2020

Application of Decline Curve Analysis to Unconventional Reservoirs

Majed Hisham Kabbani
mhk0007@mix.wvu.edu

Follow this and additional works at: <https://researchrepository.wvu.edu/etd>

Part of the [Other Engineering Commons](#)

Recommended Citation

Kabbani, Majed Hisham, "Application of Decline Curve Analysis to Unconventional Reservoirs" (2020). *Graduate Theses, Dissertations, and Problem Reports*. 7718.
<https://researchrepository.wvu.edu/etd/7718>

This Problem/Project Report is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Problem/Project Report in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Problem/Project Report has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

Application of Decline Curve Analysis to Unconventional Reservoirs

Majed H. Kabbani

Report submitted to the
Benjamin M. Statler 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

Kashy Aminian, Chair Ph.D.
Samuel Ameri, Professor
H. Ilkin Bilgesu, Ph.D.

**Department of Petroleum and Natural Gas Engineering,
Morgantown, West Virginia
2020**

Keywords: Decline Curve Analysis

Copyright 2020 Majed H. Kabbani

ABSTRACT

Application of Decline Curve Analysis to Unconventional Reservoirs

Majed H. Kabbani

Supply and demand are the main key factors for oil and gas industry. Moreover, natural gas was not important until early 18th century after the World War II. The first shale gas well was successfully drilled 27 ft deep in 1821. The well was drilled in the Devonian Dunkirk shale. Later in the 1980s producers began investigating into the more difficult tight gas sands in order to keep up with the growing market. A decade later in 1990s investors were looking at coalbed methane. Today, as demand is increasing globally, the oil and gas industry is moving toward shale.

Decline-curve analysis (DCA), is considered one of the most commonly used approaches to estimate the decline production rate and forecast future production rate for oil and gas wells. Accurate production forecast is very crucial for reserve estimation and development planning. However, shale production analysis utilizing traditional decline curve methods will not have an accurate production profile due to the nature of the reservoir properties and production behavior.

In this report, a comparison of new empirical equations has been studied specifically for shale production decline analysis. The recently developed methods are the Power Law Exponential Decline (PLE), Stretched Exponential Decline Model (SEPD) and Duong Model. The new decline curve approaches can predict future production rates for shale gas wells under transient flow. Duong model is considered simple and practical to use for predicting future forecast. Therefore, decline analysis was performed with Duong's method using actual production data for five (5) Marcellus Shale wells and the results were compared accordingly.

ACKNOWLEDGMENT

I would like to express my appreciation to my research advisor Dr. Kashy Aminian for his support and guidance during my graduate program. His support, help and professional assistance made me completed my studies, which concluded in the achievement of M.S degree.

My Sincere appreciation and thanks to Professor Sam Ameri, Department Chair, for his continues support, motivation and guidance throughout my studies at West Virginia University. I would like also to express my deepest appreciation to the professors of the Petroleum and Natural Gas Engineering Department for the knowledge and experience provided to me.

Finally, my sincere gratitude and thanks to my family and friends for their continues support, love and efforts they have given to me. A special appreciation to Saudi Aramco for sponsoring my graduate study and supporting me throughout the program.

Table of Contents

Abstract	
Acknowledgment	iii
Table of Content	iv
List of Figures	v
List of Tables	vii
Nomenclature	viii
Chapter 1: Intoduction and Problem Statement	1
Chapter 2: Background	2
2.1 ARP's Model.....	2
2.2 Power Law Exponential Decline (PLE).....	4
2.3 Stretched Exponential Decline Model (SEPD).....	5
2.4 Duong Model.....	6
Chapter 3: Methodology	7
3.1 Data Collection.....	7
3.2 Data Analysis.....	7
3.3 Decline Analysis Method.....	7
Chapter 4: Results and Discussion.....	8
4.1 Estimated Ultimate Recovery (EUR).....	8
4.2 Well No.1.....	10
4.3 Well No.2.....	15
4.4 Well No.3.....	20
4.5 Well No.4H.....	25
4.6 Well No.6H.....	30
4.7 ARP's Model Analysis Well No.1	35
Chapter 5: Conclusions	38
References.....	39
Appendix.....	40

List of Figures

Figure (1) Estimated Ultimate Recovery (EUR).....	8
Figure (2) Well No.1 q/G_p vs. time.....	10
Figure (3) Well No.1 q vs. $t_{(a,m)}$	11
Figure (4) History Matching Well No.1 Gas Flow Rates with Duong Model	13
Figure (5) Comparison of the Predicted and Actual Gas Flow Rates for Well No.1	13
Figure (6) Predicted Gas Flow Rates for Well No.1 by Duong Model.....	14
Figure (7) Comparison of Well No.1 Cumulative Production and Duong Model	14
Figure (8) Well No.2 q/G_p vs. time.....	15
Figure (9) Well No.2 q vs. $t_{(a,m)}$	16
Figure (10) History Matching Well No.2 Gas Flow Rates with Duong Model	18
Figure (11) Comparison of the Predicted and Actual Gas Flow Rates for Well No.2	18
Figure (12) Predicted Gas Flow Rates for Well No.2 by Duong Model.....	19
Figure (13) Comparison of Well No.2 Cumulative Production and Duong Model	19
Figure (14) Well No.3 q/G_p vs. time.....	20
Figure (15) Well No.3 q vs. $t_{(a,m)}$	21
Figure (16) History Matching Well No.3 Gas Flow Rates with Duong Model	23
Figure (17) Comparison of the Predicted and Actual Gas Flow Rates for Well No.3	23
Figure (18) Predicted Gas Flow Rates for Well No.3 by Duong Model.....	24
Figure (19) Comparison of Well No.3 Cumulative Production and Duong Model	24
Figure (20) Well No.4H q/G_p vs. time	25
Figure (21) Well No.4H q vs. $t_{(a,m)}$	26
Figure (22) History Matching Well No.4H Gas Flow Rates with Duong Model	28
Figure (23) Comparison of the Predicted and Actual Gas Flow Rates for Well No.4H	28
Figure (24) Predicted Gas Flow Rates for Well No.4H by Duong Model.....	29
Figure (25) Comparison of Well No.4H Cumulative Production and Duong Model	29
Figure (26) Well No.6H q/G_p vs. time	30
Figure (27) Well No.6H q vs. $t_{(a,m)}$	31
Figure (28) History Matching Well No.6H Gas Flow Rates with Duong Model	33
Figure (29) Comparison of the Predicted and Actual Gas Flow Rates for Well No.6H	33
Figure (30) Predicted Gas Flow Rates for Well No.6H by Duong Model.....	34
Figure (31) Comparison of Well No.6H Cumulative Production and Duong Model	34

Figure (32) Arp's Model Well No.1	35
Figure (33) History Matching: Well No. 1 (ARP's Model vs. Duong Models)	36
Figure (34) Comparison of the Predicted Gas Flow Rates for Well No.1 by Arps's and Duong Models..	37

List of Tables

Table (1) Well No.1 Field Data	10
Table (2) Well No.1 $t_{-(a,m)}$	11
Table (3) Well No.1 G_p Duong (Mscf)	12
Table (4) Well No.2 Field Data	15
Table (5) Well No.2 $t_{-(a,m)}$	16
Table (6) Well No.2 G_p Duong (Mscf)	17
Table (7) Well No.3 Field Data	20
Table (8) Well No.3 $t_{-(a,m)}$	21
Table (9) Well No.3 G_p Duong (Mscf)	22
Table (10) Well No.4H Field Data.....	25
Table (11) Well No.4H $t_{-(a,m)}$	26
Table (12) Well No.4H G_p Duong (Mscf)	27
Table (13) Well No.6H Field Data.....	30
Table (14) Well No.6H $t_{-(a,m)}$	31
Table (15) Well No.6H G_p Duong (Mscf)	32

Nomenclature

EUR: Estimated Ultimate Recovery

DCA: Decline Curve Analysis

BDF: Boundary Dominated Flow

PLE: Power Law Exponential Model

SEPD: Stretched Exponential Production Decline Model

d_i = Loss Ratio, 1/ time

q_i = Initial flow rate, volume/time

n = Derivative of Loss Ratio, dimensionless

D_∞ = Loss ratio at ($t=\infty$), 1/time

D_1 = Loss ratio at ($t=1$), 1/time

q = Flow rate, volume/time

$t(a,m)$ = Duong time function, dimensionless

t = time, years

Chapter 1: Introduction and Problem Statement

Oil and gas companies were not interested in the investment of gas shale reservoirs since that it was not considered economical. However, due to the current advancement in technologies and the increasing of gas prices, investors are exploring all feasible options to recover and produce the gas that was once thought impossible to produce. Shale gas is considered now a key element of the energy sources in the United States. Shales have a significant amount of organic matter (kerogen) and serve as reservoir rock and source rock (El Sgher et al. 2018). The estimated consumption of natural gas in the U.S. is about 27 million cubic feet (MMcf) annually in 2017. Moreover, Natural gas has been the largest source of electrical generation since July 2015.

