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Impact of Gas Desorption on Production from Multiply Fractured Horizontal Well in Shale

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Impact of Gas Desorption on Production from Multiply Fractured Horizontal Well in Shale

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In

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ABSTRACT

Impact of Gas Desorption on Production from Multiply Fractured Horizontal Well in Shale

Abdallah O. Arwishad

In recent years, the exploitation of unconventional gas reservoirs has become increasingly important to North American energy supply. Unconventional gas development depends on effective stimulation of low permeability reservoir by creating multiple hydraulic fractures which connects massive reservoir area to the wellbore. Hydraulic fracturing and horizontal drilling are primary techniques to obtain economical production from the shale gas reservoir. In addition to that, gas desorption can be a significant source of gas production in shale gas reservoirs.

This research will illustrate the impact of gas desorption on production from multiply fractured horizontal well in shale by using a reservoir model. This research investigates the impact of reservoir and fracture characteristic on gas desorption from shale gas reservoir.

A commercial reservoir simulator was utilized to model a single porosity reservoir with number of layers. The results were used to evaluate the impact of gas desorption and investigate the impact of reservoir and hydraulic fracture characteristic on production performance in low permeability reservoir.

DEDICATION

I would like to dedicate this thesis to almighty Allah for his guidance, giving me strength and keeping me healthy till this thesis has been finished, to my family members, especially my father and my mother, for their endless encouragements, prayers, advice, financial and moral support, to my lovely wife and my sweet daughter who have been a great source of motivation and inspiration, for their patience and understanding, to my wife's family and my friends for their endless encouragements and support during this work.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

Shale gas is an organic rich formation which has a significant capacity to store natural gas. Shale formations have become a significant source of natural gas in the U.S. Shale gas production has been growing rapidly from 0.3 trillion cubic feet in 1996 to 3.11 trillion cubic feet in 2010 in the United States. Therefore, the researchers have focused on increasing the productivity of the shale formations.

In recent years, production of natural gas has increased by using horizontal well technology. Horizontal well produces more natural gas than vertical wells for several reasons. Horizontal wells are open to a larger portion of reservoir than vertical wells. Particularly, when the horizontal wells are drilled perpendicular to the natural fracture. Moreover, horizontal wells have some of other benefits such as reducing water and gas coning, increasing the drainage area and improving well productivity.

Hydraulic fracturing is a procedure which commonly used to increase flow of gas or oil to the well. This procedure is performed by pumping fluid into the rock with high enough pressure to create network of interconnected fracture to serve as pore spaces for movement of natural gas to the wellbore.

Gas adsorption refers to the part of gas that is taken by solid when the gas comes into the contact with the solid. Gas adsorption can be a significant source of the gas production from low permeability reservoir. The objective of this study was to investigate the impact of gas desorption on production from multiply fractured horizontal well in shale reservoir using a reservoir model.

2.1 Shale Gas in the United States:-

Shale gas refers to natural gas that is extracted from the shale formations. Shale gas is basically dry gas that consists of 90% of methane or more, but some formations produce wet gas. In the recent decades, hydraulic fracturing and horizontal drilling have let to producers to access to large volume of shale gas which was not possible to produce in the past.

According U.S. Energy Information Administration, United States have massive resources of shale gas that is estimated to be 2,552 trillion cubic feet (Tcf) of natural gas resources (EIA, 2011). In 2009, shale gas made up 14% of total U.S. natural gas supply (EIA, 2011). Production of shale gas is expected to continue to increase and reach 45% of U.S. total natural gas supply in 2035 (EIA, 2011). Figure1 shows Natural Gas Supply in the U.S.
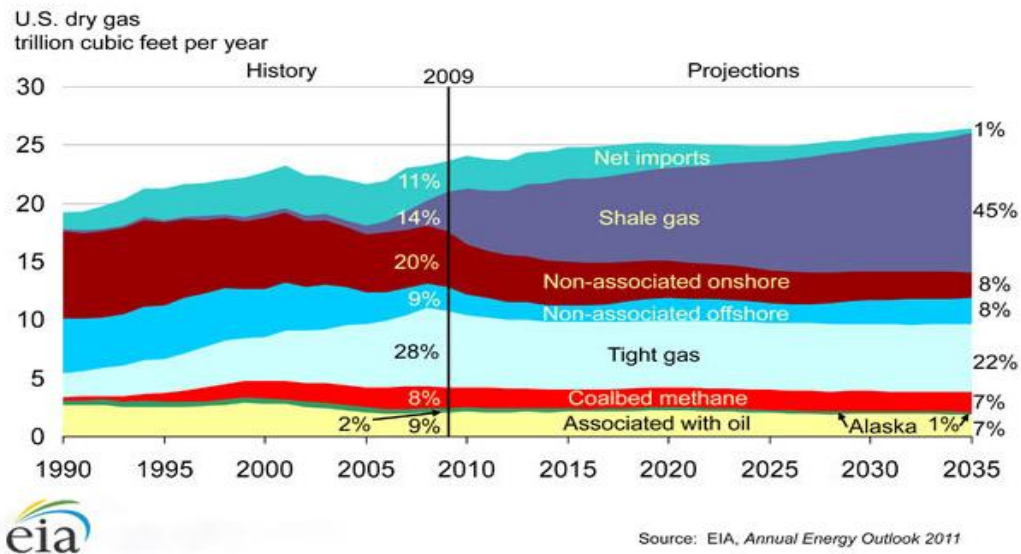
Figure 1. The U.S. Natural Gas Supply, 1990-2035 (EIA 2009)

Based on recent assessment by Energy information Administration, major shale gas basins exist throughout the lower 48 United States that have abundant resources of natural gas. In Texas, Barnett Shale play produces 6% of all natural gas produced in 48 States. In 2011, analysts have estimated most new reserves growth (50% to 60%, or approximately 3 bcf/day) will come from unconventional shale gas reservoirs (David, 2008). Figure 2 shows gas shale basins of United States with estimated gas reserves.
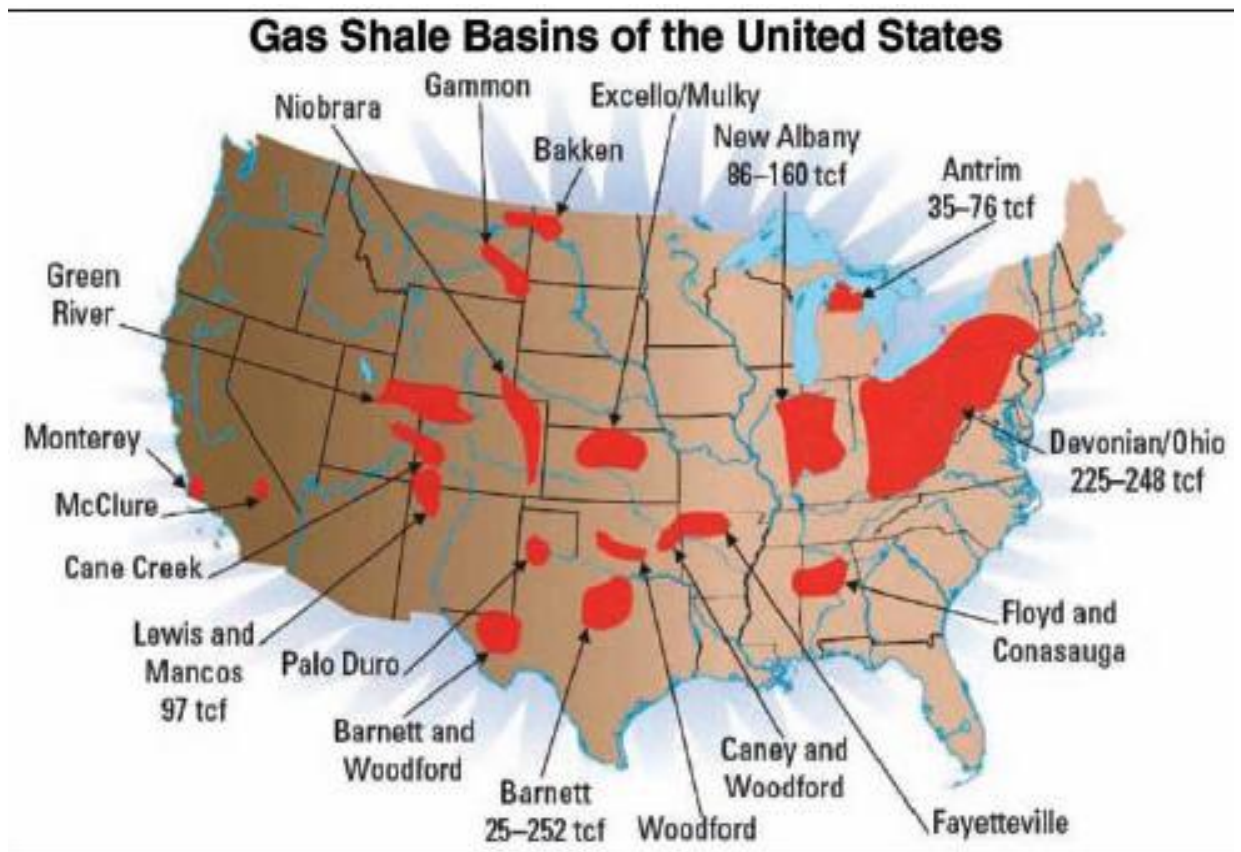
Figure 1. Gas Shale Basins of United States with Estimated Gas Reserves (Daniel Arthur, 2009)

Marcellus shale is a significant massive shale formation in eastern North of United States, which runs along 600 miles stretch between the states of West Virginia, Ohio, Pennsylvania and New York. Marcellus shale rock covers an area of 95,000 square miles with estimated depth

of4,000 to 8,500 feet, and it has an average thickness of 50 to 200 feet. The following figure shows Marcellus formation is around 600 miles long (oilshalegas.com, 2011).

According to a survey issued by Terry Englander, a geoscience professor at Pennsylvania State University, and Gary Lash, a geology professor at the State University of New York at Fredonia, Marcellus shale formation might contain more than 500 trillion cubic feet of natural gas (oilshalegas.com, 2011).

Figure 2. Marcellus Shale Formation (image: oilshalegas.com)

The following table represent the comparison of data for gas shale in the United States.

