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Alternative modeling of multiply hydraulic fractures in horizontal wells Completed in low permeability formation

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**Alternative modeling of multiply hydraulic fractures in horizontal wells
Completed in low permeability formation**

Mahmod S. Alkalawi

**Thesis submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
Petroleum and Natural Gas Engineering**

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Morgantown, West Virginia
2011**

Keywords: Unconventional gas reservoir, Fracture modeling, Horizontal wells, Total Gas Production, Hydraulic Fracturing (Longitudinal and transverse fracture).

Abstract

Alternative modeling of multiply hydraulic fractures in horizontal wells completed in low permeability formations

Mahmod S. Alkalawi

Many conventional gas reservoirs around the world have been developed and well-understood on contrary to unconventional gas reservoirs where the amount of information available to the public considered still not abundant. The unconventional reservoirs (tight formation) where permeability ranges from 0.001 millidarcy to micro-Darcy permeability is a relatively new area in some parts of the world and the details involving ways to increase productivity of wells and best fracture design yet has to be investigated. The unconventional gas reservoirs are important in the world due to its availability, future energy demand around the world, and most conventional gas reservoirs have already been utilized and exploited and its reserves are in decline. Through reservoir simulation, the tight gas formation could be studied to find the effects of these parameters on gas production. The objective of this research is to find the alternative modeling of multiply hydraulic fractures in horizontal wells completed in low permeability formation. Parameters include, Propped fracture half-length for both (longitudinal or transverse fracture), number of fractures and outermost fracture distance in the multiply fractures system.

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Chapter I. Introduction

Natural gas can be produced from both conventional and unconventional gas reservoirs. Even though conventional gas reservoirs are considered easily to exploit worldwide, their gas reserves are declining due to high demand for energy in North America. Unconventional gas reservoirs were the solution in developed countries such as the United States, where the demand for natural gas is high. However, a lot of scientific information is needed to be collected about them.

Unconventional gas reservoirs are defined by their low permeability, ranging from 0.001 millidarcies to micro-Darcy. Unconventional Gas formations are hard to produce unless the reservoir stimulated using hydraulic fracturing. Unconventional natural gas production in North America has increased nearly 65%, from 5.4 Tcf/year in 1998 to 8.9 Tcf/year in 2007⁽¹⁾. Therefore, the future in the gas industry is unconventional gas. Overall, unconventional gas resources are anticipated to become an ever increasing portion of the US proven reserves, building the bulk of the USA natural gas supply for the next 20 years, while production from conventional gas reservoirs will be declining⁽²⁾.

With advanced drilling technology in hand, not only vertical wells can be used to develop tight gas reservoirs, but horizontal drilling wells are highly effective in terms of gas productivity. Therefore, the horizontal wells applications have grown rapidly over the past decade in the world especially in the United States of America.

Hydraulic fracturing is an important technology to obtain production from the low permeability formations. Hence, it is commonly utilized to stimulate the production of oil and

natural gas. Horizontal well with hydraulic fractures are making a significant impact in what was once considered unproductive unconventional gas formations into the largest economic natural gas deposits in the world.

The Eclipse Schlumberger software simulator has been used in this study to simulate the gas production from the low permeability gas formation. In addition, applying both horizontal well and hydraulic fractures (transverse and longitudinal fractures) to measure the total gas produced from both types of hydraulic fracturing.

Chapter II. Literature Review

2.1. Definition of an Unconventional Gas Reservoir

According to the United States governments, unconventional gas reservoirs are reservoirs whose permeability would be less than 0.1md. The above definition was a political one for the USA government to determine which wells would need federal or state tax credits, in order to produce gas from low permeability formations which included; tight sand, coal-bed methane, and shale.

Actually, the industry accepted definition for unconventional gas reservoirs is affected by economic factors and physical ones, which can be explained by Darcy's Law as follows:

$$q = \frac{kh(Pr - Pwf)}{141.2 \bar{B}\bar{\mu}[\ln\left(\frac{re}{rw}\right) - 0.75 + s]}$$

The above equation clearly explains the flow rate, q , is a function of reservoir permeability k ; net pay thickness of the reservoir; average reservoir pressure $\bar{p}$; flowing pressure Pwf , formation volume factor and gas viscosity calculated at the average pressure of the reservoir, $\bar{B}\bar{\mu}$; drainage area re ; wellbore radius rw ; and formation skin factor s . Hence, to choose a single value of permeability to define “tight gas or unconventional gas” is of limited importance. As an example, in deep, high-pressure, thick reservoirs, commercial completions can be satisfied with the permeability of gas in micro-darcy range. In shallow, low-pressure, thin reservoirs, economic gas flow rates can be achieved with formation permeability of millidarcies, even after a successful fracture treatment. As a result, an unconventional gas reservoir can be found in deep or shallow formation; high pressure or low pressure and thin or thick reservoir.

