of a totally watered-out reservoir by withdrawing large volumes of water. This process is technically feasible and economically applicable in some cases. In the case of unfavorable gas relative-permeability characteristics, however, extremely large volumes of water must be removed to mobilize the gas. Also, the cost involved to rework a shut-in field and to handle large amounts of two-phase gas and water production at high water/gas ratios might be prohibitive (Arcaro & Bassiouni, 1987).

From some literature reviews, there are only a few that investigate the parameter influencing the success of improve gas recovery process. This study is intended to compare gas recovery factor from depletion-drive gas reservoir and water-drive gas reservoir through a conceptual gas reservoir model. In order to improving the gas reservoir recovery factor, the Co-production technique with sensitivity analysis are being done to the water-drive gas reservoir model to obtain the influencing parameters including: reservoir permeability (Kx), permeability anisotropy (Kv/Kh), aquifer volume (Vaq), flow rate of water production (Qw), gas tubing head pressure (THP), and gas well perforation interval (Hp).

II. METHODS

This study aims to analyze the influencing factors of improve gas recovery through sensitivity analysis, using simulation reservoir process. To carried out this study the data to build conceptual model of gas reservoir is taken from Armenta, 2003. The illustration of the gas reservoir model can be seen in the Figure 1 below:

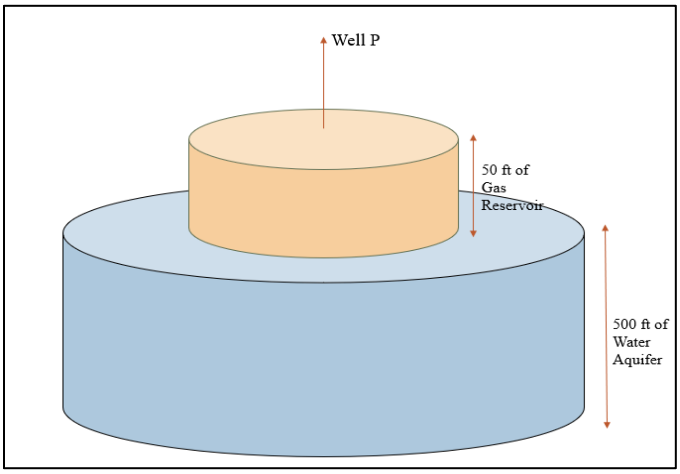

Figure 1. Reservoir Model Illustration

Gas reservoir with bottom water-drive is modeled using a radial grid and has one well located in the middle of the reservoir. This reservoir consists of 2 phases, namely the gas and water phases. Datum is at a depth of 5000 ft with a pressure of 1500 psia. This reservoir model consists of 128 layers, where gas is located in layers 1-100 with a thickness of 0.5 ft each and water is located in layers 101-128 (27 layers with a thickness of 5 ft and 1 layer with a thickness of 365 ft). The gas-water contact is at a depth of 5050 ft. This reservoir has a porosity of 25% and a horizontal permeability of 10 mD, a radial permeability of 100 mD, and a vertical permeability of 5 mD. The total thickness for the gas layer is 50 ft and the water layer is 500 ft. And the ratio between the volume of the gas column and the water column (Vaq) for this model is 40.6. PVP At surface conditions, this model has a gas density of 0.046 lb/ft3, oil density of 45 lb/ft3, and water density of 64 lb/ft3.

The gas in this model has a temperature of 120 °F. The relative permeability function curves for gas and water above come from two different regions. The first layer of this model is at a depth of 5000 ft with a pressure at that depth of 1500 psia, and the gas-water contact is at a depth of 5050 ft. This model initially has one production well, namely Well P. Well P is at a datum depth of 5000 ft with a dewatering radius of 200 ft. The preferred phase for this well is gas. A THP limit of 100 psia is used.