Table 1. Comparison of Data for Gas Shale in the United States (Daniel Arthur, 2009)

Gas Shale Basin	Barnett	Marcellus	Fayetteville	Haynesville	Woodford	Antrim	New Albany	Lewis
Estimated Basin Area, square miles	5,000	95,000	9,000	9,000	11,000	12,000	43,500	10,000
Depth, ft	6, 500 - 8,500	4,000 - 8,500	1,000 - 7,000	10,500 - 13,500	6,000 – 11,000	600 – 2,200	500 – 2,000	3,000 – 6,000
Net Thickness, ft	100-600	50-200	20-200	200- 300	120-220	70-12	50-100	200-300
Depth to Base of Treatable Water, ft[#]	~1200	~850	~500	~400	~400	~300	~400	~2000
Rock Column Thickness between Top of Pay and Bottom of Treatable Water	5,300– 7,300	2,125 - 7650	500 – 6,500	10,100 – 13,100	5,600 – 10,600	300 – 1,900	100 – 1,600	1,000 – 6,000
Total Organic Carbon, %	4.5	3-12	4.0-9.8	0.5 – 4.0	1-14	1-20	1-25	0.45-2.5
Total Porosity, %	4-5	10	2-8	8-9	3-9	9	10-14	3.0-5.5
Gas Content, scf/ton	300-350	60-100	60-220	100-330	200-300	40-100	40-80	15-45
Water Production, Barrels water/day	0	0	0	0		5-500	5-500	0
Well spacing, Acres	60-160	40-160	80-160	40-560	640	40-160	80	80-320
Original Gas-In-Place, Tcf	327	1,500	52	717	52	76	160	61.4
Reserves, Tcf	44	262, 500	41.6	251	11.4	20	19.2	20
Est. Gas Production, mcf/day/well	338	3,100	530	625-1,800	415	125-200		100-200

mcf = thousands of cubic feet of gas.

NOTE: Data derived from various sources and research analysis. Information from some basins was unable to be identified and confirmed at the time of this paper and has been left blank.

- for the Depth to base of treatable water data, the data was based on depth data from state oil and gas agencies and state geological survey data.

SOURCE: Hayden & Pursell, 2005; Halliburton, 2008; Navigant Consulting, 2008; Drilling Contractor, 2000; Boughal, 2008; Berman, 2008; Haines, 2006; Arkansas Oil and Gas Commission, 2008; Nyahay, Leone, Smith, Martin, & Jarvie, 2007; Cardott, 2004; Soeder, 1986; Vulgamore et al, 2007; Petroleum Listing Services, 2008; Jochen, 2006; Sumi, 2008; Engelder & Lash, 2008; Williams, 2008; Gas Leases, 2008; US Energy Investor, 2005.

2.2 Horizontal Wells:

In recent years, drilling horizontal wells have become one of the most significant technologies introduced in oil and gas industry. Horizontal wells techniques are used to increase productivity, improving cost of field operations and adding reserves. As a result of the advances in drilling and completion technologies in the last two decades, the efficiency and economy of horizontal wells have significantly increased. Today, horizontal well technology is applied more often and in many different types of formations. Figure 4 shows horizontal well.
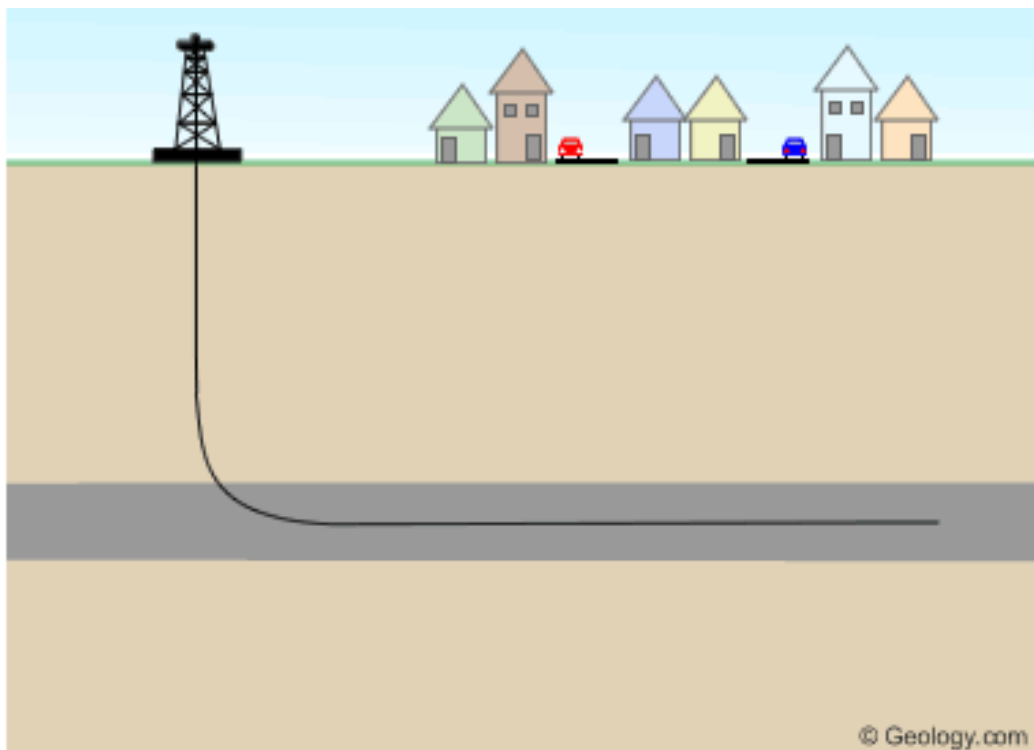
Figure 3. Horizontal Well (image: geology.com)

As a comparison to vertical wells, horizontal wells have more productivity for several reasons:-

1- Horizontal wells have been used to intersect fractures and drain them as it shown in Figure 5.
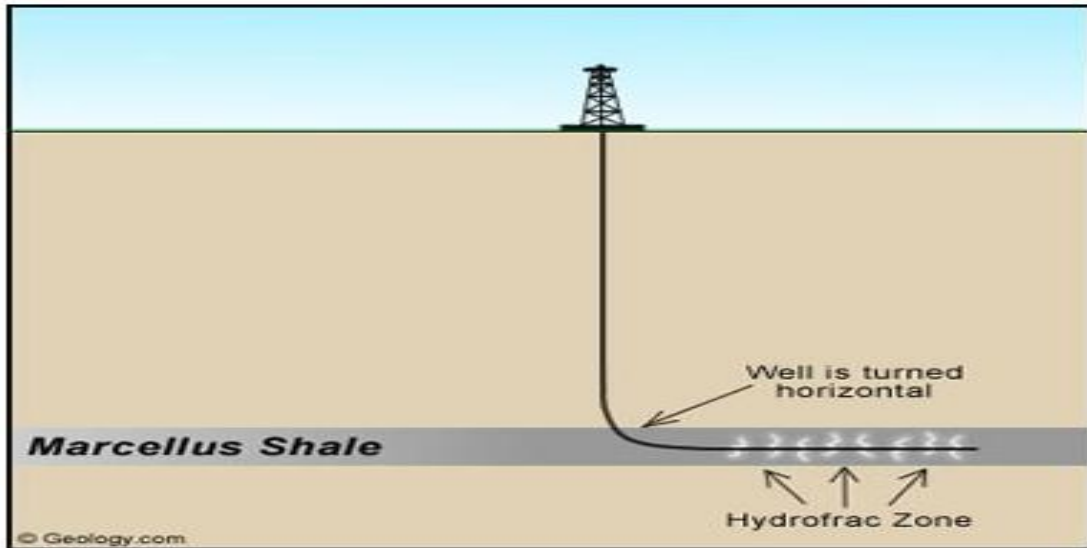
Figure 4. Horizontal Well in a Naturally Fractured Reservoir (image: geology.com)

2- Horizontal wells have been used to minimize coning problems and enhance oil or gas production as it shown in the following figure.
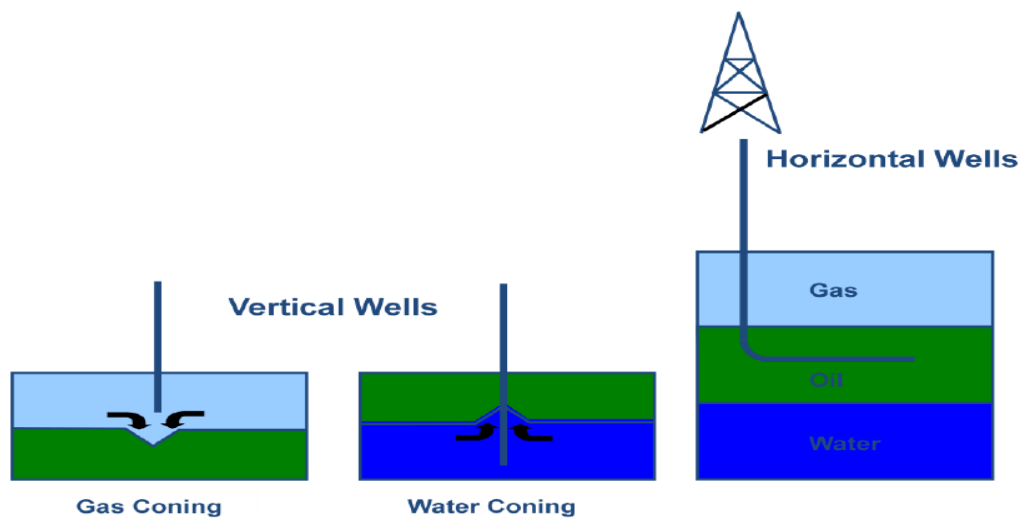
Figure 5. Gas and Water Coning in the Reservoir (Batruna & Daggez, 2010)

3- Horizontal wells can improve drainage area per well and reduce the number of wells that are required to drain the reservoir in low permeability reservoirs. However, in high permeability reservoirs, horizontal wells can be used to reduce turbulence near wellbore and improve well deliverability.

4- Horizontal wells increase injectivity, improve sweep efficiencies, and reduce the number of wells needed for water flooding and steam injection for oil recovery.

2.2.1 Advantages of Horizontal Wells:

1- Intersect many fractures in a hydrocarbon containing formation.

2- Avoid drilling into water below (or gas above) hydrocarbon or perforating adjacent to water or gas.

3- Increase both the drainage area of the well in the reservoir and the lateral surface area of the wellbore.

4- Intersect layered reservoirs at high dip angles.

5- Improved gas production (degasification).

6- Improve injection of water, gas stream, chemical, and polymer into formations.

2.2.2 Disadvantages of Horizontal Wells:-

1- Horizontal well costs more than vertical wells. The estimated cost of horizontal wells is1.5 to 2.5 times of that of vertical wells in United States (Joshi, 2003).

2- Horizontal well can be just produced from one zone if reservoir has multiple pay zones (Joshi, 2003).

3- The overall current commercial success rate of horizontal wells in the U.S. appears to be 65%. (This success ratio improves as more horizontal wells are drilled in the given

formation in a particular area). This means, initially it is probable that only 2 out of 3 drilled wells will be commercially successful (Joshi, 2003).