Some petroleum engineers summarize unconventional gas reservoirs by; reservoirs that cannot be productive economically without stimulation treatment. By utilizing hydraulic fracturing and horizontal wells, it will be necessary to improve the reservoir poor permeability and well-bore contact with the reservoir, Based on this, the productivity. Figure II-1 and Figure II-2 show the differences between conventional reservoir permeability and unconventional reservoir permeability.

Figure II- 1 . a thin section of a conventional sandstone reservoir that has been injected with blue epoxy. The blue areas are pore space and would contain natural gas in a producing gas field. The pore space can be seen to be interconnected so gas is able to flow easily from the rock. (G.C. Naik, Tight Gas Reservoirs- An Unconventional Natural Energy Source for the Future)

Figure II- 2 Thin section Photo of a tight gas sandstone. The blue areas are pores. The pores are irregularly distributed through the reservoir and the porosity of the rock can be seen to be much less than the conventional reservoir. (G. C. Naik, Tight Gas Reservoir- An Unconventional Natural Energy Source for the Future)

Poor reservoir permeability is primarily caused by fine-grained nature of the sediments, overburden pressure, or infilling of pore spaces by carbonate or silicate cements settled down from water within the reservoir, therefore, blocks the pores in the reservoir.

2.2. The Resource Triangle

The resource triangle concept is helpful in understanding the distribution of gas reservoirs and the factors that affect them was used by Masters and Gray in the 1970s ⁽³⁾. Figure II-3 illustrates the principles of the resource triangle. Conventional reservoirs are usually small and hard to find, yet easy to develop. Unconventional reservoirs are much larger and worldwide available, yet difficult to develop (Lane 1989). Unconventional reservoirs need high technology and are much more costly to develop. Due to gas demand and increasing in gas prices, the unconventional gas reservoirs can be developed and increase production.

Figure II- 3. The resource triangle for oil and gas reservoirs (Lane, 1989)

2.3- Availability of unconventional gas reservoirs

In the United States of America, unconventional gas reservoirs have received an increasing attention due to increasing demand for energy supply. However, around the world, unconventional gas reservoirs have not yet received close attention from natural gas operators. Moreover, the political conditions and gas market prices have not been helpful for development in many countries. In table II-1 below, Kawata and Fujita summarized the work of Ronger, who estimated the worldwide unconventional gas resources ⁽⁴⁾.

Table II- 1 Distribution of worldwide unconventional gas reservoirs ⁽⁵⁾

Region	Coal-bed Methane (Tcf)	Shale Gas (Tcf)	Tight-Sand Gas (Tcf)	Total (Tcf)
North America	3,017	3,842	1,371	8,228
Latin America	39	2,117	1,293	3,448
Western Europe	157	510	353	1,019
Central and Eastern Europe	118	39	78	235
Former Soviet Union	3,957	627	901	5,485
Middle East and North Africa	0	2,548	823	3,370
Sub-Sahara Africa	39	274	784	1,097
Centrally planned Asia and China	1,215	3,528	353	5,094
Pacific(Organization for Economic Cooperation and Development)	470	2,313	705	3,487
Other Asia Pacific	0	314	549	862
South Asia	39	0	196	235
World	9,051	16112	7,406	32,560

2.4- Role of Natural gas in the United States' energy portfolio

Natural gas has an effective role in satisfying U.S. energy demands. Natural gas, coal and oil supply about 85 percent of the nation's energy, with natural gas supplying about 22 percent of the total⁽⁷⁾. Figure II-4. Shows natural gas production by source (Tcf/year). As clearly seen from the figure below; onshore unconventional gas supply increases with time due to the fact that with time the technology for development becomes more accessible for gas operators. Additionally, onshore conventional gas production declines with time.

Source: EIA, 2008

Figure II- 4 shows natural gas production by source (Tcf/year) (Source: EIA, 2008)

The history and future projection of tight sands, coal-bed methane, and gas shale's (all considered unconventional gas sources) production is shown in Figure II-5 below. While tight

sands and gas shale's production generally tend to increase with time, coal bed methane tends to stay level with time.

Figure II- 5 the history and future projection of tight sands (Source: EIA AEO 2007)

2.5 Horizontal Wells

With improvements in horizontal well drilling, unconventional reservoirs have become the target of exploitation and its effectiveness in increasing productivity. Today, horizontal well technology is applied more often and in many different types of formations. The state of the art applications of horizontal well technology require better completion designs to optimize production rates, long-term economics, and ultimate producible reserves. Figure II-6 shows the variety of applications of horizontal wells. The technical objectives of horizontal wells are summarized below:

1. Expose significantly more reservoir rock to the well-bore than can be achieved by drilling of a conventional vertical well. Therefore, production rates increases and larger drainage

areas can be exploited. Figure II-7 shows horizontal and vertical well differences in wellbore contact area.