Drilling of a new well can be achieved vertically or horizontally. However, horizontal wells are more cost effective for commercial production in unconventional reservoirs (Shale). Production forecasts utilizing analytical and empirical approaches are not well established for horizontal wells with multi-stage hydraulic fractures due to limited field experience. Moreover, accurate production forecast is very crucial for reserve estimation and development planning. In addition, the production rate from unconventional reservoirs declines more rapidly than conventional reservoirs (El Sgher et al. 2018). There are many techniques for calculating and estimating shale gas reserves and performing production analysis. The most common approach to estimate the decline production rate and predict future production rate for oil and gas wells is Decline-curve analysis (DCA).

Arps' Decline Analysis (1945) can predict future production rates for conventional oil and gas wells that produce under boundary dominated flow (BDF). However, shale production analysis utilizing traditional decline curve methods will not have an accurate production profile due to the nature of the reservoir properties and production behavior. Therefore, the conventional DCA approach cannot be used to estimate production data from unconventional reservoirs. Recently, new empirical equations have been developed specifically for shale production decline analysis. These methods are the Power Law Exponential Decline (PLE), Stretched Exponential Decline Model (SEPD) and Duong Model. The new decline curve approaches can predict future production rates for shale gas wells under transient flow.

Chapter 2: Background

Decline-curve analysis (DCA), is considered one of the most common technique to estimate the decline production rate and predict future production rate for oil and gas wells. Moreover, conventional oil and gas wells can be estimated with traditional Arps' Decline Analysis equation (1945) that typically produce under boundary dominated flow. However, new empirical equations have been developed specifically for shale production decline analysis. The models will be discussed in more details below.

2.1 Arp's Models

The first forecasting approach and most common traditional techniques was proposed by J.J. Arps in 1945. This approach was used to calculate Estimated Ultimate Recovery (EUR) for conventional oil and gas wells. Arp's presented three types of production decline rates during boundary dominated flow: Exponential, Hyperbolic and Harmonic. Moreover, Arp's derived the equations based on the value of the decline exponent constant b . The derivative of the loss-ratio concept was used for all three types (Arps 1945):

Loss ratio:

$$\frac{1}{D} = -\frac{q}{dq/dt} \quad (2.1.1)$$

Loss ratio derivative:

$$n = \frac{d}{dt} = \left[-\frac{q}{\frac{dq}{dt}} \right] \quad (2.1.2)$$

- The above equation 2.2.1 can be derived for the case of pseudo-steady state flow on the wells producing under constant bottomhole flowing pressure.
- Arp's derived the hyperbolic decline model, assuming constant loss ratio, n :

$$q = qi(1 + n Di t)^{\frac{-1}{n}} \quad (2.1.3)$$

Where: q = flow rate

qi = initial flow rate

n = Arps hyperbolic parameter with value between 0 and 1 for the BDF

Di = initial decline rate

t = production time

Based on the above equations Arp's models can be:

- Exponential when $n = 0$
- Harmonic when $n = 1$
- Hyperbolic when $0 \leq n \leq 1$

The value of n can indicate the decline degree of curvature and reservoir type.

Arp's models considered the value of n between 0 and 1 which can be applied for conventional reservoirs under boundary dominated flow. However, the value of n can be more than 1 for unconventional reservoirs especially for tight gas wells (Ilk. 2008). Hence, the decline curve decreases when $n > 1$ and this can lead to invalid forecasting. Therefore, scientists have developed new equations for unconventional reservoirs with n value greater than 1. The recently developed methods are the Power Law Exponential Decline (PLE), Stretched Exponential Decline Model (SEPD) and Duong Model.

2.2 Power Law Exponential Decline (PLE)

The power law decline was developed by Ilk et al. (2008) to improve Arp's equation and better estimating the reserves for low permeability unconventional reservoirs. Moreover, PLE decline model is developed specifically for tight gas reservoirs to match early transient data and avoid over-estimation of the reserves (Seshadri, 2010).

- PLE loss-ratio model is defined by the following equation:

$$D = D_{\infty} + nD_it^{n-1} \quad (2.2.1)$$

- Loss-ratio derivative:

$$a = \frac{d}{dt} \left(\frac{1}{D} \right) = \frac{-n(n-1)D_it^{n-1}}{D^2} \quad (2.2.2)$$

- Rate-time relation:

$$q = qie \left(-D_{\infty}t - \frac{D_1}{n}t^n \right) \quad (2.2.3)$$

Where: qi = rate intercept at $t = 0$

D_{∞} = decline constant at infinite time

Di = decline constant

n = time exponent

2.3 Stretched Exponential Decline Model (SEPD)

The stretched exponential decline model was proposed by Valko (2010) to fit transient flow regimes for the unconventional reservoirs. The model was developed with physics concepts and differential equation definition. Moreover, the new equations can handle exponent value, unlike other models.

- The below equation shows the relationship of production rate declines with time:

$$q = q_0 \exp \left[- \left(\frac{t}{\tau} \right)^n \right] \quad (2.3.1)$$

Where: q = time varying production rate

q_0 = initial production rate

τ = the characteristic time parameter

n = the exponent parameter

The equation (2.4.1) looks very similar to the power law model (PLE). However, the main difference is SEPD calculation method uses two-parameters gamma functions while PLE is using a single interpretation of the parameters (Valko, 2010).

- The below expression is for cumulative production G_p :

$$Q = \frac{q_0 \tau}{n} \left\{ \Gamma \left[\frac{1}{n} \right] - \Gamma \left[\frac{1}{n}, \left(\frac{t}{\tau} \right)^n \right] \right\} \quad (2.3.2)$$

- The stretched exponential decline model is more complex than other models for decline curve analysis and more difficult to apply.

2.4 Duong Model

Duong has developed a new empirical model for fractured unconventional reservoirs. The preferred method of shale gas reservoirs development is multiple-staged hydraulic fractured horizontal wells. This is due to the linear flow time of early production in tight shale reservoirs. Moreover, Duong model is considered simple and practical to use for predicting future forecast. For example, the model is capable to analyze production data and create a range of results which include the probability of reserves distribution (Duong, 2011).

- Cumulative production vs. time in log-log plot will yield a straight line regardless of fracture type (Duong, 2011).

$$\frac{q}{G_p} = at^{-m} \quad (2.4.1)$$

$$q = q_1 t(a, m) + q_\infty \quad (2.4.2)$$

Where: q = flow rate, volume/time

a = Vertical axis intercept of $\log \frac{q}{G_p}$ vs t

m = slope of $\log - \log \frac{q}{G_p}$ vs t

G_p = Cumulative gas production

Duong's model may overestimate recovery for the first ten years if the flow regime has changed during the life of the well (Vanorsdale, 2013). However, the model can predict future forecast accurately for short production history. Therefore, Joshi and Lee (2013) have modified Duong's model to accommodate the wells with longer production history.