2.3 Hydraulic Fracturing:

Hydraulic fracturing is a process which results in creation of fractures in rocks. The technology is used to increase flow rate of oil or gas from shale formations. Hydraulic fracturing is used to create additional permeability in the formation that allows oil or gas to flow to the wellbore. Hydraulic fracturing can enhance production from low permeability reservoirs such as coalbed methane or shale reservoir. Hydraulic fracturing has been used for over 60 years which has become a significant technology used in gas industry to increase the necessary production to support an increasing demand for energy.

The first use of hydraulic fracturing for stimulation of oil and gas wells in the United States was 1947, but it was first used commercially in 1949. As a result of its success in increasing gas or oil production. Worldwide, it is performed on tens of thousands of oil and natural gas wells annually. Figure 7 illustrates the fracturing process in a horizontal well.
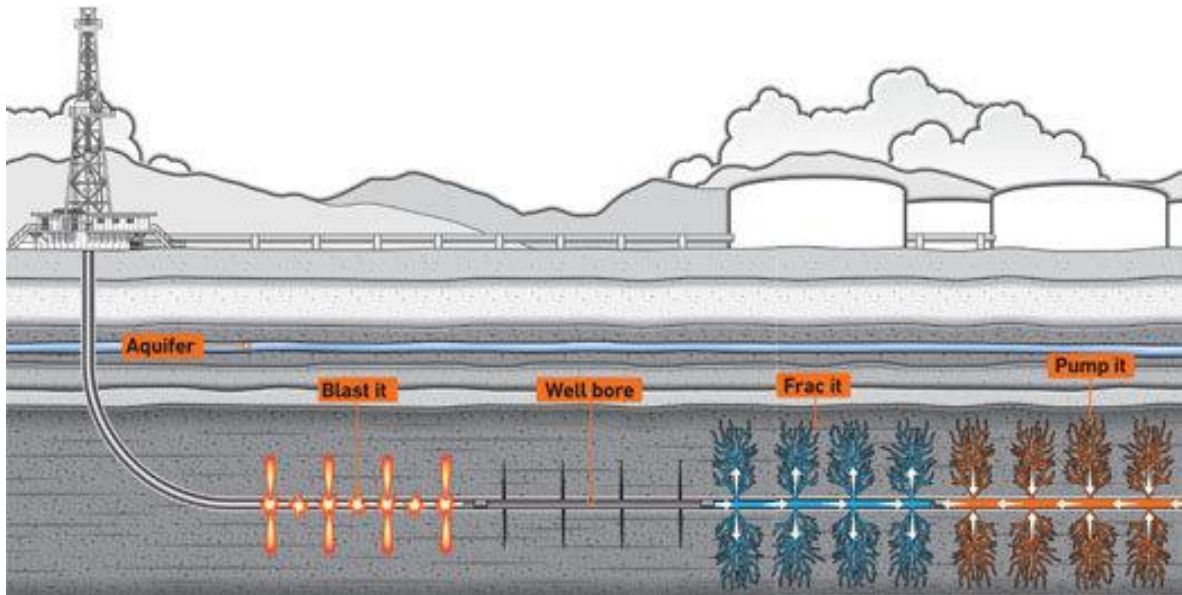
Figure 6. How to Wring Gas from a Stone (image: Koppillustration.com)

2.4 Conceptual Model for Shale Gas:

Free gas and adsorbed gas are two different mechanisms for storing natural in shale formations. Free gas molecules are stored in pore space and natural fractures in shale, but adsorbed gas molecules are stored on shale matrix surface.

Free gas storage is similar to the gas storage in the conventional gas reservoirs where the pore space provides the storage space. The pores and natural fractures in matrix provide the storage for free gas in shale gas reservoir. Hence, free gas is stored in dual porosity system. Matrix pores provide higher storage capacity than natural fracture.

Adsorbed gas is stored by a different physical mechanism that account as a minor part of gas storage in gas shale. Adsorption is the mechanism that makes gas bound on the surface of matrix particles. The Figure 8 illustrates the free gas that is stored in dual porosity system comprised of the matrix pores, the first porosity, and natural fractures, second porosity, and the gas adsorption

is considered as a third porosity. Though in fact, storage space is not pores or fractures but the particle surface.
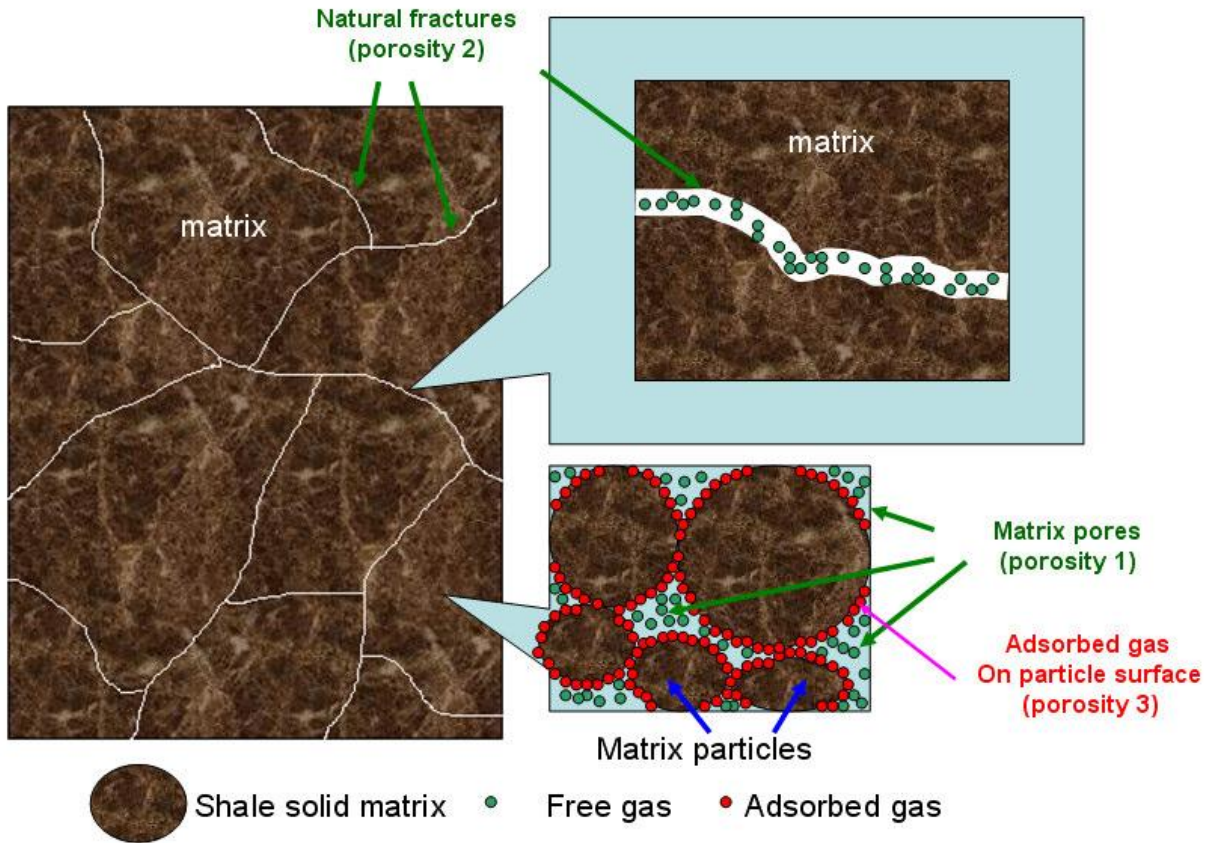
Figure 7. Storage Mechanism of Shale Gas Reservoir (Song, 2010)

The flow mechanism of shale gas reservoirs can be described as the following: free gas will flow through matrix pores into the fracture system due to pressure gradient, driven by a mechanism of fluid in porous media then free gas will flow to the wellbore through fractures. For adsorbed gas, desorption will occur when pore pressure decreases, and adsorbed gas molecules have the potential to move and diffuse to pore space from particle surfaces. The diffusion time is considered to be negligible. After that, the adsorbed gas essentially becomes free gas and the future transport will follow the same way with the original free gas, and the mechanisms of

flowing through matrix pore system and fracture system is also the same (Song, 2010). Figure 9

shows the flow mechanism of shale gas reservoirs.
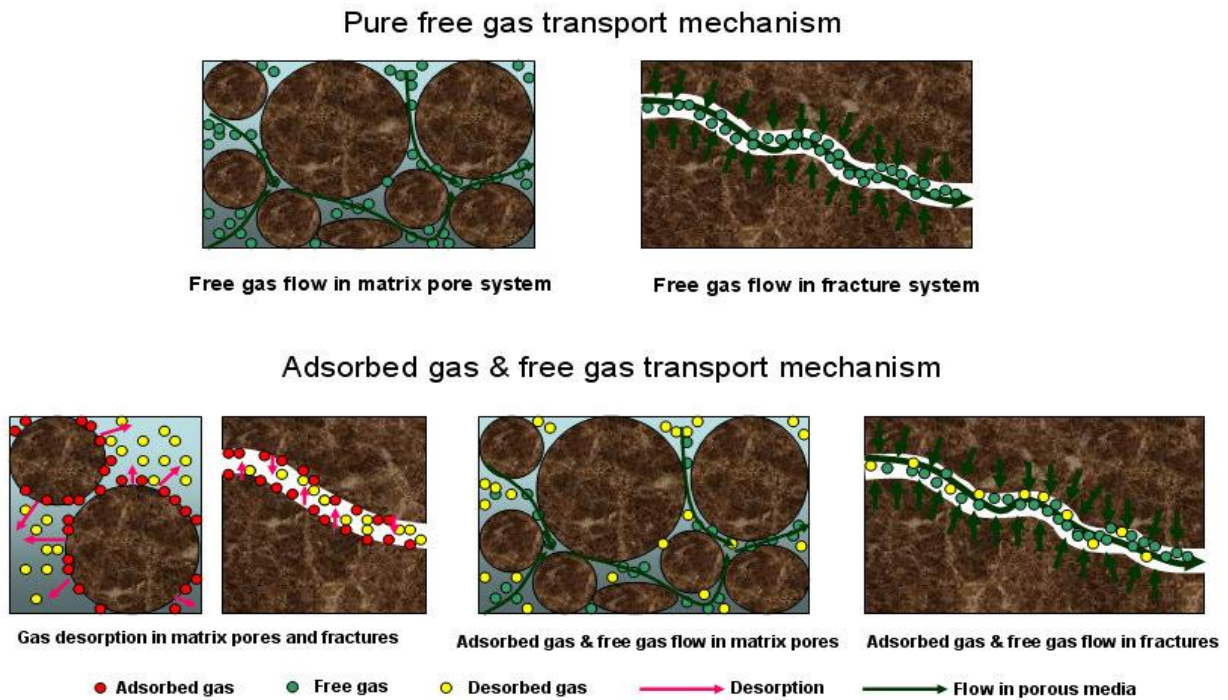
Figure 8. Flow Mechanismsin Shale Gas Reservoirs (Song, 2011)

2.5 Gas Adsorption:

Gas adsorption is a surface phenomenon and is predominately a physical bond caused by the

intermolecular attractive forces (i.e., Van der Waals forces) (Rushing et al 2008). Whereas, gas

desorption is a reverse process of gas adsorption.