2. Intersect natural fractures systems within a reservoir to increase the productivity of the reservoir.
3. The need to avoid unnecessarily premature water that would interfere with oil production.
4. Lower fluid velocities and reduced pressure drop around wellbore.
5. Reduced operating expenses because fewer wells may be required and, hence, minimal surface disturbance will be created.

Figure II- 6 Applications for horizontal wells (G. C Thakur, Chevron PTC)

Figure II- 7 Greater Length of Producing Formation Exposed to the Wellbore in a Horizontal Well (A) Than in a Vertical Well (B)(Joshi ,SPA 16868)

However, Joshi (1988) found that horizontal wells are not viable in very thick reservoirs (500 to 600 ft) and also should be restrictively used with low vertical permeability. A decrease in vertical permeability results in an increase in vertical flow resistance for horizontal wells. Consequently, the productions of oil or gas will definitely be less than expected. The horizontal well technology has three major disadvantages as explained below (Joshi, 2003):

- Horizontal wells considered costly as compared to vertical wells. For example, In the United States a new horizontal well drilled from the surface, costs 1.5 to 2.5 times more than a vertical well. A re-entry horizontal well costs about 0.4 to 1.3 times a vertical well cost.
- In most cases only one zone at a time can be produced using a horizontal well. When the reservoir consists of multiple pay-zones, particularly with large differences in vertical depth, or large differences in permeability's, it is hard to drain all the layers using a single horizontal well and to perform work over jobs when multi entry completion installations exist.

- Usually a horizontal well accompanied with multi stage hydraulic fracturing treatments, which add to the overall drilling cost, in order to reach economical flow rate.

2.6 Hydraulic fracturing

Hydraulic Fracturing is a formation stimulation technique used to improve permeability, thus allowing gas to flow freely and unrestricted to the wellbore. Fracturing has become the industry standard nowadays ⁽⁸⁾. Horizontal wells drilled in unconventional reservoirs accompanied with hydraulic fracturing can transfer the uneconomical production rate to a lucrative one.

To perform a hydraulic fracture treatment in a well, a fracturing fluid, mainly consists of water and special additives, is pumped down into the wellbore at a rate sufficient to achieve a pressure value in excess of the fracture gradient of the formation rock. To keep the fracture open after the injection stops, solid round sand is added to the fracture fluid. The propped hydraulic fracture then becomes a high permeability conduit through which the formation fluids can flow to the well. Figure II-8 shows an example of vertical well with a fracture. The purposes of performing hydraulic fracturing are:

- Bypass near-wellbore damage and return a well to its primary productivity
- Extend drainage area around the well bore through created conductive paths, hence the productivity increases in the well.
- To alter fluid flow in the formation and connect the productive zones.

Figure II- 8 Flushing fractured horizontal well with proppant (Graphic by Al Granberg).

2.6.1 Hydraulic Fracture Types

Depending on well orientation, with respect to the minimum horizontal stress, and length of the perforated interval, either a transverse or longitudinal fracture may be created.

If the horizontal well is drilled parallel to the minimum horizontal stress, and the perforated interval is shorter than four times the wellbore diameter. This is expected and the created fractures will be perpendicular to the horizontal well; i.e., transverse fractures will be created. If the horizontal well is drilled perpendicular to the minimum horizontal stress, the created fracture will be longitudinal. These two cases represent the two limiting and

recommended cases. Figure II-9 shows both longitudinal and transverse fractures in a horizontal well.

Figure II-9 shows both transverse fractures (A) and longitudinal fracture (B) in a horizontal well (Chen, C. and Raghavan 1979)

2.6.2 Dimensionless Fracture Conductivity (FCD)

The dimensionless conductivity is the ratio of the fracture ability to carry flow divided by the ability of the formation to feed the fracture. If F_{CD} is more than 100 it is considered an infinite conductivity, if F_{CD} is less than 100 it is considered a finite conductivity. For a given amount of proppant, two different types of fractures can be initiated or created, a short fat fracture can be created with a high value of fracture conductivity, Kfw , or a longer, narrow fracture can be created with a lower value of fracture conductivity, Kfw . For low permeability

reservoirs, a long, lower conductivity fracture is required. Figure II-10 shows the equation to calculate Dimensionless Fracture Conductivity (F_{CD}). Figure II-11 shows the pressure drop along the finite conductivity fracture and infinite conductivity fracture.

$$F_{CD} = (K_F * W_F) / (K * X_F) \text{ where:}$$

K_F : Fracture Permeability

W_F : Fracture Width

K : Formation Permeability

X_F : Fracture Half-length

If F_{CD} is greater than 100 the fracture is finite Conductivity

Figure II-10 Fracture conductivity Equation.

Figure II-11 Infinite-conductivity and finite-conductivity fractures (Boyer, C., Kieschnick 2006)

Chapter III Objective and Methodology

The main objective of this research is to create a system of fractures in a horizontal well whose long-term performance is identical to a single effective (big fracture) of length equal to the spacing between the outermost fractures in the multiply fractures system. Figure III-12 shows a sketch of this interpretation.