Chapter 3: Methodology

The main objective of this research is to apply a decline analysis method to actual production data and compare the results. Production data for five (5) Marcellus Shale wells were provided. The following procedures were followed to achieve this goal.

3.1 Data Collection

The data for all 5 wells were updated using the WV Geological Survey database website.

3.2 Data Analysis

The data were studied, and daily production rates were grouped into monthly production.

3.3 Decline Analysis Method

Duong's Method calculation steps:

- 1) Calculate q and G_p
- 2) Plot (q/G_p vs. time) in a Log-Log plot and find a & m values
- 3) Calculate $t(a, m)$ for the given time
- 4) Plot q vs. $t(a, m)$ on a Cartesian graph. The straight line with the slope of q_i and intercept of q_∞ .
- 5) Obtain Gas rate forecasts from parts 3 & 4.

Chapter 4: Results and Discussion

4.1 Estimated Ultimate Recovery (EUR)

- The estimated ultimate recovery using decline curve analysis were performed on all 5 wells to predict production forecast for 20 and 30 years.
- As per the chart below, well no.3 has the highest EUR production forecast while well no.2 has the lowest production among the 5 wells.

Figure 1: Estimated Ultimate Recovery (EUR)

Discussion

Decline analysis for five (5) Marcellus Shale wells was performed with Duong's method using actual production data. Moreover, a comparison of Arp's model and Duong model was also performed for well no.1. The results were compared as illustrated below.

The analysis was performed for the wells: 1,2 and 3 using the first 48 months of production data. The later part of production was utilized for prediction and comparison as shown in the figures below. However, remaining wells, no. 4H and 6H, the first 36 months was used for analysis and the remaining data was utilized for prediction and comparison. Most shale wells produce water at the beginning (frac fluid flow-back). During this early period of production, it is inclining. Therefore, the analysis was performed when the decline begins. Hence, the early production data was eliminated. In addition, for all the wells with exception of well no. 3, the decline trend is smooth. However, well no.3 shows significant fluctuations. Therefore, the data was smoothed out prior to the decline analysis to be more realistic.

Results

▪ Well No.1

✓ Field data: 111 months (Sample calculations)

Step 1: Calculate q and G_p

Table 1: Well No.1 Field Data

Given Field Data				
Time		Monthly Flow Rate	Average Daily Flow Rate	Cumulative
Month	Days	Mscf/Month	q (Mscf/day)	G _p (Mscf)
1	30	58056	1935.2	58056
2	60	53757	1791.9	111813
3	90	47962	1598.73333	159775
4	120	43370	1445.66667	203145
5	150	42172	1405.73333	245317

Step 2: Plot (q/G_p vs. time) in a Log-Log plot and find a & m

Figure 2: Well No.1 q/G_p vs. time

a	1.828
m	1.153

Step 3: Calculate $t_{(a,m)}$

$$t_{(a,m)} = t^{-m} e^{\left[\frac{a}{1-m} (t^{1-m} - 1) \right]}$$

Table 2: Well No.1 $t_{(a,m)}$

q (Mscf)	G _p (Mscf)	(q/G _p) (1/day)	$t_{(a,m)}$
1935.2	58056	0.0333333333	2.523615786
1791.9	111813	0.016025865	2.318573623
1598.733	159775	0.010006154	2.133096522
1445.667	203145	0.007116428	1.982426625
1405.733	245317	0.005730273	1.858580988

Step 4: Plot q-vs. $t_{(a,m)}$ on a Cartesian graph. The straight line with the slope of q_i and intercept of q_∞ . $q = q_1 t_{(a,m)} + q_\infty$

Figure 3: Well No.1 q vs. $t_{(a,m)}$

qi	738.63
q_∞	18.44

Where: q = flow rate, volume/time

a = Vertical axis intercept of $\log \frac{q}{G_p}$ vs t

m = slope of $\log - \log \frac{q}{G_p}$ vs t

G_p = Cumulative gas production

Step 5: Gas rate forecasts can be obtained from

Table 3: Well No.1 Gp_Duong (Mscf)

Given Field Data									
Time		Flow Rate							
Month	Days	Monthly (Mscf)	Daily (Mscf/d)	Cum. Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	58056	1935.20	58056	0.033333333	2.5236	1882.46	56473.75	56473.75
2	60	53757	1791.90	111813	0.016025865	2.3185	1731.01	51930.24	108403.99
3	90	47962	1598.73	159775	0.010006154	2.1330	1594.01	47820.27	156224.26
4	120	43370	1445.67	203145	0.007116428	1.9824	1482.72	44481.59	200705.86
5	150	42172	1405.73	245317	0.005730273	1.8585	1391.24	41737.31	242443.17

Well No.1 Estimated Ultimate Recovery (EUR)

The estimated ultimate recovery was calculated using decline curve analysis to predict production forecast for 20 and 30 years.

EUR (BCF) for 20 years
3.62
EUR (BCF) for 30 years
4.15

Figure 4: History Matching Well No.1 Gas Flow Rates with Duong Model

Figure 5: Comparison of the Predicted and Actual Gas Flow Rates for Well No.1

Figure 6: Predicted Gas Flow Rates for Well No.1 by Duong Model

Figure 7: Comparison of Well No.1 Cumulative Production and Duong Model

- Well No.2
- ✓ Field data: 112 months (Sample calculations)

Step 1: Calculate q and G_p

Table 4: Well No.2 Field Data

Time		Monthly Flow Rate	Average Daily Flow Rate	Cumulative
Month	Days	Mscf/Month	q (Mscf/day)	G_p (Mscf)
1	30	13662	455.4	13662
2	60	44888	1496.26667	58550
3	90	38747	1291.56667	97297
4	120	36641	1221.36667	133938
5	150	32207	1073.56667	166145

Step 2: Plot $(q/G_p \text{ vs. time})$ in a Log-Log plot and find a & m

Figure 8: Well No.2 q/G_p vs. time

<u>a</u>	<u>2.64</u>
<u>m</u>	<u>1.207</u>

Step 3: Calculate $t_{(a,m)}$

$$t_{(a,m)} = t^{-m} e^{\left[\frac{a}{1-m} (t^{1-m} - 1) \right]}$$

Table 5: Well No.2 $t_{(a,m)}$

q (Mscf)	Gp (Mscf)	(q/Gp) (1/day)	$t_{(a,m)}$
455.4	13662	0.033333333	10.38851046
1496.267	58550	0.025555366	10.45599806
1291.567	97297	0.013274476	9.951347153
1221.367	133938	0.009118896	9.402345861
1073.567	166145	0.006461625	8.893545267

Step 4: Plot q-vs. $t_{(a,m)}$ on a Cartesian graph. The straight line with the slope of q_i and intercept of q_∞ . $q = q_1 t_{(a,m)} + q_\infty$

Figure 9: Well No.2 q vs. $t_{(a,m)}$

qi	111.17
q∞	12.66

Where: q = flow rate, volume/time

a = Vertical axis intercept of $\log \frac{q}{G_p}$ vs t

m = slope of $\log - \log \frac{q}{G_p}$ vs t

G_p = Cumulative gas production

Step 5: Gas rate forecasts can be obtained from

Table 6: Well No.2 G_p Doung (Mscf)

Given Field Data									
Time		Flow Rate							
Month	Days	Monthly (Mscf)	Daily (Mscf/d)	Cum. Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	13662	455.40	13662	0.033333333	10.38851046	1167.55	35026.52	35026.52
2	60	44888	1496.27	58550	0.025555366	10.45599806	1175.05	35251.60	70278.12
3	90	38747	1291.57	97297	0.013274476	9.951347153	1118.95	33568.54	103846.66
4	120	36641	1221.37	133938	0.009118896	9.402345861	1057.92	31737.56	135584.22
5	150	32207	1073.57	166145	0.006461625	8.893545267	1001.36	30040.66	165624.88

Well No.2 Estimated Ultimate Recovery (EUR)

The estimated ultimate recovery was calculated using decline curve analysis to predict production forecast for 20 and 30 years.

