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Analysis of Production Data from Marcellus Shale Horizontal Wells in WV

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**Analysis of Production Data from Marcellus Shale Horizontal Wells
in WV**

Mohamed N. El sgher

**Thesis submitted to the
College of Engineering and Mineral Recourses 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
2013**

**Keywords: Unconventional Gas Reservoir, History Matching,
Horizontal Well, Hydraulic Fracture**

Mohamed N. El sgher

ABSTRACT
Analysis of Production Data from Marcellus Shale
Horizontal Wells in WV
Mohamed N. El sgher

In recent years, the interest in unconventional reservoirs has increased all over the world. The unconventional gas reservoir is a term commonly used to refer to a low permeability reservoir that produces mainly dry natural gas and is not able to produce an economic flow rate without stimulation treatments. The best way to improve the production is by a horizontal well with multiple hydraulic fractures. Hydraulic fracturing is a stimulation practice to improve the permeability in order to obtain commercial production. Horizontal wells with multiple hydraulic fracture treatments have proven to be an effective method for development of unconventional reservoirs.

The purpose of this study is to evaluate the production performance of Marcellus Shale by analyzing the available field production data. A commercial reservoir simulator (F.A.S.T Evolution) which is a single-porosity model was used for history matching. History matching was achieved for 9 horizontal wells by varying the key parameters such as reservoir drainage area, fracture half-length, fracture conductivity and matrix permeability. Once history matching has been performed, the model can be used to simulate future production with a higher degree of confidence

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LIST OF SYMBOLS/ NOMENCLATURES

K = formation permeability, md

K_m = matrix permeability, md

$\emptyset_m$ = matrix porosity, fraction

X_f = fracture half length, ft

K_{hf} = hydraulic fracture permeability, md

$\emptyset_{hf}$ = hydraulic fracture porosity, %

W_{hf} = hydraulic fracture width, in

P_L =Langmuir pressure, psia

V_L = Langmuir volume, SCF/ton

T = temperature, °F

F_{cd} = dimensionless fracture conductivity

OGIP (FREE) = original gas in place, MSCF

OGIP (Absorbed) = original gas in place, MSCF

S_g = gas saturated

h = thickness, ft

r_e = drainage radius, ft

r_w = wellbore radius, ft

P_{wf} = bottom hole pressure

A = area, acreage

P_i = reservoir pressure

CHAPTER 1

INTRODUCTION

In recent years, the demand for energy from unconventional reservoirs has increased all over the world. The depletion of production from conventional resources brought about the advancement of technology to economically produce oil and natural gas from unconventional resources. Unconventional reservoirs are different from conventional reservoirs in their methods of production. Typical unconventional reservoirs are tight-gas sands, coalbed methane, heavy oil, and shales. In this study primarily focuses is shale gas reservoirs which are source rocks for conventional reservoirs. Like other unconventional reservoirs, shale has low permeability in nano-darcy. In addition, shale gas reservoirs are organic-rich formation and are apparently the source rock as well as the reservoir. The gas is stored in the limited pore space of the rock and sizeable fraction of the gas is adsorbed on the organic material (Cipolla 2009).

Horizontal wells with multiple hydraulic fractures have recently become the key technology to achieve economic production from shale gas reservoirs. However, the production data available from these horizontal wells only reflect the short-term recovery. Reservoir simulation can be used to estimate the long-term recovery for the horizontal wells. This thesis will be a new study on the production analysis of the Marcellus Shale using reservoir simulation and history matching techniques.

The Marcellus Shale is the largest shale gas play in the U.S. Marcellus shale lies beneath much of Ohio, West Virginia, Pennsylvania and New York, as well as portions of Kentucky,

Tennessee and Maryland as it illustrates in Figure1-1. The estimated depth of the Marcellus ranges from 4,000 ft to 8,500 ft. Marcellus Shale is a Middle Devonian-aged shale bounded above by shales of the Hamilton Group and below by limestones of the Tristates. The Marcellus Shale covers an area of approximately 95,000 square miles at an average thickness of 50 ft to 200 feet. It has been estimated that as much as 1,500 Tcf of gas in place may be present in the entire Marcellus play area. The total amount of gas expected to be produced over the life of the play, referred to as the estimated ultimate recovery (EUR), for the Marcellus has recently been increased to 489 Tcf; however, as with other shale gas plays, the Marcellus' potential estimates are frequently being revised upward due to additional development. (NETL, 2010)

Figure 1- 1 Extent of the Marcellus Shale. (“Marcellus Shale”, 2012)

CHAPTER 2

LITERATURE REVIEW

2.1 Unconventional Gas Reservoirs

Conventional reservoirs, which are essentially high to medium permeability reservoirs, can be produced at economic flow rates without any special treatment. On the other hand, unconventional reservoirs cannot be produced at economic flow rates without stimulation treatments or special recovery processes and technologies (Miskimins, 2008). Typical unconventional reservoirs are tight-gas sands, shale gas, shale oil, coalbed methane and heavy oil.

The concept of the resource triangle is helpful in understanding the distribution of gas reservoirs and the factors which affect them was used by Master's, (1979). Figure 2-1 illustrates the resource triangle for conventional and unconventional reservoir. Conventional reservoirs are small in size and easy to develop, but often hard to find. The unconventional reservoirs with large volumes of oil or gas in place are generally much more difficult to develop. Unconventional reservoirs need high technology and are much more costly to develop. Due to gas demand and increasing gas prices, the unconventional gas reservoirs can be developed to meet the demand

Figure 2- 1 Resource Triangle (modified from Masters, 1979)

Figure2-2 from Energy Information Administration (EIA), illustrates the historical production and projections for natural gas from 1990-2035, while total domestic natural gas production will grow from 21.0 TCF in 2009 to 26.3 TCF in 2035, shale gas production will grow to 12.2 TCF in 2035, when it will make up 47 percent of total U.S. production—up considerably from the 16 percent share in 2009.

The production of shale gas has grown dramatically; production of natural gas from shale gas in the United States grew by an average of 17 percent per year from 2000 to 2006. Early successes in shale gas production occurred primarily in the Barnett Shale of north central Texas. By 2006, successful shale gas operations in the Barnett shale, improvements in shale gas recovery technologies, and attractive natural gas prices encouraged the industry to accelerate its development activity in other shale plays. The combination of two technologies- horizontal

drilling and hydraulic fracturing- made it possible to produce shale gas economically, and from 2006 to 2010 U.S. shale gas production grew by an average of 48 percent per year (AOE 2011).

Figure 2- 2 U.S. Natural Gas Production in TCF/year, 1990-2035 (EIA, 2011)

2.2 Shale gas

Shale is a type of clay or mud that can easily split into layers. These layers were compressed by formation pressure or other geological circumstances and turned into a fine-grained sedimentary rock. Shale formations function as source rocks and seals for conventional reservoirs. Gas migrates from source rock to sandstone or carbonate reservoirs. There, gas is accumulated and trapped in the sandstone resulting in a gas reservoir. Shale gas reservoir is

defined as highly organic formation having permeability ranging from 0.1 mD to 10⁻⁷ mD. (Siripatrachai and. Ertekin, 2012)

Figure 2- 3 (a) High Porosity Sandstone; (b) Naturally Fracture Shale (Ingrain Digital Rock Physics Lab, 2012)

In shale gas reservoirs, gas can be stored in three forms: free gas in matrix pores which has the majority of gas storage in the formation but with a very low permeability, free gas in fractures with a higher permeability but low storage capacity, and adsorbed gas on the surface of shale as it illustrates in Figure 2-4 below. Adsorbed gas can be primarily characterized by two parameters: Langmuir Volume (V_L) and Langmuir Pressure (P_L). Gas produced from shale is mostly methane, but some are wet gas.

Figure 2- 4 Shows Free Gas in Matrix, Free Gas in Fractures and Adsorbed Gas in the Solid (Song and Economides, 2011)

The adsorption / desorption mechanism is governed by Langmuir isotherm where two properties are associated with: Langmuir volume or gas content (V_L) and Langmuir pressure (P_L). The mathematic expression of this model is:

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

V_{ads} , [scf/ton], the gas volume can be absorbed by a rock of unit mass;

V_L , [scf], Langmuir volume, the maximum gas volume can be adsorbed;

P_L , [psi], Langmuir pressure, at which half of Langmuir volume gas is adsorbed;

p , [psi], pressure

To describe the adsorption/desorption of a particular reservoir rock, Langmuir pressure and Langmuir Volume are needed. Figure 2-5 shows the shape of a typical Langmuir isotherm curve

indicating the amount of gas adsorbed as pressure increases (adsorption) or desorbed as pressure decreases (desorption) (Song and Economides, 2011)

Figure 2-5 Illustration of Typical Gas Adsorption/Desorption Isotherm (Song and, Economides, 2011)

2.3 Horizontal Wells

The use of horizontal wells for the production of crude oil and natural gas has accelerated during the past several years. Horizontal well technology has been successfully applied in unconventional reservoirs to improve gas production. Horizontal drilling with multiple hydraulic fractures is the key to improve the productivity of the wells especially those which are drilled in unconventional reservoirs as it illustrates in Figure 2-6. Horizontal wells have been very successful in increasing productivity, adding reserves, and improving the overall cost-

effectiveness of field operations. Figure 2-7 shows the variety of applications of horizontal wells as listed below:

- ❖ Intersecting natural fractures.
- ❖ Exploiting thin oil and gas zones.
- ❖ Reducing water and gas coning.
- ❖ Enhancing heavy oil recovery.