This study began with gas reservoir simulation process to simulate reservoir gas depletion-drive and water-drive to compare the gas recovery factor. And continued by implementing co-production technique for water-drive gas reservoir to analyze the effect of improve gas recovery process. Co-production technique mean to produce water from aquifer to decrease the energy of the driving mechanism from water aquifer to the gas column. This method is expected to improve the gas recovery factor as it might slow down the water front from aquifer to flooding to the gas column. From the literature as stated above, there are several parameters that might affect the significance value of recovery factor improvement. Sensitivity analysis using few subsurface parameters and few surface parameters is chosen to analyze their effect to gas recovery factor. Sensitivity analysis of reservoir permeability, permeability anisotropy, aquifer volume, flow rate of water production, gas tubing head pressure, and gas well perforation interval are being done along with the implementation of co-production technique to analyze the sensitivity parameters effect.

Gas reservoir simulation process, co- production technique, and sensitivity analysis are illustrated in the Figure 2 below:

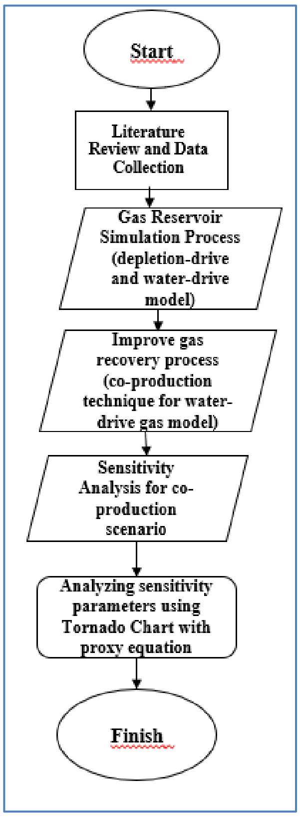

Figure 2. Flowchart of Improve Gas Recovery

III. RESULTS AND DISCUSSION

3.1. Comparison of Gas Reservoir Model

The gas reservoir performance prediction can be implemented by Pressure Decline Curve p/z method. The illustration of depletion-drive gas reservoir model compared to water-drive gas reservoir model by this method can be seen in the Figure 3 below:

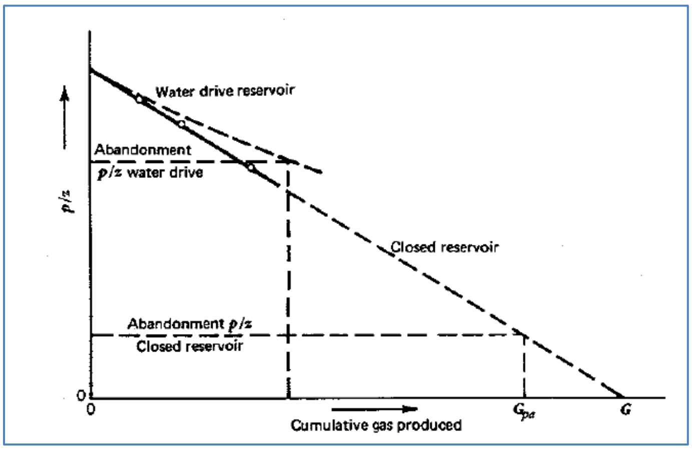

Figure 3. Pressure-Production Graph, Gas Reservoir (From Ikoku, 1992)

In order to simplified the analysis of the two models of gas reservoir as well as after improve gas recovery process, the result from reservoir simulation process will be presented in p/z graphs.

The gas reservoir model is being simulated for 30 years of production, abandonment pressure of 200 psia, and the gas producing rate is 1500 MSCF/d. From the result of the two models of gas reservoir (depletion-drive gas reservoir abbreviated as DD and water-drive gas reservoir abbreviated as WD), compared in one p/z graph in the Figure 4 below:

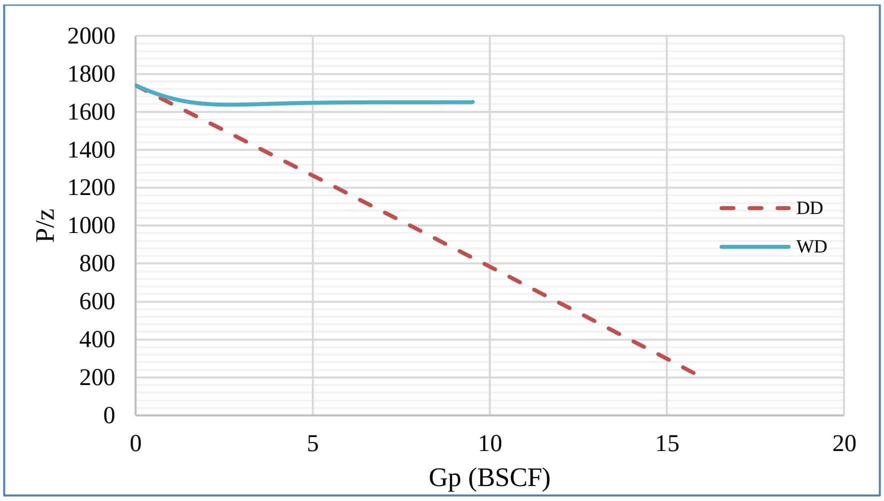

Figure 4. P/Z Graph for Depletion-Drive and Water-Drive Gas Reservoir Model

The graph of two models gas reservoir from Figure 4 above, is in accordance to the graphs that illustrated from Ikoku, 1992. The effect of water aquifer below gas column tend to lower the ultimate recovery of gas. Water aquifer below the gas column not only giving the drive mechanism for the gas but also the energy from the water aquifer can lead to water breakthrough that increase the abandonment pressure.

In order to lowering the abandonment pressure of water-drive gas reservoir, that the expected result is increase the ultimate recovery, co-production technique is implemented to the water-drive gas reservoir model by adding one well for water production. The parameters of water production rate will be sensitive later, for the first trial the water is produced at 2000 STB/d. And the result after scenario of improve gas recovery can be seen in the Figure 5 below:

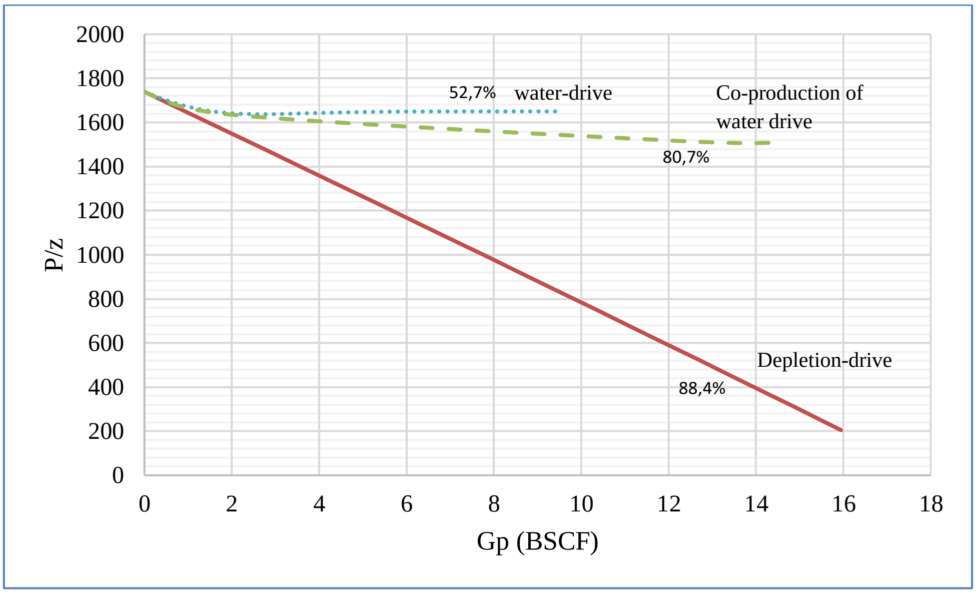

Figure 5. Comparion of p/z after co-production implementation

The scenario of improve gas recovery from this simulation, able to increasing gas recovery factor by 28%.