EUR (BCF) for 20 years
2.36
EUR (BCF) for 30 years
2.67

Figure 10: History Matching Well No.2 Gas Flow Rates with Duong Model

Figure 11: Comparison of the Predicted and Actual Gas Flow Rates for Well No.2

Figure 12: Predicted Gas Flow Rates for Well No.2 by Duong Model

Figure 13: Comparison of Well No.2 Cumulative Production and Duong Model

▪ Well No.3

✓ Field data: 124 months (Sample calculations)

Step 1: Calculate q and G_p

Table 7: Well No.3 Field Data

Given Field Data				
Time		Monthly	Average Daily	Cumulative
Month	Days	Flow Rate	Flow Rate	
1	30	24,884	829.466667	24,884
2	60	139,490	4649.66667	164374
3	90	156342	5211.4	320716
4	120	143525	4784.16667	464241
5	150	123918	4130.6	588159

Step 2: Plot (q/G_p vs. time) in a Log-Log plot and find a & m

Figure 14: Well No.3 q/G_p vs. time

<u>a</u>	<u>2.1617</u>
<u>m</u>	<u>1.197</u>

Step 3: Calculate $t_{(a,m)}$

$$t_{(a,m)} = t^{-m} e^{\left[\frac{a}{1-m} (t^{1-m} - 1) \right]}$$

Table 8: Well No.3 $t_{(a,m)}$

q (Mscf)	G _p (Mscf)	(q/G _p) (1/day)	$t_{(a,m)}$
829.4667	24,884	0.033333333	3.622038871
4649.667	164374	0.028287118	3.234910061
5211.4	320716	0.016249267	2.899940807
4784.167	464241	0.010305351	2.636605944
4130.6	588159	0.007022931	2.425791453

Step 4: Plot q-vs. $t_{(a,m)}$ on a Cartesian graph. The straight line with the slope of q_i and intercept of q_{∞} . $q = q_1 t_{(a,m)} + q_{\infty}$

Figure 15: Well No.3 q vs. $t_{(a,m)}$

q_i	1414
q_{∞}	40.73

Where: q = flow rate, volume/time

a = Vertical axis intercept of $\log \frac{q}{G_p}$ vs t

m = slope of $\log - \log \frac{q}{G_p}$ vs t

G_p = Cumulative gas production

Step 5: Gas rate forecasts can be obtained from

Table 9: Well No.3 Gp_Duong (Mscf)

Given Field Data									
Time		Flow Rate							
Month	Days	Monthly (Mscf)	Daily (Mscf/d)	Cum. Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	139,490	4649.67	139490	0.033333333	3.622038871	5163.02	154890.52	154890.52
2	60	156342	5211.40	295832	0.017616079	3.234910061	4615.54	138466.19	293356.72
3	90	143525	4784.17	439357	0.010889019	2.899940807	4141.83	124254.79	417611.50
4	120	123918	4130.60	563275	0.007333185	2.636605944	3769.42	113082.54	530694.05
5	150	116830	3894.33	680105	0.005726077	2.425791453	3471.28	104138.53	634832.58

Well No.3 Estimated Ultimate Recovery (EUR)

The estimated ultimate recovery was calculated using decline curve analysis to predict production forecast for 20 and 30 years.

EUR (BCF) for 20 years
6.69
EUR (BCF) for 30 years
7.52

Figure 16: History Matching Well No.3 Gas Flow Rates with Duong Model

Figure 17: Comparison of the Predicted and Actual Gas Flow Rates for Well No.3

Figure 18: Predicted Gas Flow Rates for Well No.3 by Duong Model

Figure 19: Well No.3 Cumulative Production vs. Duong Model

- Well No.4H

- ✓ Field data: 69 months (Sample calculations)

Step 1: Calculate q and G_p

Table 10: Well No.4H Field Data

Given Field Data				
Time		Monthly Flow Rate	Average Daily Flow Rate	Cumulative
Month	Days	Mscf/Month	q (Mscf/day)	G _p (Mscf)
1	30	37,032	1234.4	37032
2	60	82,849	2761.63333	119881
3	90	77,704	2590.13333	197585
4	120	76,042	2534.73333	273627
5	150	71,697	2389.9	345324

Step 2: Plot (q/G_p vs. time) in a Log-Log plot and find a & m

Figure 20: Well No.4H q/G_p vs. time

<u>a</u>	<u>2.773</u>
<u>m</u>	<u>1.21</u>

Step 3: Calculate $t_{(a,m)}$

$$t_{(a,m)} = t^{-m} e \left[\frac{a}{1-m} (t^{1-m} - 1) \right]$$

Table 11: Well No.4H $t_{(a,m)}$

q (Mscf)	Gp (Mscf)	(q/Gp) (1/day)	$t_{(a,m)}$
1234.4	37032	0.033333333	13.80195873
2761.633	119881	0.023036456	14.32207202
2590.133	197585	0.013108957	13.83727267
2534.733	273627	0.009263462	13.19936211
2389.9	345324	0.006920747	12.57055624

Step 4: Plot q-vs. $t_{(a,m)}$ on a Cartesian graph. The straight line with the slope of q_i and intercept of q_∞ . $q = q_1 t_{(a,m)} + q_\infty$

Figure 21: Well No.4H q vs. $t_{(a,m)}$

qi	173.29
q_∞	46.156

Where: q = flow rate, volume/time

a = Vertical axis intercept of $\log \frac{q}{G_p}$ vs t

m = slope of $\log - \log \frac{q}{G_p}$ vs t

G_p = Cumulative gas production

Step 5: Gas rate forecasts can be obtained from

Table 12: Well No.4H Gp_Duong (Mscf)

Given Field Data									
Time		Flow Rate							
Month	Days	Monthly (Mscf)	Daily (Mscf/d)	Cum. Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	37,032	1234.40	37032	0.033	13.80	2437.90	73136.92	73136.92
2	60	82,849	2761.63	119881	0.023	14.32	2528.03	75840.84	148977.76
3	90	77,704	2590.13	197585	0.013	13.83	2444.02	73320.51	222298.27
4	120	76,042	2534.73	273627	0.009	13.19	2333.47	70004.20	292302.47
5	150	71,697	2389.90	345324	0.006	12.57	2224.51	66735.23	359037.70

Well No.4 Estimated Ultimate Recovery (EUR)

The estimated ultimate recovery was calculated using decline curve analysis to predict production forecast for 20 and 30 years.

EUR (BCF) for 20 years
5.29
EUR (BCF) for 30 years
6.13

Figure 22: History Matching Well No.4H Gas Flow Rates with Duong Model

Figure 23: Comparison of the Predicted and Actual Gas Flow Rates for Well No.4H

Figure 24: Predicted Gas Flow Rates for Well No.4H by Duong Model

Figure 25: Comparison of Well No.4H Cumulative Production and Duong Model

- **Well No.6H**

- ✓ Field data: 69 months (Sample calculations)

Step 1: Calculate q and G_p

Table 13: Well No.6H Field Data

Given Field Data				
Time		Monthly	Average Daily	Cumulative
Month	Days	Flow Rate	Flow Rate	
1	30	22,174	739.133333	22174
2	60	44,127	1470.9	66301
3	90	42,766	1425.53333	109067
4	120	42,256	1408.53333	151323
5	150	39,435	1314.5	190758