Figure 2- 6 Horizontal Drilling (Geology, 2012)

Joshi (1988) found that, horizontal wells are not effective in very thick reservoirs (500 to 600 ft) and in formations with low vertical permeability. A decrease in vertical permeability results in an increase in vertical flow resistance for horizontal wells and a corresponding

decrease in oil or gas production. Horizontal drilling techniques may be ineffective in layered reservoirs where several laterals (horizontal wellbores) would have to be drilled in order to access the oil and/or gas.

Figure 2- 7 Applications for Horizontal Wells (G. C. Thakur, 1999)

The horizontal well technology has three major disadvantages as explained below (Joshi, 2003).

- High cost as compared to a vertical well. In the U.S., 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.
- Generally only one zone at a time can be produced using a horizontal well. If the reservoir has multiple pay-zones, especially with large differences in vertical depth, or

large differences in permeability, it is not easy to drain all the layers using a single horizontal well.

- 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

2.4 Hydraulic Fracturing

Hydraulic fracturing is a formation stimulation practice used to create a high conductivity pathway in producing formations. Thereby facilitates the migration of fluids to the wellbore to achieve economic production. Hydraulic fracturing can be used to overcome barriers to the flow of fluids, one of the primary reasons development of gas shales has traditionally been limited. Barriers may include naturally low permeability common in shale formations or reduced permeability resulting from near wellbore permeability impairment caused by drilling activities. While some aspects of hydraulic fracturing have been changing and maturing, this technology has been utilized by industry to increase production to support the increasing demand for energy for over 60 years (Daniel Arthur, 2009)

A hydraulic fracture is created by pumping fluid into the wellbore at a specific velocity to increase the down-hole pressure to a value in excess of the fracture gradient of the formation rock. This applied pressure causes the formation to crack, allowing the fluid to enter and extend the crack farther into the formation. To keep this fracture open after the injection stops, a solid proppant is added to the fluid. The propped hydraulic fracture then becomes a high permeability conduit through which the formation fluid can flow to the well. Figure 2-8 shows an example of horizontal well with a fracture

Figure 2- 8 Marcellus Shale Hydraulic Fracturing (Hydraulic Fracturing, 2011)

2.4.1 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 in horizontal wells.

If the horizontal well is drilled parallel to the minimum horizontal stress, the created fractures will be perpendicular to the horizontal well; i.e., transverse fractures. 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 cases (Soliman, M.Y., Azari, M., Hunt, J.L 1996). Figure 2-9 shows both longitudinal and transverse fractures in a horizontal well.

Figure 2-9 Fracture Configuration from a Horizontal Well; on the left, Multiple Transverse Fractures; on the right, A Longitudinal Fracture (M.J. Economides,2010)

2.4.1 Dimensionless Hydraulic Fracture Conductivity

Dimensionless hydraulic fracture conductivity is defined by the following equation

$$F_{CD} = \frac{k_F w_F}{k X_F}$$

Where:

k_F : Fracture Permeability

w_F : Fracture Width

k : Formation Permeability

X_F : Fracture Half-length

If dimensionless fracture conductivity is less than 100, the fracture behavior is considered a finite conductivity. However, if dimensionless fracture conductivity is more than 100, the fracture behavior is considered an infinite conductivity. Two different types of fractures can be initiated or created, if amount of proppant is given, a short fat fracture can be created with a high value of fracture conductivity, or a longer, narrow fracture can be created with a lower value of fracture conductivity. For low permeability reservoirs, a long, lower conductivity fracture is required. Figure 2-10 shows the pressure drop along the finite conductivity fracture and infinite conductivity fracture.

Figure 2-10 Infinite-Conductivity and Finite-Conductivity Hydraulic Fractures (Schlumberger, 1998)

CHAPTER 3

OBJECTIVE AND METHDOLOGY

The purpose of this study is to predict the long-term production performance of Marcellus Shale by analyzing the available limited field production data.

In order to accomplish the objective of this study, a methodology consisting of the following procedures was employed:

- Production and completion data were collected for horizontal wells completed in Marcellus Shale in WV.
- A base model was developed based on the available information.
- A commercial reservoir simulator (F.A.S.T Evolution) which is a single-porosity numerical simulator was used for history matching.
- History matching was achieved by varying the key parameters such as reservoir drainage area, fracture half-length, fracture conductivity, matrix permeability, and the flowing bottom-hole pressure.
- The long-term production was estimated using the matched model.

3.1 Data Collection

All of the necessary production data for the Marcellus Shale wells was obtained from West Virginia Geological Survey database available on-line. The completion records were also obtained from various sources. There were more than 51 horizontal wells in Marcellus Shale for which some information was available through West Virginia Geological Survey database. The production data for majority of these horizontal wells were unavailable. In addition, some of the well had production data which exhibited a lot of fluctuations. This can be for many reasons including changing bottom-hole pressures and equipment problems. For

this particular study, 9 horizontal wells in Upshur, Marshall and Wetzel counties that had a long and smooth production history were selected. Additional data for these 9 horizontal wells such as number of fracture stages, reservoir pressure, and length of the well was collected. Table 3-1 summarizes the information for each well in this study.

Table 3- 1 Horizontal Wells Data

Wells	API	Permit	Drill Date	Counties	Horizontal Length ft	Rock Pressure (psi)	Fracture Stages
Horizontal#1	4709703527	3527	8/31/2008	Upshur	3000	3000	8
Horizontal#2	4709703516	3516	8/31/2008	Upshur	1812	3000	5
Horizontal#3	4705101092	1092	7/31/2008	Marshall	2727	3000	7
Horizontal#4	4710302331	2331	12/08/08	Wetzel	3522	1858	9
Horizontal #5	4710302364	2364	09/17/08	Wetzel	3922	2000	10
Horizontal#6	4710302375	2375	10/26/08	Wetzel	3522	2120	9
Horizontal#7	4710302408	2408	03/14/09	Wetzel	4102	2500	7
Horizontal #8	4710302427	2427	05/04/09	Wetzel	4632	3953	8
Horizontal#9	4710302428	2428	04/01/09	Wetzel	4307	3958	7

3.2 Development of the Base Model

The base model is an essential part of this study because it will provide the starting point for successful history matching.

The length and width of the reservoir was selected based on the length of horizontal lateral. The reservoir thickness was obtained for some of horizontal wells using the “Pay Zone” data from the West Virginia Geological Survey database. For the wells that a thickness was not available, the thickness map of the Marcellus Shale in West Virginia was used to estimate the thickness.

The permeability and porosity were assumed based on the typical characteristics of the Marcellus Shale. It should be noted that the permeability in vertical (z) direction was assumed to be 1/10 of the permeability in horizontal (x and y) direction

Typical properties were also assigned to hydraulic fracture. The hydraulic fracture properties generally impact the initial production rate. For example, increasing the permeability of the hydraulic fracture would yield a significantly higher initial production rate. The impact of fracture half-length is however more significant and influences production performance for longer period of time.

Minimum Bottom-hole pressure (P_{wf}) was assumed to be 500 psia. The value for Langmuir pressure (P_L) and Langmuir volume (V_L) have been defined as it shows in Table3-2. Langmuir volume (V_L) is the maximum gas volume which can be adsorbed. Langmuir pressure (P_L) represents the pressure at which the gas storage capacity equals one half of the maximum storage capacity.

Table3-2 summarizes the base model parameters used in this study. The parameters given in Table 3-2 were used as the input for Fast Evolution simulator to generate production profile for the base model.