Figure III-12 Multiply-fractured-horizon-well in a tight formation and the effective (total) fracture concept ⁽⁹⁾

The summary of the above concept is as follows:

- Effective Fracture half length (X_F) for longitudinal fracture = distance between Outermost multiply fractures/2
- Effective Fracture Width ($W_{F, eff}$) for Longitudinal fracture = Total fracture length (x_f) for any one of multiply fractures.
- The conductivity of this effective fracture depends on the permeability of the reservoir and the number, distance between, and conductivities of the individual hydraulic fractures.

- Fracture Height (h) is constant in both, effective fracture system and multiplies fractures.
- The multiply fractures are uniformly spaced, have identical properties and are parallel with each other and perpendicular to the well.

The methodology to perform a system of fractures in a horizontal well was by using Schlumberger's Eclipse software to simulate production data for tight gas reservoir wells. Therefore, to make sure the data that were being used were correct, a Literature review has been done to collect all necessary data as input for Schlumberger's Eclipse software. Also, hydraulic fracture parameters were gathered to be used in the model.

The following steps were performed:

- Two models were built, one for multiply fractures and the other one for effective longitudinal fracture, to predict gas production profiles for hydraulically fractured horizontal wells in an unconventional gas reservoir.
- Total gas flow from both multiply fractures and effective longitudinal fracture has been measured.
- Evaluation of the various reservoir parameters to get the total gas flow from both models close or matched and this can be done through for example effective longitudinal fracture half-length change.
- Several simulation runs have been performed and comparisons were then made.
- The cases which were studied are multiply fractures of 300ft and 400ft fracture half length, and the number of multiply fractures was two, three, four and seven fractures.

A coal-bed methane template was used to enter gas reservoir properties for all cases. This template was the best option to represent unconventional gas production and all the cases were

run for a 20 year period. The procedure for entering data through the template and performing a simulation are given in appendix A.

3.1 Parameters used in the model

The reservoir data are summarized below in the Table III-1. The simulation was run for 20 years for all runs shows some of the important parameters that were used in the modeling process. The reservoir was consisting of four layers which have the same thickness of 40 ft. The total reservoir thickness and depth were 120 ft and 7000ft respectively. The shape of the reservoir was a rectangular of dimensions 4000 ft by 1000ft except for one case which was 4000ft by 2000ft. Therefore, this reservoir well, horizontal well, makes a drainage area of almost 92 acres. The reservoir (tight gas) permeability was equal to 0.001 md. Also, a porosity value of three percent was used in the model. Initial reservoir pressure and initial water saturation was 3500 psi and 15 percent respectively. All above data was based on literature review.

Table III- 1 reservoir data used in the model

Parameters	Values
Reservoir depth	7000ft
Reservoir total thickness	120ft
Period of production	20 years
Porosity %	3
Reservoir permeability	0.001 md
Reservoir pressure	3500 psi

Reservoir area	4000 ft by 1000 ft (92 acres)
Horizontal lateral section length	3000 ft
Number of layers in the reservoir	4 layers of 20 ft thickness each
Initial water saturation, fraction	0.15

Table III-2 below summarizes the fracture parameters that have been used in the model.

Also, some other data such as fluid properties are shown in Table III-3.

Table III- 2 Fracture Parameters used in the model

Parameters	Values
Multiply fractures Half Length (ft)	300,400
Width (in)	0.01
Height of the fracture (ft)	120
Number of multiply fractures	2,3,4,7
X-center (ft)	Equally divided on no. of fracs.
Y-center (ft)	500
Permeability (mD)	20000
Porosity fraction	0.2
Top of Fracture, ft	7000
Bottom of Fracture, ft	7120

Table III- 3 Fluid properties and Adsorption data

Fluid properties	
Standard Pressure ,psia	14.7
Standard Temperature, Fahrenheit	60
Reference Temperature, Fahrenheit	120
Well Production Controls	
Pwf, psia	350
Adsorption data	
Diffusion coefficient, ft ² /day	1
Sorption Time, day	62
Langmuir Pressure, psia	635
Langmuir Concentration, MSCF/ton	0.08899

3.2- Model generation Top view

Figure III-13 below shows a horizontal well with three multiply fractures as an example of model generation by Eclipse Schlumberger's software whereas Figure III-14 shows a horizontal well with an effective longitudinal fracture.

Figure III-13 Top view of the model with three multiply fractures

Figure III-14 Top view of effective longitudinal fracture

Chapter IV Results and Discussion

In this chapter, the results from the simulation runs are presented with discussion on the production performance of multiply fractures vs. effective fracture. One horizontal well with a lateral section of 3000ft was considered in this study. Two, three, four and seven transverse fractures were in a horizontal well and evaluated with effective longitudinal fracture for each case. The transverse fractures were equally spaced in each case. The Raghavan and Chen, 1997⁽⁹⁾ concept has been followed but the effective longitudinal fracture half-length has been modified during the simulation runs for each case separately to achieve the closest production match from both transverse fractures and effective longitudinal fracture. The production profile was generated for a period of twenty years due to the long term production capability of unconventional gas reservoirs. Table IV-1 and IV-2 below summarize the results of the modifications necessary to achieve a good match.