Step 2: Plot (q/G_p vs. time) in a Log-Log plot and find a & m

Figure 26: Well No.6H q/G_p vs. time

a	<u>2.239</u>
m	<u>1.18</u>

Step 3: Calculate $t_{(a,m)}$

$$t_{(a,m)} = t^{-m} e^{\left[\frac{a}{1-m} (t^{1-m} - 1) \right]}$$

Table 14: Well No.1 $t_{(a,m)}$

q (Mscf)	Gp (Mscf)	(q/Gp) (1/day)	$t_{(a,m)}$
739.1333	22174	0.033333333	5.374966637
1470.9	66301	0.022185186	5.232333044
1425.533	109067	0.013070253	4.930221136
1408.533	151323	0.009308125	4.642152034
1314.5	190758	0.00689093	4.387398992

Step 4: Plot q-vs. $t_{(a,m)}$ on a Cartesian graph. The straight line with the slope of q_i and intercept of q_∞ . $q = q_1 t_{(a,m)} + q_\infty$

Figure 27: Well No.6H q vs. $t_{(a,m)}$

qi	273.66
q_∞	5.313

Where: q = flow rate, volume/time

a = Vertical axis intercept of $\log \frac{q}{G_p}$ vs t

m = slope of $\log - \log \frac{q}{G_p}$ vs t

G_p = Cumulative gas production

Step 5: Gas rate forecasts can be obtained from

Table 15: Well No.6H Gp_Doung (Mscf)

Given Field Data									
Time		Flow Rate							
Month	Days	Monthly (Mscf)	Daily (Mscf/d)	Cum. Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Doung (Mscf)
1	30	22,174	739.13	22174	0.033333333	5.374966637	1517.56	45526.89	45526.89
2	60	44,127	1470.90	66301	0.022185186	5.232333044	1477.91	44337.20	89864.09
3	90	42,766	1425.53	109067	0.013070253	4.930221136	1393.91	41817.31	131681.40
4	120	42,256	1408.53	151323	0.009308125	4.642152034	1313.82	39414.56	171095.95
5	150	39,435	1314.50	190758	0.00689093	4.387398992	1242.99	37289.69	208385.64

Well No. 6H Estimated Ultimate Recovery (EUR)

The estimated ultimate recovery was calculated using decline curve analysis to predict production forecast for 20 and 30 years.

EUR (BCF) for 20 years
2.77
EUR (BCF) for 30 years
3.20

Figure 28: History Matching Well No.6H Gas Flow Rates with Duong Model

Figure 29: Comparison of the Predicted and Actual Gas Flow Rates for Well No.6H

Figure 30: Predicted Gas Flow Rates for Well No.6H by Duong Model

Figure 31: Comparison of Well No.6H Cumulative Production and Duong Model

▪ ARP's Model Calculation & Analysis for Well No.1

$$\frac{1}{q} \frac{\partial q}{\partial t} = -D \left(\frac{q}{q_i} \right)^b$$

Where: D: (nominal) Decline rate [t-1], month-1, year-1
b: Decline exponent, dimensionless, $0 \leq b \leq 1$
 q_i (q_0): Initial flow rate
q: flow rate at time t

$0 < b < 1$ **→** $\frac{1}{q} \frac{\partial q}{\partial t} = -D \left(\frac{q}{q_i} \right)^b$ **Hyperbolic Decline**

b = 0.54

Table 16: Well No.1 ARP's Model Calculations

<i>b</i>	0.54	<i>Avg-q</i>	877.2138211	<i>Avg-Gp</i>	693,066
<i>Di</i>	1.12E-03	<i>SSD</i>	591682.3414	<i>SSD</i>	76656901230
<i>qi</i>	1484.595661	<i>SST</i>	4008699.344	<i>SST</i>	3,958,698,141,616
<i>Slope</i>	1.18E-05	<i>R²</i>	85.24%	<i>R²</i>	98.06%
<i>Int.</i>	1.94E-02				

Figure 32: Arp's Model Well No.1

Figure 33: History Matching: Well No. 1 (ARPs's Model vs. Duong Models)

Figure 34: Comparison of the Predicted Gas Flow Rates for Well No.1 by Arp's and Duong Models

Chapter 4: Conclusions

- Shale production analysis utilizing traditional decline curve methods will not have an accurate production forecast due to the nature of the reservoir properties and production behavior.
- Duong model is considered simple and practical to use for predicting future forecast.
- Well no.3 has the highest EUR production forecast while well no.2 has the lowest production among the 5 wells.
- The new decline curve approaches can predict future production rates for shale gas wells under transient flow.
- Arp's models considered the value of n between 0 and 1 which can be applied for conventional reservoirs under boundary dominated flow only.
- PLE decline model is developed specifically for tight gas reservoirs to match early transient data.
- The stretched exponential decline model is more complex than other models for decline curve analysis and more difficult to apply.

References

1. Arps, J. J. (1945). Analysis of decline curves. Transactions of the AIME, 160(01), 228-247.
2. Duong, A. N. (2011, June 1). Rate-Decline Analysis for Fracture-Dominated Shale Reservoirs. SPE. doi:10.2118/137748-PA
3. El sgher, M., Aminian, K., & Ameri, S. (2018, January 23). The Impact of Stress on Propped Fracture Conductivity and Gas Recovery in Marcellus Shale. Society of Petroleum Engineers. doi:10.2118/189899-MS
4. El Sgher, M., Aminian, K., & Ameri, S. (2018, April 22). Geomechanical Impact on Gas Recovery from Marcellus Shale. Society of Petroleum Engineers. doi:10.2118/190054-MS
5. Ilk, D. et. al. 2008. Exponential vs. Hyperbolic Decline in Tight Gas Sands: Understanding the Origin and Implications for Reserve Estimates Using Arps' Decline Curves. Paper 116731-MS presented at the SPE Annual Technical Conference and Exhibition, Denver, Colorado, USA, 21-24 September 2008. DOI: 10.2118/116731-MS.
6. Joshi, K., & Lee, W. J. (2013, February 4). Comparison of Various Deterministic Forecasting Techniques in Shale Gas Reservoirs. Society of Petroleum Engineers. doi:10.2118/163870-MS
7. Seshadri, Jagan Nathan, and Louis Mattar. "Comparison of power law and modified hyperbolic decline methods." In Canadian Unconventional Resources and International Petroleum Conference. Society of Petroleum Engineers, 2010.
8. Valko, P. P., & Lee, W. J. (2010, January 1). A Better Way to Forecast Production from Unconventional GasWells. Society of Petroleum Engineers. doi:10.2118/134231-MS
9. Vanorsdale, C., 2013. Production Decline Analysis Lessons from Classic Shale Gas Wells. Paper SPE 166205 Presented at the 2013 SPE Annual Technical Conference and Exhibition, New Orleans, LA, USA, 30 September 2 October. SPE-177300-MS 31

Appendix

Well No. 1 Calculations (Duong Model)