Table 3- 2 Base Model Parameters

Basic Model Parameters		
Reservoir Parameters		
Depth	7000	ft
Thickness	75	ft
Rock Properties		
Porosity Type	Single	
Matrix Porosity	0.05	fracture
Matrix permeability Kx	0.002	md
Matrix permeability Ky	0.002	md
Matrix permeability Kz	0.0002	md
water saturation	0.15	fracture
Hydraulic Fracture Properties		
Half Length	500	ft
Fracture Permeability	20,000	md
width	0.01	in
Top of Fracture	7000	ft
Bottom of Fracture	7075	ft
Constraints		
Pwf	500	psi
Time Step	1	month
Maximum Rate Limitation	10	MMscf/d
Fluid Properties		
Gas Gravity	0.8	
CO2	0	%
N2	0	%
H2O	0	%
Adsorption		
Gas Diffusion Coefficient	1	ft ² /day
Sorption Pressure	62	day
Langmuir Pressure	635	psia
Langmuir Volume	0.08899	mscf/ton
Rock Denisty	150	lb/ft ³

3.3 History Matching

History matching was initiated with the base model and the final match was achieved by varying the key parameters such as reservoir drainage area, fracture half-length, fracture conductivity, permeability, and the flowing bottom-hole pressure. In this part of the study, history match was achieved for all 9-horizontal wells. Various model parameters needed to be changed for each well in order to match the field production history.

Figure 3-1 shows the results of the history matching for horizontal well#1. Production data for two years (2008 and 2009) was used to for history matching by changing parameters. Subsequently, the matched model was used to predict the production for the following two years (2010 and 2011) to verify accuracy and reliability of the matched model. The predicted production rate closely matched the actual data as it can be seen in Figure 3-1. These results confirmed the reliability of the matched model.

Figure 3- 1 History Match and Predictions for Horizontal well #1

3.4 Long-Term Production Performance

The matched model for each well was utilized to predict the gas recovery after 15 years of production for each well. The results were utilized to investigate the impact of various parameters on the gas recovery

CHAPTER 4

RESULTS AND DISCUSSIONS

The following sections summarize the results of history matching for each horizontal well:

4.1 Horizontal Well #1

This well is located in Upshur County. The thickness of this well is about 75 ft. it has been taken from thickness map of Upshur County. In addition, the length of this reservoir is about 3000 ft. which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular drainage area for this reservoir is assumed to be $4000 \times 2000 \text{ ft}^2$ in dimensions. The initial reservoir pressure was 3000 psia. The Table 4-1 shows the initial parameter and final parameter for history matching.

As we can see in the Figure 4-2, different parameter has been changed to get a good history match for horizontal well#1. To obtain a good history match for this well, permeability was reduced from 0.002 md to 0.001 md. Moreover, fracture half length (x_f) was reduced from 500 ft. to 400 ft. The Figure 4-1 illustrates that the well has 8 stages and the spacing between each fracture is about 500 ft. and the location of the horizontal well is at the center of the rectangular reservoir.

Table 4- 1 the Initial and Final Parameter for Horizontal Well#1

Horizontal length	3000	ft	Horizontal length	3000	ft
Area	183.908046	Acre	Area	183.908046	Acre
Top of Fracture	7000	ft	Top of Fracture	7000	ft
Bottom of Fracture	7075	ft	Bottom of Fracture	7075	ft
Thickness	75	ft	Thickness	75	ft
Porosity	5.5	%	Porosity	5.5	%
Matrix Perm ,i,j,k	0.002,0.002, 0.0002	md	Matrix Perm ,i,j,k	0.001,0.001, 0.0001	md
Dimesions	4000*2000	ft ²	Dimesions	4000*2000	ft ²
Pressure	3000	psia	Pressure	3000	psia
Sg	85	%	Sg	85	%
Hydraulic Fracture	8		Hydraulic Fracture	8	
Half length	500	ft	Half length	400	ft
Frature permeability	20,000	md	Fracture permeability	10,000	md
width	0.01	in	width	0.01	in
pwf	500	psia	pwf	500	psia
F _{CD}	16.66666667		F _{CD}	20.83333333	
Langmuir Pressure	635	psia	Langmuir Pressure	635	psia
Langmuir Conc.	0.088999999	Mscf/ton	Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton	Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³	Rock Denisty	150	lb/ft ³

Figure 4- 1 Horizontal Well #1 with Eight Fractures

Figure 4- 2 History Matching for Horizontal Well#1

Figure 4- 3 Final Match for Horizontal Well #1

Figure 4- 4 Final Match for Horizontal Well #1 (Cumulative Gas)

Ellipse has been used for the horizontal well#1. As it illustrates in Figure 4-5 the same parameter which was used in Fast Evaluation was used in the Eclipse. It gave a good match

Figure 4- 5 Final Match for Horizontal Well #1 Using Eclipse

As we can see in Figure 4-6, the comparison between Ellipse and Fast Evolution

Figure 4- 6 Compared Ellipse and Fast Evolution

4.2 Horizontal Well #2

The second well is also located in Upshur County. The thickness of this well is about 75 ft. it has been taken from thickness map of Upshur County. In addition, the length of this reservoir is about 1812ft. which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular drainage area for this reservoir is assumed to be $3624 \times 1812 \text{ ft}^2$ in dimensions. The initial reservoir pressure was about 3000 psia. The Table 4-2 shows the initial parameter and final parameter for history matching.

Table 4- 2 the Initial and Final Parameter for Horizontal Well#2

Horizontal length	1812	ft	Horizontal length	1812	ft
Area	150.958345	Acre	Area	150.9583448	Acre
Top of Fracture	7000	ft	Top of Fracture	7000	ft
Bottom of Fracture	7075	ft	Bottom of Fracture	7075	ft
Thickness	75	ft	Thickness	75	ft
Porosity	5.5	%	Porosity	4.5	%
Matrix Perm	0.002	md	Matrix Perm	0.002	md
Dimesions	1812*3624	ft ²	Dimesions	1812*3624	ft ²
Pressure	3000	psia	Pressure	3000	psia
Sg	85	%	Sg	85	%
Hydraulic Fracture	5		Hydraulic Fracture	5	
Half length	500	ft	Half length	350	ft
Fracture permeability	20,000	md	Frature permeability	10,000	md
width	0.01	in	width	0.01	in
pwf	500	psia	pwf	500	psia
F _{CD}	16.6666667		F _{CD}	11.9047619	
Langmuir Pressure	635	psia	Langmuir Pressure	635	psia
Langmuir Conc.	0.089	Mscf/ton	Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton	Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³	Rock Denisty	150	lb/ft ³

To obtain good match for horizontal well#2, Fracture half length (x_f) was reduced from 500ft to 350ft. Fracture half length (x_f) has a huge impact on production. It makes decline curve goes down and up. Porosity was changed from 5.5% to 4.5% to get a good matching for initial production because porosity has a little bit impact on initial production and it does not have much impact on late production performance. The Figure 4-7 illustrates that the well has 5 stages. The location of the horizontal well is at the center of the rectangular reservoir.

Figure 4- 7 Horizontal Well#2 with Five Fractures

Figure 4- 8 Final Match For Horizontal Well #2

Figure 4- 9 Final Match for Horizontal Well #2 (Cumulative Gas)

4.3 Horizontal Well #3

The second well is located in Marshall County. The thickness of this well is about 75 ft. it has been taken from thickness map of Marshall County. In addition, the length of this reservoir is about 2727ft which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular drainage area for this reservoir is assumed to be $4000 \times 2000 \text{ ft}^2$ in dimensions. The initial reservoir pressure is about 3000psia. The Table 4-3 shows the initial parameter and final parameter for history matching.

As we can see in this well, the well has a lot of fluctuation in production data; the best way to get a good match is to let the model goes in middle of the real production data, so the cumulative gas production will be matched. To make this happen, permeability was increased from 0.002md to 0.005 md. In addition, porosity was decreased from 5.5% to 5% to get a good

match at the beginning. The Figure 4-10 illustrates that this well has 7 stages. The location of the horizontal well is at the center of the rectangular reservoir.

Table 4- 3 the Initial and Final Parameter for Horizontal Well#3

Horizontal length	2727	ft	Horizontal length	2727	ft
Area	183.908046	Acre	Area	183.908046	Acre
Top of Fracture	7000	ft	Top of Fracture	7000	ft
Bottom of Fracture	7075	ft	Bottom of Fracture	7075	ft
Thickness	75	ft	Thickness	75	ft
Porosity	5.5	%	Porosity	5	%
Matrix Perm	0.002	md	Matrix Perm	0.005	md
Dimesions	4000*2000	ft ²	Dimesions	4000*2000	ft ²
Pressure	3000	psia	Pressure	3000	psia
Sg	85	%	Sg	85	%
Hydraulic Fracture	7		Hydraulic Fracture	7	
Half length	500	ft	Half length	500	ft
permeability	20,000	md	permeability	20,000	md
width	0.01	in	width	0.01	in
pwf	500 psi	psia	pwf	500 psi	psia
F_{CD}	16.66666667		F_{CD}	6.666666667	
Langmuir Pressure	635	psia	Langmuir Pressure	635	psia
Langmuir Conc.	0.088999999	Mscf/ton	Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton	Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³	Rock Denisty	150	lb/ft ³

Figure 4- 10 Horizontal Well#3 with Seven Fractures

Figure 4- 11 Final Match for Horizontal well #3

Figure 4- 12 Final Match for Horizontal well#3 (cumulative gas)

4.4 Horizontal Well #4

The well is located in Wetzel County. The thickness of this well is about 75 ft. it has been taken from thickness map of Wetzel County. In addition, the length of this reservoir is about 3522ft which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular of this reservoir is assumed to be 4110×2000 ft² in dimensions. The initial reservoir pressure is about 1858 psia. The Table 4-4 shows the initial parameter and final parameter for history matching.