3.2. Sensitivity Analysis of Parameters

There are a lot aspects that influence the success of co-production technique. Both from reservoir and production aspects. To analyze these effects, some parameters will be sensitive using reservoir simulation. Experimental design or known as Design of experiments (DOE) is a well-known technique to get maximum information with simultaneous varying of all parameters and required a smaller number of performing time consuming numerical tests.

From the research by Naderi et al., 2014 and because it is a conceptual reservoir model with a fixed amount of initial gas reserves, the parameters to be analyzed for sensitivity are: reservoir permeability (Kh), permeability anisotropy (Kv/Kh), and ratio of gas column volume to water color volume (Vaq) for factors from the reservoir. As well as water production rate (Qw), perforation interval (Hp), and tubing head pressure (THP) of gas production wells for surface factors.

The simulation for DOE sensitivity analysis run orders are shown in Table 1 below:

Table 1. Design of Experiments Run Orders

RunOrder	K_h	K_v/K_h	V_{aq}	Q_w	H_p	THP
1	-1	-1	1	-1	1	1
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	-1	1	1	1	1	-1
5	0	0	0	0	0	0
6	1	-1	1	-1	-1	1
7	1	-1	-1	1	-1	-1
8	1	1	1	1	-1	1
9	-1	1	-1	1	-1	1
10	0	0	0	0	0	0
11	1	1	-1	-1	1	-1
12	0	0	0	0	0	0
13	1	1	-1	-1	1	1
14	0	0	0	0	0	0
15	-1	-1	-1	1	1	1
16	-1	-1	-1	-1	-1	-1
17	-1	1	1	-1	-1	-1
18	1	-1	1	1	1	-1

To simplified the data input process for reservoir simulation, the Design of Experiments is converted into expected range value for every parameter using transfer function shown in Table 2 below:

Table 2. Range Factor and Transfer Function

Factor	Level			Transfer function
K_h (mD)	10	100	1000	$Log(K_h) - 2$
K_v/K_h (fraksi)	0.01	0.1	1	$Log\left({}^{K_v}/_{K_h}\right) + 1$
V_{aq} (fraksi)	1	10	100	$Log(V_{aq}) - 1$
Q_w (STB/D)	500	2750	5000	$\frac{Q_w - 2750}{2250}$
H_p (%)	30	60	90	$\frac{H_p - 60}{30}$
THP (psi)	100	300	500	$\frac{THP - 300}{200}$

The water-drive co production gas reservoir model, is being sensitive with the number of parameters and also the recovery factor for each run orders are shown in Table 3 below:

Table 3. Parameters Run Orders and Recovery Factor

RunOrder	K_h*(mD)*	K_h/K_v	Q_w *(bwpd)*	H_p *(ft)*	*THP (psia)*	V_{aq} *(acre.ft)*	*RF (fraction)*
1	10	0.01	500	90	500	100	0.44
2	100	0.1	2750	60	300	10	0.89
3	100	0.1	2750	60	300	10	0.89
4	10	1	5000	90	100	100	0.76
5	100	0.1	2750	60	300	10	0.89
6	1000	0.01	500	30	500	100	0.81
7	1000	0.01	5000	30	100	1	0.96
8	1000	1	5000	30	500	100	0.77
9	10	1	5000	30	500	1	0.75
10	100	0.1	2750	60	300	10	0.89
11	1000	1	500	90	100	1	0.96
12	100	0.1	2750	60	300	10	0.89
13	1000	1	500	90	500	1	0.97
14	100	0.1	2750	60	300	10	0.89
15	10	0.01	5000	90	500	1	0.76
16	10	0.01	500	30	100	1	0.83
17	10	1	500	30	100	100	0.14
18	1000	0.01	5000	90	100	100	0.85