4.1 Multiply fractures of 300 ft fracture half-length with effective longitudinal fracture.

a) Two-fracture case

Figure IV-1 below compares the production from two fractures with fracture half-length of 300 ft against corresponding effective longitudinal fracture. The properties of two fractures are identical. Effective longitudinal half-length fracture has been modified during the runs from 250ft to 650ft to simulate the production from two fractures. The concept of the Raghavan and Chen, 1997⁽⁹⁾ has been followed. The modifications brought the total gas production very close to the two fracture case.

Figure IV- 1 two fractures vs. effective longitudinal fracture

b) Three -fracture case

Figure IV-2 shows three multiply fractures ($x_f=300\text{ ft}$) with corresponding effective longitudinal fracture. Effective longitudinal half-length fracture has been modified during runs

Figure IV- 2 three fractures vs. effective longitudinal fracture

from 600ft to 1000ft to simulate the two multiply fractures in terms of total gas production. Therefore, as seen from the graph above the total gas production from the effective longitudinal fracture and three multiply fractures were very close.

c) Four multiply fractures case

Figure IV-3 compares production from four fractures with effective longitudinal fracture. The effective fracture in this case has been modified after several runs to get the closest match with four fractures in terms of gas production. The fracture half-length of effective fracture has been modified during runs from 600ft to 1200ft.

Figure IV- 3 four fractures vs. effective longitudinal fracture

d) Seven multiply fractures case

Figure IV-4 compares production from seven fractures with effective longitudinal fracture. The effective longitudinal fracture half-length has been modified to get the best match with seven fractures in terms of total gas production. The effective fracture half-length has been modified during runs from 700 ft to 1500 ft.

Figure IV- 4 seven fractures vs. effective longitudinal fracture

4.2 Multiply fractures of 400 ft fracture half-length with effective longitudinal fracture.

1. Two fracture case

Figure IV-5 below compares the production from two fractures, whose fracture half-length(x_f)=400 ft, with corresponding effective longitudinal fracture. Effective longitudinal half-length fracture has been modified during runs from 600ft to 900ft to simulate the two fractures in terms of total gas production.

Figure IV- 5 two fractures vs. effective longitudinal fracture

2. Three fracture case

Figure IV-6 compares the production from three fractures with effective longitudinal fracture. In this case the effective longitudinal fracture half-length has been modified during simulation runs from 600ft to 1200ft to achieve the match with total gas production of three fractures. The increase in fracture half-length was doubled in this case as seen below.

Figure IV- 6 three fractures vs. effective longitudinal fracture

3. Four fracture case

Figure IV-7 compares production from four fractures with effective longitudinal fracture. In this case the effective longitudinal fracture has been modified during simulation runs from 600 ft to 1400 ft.

Figure IV- 7 four multiply fractures vs. effective longitudinal fracture

4. Seven fracture case

Both figures IV-8 and IV-9 compare production from seven fractures with effective longitudinal fracture. Figure IV-8 does not show a good match between the production from the effective longitudinal fracture and seven fractures even after several simulation runs due to high number in fractures in such a small derange area. However, Figure IV-9 below shows good results because the reservoir dimensions has been increased from (4000ft by 1000ft) to (4000ft by 2000ft). The effective longitudinal fracture has been modified during runs from 700 ft to 1800 ft.

Figure IV- 8 seven fractures vs. effective longitudinal fracture (reservoir dimensions= 4000ft by 1000ft)

Figure IV- 9 seven fractures vs. effective longitudinal fracture (reservoir dimensions= 4000ft by 2000ft)

Table IV- 1 summary results of multiply fractured (xf=300ft) horizontal well and effective longitudinal fracture.

Multiply fractured horizontal well(xf=300ft) and effective longitudinal fracture summary								
Fracture. Property	Case 1		Case 2		Case 3		Case 4	
	Nf=2	Longitudinal Fracture	Nf=3	Longitudinal Fracture	Nf=4	Longitudinal Fracture	Nf=7	Longitudinal Fracture
Fracture half length(xf, ft)Initial value	300	250 ft	300	600ft	300	600ft	300	700 ft
Fracture half-length(Match value)		650 ft		1000ft		1200ft		1500ft
Out-most distance between fractures.	500ft		1200ft		1200ft		1400ft	
Fracture permeability(kf,md)	20000	0.477	20000	0.501	20000	0.556	20000	0.687
Fracture width	0.01 in	600 ft	0.01 in	600 ft	0.01 in	600 ft	0.01 in	600 ft

Table IV- 2 summary results of multiply fractured (xf= 400ft) horizontal well and effective longitudinal fracture.