Table 4- 4 the Initial and Final Parameter for Horizontal Well#4

Horizontal length	3522	ft	Horizontal length	3522	ft
Area	188.9655172	Acre	Area	188.9655172	Acre
Top of Fracture	7000	ft	Top of Fracture	7000	ft
Bottom of Fracture	7075	ft	Bottom of Fracture	7075	ft
Thickness	75	ft	Thickness	75	ft
Porosity	5.5	%	Porosity	6.5	%
Matrix Perm	0.002	md	Matrix Perm	0.007	md
Dimesions	4110*2000	ft ²	Dimesions	4110*2000	ft ²
Pressure	1858	psia	Pressure	1858	psia
Sg	85	%	Sg	85	%
Hydraulic Fracture	9		Hydraulic Fracture	9	
Half length	500	ft	Half length	500	ft
Fracture permeability	20,000	md	Fracture permeability	20,000	md
width	0.01	in	width	0.01	in
pwf	500 psi	psia	pwf	500 psi	psia
F _{CD}	16.66666667		F _{CD}	4.761904762	
Langmuir Pressure	635	psia	Langmuir Pressure	635	psia
Langmuir Conc.	0.088999999	Mscf/ton	Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton	Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³	Rock Denisty	150	lb/ft ³

It is so difficult to get a good history matching for this wells because at the beginning this well has low production after that the well starts having fluctuation in gas production. Permeability was increased from 0.002md to 0.007 md. In addition, porosity was increased from

5.5% to 6.5% to get a good match at the beginning of the production. Also, the cumulative gas production was matched as it illustrates in Figure 4 -15.

The Figure 4-13 illustrates that this well has 9 stages. The location of the horizontal well is at the center of the rectangular reservoir.

Figure 4- 13 Horizontal Well#4 with Nine Fractures

Figure 4- 14 Final Match for Horizontal Well #4

Figure 4- 15 Final Match for Horizontal Well #4 (Cumulative Gas)

4.5 Horizontal Well# 5

The well is located in Wetzel County. The thickness of this well is about 75 ft. it has been taken from thickness map of Wetzel County. In addition, the length of this reservoir is about 3900ft which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular drainage area for this reservoir is assumed to be $4200 \times 2000 \text{ ft}^2$ in dimensions. The initial reservoir pressure is about 2000 psia. The Table 4-5 shows the initial parameter and final parameter for history matching.

This well has low production in middle and has high production at the end. It was matched from the beginning as it illustrates in Figure 4-17. Porosity was decreased from 5.5% to 5%. Moreover, permeability was increased from 0.002md to 0.0025md to obtain a good match.

In addition, cumulative gas production was matched by changing porosity and permeability as it mentioned above

Table 4- 5 the Initial and Final Parameter for Horizontal Well#5

Horizontal length	3900	ft	Horizontal length	3900	ft
Area	193.1034483	Acre	Area	193.1034483	Acre
Top of Fracture	7000	ft	Top of Fracture	7000	ft
Bottom of Fracture	7075	ft	Bottom of Fracture	7075	ft
Thickness	75	ft	Thickness	75	ft
Porosity	5.5	%	Porosity	5	%
Matrix Perm	0.002	md	Matrix Perm	0.0025	md
Dimesions	4200*2000	ft ²	Dimesions	4200*2000	ft ²
Pressure	2000	psia	Pressure	2000	psia
Sg	85	%	Sg	85	%
Hydraulic Fracture	10		Hydraulic Fracture	10	
Half length	500	ft	Half length	500	ft
permeability	20,000	md	permeability	20,000	md
width	0.01	in	width	0.01	in
pwf	500 psi	psia	pwf	500 psi	psia
F_{CD}	16.66666667		F_{CD}	13.33333333	
Langmuir Pressure	635	psia	Langmuir Pressure	635	psia
Langmuir Conc.	0.088999999	Mscf/ton	Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton	Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³	Rock Denisty	150	lb/ft ³

Figure 4- 16 Horizontal Well#5 with Ten Fractures

Figure 4- 17 Final Match for Horizontal Well#5

Figure 4- 18 Final Match for Horizontal Well#5 (Cumulative Gas)

4.6 Horizontal Well #6

The well is located in Wetzel County. The thickness of this well is about 75 ft. it has been taken from thickness map of Wetzel County. In addition, the length of this reservoir is about 3522ft which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular drainage area for this reservoir is assumed to be 4599×2000 ft² in dimensions. The initial reservoir pressure is about 2120 psia. The Table 4-6 shows the initial parameter and final parameter for history matching.

Table 4- 6 the Initial and Final Parameter for Horizontal Well#6

Horizontal length	3522	ft		Horizontal length	3522	ft
Area	211.44828	Acre		Area	211.4483	Acre
Top of Fracture	7000	ft		Top of Fracture	7000	ft
Bottom of Fracture	7075	ft		Bottom of Fracture	7075	ft
Thickness	75	ft		Thickness	75	ft
Porosity	5.5	%		Porosity	6.5	%
Matrix Perm	0.002	md		Matrix Perm	0.006	md
Dimesions	4599*2000	ft ²		Dimesions	4599*2000	ft ²
Pressure	2120	psia		Pressure	2120	psia
Sg	85	%		Sg	85	%
Hydraulic Fracture	9			Hydraulic Fracture	9	
Half length	500	ft		Half length	500	ft
permeability	20,000	md		permeability	20,000	md
width	0.01	in		width	0.01	in
pwf	500	psia		pwf	500	psia
F _{CD}	16.666667			F _{CD}	5.555556	
Langmuir Pressure	635	psia		Langmuir Pressure	635	psia
Langmuir Conc.	0.089	Mscf/ton		Langmuir Conc.	0.089	Mscf/ton
Langmuir Conc.	88.999999	scf/ton		Langmuir Conc.	89	scf/ton
Rock Denisty	150	lb/ft ³		Rock Denisty	150	lb/ft ³

To obtain a match for this case, permeability was increased from 0.002 md to 0.006 md in order for the curve to shift upward. By increasing permeability, the entire decline curve shifts

upward. In addition, porosity was increased as well (from 5.5% to 6.5%) in order to increase the initial production. It is obvious that porosity does not have huge impact on the production decline curve and its little impact is only visible at the beginning of the production. The Figure 4-19 illustrates that this well has 9 stages. The location of the horizontal well is at the center of the rectangular reservoir.

Figure 4- 19 Horizontal Well#6 with Nine Fractures

Figure 4- 20 Final Match for Horizontal Well #6

Figure 4- 21 Final Match for Horizontal Well #6 (Cumulative Gas)

4.7 Horizontal Well #7

The well is located in Wetzel County. The thickness of this well is about 75 ft. it has been taken from thickness map of Wetzel County. In addition, the length of this reservoir is about 4102ft which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular drainage area for this reservoir is assumed to be $4500 \times 2000 \text{ ft}^2$ in dimensions. The initial reservoir pressure is about 2500 psia. The Table 4-7 shows the initial parameter and final parameter for history matching.

To historically match this well, fracture half length (x_f) was changed from 500 md to 350md because it has a great impact on the production decline curve by bringing the curve up and down. In addition, Permeability was increased from 0.002md to 0.0025. Figure 4- 22

illustrates that this well has 7 stages. The location of the horizontal well is at the center of the rectangular reservoir.

Table 4- 7 the Initial and Final Parameter for Horizontal Well#7

Horizontal length	4102	ft	Horizontal length	4102	ft
Area	206.8965517	Acre	Area	206.8965517	Acre
Top of Fracture	7000	ft	Top of Fracture	7000	ft
Bottom of Fracture	7075	ft	Bottom of Fracture	7075	ft
Thickness	75	ft	Thickness	75	ft
Porosity	5.5	%	Porosity	5.5	%
Matrix Perm	0.002	md	Matrix Perm	0.0025	md
Dimesions	4500*2000	ft ²	Dimesions	4500*2000	ft ²
Pressure	2500	psia	Pressure	2500	psia
Sg	85	%	Sg	85	%
Hydraulic Fracture	7		Hydraulic Fracture	7	
Half length	500	ft	Half length	350	ft
permeability	20,000	md	permeability	20,000	md
width	0.01	in	width	0.01	in
pwf	500	psia	pwf	500	psia
F _{CD}	16.66666667		F _{CD}	19.04761905	
Langmuir Pressure	635	psia	Langmuir Pressure	635	psia
Langmuir Conc.	0.088999999	Mscf/ton	Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton	Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³	Rock Denisty	150	lb/ft ³

Figure 4- 23 Horizontal Well#7 with Seven Fractures 4500 ft

Figure 4- 24 Final Match for Horizontal Well #7

As we can see that the well has been matched from beginning. The Figure4-24 illustrates final matching for horizontal well#7

Figure 4- 25 Final Match for Horizontal Well #7 (Cumulative Gas)

4.8 Horizontal Well #8

The well is located in Wetzel County. The thickness of this well is about 75 ft. it has been taken from thickness map of Wetzel County. In addition, the length of this reservoir is about 4632ft which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular drainage area for this reservoir is assumed to be 5000×2000 ft² in dimensions. The initial reservoir pressure is about 3953 psia. The Table 4-8 shows the initial parameter and final parameter for history matching.