To obtain the relationship between parameters, we use Response Surface Methodology. Response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables to obtain an optimal response. The function that is obtained from the simulation results is:

$$RF\ (fraksi) = 0{,}8874 + 0{,}1777[Log\ (K_h) - 2] - 0{,}06480\left[Log\left({}^{K_v}/_{K_h}\right) + 1\right] + 0{,}08127\left[\frac{Q_w - 2750}{2250}\right] + 0{,}08375\left[\frac{H_p - 60}{30}\right] - 0{,}04849\left[\frac{THP - 300}{200}\right] - 0{,}1584[Log\ (V_{aq}) - 1] - 0{,}1373\,[Log\ (K_h) - 2]^2 + 0{,}000975\,[Log\ (K_h) - 2]\left[Log\left({}^{K_v}/_{K_h}\right) + 1\right] - 0{,}04223\,[Log\ (K_h) - 2]\left[\frac{Q_w - 2750}{2250}\right] + 0{,}01905\,[Log\ (K_h) - 2]\left[\frac{H_p - 60}{30}\right] + 0{,}04982\,[Log\ (K_h) - 2]\left[\frac{THP - 300}{200}\right] + 0{,}1220\left[Log\left({}^{K_v}/_{K_h}\right) + 1\right]\left[\frac{Q_w - 2750}{2250}\right] \qquad (1)$$

The function is then being input to Monte-Carlo simulation to generate the Tornado Chart shown in Figure 6 below:

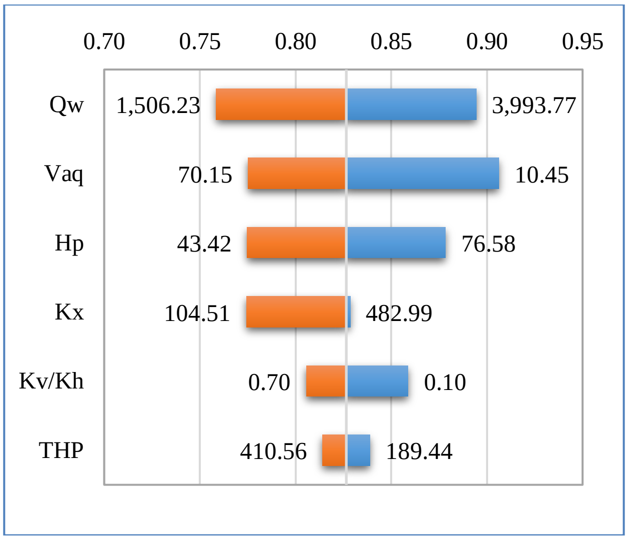

Figure 6. Tornado Chart of Gas Recovery Factor

From the Tornado Chart above, it can be seen that the factors that have a major influence on the amount of gas recovery factor are the flow rate of water production (Qw), then aquifer size (Vaq), perforation interval (Hp), reservoir permeability (Kh), permeability anisotropy (Kv/Kh), and finally tubing head pressure (THP) for gas wells.

IV. CONCLUSION

Co-production technique is one of improve gas recovery method that producing the water from aquifer in order to slow the water breakthrough to the gas well. In Figure 4 it can be seen that there is quite a large separation between the P/z vs Gp depletion-drive and water-drive curves. In addition, there is a difference in recovery factor around 36% between the two types of gas reservoirs. This might be occurred due to water breakthrough which has started since the beginning of the reservoir's production. This water breakthrough causes the production well to be filled with water, leaving gas with quite high pressure in the reservoir.

To see how much pressure due to water influx can be reduced after water is produced, Figure 5 shows a comparison of the P/z vs Gp curves for the three cases. Even though it turns out that the pressure that can be reduced is not too much, the increase in gas recovery factor after the application of this co-production technique can be said to be quite significant. Where there is an increase in the recovery factor value of 28% after water production in the water-drive reservoir. Or, only a difference of 8.3% from if the reservoir were depletion-drive.

From the gas reservoir model in this study, co-production technique is able to increase gas recovery factor by 28%. There are a lot of aspects that affect the success of this method, from some parameters that being analyzed and using the range that has mentioned, the water production rate become the most influencing factor of gas recovery factor.

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