The most common model used to describe gas adsorption or gas desorption is Langmuir

Model, and the following equation describes the gas adsorption capacity of rock as pressure

changes under isothermal conditions.

$$V_{ads} = \frac{V_L P}{P_L + P}$$ ………………………………………………………………………… (1)

Where:-

V_{ads}: Gas volume which is adsorbed by unit mass of the rock. (SCF/Ton)

P : Pore pressure. (psi)

V_L : Langmuir volume which is the maximum gas volume can be adsorbed. (SCF/Ton)

P_L : Langmuir pressure, the pressure at which half of Langmuir volume gas is adsorbed. (psi)

   In the following figure shows typical Langmuir isothermal curve that assumes no change in temperature because the temperature will affect in capacity of gas adsorption, especially, if the temperature is high, the gas adsorbed will be less and indicates the amount of gas adsorbed as pressure increase.
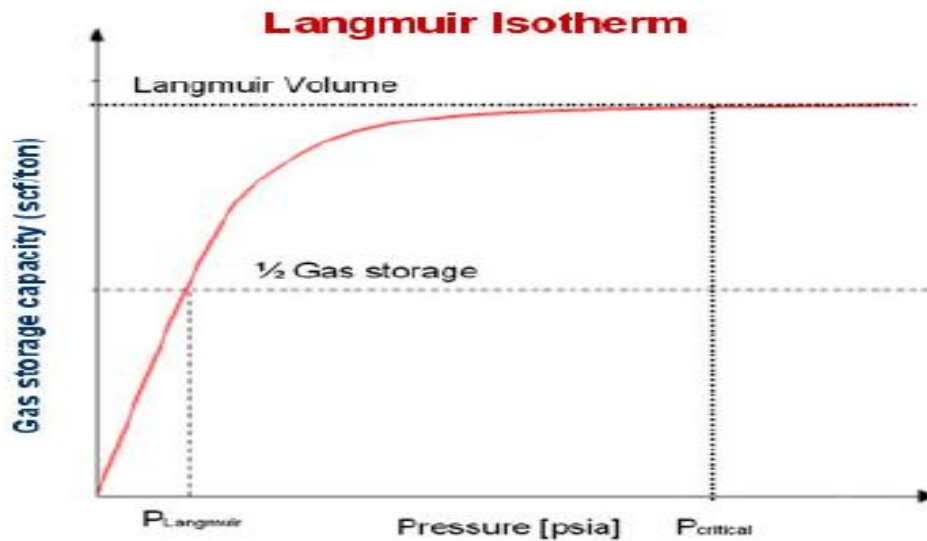
Figure 9. Typical Langmuir Isothermal Curve (Song, 2011)

CHAPTER 3

OBJECTIVE AND METHODOLOGY

As a demand for natural gas has increased in the recent years, the need for reliable forecasting methods has also increased. Therefore, the objective of this research is to investigate the impact of gas desorption on production from multiply fractured horizontal well in shale by using a reservoir model. In addition to that, this research will focus on identifying the effects of reservoir and fracture characteristic on gas desorption from shale gas reservoir.

The objectives of this study are as follows:

1- To evaluate the impact of gas desorption on production from multiply fractured horizontal wells.

2- To investigate the impact of reservoir and hydraulic fracture characteristics on gas desorption and production performance.

The methodology employed in this study to achieve the objectives is as follows:

1- Develop a numerical reservoir model to predict the production performance of the ultra-low permeability reservoir with gas adsorption.

2- Utilize the model to evaluate the impact of gas desorption on production from multiply fractured horizontal wells.

3- Conduct parametric studies to investigate the impact of reservoir and hydraulic fracture characteristics on gas desorption and production performance.

3.1 Numerical Model:

Reservoir simulation model (Eclipse Office) is developed by Schlumberger Company, which used to solve one, two or three dimensional problems. Eclipse Office (CBM template) is a single porosity reservoir model that allows engineers to generate the reservoir model which includes the gas adsorption. Figure 11 shows CBM template workflow chart. In this study, a natural reservoir model was designed as a 3-imensional model, single porosity system with five layers. The base model schematic horizontal well is shown in Figure 12.Table 2 lists the base model parameters.
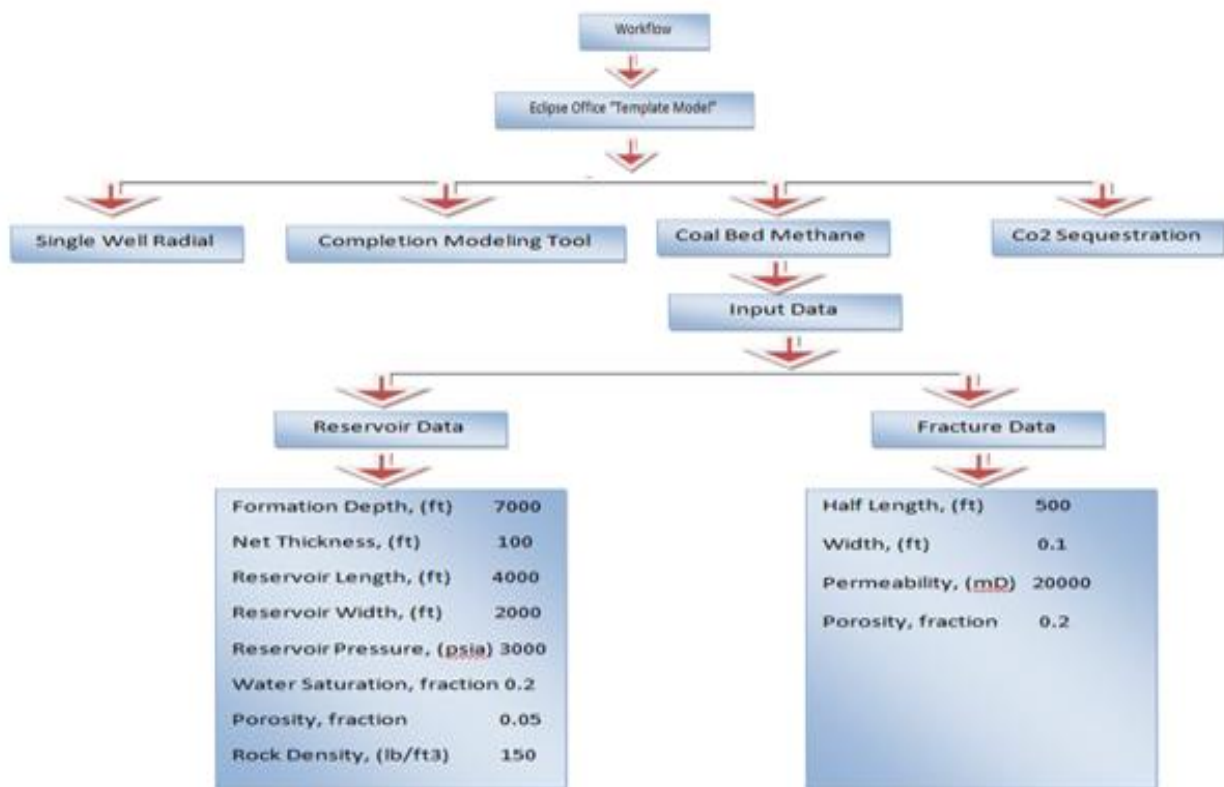
Figure 10. CBM Template Workflow Chart

Top View

2Xe

Ye

L

Kx

Ky

Side View

| Layer1 |
| Layer2 |
| Layer3 |
| Layer4 |
| Layer5 |

H

H/2

Kz
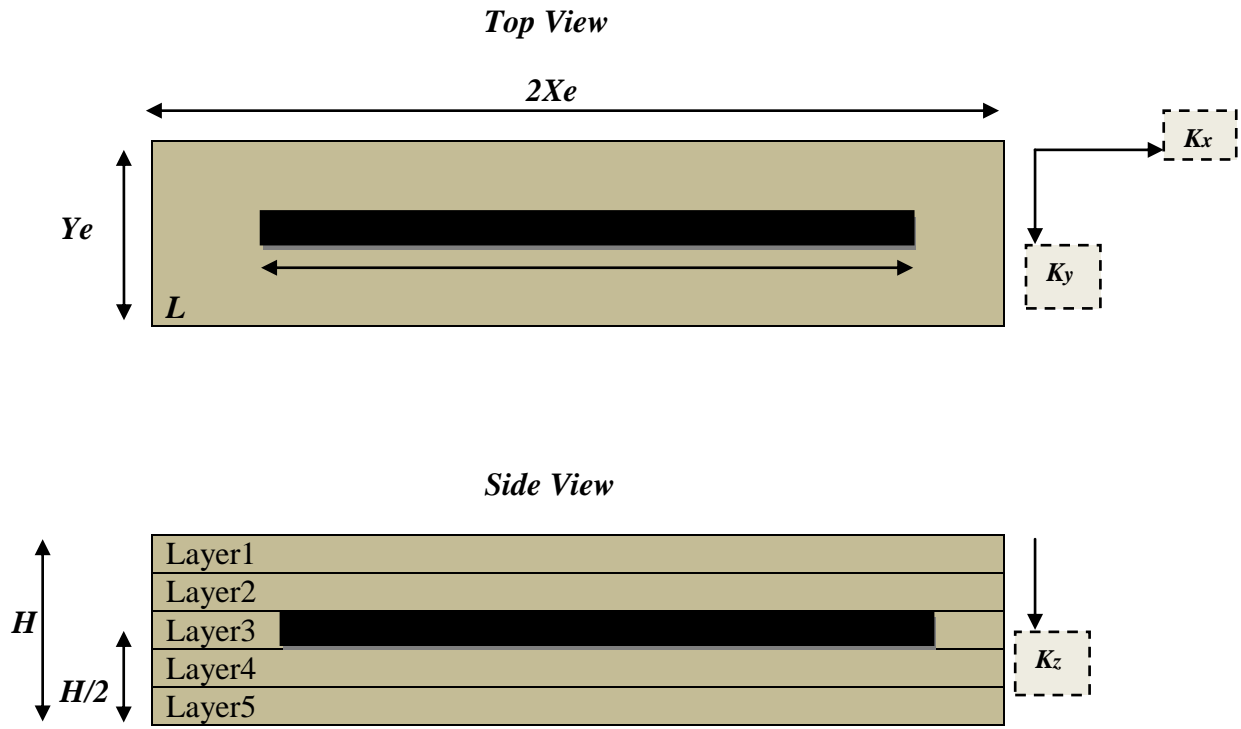
Figure 11. Base Model Schematic

Table 2. Base Model Parameters

Base Model Parameters	
Reservoir Parameters	
Depth, ft	7000
Thickness, ft	100
Length (2Xe), ft	4000
Width (Ye), ft	2000
Well Length (L), ft	3000
Rock Properties	
Matrix Porosity, Fraction	0.05
Bulk Perm. x, y, z mD	0.001, 0.001, 0.0001
Compressibility, 1/psia	1.E-06
Density, lb/ft^3	150
Initial Conditions	
Reservoirs Pressure, psia	3000
Water Saturation, Fraction	0.2
Hydraulic Fracture Properties	
Half Length, ft	500
Width, in	0.1
Top of Fracture, ft	7000
Bottom of Fracture, ft	7100
Permeability, mD	20000
Porosity, Fraction	0.2
Well Production Controls	
Pwf, psia	500
Fluid Properties	
Standard Pressure, psia	14.7
Standard Temperature, ˚F	60
Reference Temperature, ˚F	115
Adsorption	
Diffusion Coefficient, ft^2/day	1
Sorption Time, day	62
Langmuir Pressure, psia	635
Langmuir Concentration, SCF/Ton	0.08899

3.2 Model Parameters and Ranges

Table 3.Summarizes the parameters that were used in the simulation model in order to compare the effects of reservoir and fracture characteristic on gas desorption.