Table 4- 8 the Initial and Final Parameter for Horizontal Well#8

Horizontal length	4632	ft	Horizontal length	4632	ft
Area	229.8850575	Acre	Area	229.8850575	Acre
Top of Fracture	7000	ft	Top of Fracture	7000	ft
Bottom of Fracture	7075	ft	Bottom of Fracture	7075	ft
Thickness	75	ft	Thickness	75	ft
Porosity	5.5	%	Porosity	5	%
Matrix Perm	0.002	md	Matrix Perm	0.002	md
Dimesions	5000*2000	ft ²	Dimesions	5000*2000	ft ²
Pressure	3953	psia	Pressure	3953	psia
Sg	85	%	Sg	85	%
Hydraulic Fracture	8		Hydraulic Fracture	8	
Half length	500	ft	Half length	350	ft
permeability	20,000	md	permeability	20,000	md
width	0.01	in	width	0.01	in
pwf	500	psia	pwf	500	psia
F _{CD}	16.66666667		F _{CD}	23.80952381	
Langmuir Pressure	635	psia	Langmuir Pressure	635	psia
Langmuir Conc.	0.088999999	Mscf/ton	Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton	Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³	Rock Denisty	150	lb/ft ³

Figure 4-26 illustrates that the well has a lot of fluctuation. Maybe, this well has been shut and opened many times. So in this case, history matching was done to cumulative gas production as it illustrates in Figure 4- 29. Figure 4-28 shows that the model has a high

production compared by real data. Fracture half length (x_f) was decreased from 500ft to 350ft to decrease the production. Porosity was decreased from 5.5% to 5%. The Figure 4-25 illustrates that the well has 8 stages and the spacing between each fracture is about 662 ft and the location of the horizontal well is at the center of the rectangular reservoir.

Figure 4- 26 Horizontal Well#8 with Eight Fractures

Before history matching

Figure 4- 27 History Matching For Horizontal Well#8

After history matching

Figure 4- 28 Final Match for Horizontal Well #8

Before history matching

Figure 4- 29 History Matching For Horizontal Well #8 (Cumulative Gas)

After history matching

Figure 4- 30 Final Match for Horizontal Well#8 (Cumulative Gas)

4.9 Horizontal Well #9

The well is located in Wetzel County. The thickness of this well is about 75 ft. it has been taken from thickness map of Wetzel County. In addition, the length of this reservoir is about 4307ft which is provided from well data section of West Virginia University Geological Survey. As a result of that the rectangular of this reservoir is assumed to be $4800 \times 2000 \text{ ft}^2$ in dimensions. The initial reservoir pressure is about 3953 psia. The Table 4-9 shows the initial parameter and final parameter for history matching.

The well has a lot of fluctuation in gas production. Fracture half length (x_f) was decreased from 500ft to 350ft to decrease gas production as it shows in Figure 4-34. Porosity was decreased from 5.5% to 4.6%. The Figure 4-30 illustrates that the well has 7 stages and the

spacing between each fracture is about 717 ft and the location of the horizontal well is at the center of the rectangular reservoir.

Table 4- 9 the Initial and Final Parameter for Horizontal Well#9

Horizontal length	4307	ft		Horizontal length	4307	ft
Area	220.6896552	Acre		Area	220.6896552	Acre
Top of Fracture	7000	ft		Top of Fracture	7000	ft
Bottom of Fracture	7075	ft		Bottom of Fracture	7075	ft
Thickness	75	ft		Thickness	75	ft
Porosity	5.5	%		Porosity	4.6	%
Matrix Perm	0.002	md		Matrix Perm	0.002	md
Dimesions	4800*2000	ft ²		Dimesions	4800*2000	ft ²
Pressure	3953	psia		Pressure	3953	psia
Sg	85	%		Sg	85	%
Hydraulic Fracture	7			Hydraulic Fracture	7	
Half length	500	ft		Half length	350	ft
permeability	20,000	md		permeability	20,000	md
width	0.01	in		width	0.01	in
pwf	500	psia		pwf	500	psia
F _{CD}	16.66666667			F _{CD}	23.80952381	
Langmuir Pressure	635	psia		Langmuir Pressure	635	psia
Langmuir Conc.	0.088999999	Mscf/ton		Langmuir Conc.	0.088999999	Mscf/ton
Langmuir Conc.	88.999999	scf/ton		Langmuir Conc.	88.999999	scf/ton
Rock Denisty	150	lb/ft ³		Rock Denisty	150	lb/ft ³

Figure 4- 31 Horizontal Well#9 with Seven Fractur 4800 ft

Before history matching

Figure 4- 32 History Matching for Horizontal Well #9

After history matching

Figure 4- 33 Final History Matching for Horizontal Well #9

Before history matching

Figure 4- 34 Match for Horizontal Well #9 (Cumulative Gas)

After history matching

Figure 4- 35 Final Match for Horizontal Well #9 (Cumulative Gas)

4.10 Final Models for all 9 Horizontal wells

Table 4-10, Table 4-11 and Table 4-12 show the final parameters for all of the horizontal wells used to history match.

Table 4- 10 Final Parameters for Horizontal Wells

Wells	API	Permit	Drill Date	county	Area (Acres)	dimension ft ²	Thickness
Horizontal well#1	4709703527	3527	8/31/2008	Upshur	183.90805	4000*2000	75
Horizontal well#2	47097003516	3516	8/31/2008	Upshur	150.95834	1812*3624	75
Horizontal well#3	4705101092	1092	7/31/2008	Marshall	183.90805	4000*2000	75
Horizontal well#4	47103023310000	47-103-02331	12/08/08	Wetzel	188.96552	4110*2000	75
Horizontal well#5	47103023640000	47-103-02364	09/17/08	Wetzel	193.10345	4200*2000	75
Horizontal well#6	47103023750000	47-103-02375	10/26/08	Wetzel	211.44828	4599*2000	75
Horizontal well#7	47103024080000	47-103-02408	03/14/09	Wetzel	206.89655	4500*2000	75
Horizontal well#8	47103024270000	47-103-02427	05/04/09	Wetzel	229.88506	5000*2000	75
Horizontal well#9	47103024280000	47-103-02428	04/01/09	Wetzel	220.68966	4800*2000	75

Table 4- 11 Final Parameters for Horizontal Wells

Wells	Horizontal Length	Rock Pressure (psi)	Bottom hole Pressure	Matrix Permeability, md	Porosity %
Horizontal well#1	3000	3000	500	0.001	5.5
Horizontal well#2	1812	3000	500	0.002	4.5
Horizontal well#3	2727	3000	500	0.005	5
Horizontal well#4	3522	1858	500	0.007	6.5
Horizontal well#5	3922	2000	500	0.0025	5
Horizontal well#6	3522	2120	500	0.006	6.5
Horizontal well#7	4102	2000	500	0.0025	5.5
Horizontal well#8	4632	3953	500	0.002	5
Horizontal well#9	4307	3958	500	0.002	4.6

Table 4- 12 Final Parameters for Horizontal Wells

Hydraulic fracture properties

Wells	STAGES	Fracture Half Length ft	Fracture Permeability, md	Frature width in	FC md.in	Fcd
Horizontal well#1	8	400	10,000	0.01	100	20.8333
Horizontal well#2	5	350	10,000	0.01	100	11.9048
Horizontal well#3	7	500	20,000	0.01	200	6.66667
Horizontal well#4	9	500	20,000	0.01	200	4.7619
Horizontal well#5	10	500	20,000	0.01	200	13.3333
Horizontal well#6	9	500	20,000	0.01	200	5.55556
Horizontal well#7	7	350	20,000	0.01	200	19.0476
Horizontal well#8	8	350	20,000	0.01	200	23.8095
Horizontal well#9	7	355	20,000	0.01	200	23.4742

4.11 Impact of the Parameters on Recovery

After history matching has been achieved for 9 horizontal wells, some of the parameters were found to have a significant impact on recovery factor. The wells which have high formation permeability have high recovery factor. As it illustrate in Figure 4-36. In addition, two wells have the same formation permeability but they have different fracture half length. The well which has higher fracture half-length has higher recovery factor. As it illustrates in Table 4-13

Figure 4- 36 Shows Formation Permeability VS Recovery Factor

Table 4- 13 Shows Recovery Factor with Fracture Have Length

Wells	Formation Permeability, md	Fracture Half Length, ft	RF
Horizontal well#2	0.002	350	28.261
Horizontal well#5	0.0025	500	38.980

CHAPTER 5

CONCLUSIONS

The purpose of this study is to evaluate the production performance of Marcellus Shale by analyzing the available field production data. 9 horizontal wells have been studied to understand the importance of each parameter. In addition, history matching has been done for these 9 horizontal wells. F.A.S.T Evolution software has been used to achieve the goal of this project. It gives the same results when it was compared by Ellipse. The following points have been reached:

- ▶ Hydraulic fracture half-length and formation permeability have a significant impact on gas recovery.
- ▶ Porosity only affects the initial production and it has no impact on the recovery.
- ▶ The spacing of hydraulic fracture stages is more important than the number of hydraulic fracture stages.
- ▶ The commercial success of the well will depend on the hydraulic fracture properties, i.e. half-length and permeability, which have significant impacts on the early production rates.