Multiply-fractured-horizontal-well(xf=400ft) and effective- longitudinal fracture summary.								
Fracture. Property	Case 1		Case 2		Case 3		Case 4	
	Nf=2	Longitudinal Fracture	Nf=3	Longitudinal Fracture	Nf=4	Longitudinal Fracture	Nf=7	Longitudinal Fracture
Fracture half length(xf, ft)initial value	400	600 ft	400	600ft	400	600ft	400	700 ffft
Fracture half length(match value)		900 ft		1200ft		1400ft		1700ft
Out-most distance between fractures.	1200ft		1200ft		1200ft		1400ft	
Fracture permeability(kf,md)	20000	0.0321	20000	0.0349	20000	0.0396	20000	0.0534
Fracture width	0.01 in	800 ft	0.01 in	800 ft	0.01 in	800 ft	0.01 in	800 ft

Chapter V. Conclusions and recommendations

The main purpose of this study is to create a system of fractures in a horizontal well whose long-term performance is identical to a single effective longitudinal fracture of length equal to the spacing between the outermost fractures in the multiply fractures system.

The approach to perform a system of fractures in a horizontal well was by using Schlumberger's Eclipse software to simulate production data for tight gas reservoir wells. Therefore, to make sure the data that were being used were correct, a Literature review has been done to collect all necessary data as input for Schlumberger's Eclipse software. Also, hydraulic fracture parameters were gathered to be used in the model. The following points have been reached:

- Outer most distance between multiple fractures plays a significant role in determining the fracture-half-length of the alternative effective longitudinal fracture.
- The parameter that has a major impact in this study was effective longitudinal fracture half-length in all cases.
- Effective fracture width modification has limited effect on just early period of gas production and hence, results were not shown in this research.
- To use a heterogeneous formation properties such as porosity of the reservoir and permeability and figuring out its effects on gas production from tight gas formation(dual porosity formation)

NOMENCLATURE

PR = Reservoir pressure (psia)

Pi = Initial Reservoir Pressure, (psia)

Pwf = Bottom-hole flowing pressure (psia)

K= reservoir permeability, md

ϕ = Porosity (%)

h = Thickness (ft)

P = Pressure (psia)

P = Pseudo-pressure, psi²/cp

B= formation volume factor

μ = gas viscosity, cp

q = Gas rate (Mscf/day)

t = Time (years)

L = Length of lateral (ft)

Gp = Cumulative gas production (Mscf)

Re= drainage radius,ft

Rw=well radius, ft

S= skin factor

Xf=fracture half length, ft

Kf=fracture permeability, md

Wf= width of fracture, in

Fcd= dimensionless fracture conductivity

Nf= number of fractures

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Appendix A

Appendix A shows a procedure to enter data and run Schlumberger Eclipse software which was used to model the tight gas formation in this study. A coal bed methane template was used to enter tight gas formation for all cases.

Figure A-1 shows the Schlumberger Eclipse software landscape or main window through which when we hit Eclipse button on the top left corner we can create a new project of work

Figure A- 1 Schlumberger's Eclipse software main window

After creating work file and saving it as shown in Figure A-2 below, the next step will be entering data into the software as shown in Figure A-3.

Figure A- 2 creating file work and saving work in it

Figure A-3 shows simulation model definition which includes simulation length and reporting of output production data. On the left hand side, a workflow tree appears.

Figure A- 3 window shows simulation run period for gas production and main model options

Four layers have been created with 40 ft thickness each and 120ft thickness total. Figure A-4 shows reservoir description window with five taps among which highlighted tap is Layers option.

Coal Bed Methane Modeling Tool - ECLIPSE Office

File Help

Workflow

- Model Definition
- Reservoir Description
- Wells
- Production
- Fluid Properties
- Simulation Controls
- Economics

Generate Model

Run ECLIPSE

View Results

Layers Rock Properties Non-Equilibrium Initial Conditions Aquifers Fractures

<< Previous Page

Next Page >>

Layers

Row	Layer Name	Rock Name	Top Depth Left (ft)	Top Depth Right (ft)	Horiz. Disp. (ft)	Thickness (ft)	Length (ft)	Width (ft)
1	layer1	RESERVOIR	7000	7000	0	30	4000	2000
2	layer2	RESERVOIR	7030	7030	0	30	4000	2000
3	layer3	RESERVOIR	7060	7060	0	30	4000	2000
4	layer4	RESERVOIR	7090	7090	0	30	4000	2000
5								
6								
7								
8								
9								
10								
11								
12								

Apply Help

Figure A- 4 reservoir description window (Layers option)

Next tap in the reservoir description was reservoir rock properties data entry as shown below in figure A-5. Permeability in x, y and z direction plus porosity and other data were specified and appointed in this tap.