Time		Flow Rate							
Month	Days	Mscf/Month	q (Mscf/d)	Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	58056	1935.20	58056	0.0333	2.524	1882	56474	56474
2	60	53757	1791.90	111813	0.0160	2.319	1731	51930	108404
3	90	47962	1598.73	159775	0.0100	2.133	1594	47820	156224
4	120	43370	1445.67	203145	0.0071	1.982	1483	44482	200706
5	150	42172	1405.73	245317	0.0057	1.859	1391	41737	242443
6	180	39718	1323.93	285035	0.0046	1.755	1315	39435	281878
7	210	34057	1135.23	319092	0.0036	1.666	1249	37468	319347
8	240	36048	1201.60	355140	0.0034	1.589	1192	35761	355108
9	270	33385	1112.83	388525	0.0029	1.521	1142	34261	389369
10	300	32712	1090.40	421237	0.0026	1.461	1098	32928	422296
11	330	32507	1083.57	453744	0.0024	1.407	1058	31732	454028
12	360	31938	1064.60	485682	0.0022	1.358	1022	30652	484680
13	390	31091	1036.37	516773	0.0020	1.314	989	29669	514349
14	420	29312	977.07	546085	0.0018	1.273	959	28770	543119
15	450	28978	965.93	575063	0.0017	1.236	931	27942	571062
16	480	27224	907.47	602287	0.0015	1.202	906	27178	598239
17	510	28059	935.30	630346	0.0015	1.170	882	26468	624708
18	540	27138	904.60	657484	0.0014	1.140	860	25808	650516
19	570	23676	789.20	681160	0.0012	1.112	840	25190	675706
20	600	25641	854.70	706801	0.0012	1.086	820	24612	700317
21	630	23698	789.93	730499	0.0011	1.061	802	24068	724385
22	660	23181	772.70	753680	0.0010	1.038	785	23555	747941
23	690	22711	757.03	776391	0.0010	1.016	769	23072	771012
24	720	13557	451.90	789948	0.0006	0.996	754	22614	793626
25	750	24718	823.93	814666	0.0010	0.976	739	22179	815805
26	780	23170	772.33	837836	0.0009	0.957	726	21767	837572
27	810	22370	745.67	860206	0.0009	0.940	712	21374	858946
28	840	19851	661.70	880057	0.0008	0.923	700	21000	879946
29	870	19879	662.63	899936	0.0007	0.907	688	20643	900588
30	900	19667	655.57	919603	0.0007	0.891	677	20301	920889
31	930	18131	604.37	937734	0.0006	0.876	666	19974	940864
32	960	9692	323.07	947426	0.0003	0.862	655	19661	960525

33	990	18468	615.60	965894	0.0006	0.849	645	19361	979885
34	1020	26389	879.63	992283	0.0009	0.836	636	19072	998957
35	1050	19614	653.80	1011897	0.0006	0.823	626	18794	1017751
36	1080	18682	622.73	1030579	0.0006	0.811	618	18527	1036278
37	1110	17402	580.07	1047981	0.0006	0.800	609	18270	1054548
38	1140	18456	615.20	1066437	0.0006	0.788	601	18021	1072570
39	1170	17796	593.20	1084233	0.0005	0.778	593	17782	1090352
40	1200	17819	593.97	1102052	0.0005	0.767	585	17551	1107902
41	1230	17786	592.87	1119838	0.0005	0.757	578	17327	1125229
42	1260	17191	573.03	1137029	0.0005	0.747	570	17111	1142340
43	1290	17449	581.63	1154478	0.0005	0.738	563	16901	1159241
44	1320	14965	498.83	1169443	0.0004	0.729	557	16698	1175939
45	1350	15517	517.23	1184960	0.0004	0.720	550	16502	1192441
46	1380	15034	501.13	1199994	0.0004	0.711	544	16311	1208752
47	1410	15497	516.57	1215491	0.0004	0.703	538	16126	1224878
48	1440	15564	518.80	1231055	0.0004	0.695	532	15946	1240825
49	1470	15228	507.60	1246283	0.0004	0.687	526	15772	1256597
50	1500	14806	493.53	1261089	0.0004	0.679	520	15602	1272199
51	1530	14252	475.07	1275341	0.0004	0.672	515	15437	1287636
52	1560	14863	495.43	1290204	0.0004	0.664	509	15277	1302912
53	1590	15708	523.60	1305912	0.0004	0.657	504	15120	1318033
54	1620	13326	444.20	1319238	0.0003	0.651	499	14968	1333001
55	1650	15377	512.57	1334615	0.0004	0.644	494	14820	1347820
56	1680	15286	509.53	1349901	0.0004	0.637	489	14675	1362495
57	1710	16111	537.03	1366012	0.0004	0.631	484	14534	1377030
58	1740	13951	465.03	1379963	0.0003	0.625	480	14397	1391426
59	1770	13975	465.83	1393938	0.0003	0.619	475	14262	1405688
60	1800	12817	427.23	1406755	0.0003	0.613	471	14131	1419819
61	1830	12595	419.83	1419350	0.0003	0.607	467	14003	1433823
62	1860	12957	431.90	1432307	0.0003	0.601	463	13878	1447701
63	1890	12512	417.07	1444819	0.0003	0.596	459	13756	1461457
64	1920	12833	427.77	1457652	0.0003	0.590	455	13636	1475093
65	1950	12768	425.60	1470420	0.0003	0.585	451	13520	1488612
66	1980	11468	382.27	1481888	0.0003	0.580	447	13405	1502018
67	2010	12951	431.70	1494839	0.0003	0.575	443	13293	1515311
68	2040	13154	438.47	1507993	0.0003	0.570	439	13184	1528495
69	2070	13186	439.53	1521179	0.0003	0.565	436	13077	1541571
70	2100	12946	431.53	1534125	0.0003	0.560	432	12972	1554543
71	2130	13311	443.70	1547436	0.0003	0.556	429	12869	1567412
72	2160	12993	433.10	1560429	0.0003	0.551	426	12768	1580179

73	2190	12568	418.93	1572997	0.0003	0.547	422	12669	1592848
74	2220	12885	429.50	1585882	0.0003	0.542	419	12572	1605421
75	2250	12484	416.13	1598366	0.0003	0.538	416	12477	1617898
76	2280	12511	417.03	1610877	0.0003	0.534	413	12384	1630282
77	2310	11852	395.07	1622729	0.0002	0.530	410	12293	1642574
78	2340	10063	335.43	1632792	0.0002	0.526	407	12203	1654777
79	2370	12000	400.00	1644792	0.0002	0.522	404	12115	1666892
80	2400	11469	382.30	1656261	0.0002	0.518	401	12028	1678920
81	2430	11858	395.27	1668119	0.0002	0.514	398	11943	1690863
82	2460	11731	391.03	1679850	0.0002	0.510	395	11860	1702723
83	2490	11994	399.80	1691844	0.0002	0.507	393	11778	1714501
84	2520	11661	388.70	1703505	0.0002	0.503	390	11697	1726199
85	2550	11221	374.03	1714726	0.0002	0.499	387	11618	1737817
86	2580	11637	387.90	1726363	0.0002	0.496	385	11541	1749358
87	2610	10746	358.20	1737109	0.0002	0.492	382	11464	1760822
88	2640	10886	362.87	1747995	0.0002	0.489	380	11389	1772211
89	2670	21386	712.87	1769381	0.0004	0.486	377	11315	1783526
90	2700	20962	698.73	1790343	0.0004	0.482	375	11242	1794768
91	2730	22794	759.80	1813137	0.0004	0.479	372	11171	1805939
92	2760	21550	718.33	1834687	0.0004	0.476	370	11100	1817040
93	2790	22830	761.00	1857517	0.0004	0.473	368	11031	1828071
94	2820	10674	355.80	1868191	0.0002	0.470	365	10963	1839034
95	2850	10503	350.10	1878694	0.0002	0.467	363	10896	1849929
96	2880	10111	337.03	1888805	0.0002	0.464	361	10830	1860759
97	2910	10111	337.03	1898916	0.0002	0.461	359	10765	1871524
98	2940	10951	365.03	1909867	0.0002	0.458	357	10701	1882224
99	2970	10357	345.23	1920224	0.0002	0.455	355	10637	1892862
100	3000	10025	334.17	1930249	0.0002	0.452	353	10575	1903437
101	3030	9657	321.90	1939906	0.0002	0.450	350	10514	1913951
102	3060	9270	309.00	1949176	0.0002	0.447	348	10454	1924405
103	3090	10061	335.37	1959237	0.0002	0.444	346	10394	1934799
104	3120	7703	256.77	1966940	0.0001	0.441	345	10335	1945134
105	3150	6926	230.87	1973866	0.0001	0.439	343	10278	1955412
106	3180	10142	338.07	1984008	0.0002	0.436	341	10221	1965632
107	3210	2864	95.47	1986872	0.0000	0.434	339	10164	1975797
108	3240	4619	153.97	1991491	0.0001	0.431	337	10109	1985905
109	3270	9989	332.97	2001480	0.0002	0.429	335	10054	1995960
110	3300	8405	280.17	2009885	0.0001	0.426	333	10000	2005960
111	3330	6020	200.67	2015905	0.0001	0.424	332	9947	2015907