Table 3. Summary of the Parameters Used in Simulation

Parameter	Range	Values Used
Reservoir Shape	Rectangular	Rectangular
Well Penetration Ratio (L/2Xe)	0.5-1	0.5, 0.75, 1
Reservoir Permeability (mD)	0.0001-0.005	0.0001, 0.001, 0.005
Fracture half length (ft)	300-600	300, 400, 500, 600
2Xe * Ye (ft^2)	5000 * 2000-3000 * 2000	5000 * 2000,4000 * 2000, 3000 * 2000
Flowing Bottom Hole Pressure (psia)	250-750	250, 500, 750
Langmuir Pressure (psia)	200-1000	200, 400, 635, 800, 1000
Langmuir Volume (SCF/Ton)	0.01-0.15	0.01, 0.05, 0.08899, 0.1,0.15
Fractures Number	1-13	1, 2, 3, 4, 7, 13

3.3 Evaluation Method

In order to investigate the impact of desorption on gas production, the 50-year production profiles with and without adsorbed gas were compared as it shown in Figure 13. The percentage increase due to desorption was then evaluated by equation 2.
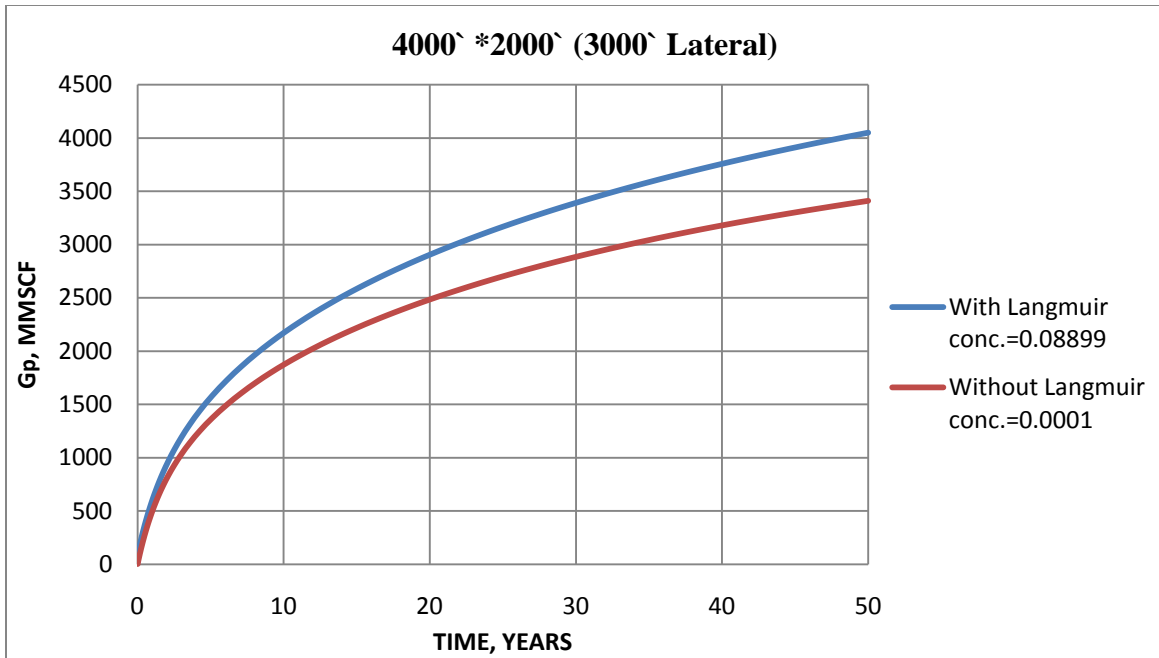
Figure 12. Production Profile With and Without Desorption

$$\Delta G_p \% = \frac{(G_{pw} - G_{pwo}) \times 100}{G_{pwo}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

Where:

G_p : Percentage Increase in Cumulative Production due to Desorption. (%)

G_{pw} : Cumulative Gas Production with Adsorbed Gas Concentration of 0.08899. (MMSCF)

G_{pwo} : Cumulative Gas Production without Adsorbed Gas Concentration of 0.0001. (MMSCF)

Note: The value of 0.0001 for gas concentration was used to represent production without adsorption. Using zero for gas concentration causes the model to crash.

CHAPTER 4

RESULTS AND DISCUSSION

Reservoir simulation model can be a useful tool to serve as quick and reliable tool for prediction the impact of gas desorption, reservoir and fracture characteristics on production. The results which illustrate the impact of various parameters are discussed below.

4.1. Drainage Area

Different drainage areas were considered based as provided in Table 3.Thebase model was a rectangular drainage 4000 ft by 2000 ft with a 3000 ft of horizontal lateral. First, Figure 14 compares the percentage increase due to desorption from horizontal well with 4 uniformly spaced hydraulic fractures with reservoir length (2Xe) of 5000 ft, 4000 ft and 3000 ft. As it can be seen, the percentages increases are very close in first month. However, the contribution of gas desorption after 50 years for cases 5000 ft, 4000 ft and 3000 ft are 14.05%, 15.06% and 16.3% respectively. This indicates the impact of gas desorption is decreasing sa reservoir length increase.

Second, Figure 15 compares the percentage increase for hydraulic fractured horizontal well based on changing reservoir width (Ye), which is 3000 ft, 2000 ft and 1000 ft. As it can be seen, the percentages increase in the first month are almost the same for all cases, but at 50 years, percentages of cumulative gas production for the cases of 3000ft, 2000ft and 1000 ft are 12.8%, 15.06% and 22.8% respectively. And also as it appears in Figure 15for both 2000 ft and 3000ft have the same cumulative production percentage up to 15 years compared to case of 1000 ft which has higher percentage.
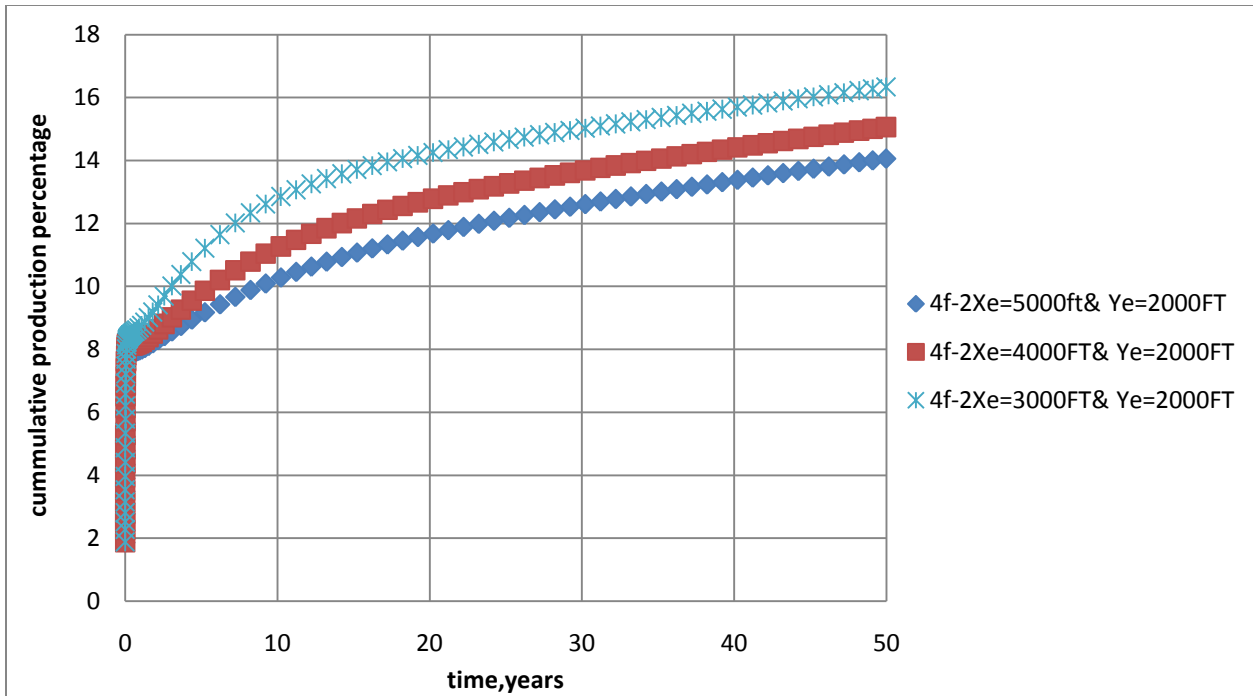
Figure 13. Impact of Drainage Area by Changing Reservoir Length on Production from Hydraulic Fractured Horizontal Well
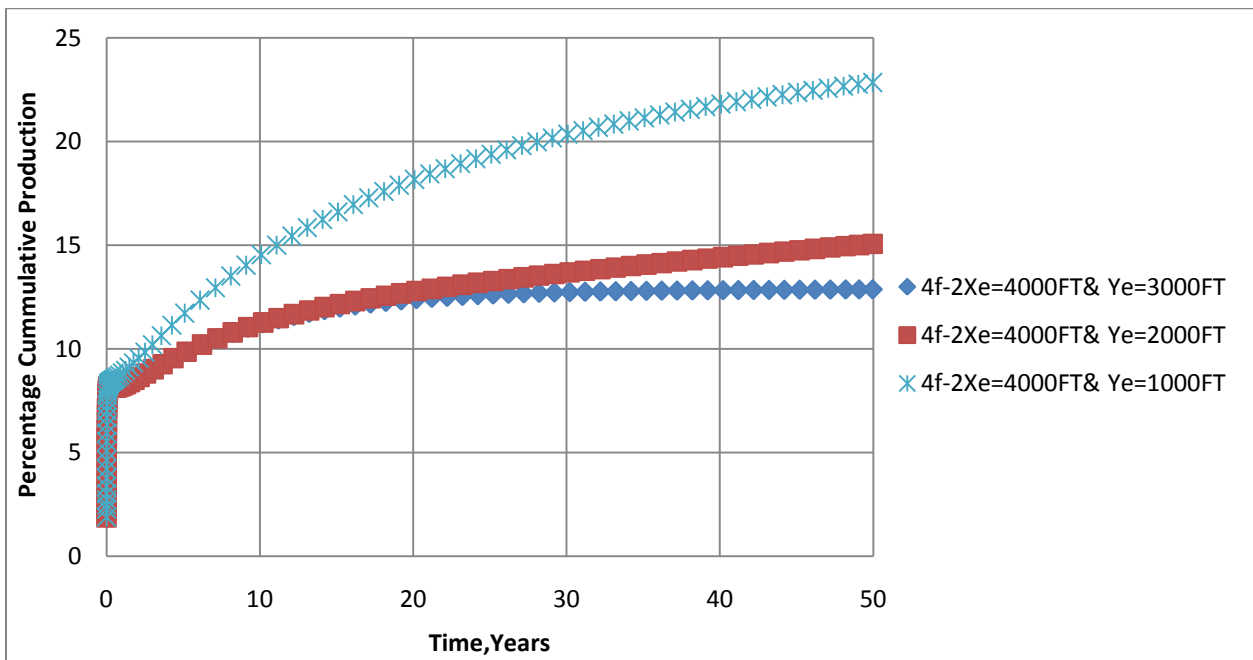