Coal Bed Methane Modeling Tool - ECLIPSE Office

File Help

Workflow

- Model Definition
- Reservoir Description
- Wells
- Production
- Fluid Properties
- Simulation Controls
- Economics

Generate Model

Run ECLIPSE

View Results

Layers Rock Properties Non-Equilibrium Initial Conditions Aquifers Fractures

<< Previous Page Next Page >>

Rock Properties

Define properties for individual coal types.

Row	Rock Name	Fracture Porosity	Bulk X-dir Perm. (mD)	Bulk Y-dir Perm. (mD)	Bulk Z-dir Perm. (mD)	Coal Compress. (/psi)	Rock Density (lb /ft^3)
1	RESERVOIR	0.03	0.001	0.001	0.0001	1E-6	87.5
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

Apply Help

Figure A- 5 rock properties screen

Figure A-6 shows highlighted tap of non-equilibrium initial conditions which includes as shown in the screen below; initial reservoir pressure and water saturation.

Coal Bed Methane Modeling Tool - ECLIPSE Office

File Help

Workflow

- Model Definition
- Reservoir Description
- Wells
- Production
- Fluid Properties
- Simulation Controls
- Economics

Generate Model

Run ECLIPSE

View Results

Layers Rock Properties Non-Equilibrium Initial Conditions Aquifers Fractures

<< Previous Page Next Page >>

Non-Equilibrium Initial Conditions

Define initial conditions for RESERVOIR as a whole

Pressure 3000 psia

Water Saturation 0.15 fraction

Apply Help

Figure A- 6 non-equilibrium conditions screen

Figure A-7 shows the fractures tab for reservoir description. For this example a threestage fracture is shown. Each fracture with half length of 300 ft and other properties were identical between fractures. These multiply fractures are perpendicular to wellbore of horizontal lateral part.

Figure A- 7 shows fractures screen

Figure A-8 shows the wells section of the workflow where vertical and horizontal wells can be added to the reservoir. The snap shot below explains the depth of vertical portion of the well up to the reservoir.

Figure A- 8 shows wells section of the workflow

Figure A-9 still in well section window but shows how to create lateral portion in the well, which in this case extends up to 3000ft across the 4000 ft reservoir length.

Figure A- 9 shows lateral section creation screen

Figure A-10 shows the production section of workflow. Once the well is defined different types of events can be selected, production is one of the events that needs to be added. Once production is added, well controls can be set.

Figure A- 10 shows production section of workflow screen

Figure A-11 shows workflow section of fluid properties such as standard pressure, standard temperature and reservoir temperature. Also, gas components percentage can be seen.

Coal Bed Methane Modeling Tool - ECLIPSE Office

File Help

Workflow

- Model Definition
- Reservoir Description
- Wells
- Production
- Fluid Properties**
- Simulation Controls
- Economics

Generate Model

Run ECLIPSE

View Results

Define and create named properties:
Each named region of the model will be assigned the corresponding named properties. If no such named property has been defined the region will be assigned the default RESERVOIR properties.

Properties for fluid: **RESERVOIR** Properties for rock: **RESERVOIR**

<< Prev Property Next Property >>

PVT Composition | Rel. Perm. | Coal Bed Methane | Advanced

Standard Pressure: 14.7 psia

Standard Temperature: 60 F

Reference Temperature: 120 F

No	Component	Fraction
1	N2	0
2	CO2	0
3	H2S	0
4	C1	1
5	C2	0
6	C3	0
7	iC4	0
8	nC4	0
9	iC5	0
10	nC5	0
11	C6	0
12	C7+	0

C7+ molecular weight: 200

Apply Help

Figure A- 11 fluid properties screen

Since coal bed methane template has been used, its properties such as Langmuir pressure, Langmuir concentration and sorption time has to be defined and are shown in Figure A-12 below.

Coal Bed Methane Modeling Tool - ECLIPSE Office

File Help

Workflow

- Model Definition
- Reservoir Description
- Wells
- Production
- Fluid Properties
- Simulation Controls
- Economics

Generate Model

Run ECLIPSE

View Results

Define and create named properties:
Each named region of the model will be assigned the corresponding named properties. If no such named property has been defined the region will be assigned the default RESERVOIR properties.

Properties for fluid: RESERVOIR Properties for rock: RESERVOIR

<< Prev Property Next Property >>

PVT Composition Rel. Perm. Coal Bed Methane Advanced

No	Compor	Langmuir Press. (psia)	Langmuir Conc. (Mscf /USton (daf))	Sorption Time (day)	Re-adsorption Coeff.
1	N2	0	0	0	1
2	CO2	0	0	0	1
3	H2S	0	0	0	1
4	C1	635	0.088989999	62	1
5	C2	0	0	0	1
6	C3	0	0	0	1
7	iC4	0	0	0	1
8	nC4	0	0	0	1
9	iC5	0	0	0	1
10	nC5	0	0	0	1
11	C6	0	0	0	1
12	C7+	0	0	0	1

Apply Help

Figure A- 12 coal bed Methane properties screen

Figure A-13 shows workflow section of simulation controls which includes reservoir grids size and they are adoptable upon desire of grid size of the reservoir because this option controls the speed of completion of the entire run. the larger grid size, the faster simulation run is done .