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APPENDIX A

Appendix A shows a procedure to enter data and run Schlumberger Eclipse software which was used to model horizontal wells completed in shale. A coal bed methane template was used shale in this research. Figure A-1 shows an Eclipse software launcher screen.

Figure A- 1 ECLIPSE Launcher

The user selects ECLIPSE “Office” from the ECLIPSE launcher that is shown in figure A-1, then The ECLIPSE office launcher pops up after clicking on “Office” as shown in Figure A-2.

Figure A- 2ECLIPSE Office Launcher

The user selects file-new project from the top menu bar as shown in Figure A-3. The file name is entered and saved in the directory. Make sure that the file name has a default extension type of (.off) for example. “El sgher.off”

Figure A- 3 ECLIPSE Office Screen

Then the user selects “add template case” as shown below.

Figure A- 4 add ECLIPSE Template Screen

After that, the template selection panel will be displayed as shown in Figure A-5. There are four different template models in the ECLIPSE including single well radial, completion modeling tool, coal bed methane, and CO2 sequestration. However, coal bed methane model was used for shale properties because shale has the two forms of flow, “free” gas and adsorbed gas.

Figure A- 5 ECLIPSE Template Selection

Figure A-6 shows simulation model definition. Model definition properties including start day, end day, time intervals, model properties, single porosity model is chosen

Figure A- 6 Model Definition Section

Five layers have been created with 15ft thickness each and 75 ft thickness total. Figure A-7 shows reservoir description window with five taps among which highlighted tap is Layers option.

Figure A- 7 Reservoir Layers Description

Next tap in the reservoir description was reservoir rock properties data entry “Single Porosity Model,” as shown below in figure A-8. Matrix porosity and Permeability in x, y and z direction 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	0.06	0.001	0.001	0.0001	1E-6	100
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

Apply Help

Figure A- 8 Reservoir Description for Rock Properties

Figure A-9 shows 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- 9 Non-Equilibrium Initial Conditions

Figure A-10 shows the fractures tab for reservoir description. Parameters have been entered including fracture half length, width, top and bottom of fracture, fracture permeability and fracture porosity

Figure A- 10 Shows Fractures Screen

Figure A-11 illustrates that 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- 11 Wells For Deviation Survey Screen

Figure A-12 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- 12 Shows Lateral Creation

Figure A-13 shows the production section. As soon as 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- 13 Shows Production Section

In addition, the user selects “perforation_1” from the available event as it illustrates in figure 14

Figure A- 14 Production for Perforation Control

Fluid properties have been entered such as standard pressure, standard temperature and reservoir temperature as it illustrates in figure A-15. In addition, gas component (C1-C7+) fraction was entered as it illustrates in figure A-15

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- 15 Fluid Properties

Since shale reservoir has both free and sorbed gas, Langmuir pressure, Langmuir concentration and sorption time has been entered as it illustrates in figure A-16.

Figure A- 16 Fluid Properties for Coal Bed Methane

Figure A-17 shows workflow section of simulation controls which includes reservoir grids size and they have been upon desire of grid size of the reservoir because this controls speed of completion of the entire run. The larger grid size, the faster simulation run is done.

Figure A- 17 Simulation Control for Gridding Control

Finally, the model in Eclipse is completed, so it can be run by clicking on “RUN ECLIPSE”. Depending on the PC speed, the model can take one days for complicated horizontal wells with different numbers of stages. After the model has been run successfully, “View Results” can be selected to analyze the model.

In addition, Appendix A shows a procedure to enter in F.A.S.T Evolution software. Reservoir parameters was entered such as matrix permeability, total porosity, thickness, gas saturation, drainage area, gas specific gravity, lagmour pressure, langmure volume, bottom hole pressure and time step as it illustrates in figure 2-1. In right side of the figure 2-1, horizontal length, fracture half length, number of fracture and dimensionless fracture conductivity have been entered. The spacing between the fractures can be easily done

The screenshot displays the F.A.S.T Evolution software interface. The left panel contains 'Reservoir Parameters' and 'Wells' sections. The right panel shows 'Auto-Layout Wells' and a 'Field Layout' diagram. Below the diagram is a table with well data.

Reservoir Parameters:

- Reservoir:** P_i 3000 psi(a), T_R 100.0 °F, k_x 0.001000 md, k_y 0.001000 md, k_z 0.000100 md, h 75.0 ft, ϕ 5.50 %, S_{gi} 85.00 %, c_r 6.231e-06 1/psi, X_g 4000 ft, Y_g 2000 ft, A_D 184 acres, OGIP 10.533 Bscf, OGIP_F 7.268 Bscf, OGIP_A 3.264 Bscf.
- Fluid:** G 0.800, CO_2 %, N_2 %, H_2S %.
- Constraints:** P_{wf} 500 psi(a), t_{row} 370 month, t_{step} 1.000 month, $Q_{gi}(MRL)$ 30.000 MMscfd, $Q_{gas}/Well$ 0.000 MMscfd.
- Wells:** r_w 0.300 ft.

Auto-Layout Wells:

- Wells: 1
- Type: HorizXwFracs
- S_d 0.000
- L_{sk} 3000 ft
- Fracs: 8
- x_{η} 400 ft
- F_{CD} 20.83

Field Layout: A diagram showing a horizontal well (1) with 8 fractures (2-9) spaced along its length.

Well Type	Start Time	Automatic Scheduling	x_L	x_{η}	F_{CD}	L_{sk}	L_{η}	S_d	x_w	y_w	Well Cost
	month		ft	ft		ft	ft		ft	ft	\$/Well
1 HorizXwFracs	0	☐				3000		0.000	1828	1049	
2 FractureY	0	☐		400	20.8				328	1049	
3 FractureY	0	☐		400	20.8				756	1049	
4 FractureY	0	☐		400	20.8				1185	1049	
5 FractureY	0	☐		400	20.8				1614	1049	
6 FractureY	0	☐		400	20.8				2042	1049	
7 FractureY	0	☐		400	20.8				2471	1049	
8 FractureY	0	☐		400	20.8				2899	1049	
9 FractureY	0	☐		400	20.8				3328	1049	

Figure A- 18 F.A.S.T Evolution Software

APPENDIX B

Horizontal well 1

Country	County Upshare			
API	4709703527			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
8/31/2008	58056	1,935.20	1,935.20	0
9/30/2008	53757	1,791.90	3,727.10	0
10/31/2008	47962	1,598.73	5,325.83	0
11/30/2008	43370	1,445.67	6,771.50	0
12/31/2008	42172	1,405.73	8,177.23	0
1/31/2009	39718	1,323.93	9,501.17	0
2/28/2009	34057	1,135.23	10,636.40	0
3/31/2009	36048	1,201.60	11,838.00	0
4/30/2009	33385	1,112.83	12,950.83	0
5/31/2009	32712	1,090.40	14,041.23	0
6/30/2009	32507	1,083.57	15,124.80	0
7/31/2009	31938	1,064.60	16,189.40	0
8/31/2009	31091	1,036.37	17,225.77	0
9/30/2009	29312	977.07	18,202.83	0
10/31/2009	28978	965.93	19,168.77	0
11/30/2009	27224	907.47	20,076.23	0
12/31/2009	28059	935.30	21,011.53	0
1/31/2010	27138	904.60	21,916.13	0
2/28/2010	23676	789.20	22,705.33	0
3/31/2010	25641	854.70	23,560.03	0
4/30/2010	23698	789.93	24,349.97	0
5/31/2010	23181	772.70	25,122.67	0
6/30/2010	22711	757.03	25,879.70	0
7/31/2010	13557	451.90	26,331.60	0
8/31/2010	24718	823.93	27,155.53	0
9/30/2010	23170	772.33	27,927.87	0
10/31/2010	22370	745.67	28,673.53	0
11/30/2010	19851	661.70	29,335.23	0
12/31/2010	19879	662.63	29,997.87	0
1/31/2011	19667	655.57	30,653.43	0
2/28/2011	18131	604.37	31,257.80	0
3/31/2011	9692	323.07	31,580.87	0
5/31/2011	18468	615.60	32,196.47	0
6/30/2011	26389	879.63	33,076.10	0
7/31/2011	19614	653.80	33,729.90	0
8/31/2011	18682	622.73	34,352.63	0
9/30/2011	17402	580.07	34,932.70	0
10/31/2011	18456	615.20	35,547.90	0
11/30/2011	17796	593.20	36,141.10	0
12/31/2011	17819	593.97	36,735.07	0