Figure 14. Impact of Drainage Area by Changing Reservoir Width on Production from Hydraulic Fractured Horizontal Well

These results indicates that as reservoir dimensions are increased the percentage increase due to desorption declines. This primarily is due to the fact that the amount of free gas production increases with the increase in dimensions while the desorbed gas does not increase. Therefore, desorption is limited to the areas close to the wellbore and the hydraulic fractures.

4.2. Horizontal Well Length

Figure 16 compares the percentage increase for 4000 ft, 3000 ft and 2000 ft of horizontal laterals with 4 hydraulic fractures which are 100%, 75% and 50% of reservoir length respectively. Hydraulic fractures are assumed to be uniformly spaced and parallel with each other and perpendicular to the well. As it can be seen, cases of 4000 ft and 3000 ft lateral length have almost the same percentage increase in the first month, but 2000 ft lateral length has higher percentage increase. In Figure 16 one can see, for the first 5 years of production, that the lateral length of 2000 ft, which is 50% of reservoir length, has higher percentage increase than the cases of laterals lengths of 3000 ft and 4000 ft, which are 100% and 75% respectively. However, the case of 50% penetration shows 11.6 percent of cumulative production for 20 years and after that remains constant up to 50 years. For cases of 100% and 75% penetration, the percentages are increasing gradually and differently, which reach to 15.28% and 13.82% after 50 years. These results confirms that desorption primarily occurs near the wellbore.
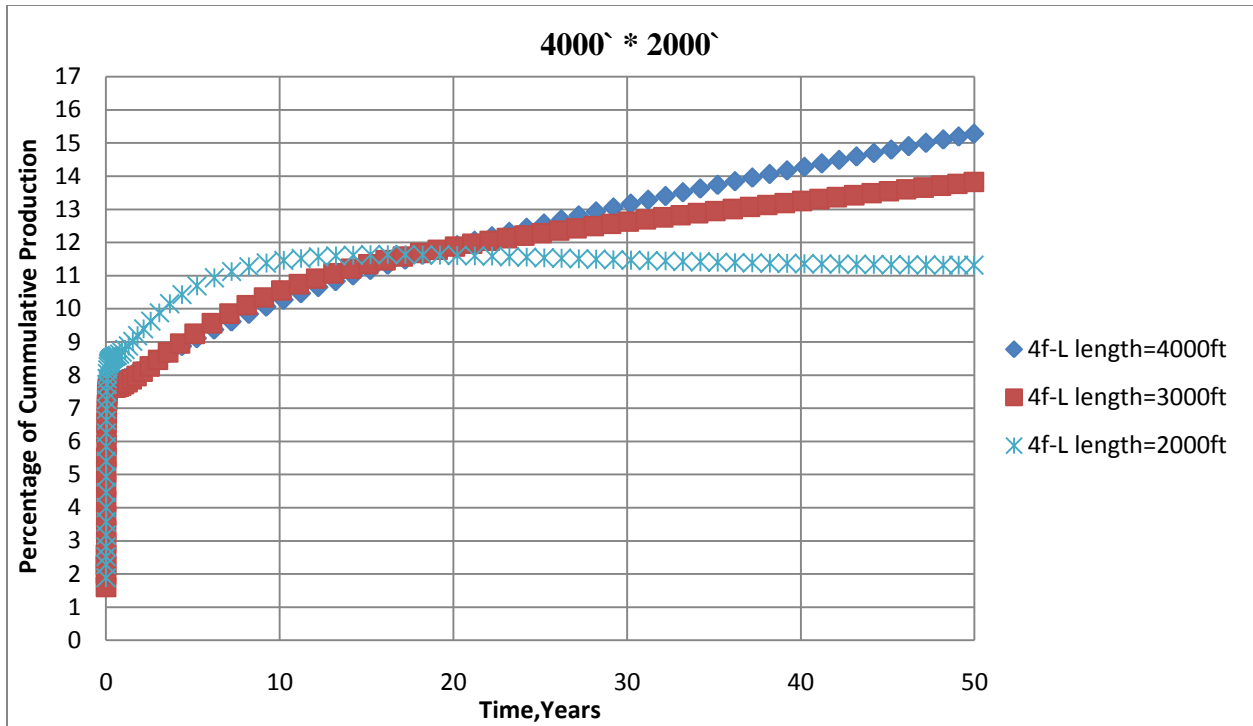
Figure 15. Impact of Lateral Length on Production from Hydraulic Fractured Horizontal Well

4.3. Impact of Hydraulic Fracture Properties

Figure 17 illustrates the percentage increase for different numbers of hydraulic fracture from 1 to 13. The spaces between fractures are uniformly divided and the fractures are parallel with each other and perpendicular to the horizontal well. As it can be seen, percentage increase improves as the number of fractures is increased. However, majority of the improvement appears to occur early as the curves are almost parallel after 10 years. Figure18 compares percentage increase for different number of fractures. As it can be observed, the percentage increases as the number of fractures increase. However, the improvement is not significant after 7 fractures.
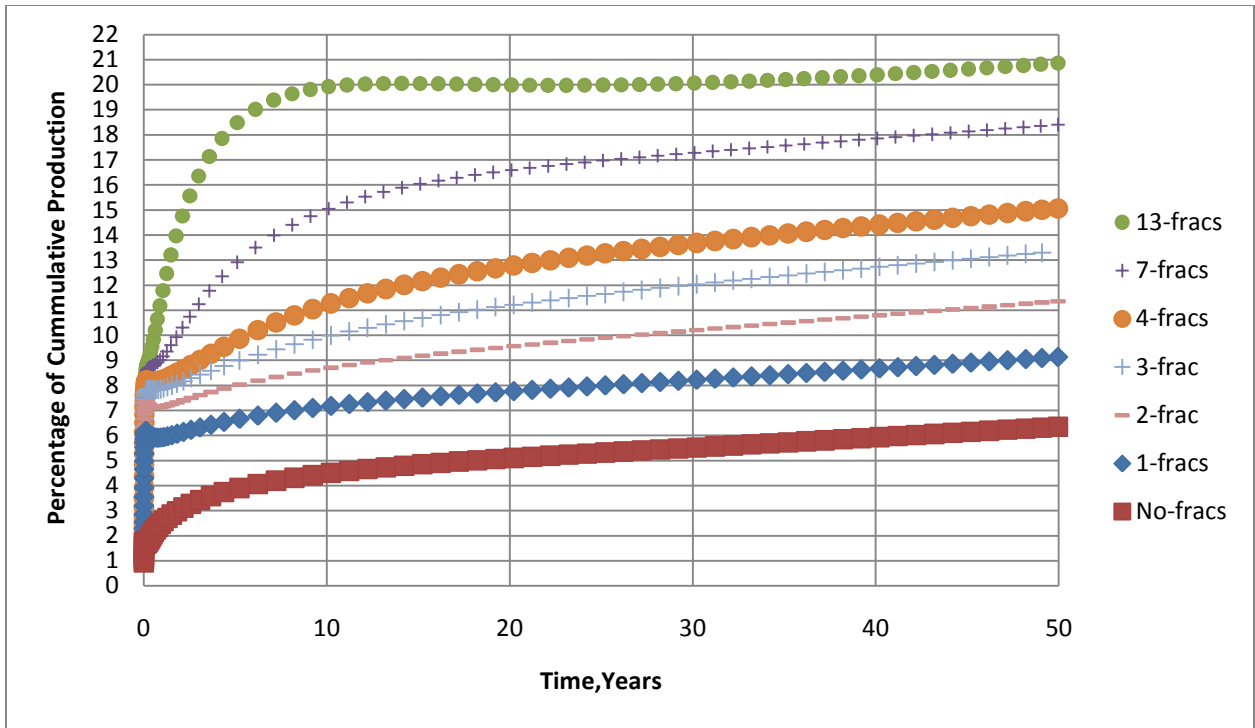
23