Well No. 2 Calculations (Duong Model)

Time		Flow Rate							
Month	Days	Mscf/Month	q (Mscf/d)	Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	13662	455.40	13662	0.0333	10.3885	1167.5507	35026.5212	35026.5212
2	60	44888	1496.27	58550	0.0256	10.4560	1175.0533	35251.5991	70278.1204
3	90	38747	1291.57	97297	0.0133	9.9513	1118.9513	33568.5379	103846.6583
4	120	36641	1221.37	133938	0.0091	9.4023	1057.9188	31737.5637	135584.2219
5	150	32207	1073.57	166145	0.0065	8.8935	1001.3554	30040.6628	165624.8848
6	180	30926	1030.87	197071	0.0052	8.4375	950.6598	28519.7928	194144.6775
7	210	28869	962.30	225940	0.0043	8.0312	905.4924	27164.7728	221309.4504
8	240	24773	825.77	250713	0.0033	7.6684	865.1607	25954.8210	247264.2714
9	270	26040	868.00	276753	0.0031	7.3429	828.9722	24869.1646	272133.4360
10	300	23876	795.87	300629	0.0026	7.0492	796.3211	23889.6330	296023.0689
11	330	24049	801.63	324678	0.0025	6.7828	766.6992	23000.9774	319024.0463
12	360	22355	745.17	347033	0.0021	6.5398	739.6854	22190.5618	341214.6081
13	390	22628	754.27	369661	0.0020	6.3171	714.9310	21447.9303	362662.5384
14	420	21671	722.37	391332	0.0018	6.1121	692.1467	20764.4010	383426.9394
15	450	20383	679.43	411715	0.0017	5.9227	671.0908	20132.7250	403559.6644
16	480	20220	674.00	431935	0.0016	5.7471	651.5604	19546.8112	423106.4757
17	510	18870	629.00	450805	0.0014	5.5836	633.3836	19001.5071	442107.9828
18	540	19271	642.37	470076	0.0014	5.4309	616.4142	18492.4258	460600.4087
19	570	18656	621.87	488732	0.0013	5.2880	600.5270	18015.8086	478616.2173
20	600	16235	541.17	504967	0.0011	5.1539	585.6139	17568.4156	496184.6328
21	630	17690	589.67	522657	0.0011	5.0276	571.5813	17147.4384	513332.0713
22	660	16727	557.57	539384	0.0010	4.9086	558.3477	16750.4297	530082.5009
23	690	17156	571.87	556540	0.0010	4.7961	545.8415	16375.2460	546457.7469
24	720	15455	515.17	571995	0.0009	4.6896	534.0000	16020.0014	562477.7483
25	750	9025	300.83	581020	0.0005	4.5885	522.7676	15683.0290	578160.7773
26	780	17522	584.07	598542	0.0010	4.4925	512.0950	15362.8498	593523.6271
27	810	15542	518.07	614084	0.0008	4.4012	501.9382	15058.1460	608581.7731
28	840	16045	534.83	630129	0.0008	4.3141	492.2580	14767.7395	623349.5125
29	870	15087	502.90	645216	0.0008	4.2310	483.0191	14490.5734	637840.0859
30	900	15673	522.43	660889	0.0008	4.1516	474.1899	14225.6963	652065.7823
31	930	15,215	507.17	676104	0.0008	4.0756	465.7417	13972.2496	666038.0318
32	960	13,311	443.70	689415	0.0006	4.0028	457.6485	13729.4555	679767.4874
33	990	10,199	339.97	699614	0.0005	3.9330	449.8869	13496.6083	693264.0957
34	1020	10,204	340.13	709818	0.0005	3.8659	442.4355	13273.0655	706537.1611

35	1050	10,721	357.37	720539	0.0005	3.8015	435.2747	13058.2407	719595.4019
36	1080	11,510	383.67	732049	0.0005	3.7396	428.3866	12851.5981	732447.0000
37	1110	12,280	409.33	744329	0.0005	3.6799	421.7549	12652.6461	745099.6461
38	1140	11,711	390.37	756040	0.0005	3.6224	415.3645	12460.9336	757560.5797
39	1170	11,076	369.20	767116	0.0005	3.5670	409.2015	12276.0452	769836.6249
40	1200	11,404	380.13	778520	0.0005	3.5135	403.2533	12097.5979	781934.2228
41	1230	10,900	363.33	789420	0.0005	3.4618	397.5079	11925.2380	793859.4608
42	1260	11,100	370.00	800520	0.0005	3.4118	391.9546	11758.6382	805618.0990
43	1290	10,443	348.10	810963	0.0004	3.3635	386.5832	11597.4951	817215.5940
44	1320	9,999	333.30	820962	0.0004	3.3168	381.3842	11441.5269	828657.1210
45	1350	11,114	370.47	832076	0.0004	3.2715	376.3491	11290.4719	839947.5929
46	1380	9,934	331.13	842010	0.0004	3.2276	371.4695	11144.0861	851091.6790
47	1410	10,182	339.40	852192	0.0004	3.1850	366.7381	11002.1422	862093.8212
48	1440	9,791	326.37	861983	0.0004	3.1437	362.1476	10864.4278	872958.2490
49	1470	10,037	334.57	872020	0.0004	3.1036	357.6915	10730.7444	883688.9934
50	1500	9,934	331.13	881954	0.0004	3.0647	353.3635	10600.9062	894289.8997
51	1530	9,527	317.57	891481	0.0004	3.0269	349.1580	10474.7391	904764.6388
52	1560	9,679	322.63	901160	0.0004	2.9901	345.0693	10352.0795	915116.7183
53	1590	9,237	307.90	910397	0.0003	2.9543	341.0925	10232.7741	925349.4924
54	1620	9,581	319.37	919978	0.0003	2.9195	337.2226	10116.6783	935466.1707
55	1650	9,533	317.77	929511	0.0003	2.8856	333.4552	10003.6564	945469.8270
56	1680	8,632	287.73	938143	0.0003	2.8526	329.7860	9893.5802	955363.4072
57	1710	9,691	323.03	947834	0.0003	2.8205	326.2110	9786.3289	965149.7361
58	1740	9,387	312.90	957221	0.0003	2.7891	322.7263	9681.7885	974831.5246
59	1770	9,792	326.40	967013	0.0003	2.7586	319.3284	9579.8512	984411.3758
60	1800	9,027	300.90	976040	0.0003	2.7287	316.0138	9480.4151	993891.7909
61	1830	9,390	313.00	985430	0.0003	2.6996	312.7795	9383.3836	1003275.1745
62	1860	9,374	312.47	994804	0.0003	2.6712	309.6222	9288.6654	1012563.8399
63	1890	9,025	300.83	1003829	0.0003	2.6435	306.5391	9196.1737	1021760.0136
64	1920	9,180	306.00	1013009	0.0003	2.6164	303.5275	9105.8262	1030865.8398
65	1950	8,799	293.30	1021808	0.0003	2.5900	300.5848	9017.5449	1039883.3846
66	1980	8,849	294.97	1030657	0.0003	2.5641	297.7085	8931.2554	1048814.6401
67	2010	8,511	283.70	1039168	0.0003	2.5388	294.8962	8846.8873	1057661.5274
68	2040	7,665	255.50	1046833	0.0002	2.5140	292.1458	8764.3732	1066425.9006
69	2070	8,705	290.17	1055538	0.0003	2.4898	289.4550	8683.6492	1075109.5497
70	2100	8,402	280.07	1063940	0.0003	2.4661	286.8218	8604.6542	1083714.2040
71	2130	8,088	269.60	1072028	0.0003	2.4430	284.2443	8527.3302	1092241.5342
72	2160	8,275	275.83	1080303	0.0003	2.4203	281.7207	8451.6216	1100693.1559
73	2190	8,685	289.50	1088988	0.0003	2.3980	279.2492	8377.4755	1109070.6314
74	2220	8,422	280.73	1097410	0.0003	2.3763	276.8280	8304.8412	1117375.4726