Horizontal well 2

Country	County Upshare			
API	47097003516			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
7/31/2008	13662	455.40	455.40	
8/31/2008	44888	1,496.27	1,951.67	0
9/30/2008	38747	1,291.57	3,243.23	0
10/31/2008	36641	1,221.37	4,464.60	0
11/30/2008	32207	1,073.57	5,538.17	0
12/31/2008	30926	1,030.87	6,569.03	0
1/31/2009	28869	962.30	7,531.33	0
2/28/2009	24773	825.77	8,357.10	0
3/31/2009	26040	868.00	9,225.10	0
4/30/2009	23876	795.87	10,020.97	0
5/31/2009	24049	801.63	10,822.60	0
6/30/2009	22355	745.17	11,567.77	0
7/31/2009	22628	754.27	12,322.03	0
8/31/2009	21671	722.37	13,044.40	0
9/30/2009	20383	679.43	13,723.83	0
10/31/2009	20220	674.00	14,397.83	0
11/30/2009	18870	629.00	15,026.83	0
12/31/2009	19271	642.37	15,669.20	0
1/31/2010	18656	621.87	16,291.07	0
2/28/2010	16235	541.17	16,832.23	0
3/31/2010	17690	589.67	17,421.90	0
4/30/2010	16727	557.57	17,979.47	0
5/31/2010	17156	571.87	18,551.33	0
6/30/2010	15455	515.17	19,066.50	0
7/31/2010	9025	300.83	19,367.33	0
8/31/2010	17522	584.07	19,951.40	0
9/30/2010	15542	518.07	20,469.47	0
10/31/2010	16045	534.83	21,004.30	0
11/30/2010	15087	502.90	21,507.20	0
12/31/2010	15673	522.43	22,029.63	0
1/31/2011	15215	507.17	22,536.80	0
2/28/2011	13311	443.70	22,980.50	0
3/31/2011	10199	339.97	23,320.47	0
4/30/2011	10204	340.13	23,660.60	0
5/31/2011	10721	357.37	24,017.97	0
6/30/2011	11510	383.67	24,401.63	0
7/31/2011	12280	409.33	24,810.97	0
8/31/2011	11711	390.37	25,201.33	0
9/30/2011	11076	369.20	25,570.53	0
10/31/2011	11404	380.13	25,950.67	0
11/30/2011	10900	363.33	26,314.00	0
12/31/2011	11100	370.00	26,684.00	0

Table B- 1 Production Data for Horizontal Wells

Horizontal well 3

Country	County Marshall			
API	4705101092			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
7/31/2008	156342	5,211.40	5,211.40	0
8/31/2008	143525	4,784.17	9,995.57	0
9/30/2008	123918	4,130.60	14,126.17	0
10/31/2008	116830	3,894.33	18,020.50	0
11/30/2008	98102	3,270.07	21,290.57	0
12/31/2008	88543	2,951.43	24,242.00	0
1/31/2009	60454	2,015.13	26,257.13	0
2/28/2009	46030	1,534.33	27,791.47	0
3/31/2009	58339	1,944.63	29,736.10	0
4/30/2009	52154	1,738.47	31,474.57	0
5/31/2009	48045	1,601.50	33,076.07	0
6/30/2009	41601	1,386.70	34,462.77	0
7/31/2009	41623	1,387.43	35,850.20	0
8/31/2009	2362	78.73	35,928.93	0
9/30/2009	18652	621.73	36,550.67	0
10/31/2009	16549	551.63	37,102.30	0
11/30/2009	11246	374.87	37,477.17	0
2/28/2010	62059	2,068.63	39,545.80	0
3/31/2010	59340	1,978.00	41,523.80	0
4/30/2010	46266	1,542.20	43,066.00	0
5/31/2010	25330	844.33	43,910.33	0
6/30/2010	49801	1,660.03	45,570.37	0
7/31/2010	36184	1,206.13	46,776.50	0
8/31/2010	15920	530.67	47,307.17	0
9/30/2010	38899	1,296.63	48,603.80	0
10/31/2010	59044	1,968.13	50,571.93	0
11/30/2010	27573	919.10	51,491.03	0
1/31/2011	49524	1,650.80	53,141.83	0
2/28/2011	62830	2,094.33	55,236.17	0
3/31/2011	66977	2,232.57	57,468.73	0
4/30/2011	57594	1,919.80	59,388.53	0
5/31/2011	57390	1,913.00	61,301.53	0
6/30/2011	49702	1,656.73	62,958.27	0
7/31/2011	48909	1,630.30	64,588.57	0
8/31/2011	49114	1,637.13	66,225.70	0
9/30/2011	44564	1,485.47	67,711.17	0
10/31/2011	44412	1,480.40	69,191.57	0
12/31/2011	3219	107.30	69,298.87	0

Horizontal well 4

Country	Wetzel			
API	47103023310000			
	GAS	GAS	Cumulative	OIL
	MSCF/Mon	MSCF/Day	MSCF/Day	Bbl/month
3/31/2009	83084	2,769.47	2,769.47	
4/30/2009	110219	3,673.97	6,443.43	
5/31/2009	111140	3,704.67	10,148.10	
6/30/2009	100870	3,362.33	13,510.43	
7/31/2009	96323	3,210.77	16,721.20	
8/31/2009	85027	2,834.23	19,555.43	106
9/30/2009	62580	2,086.00	21,641.43	126
10/31/2009	69212	2,307.07	23,948.50	49
11/30/2009	41190	1,373.00	25,321.50	22
2/28/2010	42379	1,412.63	26,734.13	10
3/31/2010	66757	2,225.23	28,959.37	39
4/30/2010	73191	2,439.70	31,399.07	144
5/31/2010	69437	2,314.57	33,713.63	44
6/30/2010	67304	2,243.47	35,957.10	26
7/31/2010	70597	2,353.23	38,310.33	193
8/31/2010	67975	2,265.83	40,576.17	192
9/30/2010	61068	2,035.60	42,611.77	181
10/31/2010	57114	1,903.80	44,515.57	183
11/30/2010	25983	866.10	45,381.67	66
12/31/2010	40507	1,350.23	46,731.90	21
1/31/2011	58463	1,948.77	48,680.67	18
2/28/2011	58191	1,939.70	50,620.37	13
3/31/2011	53812	1,793.73	52,414.10	9
4/30/2011	54795	1,826.50	54,240.60	90
5/31/2011	24498	816.60	55,057.20	17
6/30/2011	61014	2,033.80	57,091.00	24
7/31/2011	64509	2,150.30	59,241.30	12
8/31/2011	60333	2,011.10	61,252.40	2
9/30/2011	57557	1,918.57	63,170.97	1
10/31/2011	37008	1,233.60	64,404.57	1
11/30/2011	24323	810.77	65,215.33	1
12/31/2011	51742	1,724.73	66,940.07	2

Table B- 2 Production Data for Horizontal Wells

Horizontal well 5

Country	Wetzel			
API	47103023640000			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
2/28/2009	24947	831.57	831.57	
3/31/2009	64162	2,138.73	2,970.30	
4/30/2009	54539	1,817.97	4,788.27	
5/31/2009	75056	2,501.87	7,290.13	
6/30/2009	67592	2,253.07	9,543.20	
7/31/2009	64984	2,166.13	11,709.33	
8/31/2009	62264	2,075.47	13,784.80	645
9/30/2009	60229	2,007.63	15,792.43	535
10/31/2009	55432	1,847.73	17,640.17	574
11/30/2009	19867	662.23	18,302.40	283
2/28/2010	705	23.50	18,325.90	0
3/31/2010	17499	583.30	18,909.20	383
4/30/2010	9602	320.07	19,229.27	167
5/31/2010	49210	1,640.33	20,869.60	726
6/30/2010	55389	1,846.30	22,715.90	606
7/31/2010	52919	1,763.97	24,479.87	549
8/31/2010	28158	938.60	25,418.47	310
9/30/2010	79684	2,656.13	28,074.60	612
10/31/2010	76347	2,544.90	30,619.50	667
11/30/2010	66439	2,214.63	32,834.13	486
12/31/2010	3804	126.80	32,960.93	17
2/28/2011	64650	2,155.00	35,115.93	425
3/31/2011	78120	2,604.00	37,719.93	357
4/30/2011	46583	1,552.77	39,272.70	409
5/31/2011	64122	2,137.40	41,410.10	301
6/30/2011	60369	2,012.30	43,422.40	222
7/31/2011	44848	1,494.93	44,917.33	249
8/31/2011	59846	1,994.87	46,912.20	212
9/30/2011	65494	2,183.13	49,095.33	202
10/31/2011	62233	2,074.43	51,169.77	194
11/30/2011	56506	1,883.53	53,053.30	161
12/31/2011	56572	1,885.73	54,939.03	192