Figure 16. Impact of Number of Hydraulic Fractures on Percentage of Cumulative Production
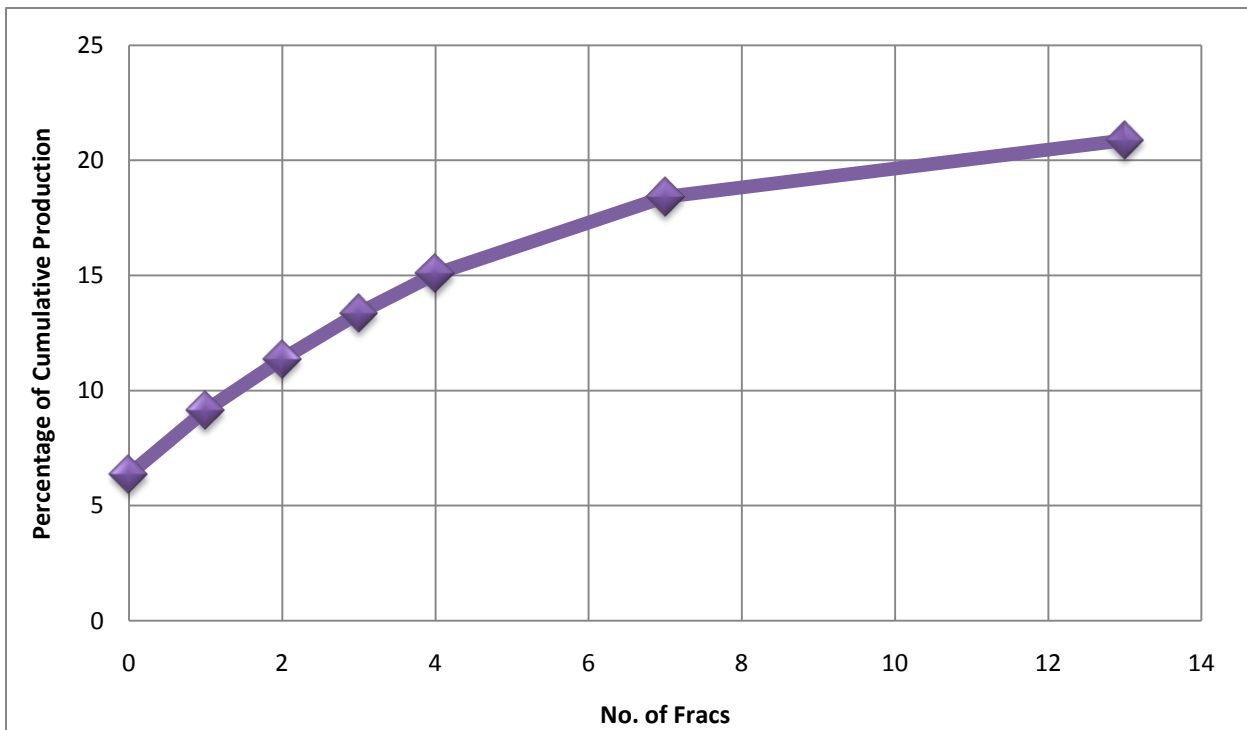

Figure 17. Impact of Number of Hydraulic Fractures on Percentage of Cumulative Production

24

These results again reflect the fact that the desorption occur primarily near the wellbore and the hydraulic fractures where there is significant pressure reduction in the reservoir. In areas away from the hydraulic fracture limited or no desorption takes place.

4.4. Hydraulic Fracture Half-Length

Figure 19 illustrates the percentage increase for various fracture half length. As it can be seen, different fractures half-lengths have almost the same impact on percentage increase in early years of production. However, the long-term production indicates the improvement in percentage increase as the fracture half length is increased.

4.5. Langmuir Constants

Figure 20 compares the percentage increase for different values of Langmuir volume. As it can be clearly seen, the early percentage increase is significantly impacted by the Langmuir volume.

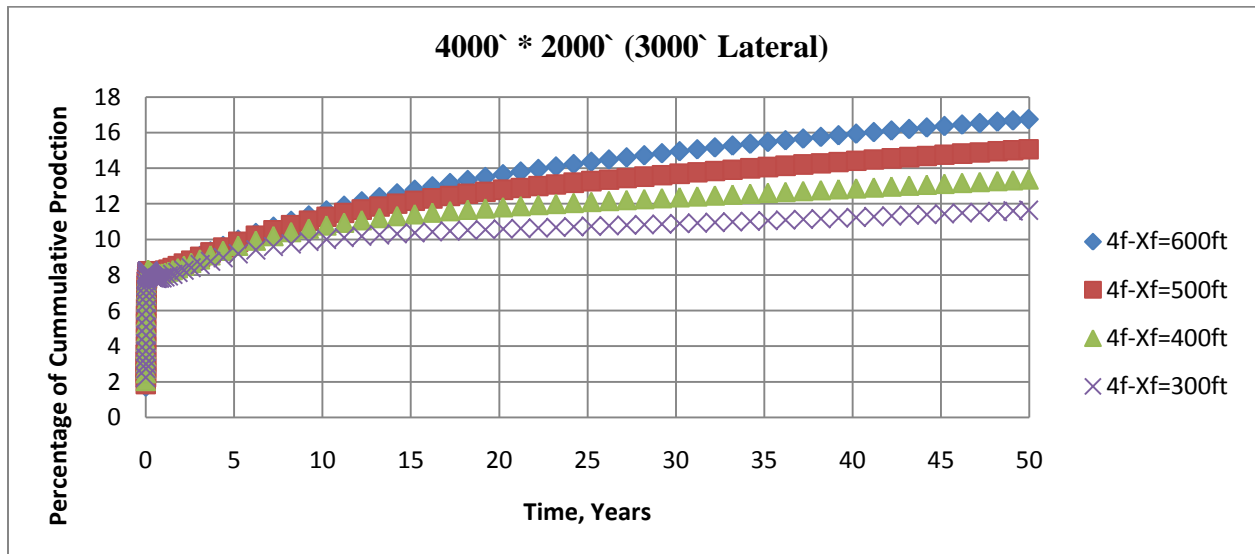Figure 18. Impact of Fracture Half Length on Percentage of Cumulative Production
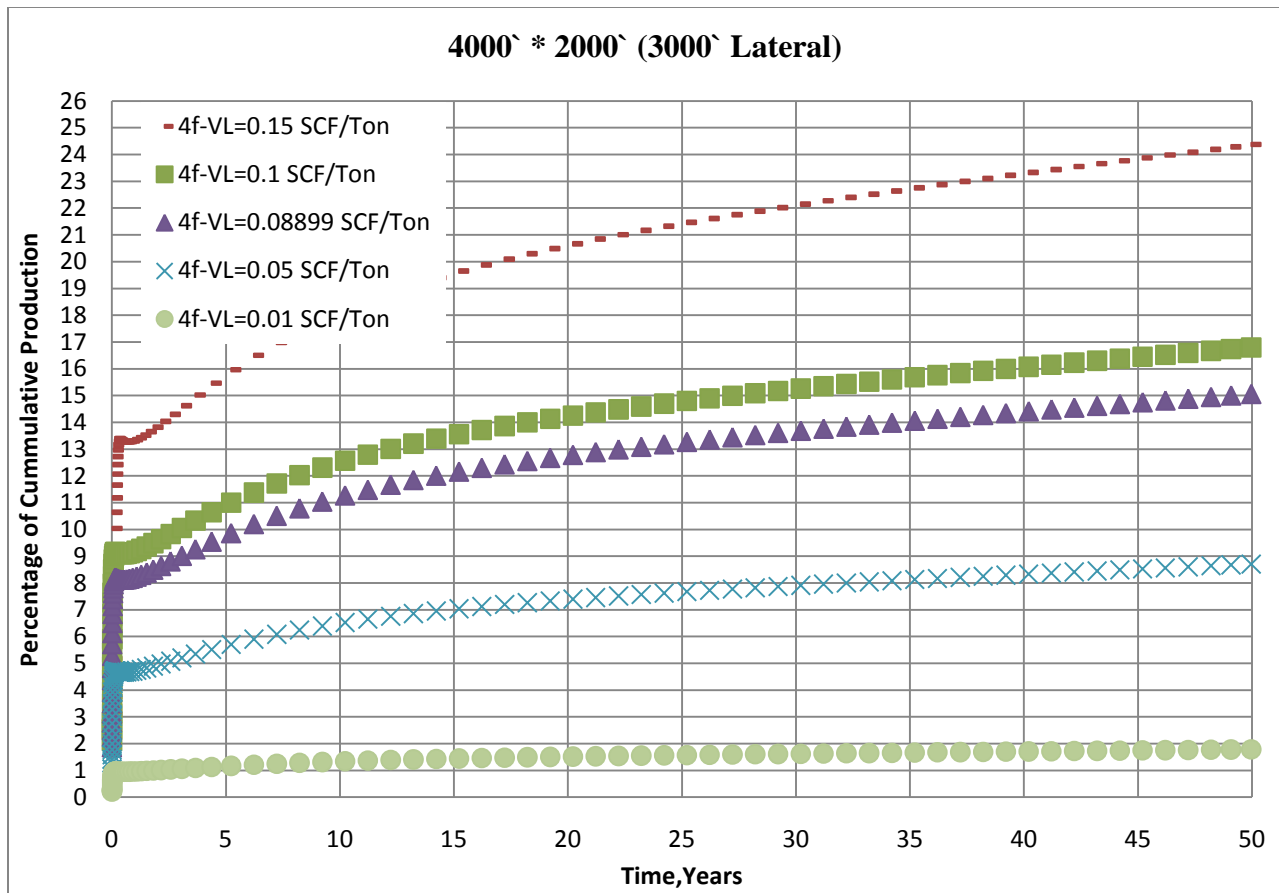
Figure 19. Impact of Langmuir Volume Concentration on Percentage of Cumulative Production