Figure A- 13 simulation controls screen

The workflow is followed by generalizing the model with proper specifications. FigureA-14 shows the generated model for the 3000 ft horizontal well with three fracture treatments of 300 ft half length just as an example. The wellbore and generated fractures are shown as solid lines. The three lines in y direction are fractures whereas the central white line in x direction is the well bore. The heel of the well bore is marked by P1 and the too is all the way in x direction up to the tip of the reservoir. Figure A-15 shows the generated model of effective longitudinal

fracture as an example. The red line in the center is the created longitudinal fracture along the lateral parts of the well I the x axis direction.

Figure A- 14 generated model of horizontal well with three multiply fractures

Figure A- 15 generated model in case of effective longitudinal fracture

Figure A-16 shows the simulation in the run, when the simulation calculates the values to give out the final results.

MIF ;	2.0	0.30	0.0	0.0	0.0	0.0	6108.3	2966.2	0.0	0.0
2										
MIF ;	2.4	0.36	0.0	0.0	0.0	0.0	5704.9	2965.2	0.0	0.0
2										
MIF ;	2.8	0.43	0.0	0.0	0.0	0.0	5286.6	2964.1	0.0	0.0
2										
MIF ;	3.4	0.52	0.0	0.0	0.0	0.0	4861.8	2962.8	0.0	0.0
2										
MIF ;	4.0	0.62	0.0	0.0	0.0	0.0	4439.7	2961.5	0.0	0.0
2										
MIF ;	4.7	0.75	0.0	0.0	0.0	0.0	4030.0	2960.1	0.0	0.0
2										
MIF ;	5.6	0.90	0.0	0.0	0.0	0.0	3641.4	2958.5	0.0	0.0
2										
MIF ;	6.7	1.07	0.0	0.0	0.0	0.0	3281.0	2956.8	0.0	0.0
2										
MIF ;	8.0	1.29	0.0	0.0	0.0	0.0	2953.7	2955.0	0.0	0.0
2										
MIF ;	9.5	1.55	0.0	0.0	0.0	0.0	2661.6	2953.0	0.0	0.0
2										
MIF ;	11.4	1.86	0.0	0.0	0.0	0.0	2404.4	2950.8	0.0	0.0
2										
MIF ;	13.6	2.23	0.0	0.0	0.0	0.0	2179.8	2948.3	0.0	0.0
2										

Figure A- 16 simulation in the run screen

When the run is completed, a Display window will appear as shown below in figure A-17 below. White and yellow comments mean that everything is correct and acceptable even with some warnings but if red comments appear in the window, then a mistake will prevent a complete run to give good results

Row	Type	Date	Time	Description
1	Warning	0/0/0	0.000	SCFDIMS IGNORED AS NO FRACTURES DEFINED
2	Message	1/1/2011	0.000	CHECKING FOR LICENSES
3	Message	1/1/2011	0.000	CHECKING FOR LICENSES
4	Message	1/1/2011	0.000	CHECKING FOR LICENSES
5	Message	1/1/2011	0.000	ECLIPSE LICENSE EXPIRES 18-FEB-2013
6	Message	1/1/2011	0.000	READING FROM INCLUDE FILE MAHMOD-1_GGO.INC
7	Warning	1/1/2011	0.000	KEYWORD NODPPM SHOULD ONLY OCCUR ONCE
8	Warning	1/1/2011	0.000	KEYWORD DPGRID SHOULD ONLY OCCUR ONCE
9	Message	1/1/2011	0.000	READING FROM INCLUDE FILE MAHMOD-1_GPRO.INC
10	Message	1/1/2011	0.000	PROCESSING GRID DATA

Below the table are checkboxes for filtering: Error, Message, Bugs, Comment, Warning, Problems. A search bar labeled 'Search in Description' and a 'Find' button are also present. At the bottom are 'Close', 'Help', and 'Open Current PRT File' buttons.

Figure A- 17 display window of comments

Figure A-18 shows results of the model. As seen below, total gas production of the model with time is in display

Figure A- 18 total gas production display screen

Field pressure drop is displayed in figure A-19 below. An example of field pressure drop after 20 years of gas production is shown in figure A-19. On the left hand side of the window, results flow tree is shown.

Figure A- 19 display screen of field pressure

Figure A-20 shows pressure drop around three multiply fractures after 20 years of gas production. The blue lines are the fractures with the least pressure value whereas the red area represents the distribution of the gas pressure in the reservoir around the fractures.

Figure A- 20 shows pressure distribution in and around fractures after 20 years of gas production