Horizontal well 6

Country	Wetzel			
API	47103023750000			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
3/31/2009	112747	3,758.23	3,758.23	
4/30/2009	141018	4,700.60	8,458.83	
5/31/2009	133262	4,442.07	12,900.90	
6/30/2009	120620	4,020.67	16,921.57	
7/31/2009	105129	3,504.30	20,425.87	
8/31/2009	75169	2,505.63	22,931.50	398
9/30/2009	65906	2,196.87	25,128.37	250
10/31/2009	71094	2,369.80	27,498.17	156
11/30/2009	45209	1,506.97	29,005.13	63
2/28/2010	31065	1,035.50	30,040.63	63
3/31/2010	45982	1,532.73	31,573.37	73
4/30/2010	61532	2,051.07	33,624.43	100
5/31/2010	73417	2,447.23	36,071.67	67
6/30/2010	67639	2,254.63	38,326.30	80
7/31/2010	64437	2,147.90	40,474.20	42
8/31/2010	80975	2,699.17	43,173.37	26
9/30/2010	75257	2,508.57	45,681.93	58
10/31/2010	66623	2,220.77	47,902.70	132
11/30/2010	31037	1,034.57	48,937.27	63
12/31/2010	36557	1,218.57	50,155.83	1
1/31/2011	68120	2,270.67	52,426.50	43
2/28/2011	64742	2,158.07	54,584.57	14
3/31/2011	72549	2,418.30	57,002.87	25
4/30/2011	66468	2,215.60	59,218.47	19
5/31/2011	45897	1,529.90	60,748.37	44
6/30/2011	68434	2,281.13	63,029.50	59
7/31/2011	72130	2,404.33	65,433.83	30
8/31/2011	67245	2,241.50	67,675.33	5
9/30/2011	58025	1,934.17	69,609.50	3
10/31/2011	38760	1,292.00	70,901.50	2
11/30/2011	33426	1,114.20	72,015.70	1
12/31/2011	56956	1,898.53	73,914.23	3

Table B- 3 Production Data for Horizontal Wells

Horizontal well 7

Country	Wetzel			
API	47103024080000			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
5/31/2009	51616	1,720.53	1,720.53	
6/30/2009	71338	2,377.93	4,098.47	
7/31/2009	68263	2,275.43	6,373.90	
8/31/2009	60068	2,002.27	8,376.17	493
9/30/2009	58531	1,886.37	10,262.53	465
10/31/2009	46043	1,534.77	11,797.30	395
11/30/2009	26223	874.10	12,671.40	205
1/31/2010	2363	78.77	12,750.17	
2/28/2010	8092	269.73	13,019.90	112
3/31/2010	48787	1,626.23	14,646.13	544
4/30/2010	44688	1,489.60	16,135.73	407
5/31/2010	61883	2,062.77	18,198.50	484
6/30/2010	47634	1,587.80	19,786.30	394
7/31/2010	47332	1,579.73	21,366.03	340
8/31/2010	19467	648.90	22,014.93	181
9/30/2010	54973	1,832.43	23,847.37	346
10/31/2010	16643	554.77	24,402.13	244
11/30/2010	10643	354.77	24,756.90	21
3/31/2011	6558	218.60	24,975.50	156
4/30/2011	6322	210.73	25,186.23	91
5/31/2011	52724	1,757.47	26,943.70	555
6/30/2011	77139	2,571.30	29,515.00	385
7/31/2011	71467	2,382.23	31,897.23	206
8/31/2011	62613	2,087.10	33,984.33	255
9/30/2011	56112	1,870.40	35,854.73	242
10/31/2011	53222	1,774.07	37,628.80	214
11/30/2011	46310	1,543.67	39,172.47	448
12/31/2011	45771	1,525.70	40,698.17	130

Horizontal well 8

Country	Wetzel			
API	47103024270000			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
7/31/2009	32837	1,094.57	1,094.57	
8/31/2009	88995	2,966.50	4,061.07	559
9/30/2009	95408	3,180.27	7,241.33	474
10/31/2009	76024	2,534.13	9,775.47	219
11/30/2009	53608	1,786.93	11,562.40	139
2/28/2010	36443	1,214.77	12,777.17	78
3/31/2010	82119	2,737.30	15,514.47	423
4/30/2010	49604	1,653.47	17,167.93	284
5/31/2010	77311	2,577.03	19,744.97	235
6/30/2010	75496	2,516.53	22,261.50	252
7/31/2010	71798	2,393.27	24,654.77	184
8/31/2010	32766	1,092.20	25,746.97	52
9/30/2010	72178	2,405.93	28,152.90	196
10/31/2010	66980	2,232.67	30,385.57	85
11/30/2010	60216	2,007.20	32,392.77	152
12/31/2010	141	4.70	32,397.47	
2/28/2011	27733	924.43	33,321.90	54
3/31/2011	87447	2,914.90	36,236.80	143
4/30/2011	17895	596.50	36,833.30	25
5/31/2011	1642	54.73	36,888.03	1
6/30/2011	77262	2,575.40	39,463.43	65
7/31/2011	77695	2,589.83	42,053.27	59
8/31/2011	71804	2,393.47	44,446.73	41
9/30/2011	65092	2,169.73	46,616.47	28
10/31/2011	64699	2,156.63	48,773.10	24
11/30/2011	56434	1,881.13	50,654.23	19
12/31/2011	60533	2,017.77	52,672.00	21

Table B- 4 Production Data for Horizontal Wells

Horizontal well 9

Country	Wetzel			
API	47103024280000			
	GAS	GAS	Cumulative	OIL
	MSCF/Month	MSCF/Day	MSCF/Day	Bbl/month
7/31/2009	27101	903.37	903.37	
8/31/2009	83346	2,778.20	3,681.57	645
9/30/2009	92124	3,070.80	6,752.37	375
10/31/2009	68040	2,268.00	9,020.37	237
11/30/2009	46552	1,551.73	10,572.10	142
2/28/2010	27574	919.13	11,491.23	9
3/31/2010	65432	2,181.07	13,672.30	77
4/30/2010	67942	2,264.73	15,937.03	142
5/31/2010	39910	1,330.33	17,267.37	130
6/30/2010	59492	1,983.07	19,250.43	329
7/31/2010	64750	2,158.33	21,408.77	218
8/31/2010	35748	1,191.60	22,600.37	54
9/30/2010	69781	2,326.03	24,926.40	95
10/31/2010	22880	762.67	25,689.07	43
11/30/2010	52897	1,763.23	27,452.30	291
12/31/2010	163	5.43	27,457.73	
2/28/2011	27638	921.27	28,379.00	234
3/31/2011	75743	2,524.77	30,903.77	585
4/30/2011	17543	584.77	31,488.53	104
5/31/2011	994	33.13	31,521.67	4
6/30/2011	71069	2,368.97	33,890.63	265
7/31/2011	68905	2,296.83	36,187.47	243
8/31/2011	58069	1,935.63	38,123.10	170
9/30/2011	57334	1,911.13	40,034.23	116
10/31/2011	52795	1,759.83	41,794.07	100
11/30/2011	49242	1,641.40	43,435.47	76
12/31/2011	54667	1,822.23	45,257.70	87

Table B- 5 Production Data for Horizontal Wells

APPENDIX C

Horizontal #1:

Figure C- 1 Decline Curve for Horizontal #1

Horizontal #2:

Figure C- 2 Decline Curve for Horizontal #2

Horizontal #3:

Figure C- 3 Decline Curve for Horizontal #3

Horizontal #4:

Figure C- 4 Decline Curve for Horizontal #4

Horizontal #5:

Figure C- 5 Decline Curve for Horizontal #5

Horizontal #6:

Figure C- 6 Decline Curve for Horizontal #6

Horizontal #7:

Figure C- 7 Decline Curve for Horizontal #7

Horizontal #8:

Figure C- 8 Decline Curve for Horizontal #8

Horizontal #9:

Figure C- 9 Decline Curve for Horizontal #9