Figure 21 illustrates the impact of Langmuir pressure on cumulative production percentage. As it can be seen, the Langmuir pressure has significant impact on percentage increase in early time similar to what was observed with Langmuir volume.
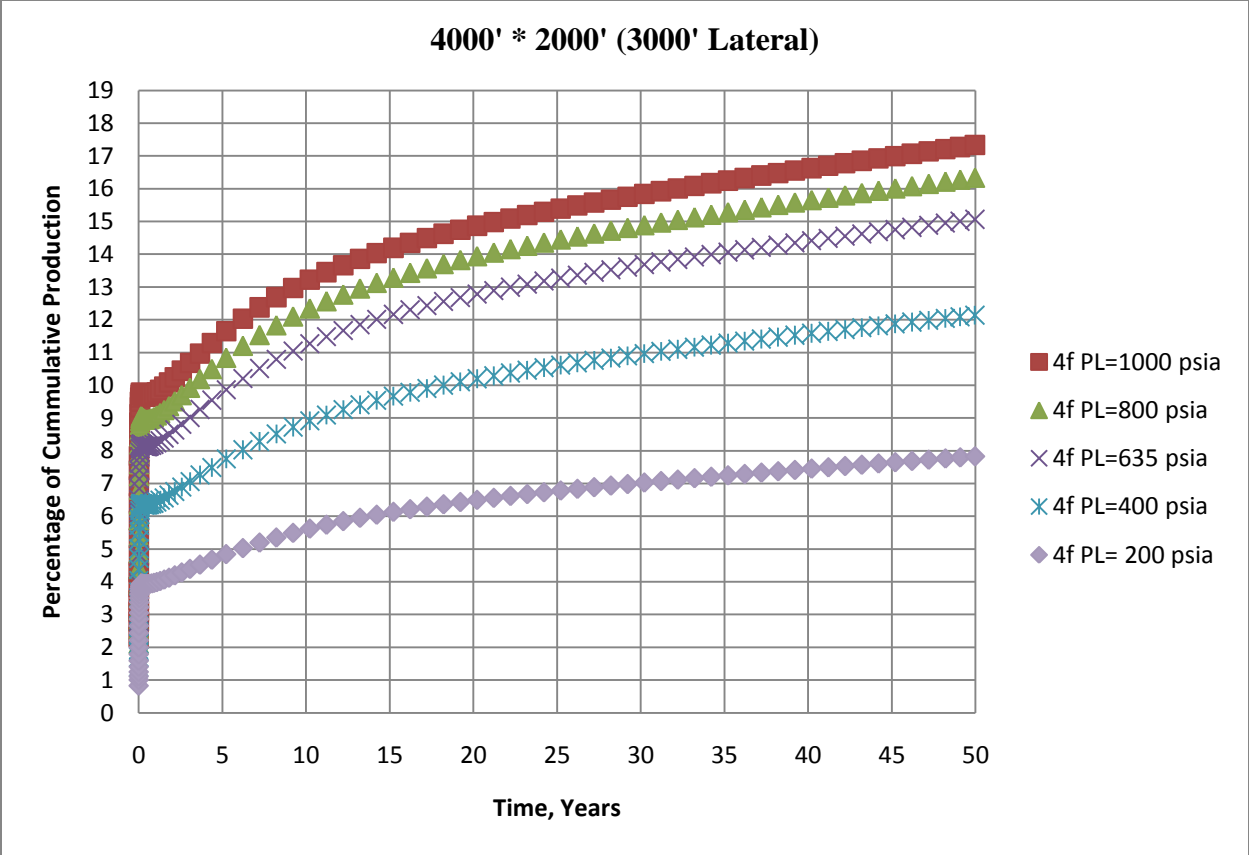
Figure 20. Impact of Langmuir Pressure on Percentage of Cumulative Production

4.6. Flowing Well Pressure

Figure 22 shows the impact of percentage increase for wellbore pressure. As it can be seen from the figure, the low wellbore pressure has much higher percentage increase than high reservoir pressure which has lower percentage increase.

4.7. Permeability

Figure 23 compares the percentage increase for various reservoir permeabilities. As it can be observed, the long term of production indicates the improvement of percentage increase as a reservoir permeability increase.
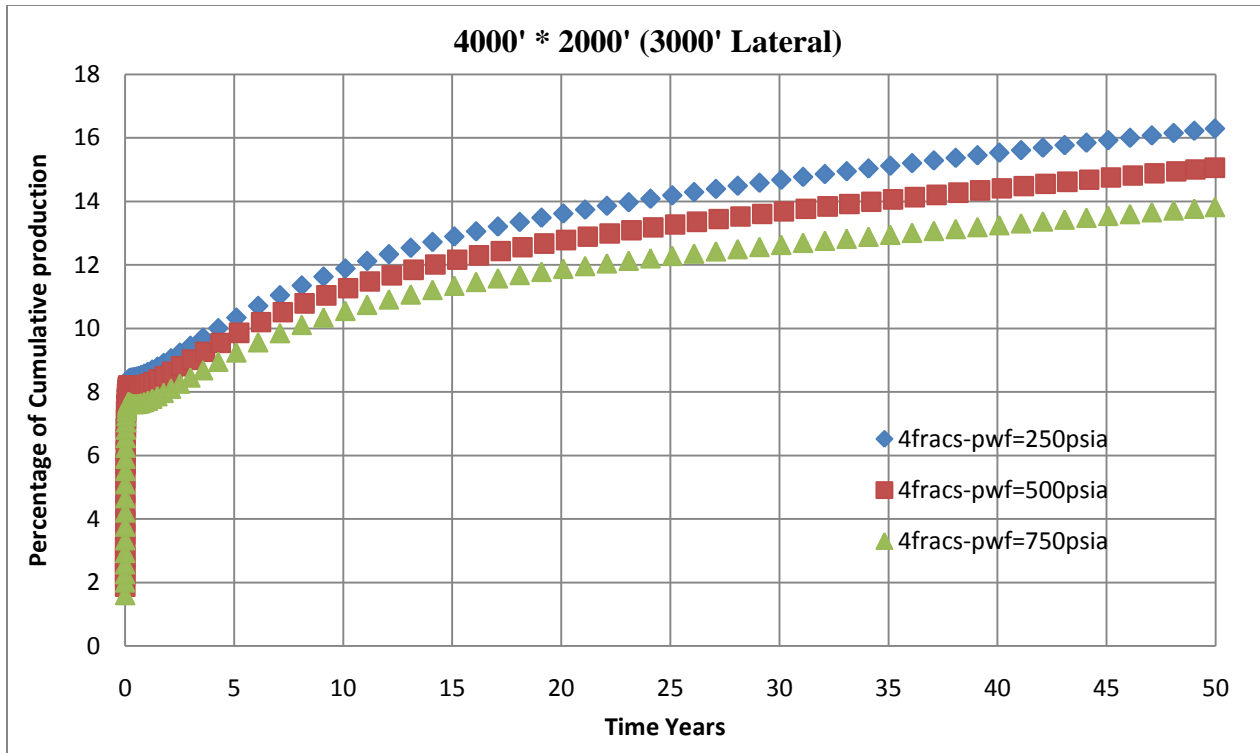
Figure 21. Impact of Reservoir Pressure on Percentage of Cumulative Production
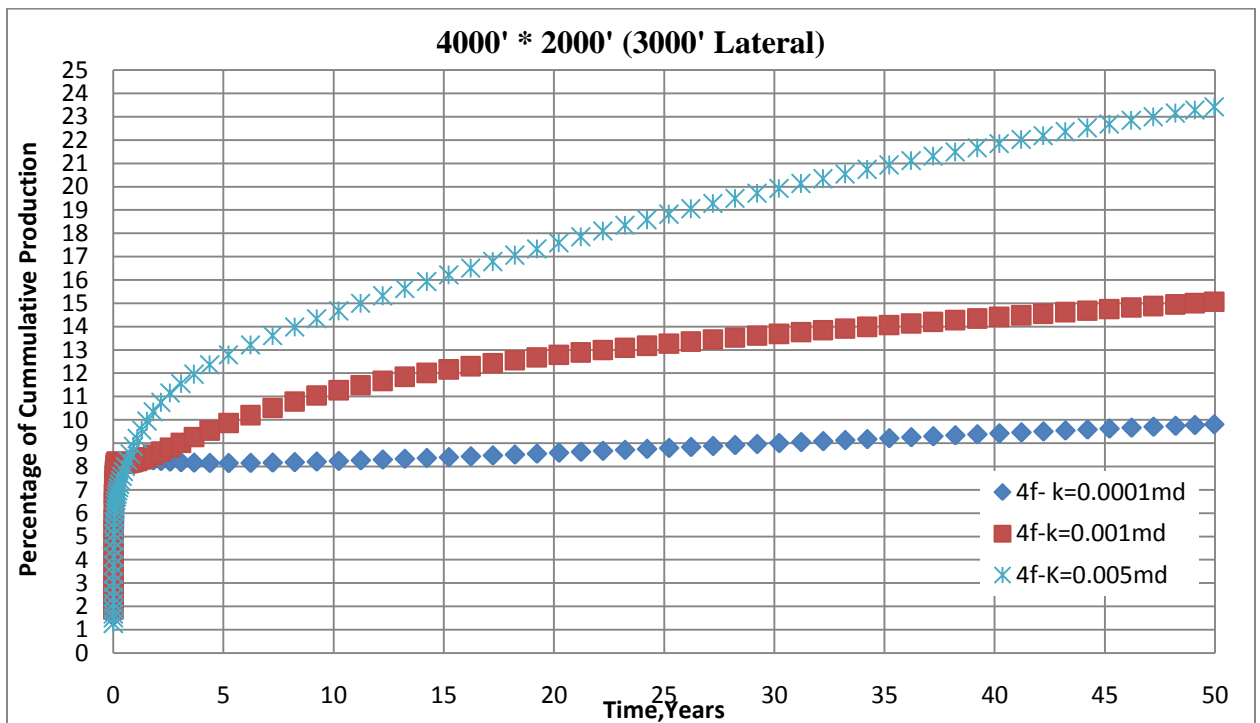

Figure 22. Impact of Reservoir Permeability on Percentage of Cumulative Production

28

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to investigate the impact of gas desorption on production from multiply fractured horizontal well in shale by using a reservoir model. In addition to that, this research focused on identifying the effects of reservoir and fracture characteristic on gas desorption from shale reservoir. Based on my results, the following conclusion and recommendation were reached.

1- Drainage area has insignificant impact on percentage of the gas desorbed in shale reservoirs.

2- Percentage of the gas desorbed increases with the lateral length.

3- Percentage of the gas desorbed is improved with the number of hydraulic fractures.

4- Increases in length of hydraulic fracture increases the desorbed gas percentage.

5- Langmuir volume and pressure have significant impacts on gas desorption only during early production period.

6- The flowing well pressure has significant impact on desorbed gas percentage.

7- The increase in reservoir permeability results in increased desorbed gas percentage.

It is recommended to extend this study to evaluate the impact of gas desorption on production from multiply hydraulic fractured horizontal well using a dual porosity reservoir model.

NOMENCLATURE

G_p=Percentage Increase in Cumulative Production due to Desorption. (%)

G_{pw}=Cumulative Gas Production with Adsorbed Gas Concentration of 0.08899. (MMSCF)

G_{pwo}=Cumulative Gas Production without Adsorbed Gas Concentration of 0.0001. (MMSCF)

V_{ads}= Gas volume which can be adsorbed by a rock of unit mass, (SCF/Ton)

P = Pore pressure, (psia)

V_L= Langmuir volume which is the maximum gas volume can be adsorbed, (SCF/Ton)

P_L= Langmuir pressure at which half of Langmuir volume gas can be adsorbed, (psia)

H= Reservoir thickness, (ft)

K= Reservoir permeability, (mD)

K_f= Fracture permeability, (mD)

K_x= Reservoir permeability in X-direction, (mD)

K_y= Reservoir permeability in Y-direction, (mD)

K_z= Reservoir permeability in Z-direction, (mD)

L= Lateral Length, (ft)

$2X_e$= Width of reservoir, (ft)

Y_e = Length of reservoir (ft)

P_{wf}= Wellbore pressure, (psia)

A= Area, (ft^2)

Δt= Time, (years)

W= Reservoir width, (ft)

W_f= Fracture width,(ft)

X_f=Fracture half length, (ft)

φ= Porosity, (%)

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