75	2250	7,936	264.53	1105346	0.0002	2.3549	274.4557	8233.6704	1125609.1431
76	2280	8,090	269.67	1113436	0.0002	2.3340	272.1306	8163.9168	1133773.0599
77	2310	7,675	255.83	1121111	0.0002	2.3135	269.8512	8095.5361	1141868.5960
78	2340	7,652	255.07	1128763	0.0002	2.2934	267.6162	8028.4859	1149897.0819
79	2370	7,439	247.97	1136202	0.0002	2.2737	265.4242	7962.7257	1157859.8076
80	2400	6,462	215.40	1142664	0.0002	2.2543	263.2739	7898.2164	1165758.0240
81	2430	7,867	262.23	1150531	0.0002	2.2354	261.1640	7834.9208	1173592.9449
82	2460	7,713	257.10	1158244	0.0002	2.2167	259.0934	7772.8032	1181365.7480
83	2490	8,128	270.93	1166372	0.0002	2.1984	257.0610	7711.8290	1189077.5770
84	2520	7,740	258.00	1174112	0.0002	2.1805	255.0655	7651.9653	1196729.5423
85	2550	7,846	261.53	1181958	0.0002	2.1629	253.1060	7593.1805	1204322.7229
86	2580	7,662	255.40	1189620	0.0002	2.1456	251.1815	7535.4440	1211858.1669
87	2610	7,270	242.33	1196890	0.0002	2.1285	249.2909	7478.7266	1219336.8936
88	2640	7,449	248.30	1204339	0.0002	2.1118	247.4333	7423.0001	1226759.8937
89	2670	6,966	232.20	1211305	0.0002	2.0954	245.6079	7368.2374	1234128.1311
90	2700	7,369	245.63	1218674	0.0002	2.0793	243.8137	7314.4123	1241442.5433
91	2730	14,248	474.93	1232922	0.0004	2.0634	242.0500	7261.4997	1248704.0430
92	2760	13,208	440.27	1246130	0.0004	2.0478	240.3158	7209.4754	1255913.5185
93	2790	14,394	479.80	1260524	0.0004	2.0325	238.6105	7158.3161	1263071.8346
94	2820	13,534	451.13	1274058	0.0004	2.0174	236.9333	7107.9992	1270179.8338
95	2850	14,438	481.27	1288496	0.0004	2.0025	235.2834	7058.5030	1277238.3368
96	2880	7,017	233.90	1295513	0.0002	1.9879	233.6602	7009.8066	1284248.1434
97	2910	7,049	234.97	1302562	0.0002	1.9736	232.0630	6961.8897	1291210.0331
98	2940	6,638	221.27	1309200	0.0002	1.9594	230.4911	6914.7329	1298124.7660
99	2970	6,458	215.27	1315658	0.0002	1.9455	228.9439	6868.3172	1304993.0833
100	3000	6,886	229.53	1322544	0.0002	1.9318	227.4208	6822.6245	1311815.7077
101	3030	6,889	229.63	1329433	0.0002	1.9183	225.9212	6777.6371	1318593.3448
102	3060	6,785	226.17	1336218	0.0002	1.9051	224.4446	6733.3380	1325326.6828
103	3090	6,536	217.87	1342754	0.0002	1.8920	222.9904	6689.7107	1332016.3934
104	3120	6,111	203.70	1348865	0.0002	1.8791	221.5580	6646.7393	1338663.1327
105	3150	6,628	220.93	1355493	0.0002	1.8664	220.1469	6604.4084	1345267.5411
106	3180	5,820	194.00	1361313	0.0001	1.8539	218.7568	6562.7030	1351830.2441
107	3210	4,844	161.47	1366157	0.0001	1.8416	217.3870	6521.6088	1358351.8529
108	3240	2,578	85.93	1368735	0.0001	1.8294	216.0371	6481.1117	1364832.9646
109	3270	1,009	33.63	1369744	0.0000	1.8175	214.7066	6441.1981	1371274.1627
110	3300	7,538	251.27	1377282	0.0002	1.8057	213.3952	6401.8550	1377676.0177
111	3330	6,780	226.00	1384062	0.0002	1.7940	212.1023	6363.0695	1384039.0872
112	3360	5,067	168.90	1389129	0.0001	1.7826	210.8276	6324.8294	1390363.9166

Well No. 3 Calculations (Duong Model)

Time		Flow Rate							
Month	Days	Mscf/Month	q (Mscf/d)	Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	139490	4650	139490	0.0333	3.62	5163.02	154890.52	154890.52
2	60	156342	5211	295832	0.0176	3.23	4615.54	138466.19	293356.72
3	90	143525	4784	439357	0.0109	2.90	4141.83	124254.79	417611.50
4	120	123918	4131	563275	0.0073	2.64	3769.42	113082.54	530694.05
5	150	116830	3894	680105	0.0057	2.43	3471.28	104138.53	634832.58
6	180	98102	3270	778207	0.0042	2.25	3226.68	96800.36	731632.94
7	210	88543	2951	866750	0.0034	2.11	3021.64	90649.30	822282.23
8	240	60454	2015	927204	0.0022	1.98	2846.70	85401.10	907683.33
9	270	46030	1534	973234	0.0016	1.88	2695.24	80857.24	988540.56
10	300	58339	1945	1031573	0.0019	1.78	2562.50	76874.93	1065415.50
11	330	52154	1738	1083727	0.0016	1.70	2444.96	73348.71	1138764.21
12	360	48045	1602	1131772	0.0014	1.63	2339.96	70198.82	1208963.02
13	390	41601	1387	1173373	0.0012	1.56	2245.46	67363.70	1276326.72
14	420	41623	1387	1214996	0.0011	1.50	2159.83	64795.01	1341121.73
15	450	62059	2069	1277055	0.0016	1.44	2081.81	62454.18	1403575.91
16	480	59340	1978	1336395	0.0015	1.39	2010.33	60310.00	1463885.91
17	510	46266	1542	1382661	0.0011	1.35	1944.56	58336.93	1522222.84
18	540	49801	1660	1432462	0.0012	1.30	1883.79	56513.84	1578736.68
19	570	36184	1206	1468646	0.0008	1.26	1827.43	54823.04	1633559.72
20	600	38899	1297	1507545	0.0009	1.23	1774.99	53249.66	1686809.38
21	630	59044	1968	1566589	0.0013	1.19	1726.03	51781.02	1738590.40
22	660	27573	919	1594162	0.0006	1.16	1680.21	50406.29	1788996.69
23	690	49524	1651	1643686	0.0010	1.13	1637.20	49116.14	1838112.83
24	720	62830	2094	1706516	0.0012	1.10	1596.75	47902.48	1886015.31
25	750	66977	2233	1773493	0.0013	1.07	1558.61	46758.24	1932773.55
26	780	57594	1920	1831087	0.0010	1.05	1522.57	45677.24	1978450.79
27	810	57390	1913	1888477	0.0010	1.02	1488.47	44654.05	2023104.84
28	840	49702	1657	1938179	0.0009	1.00	1456.13	43683.84	2066788.69
29	870	48909	1630	1987088	0.0008	0.98	1425.41	42762.35	2109551.04
30	900	49114	1637	2036202	0.0008	0.96	1396.19	41885.76	2151436.80
31	930	44564	1485	2080766	0.0007	0.94	1368.36	41050.66	2192487.46
32	960	44412	1480	2125178	0.0007	0.92	1341.80	40253.99	2232741.45
33	990	51766	1726	2176944	0.0008	0.90	1316.43	39492.99	2272234.44

34	1020	49955	1665	2226899	0.0007	0.88	1292.17	38765.18	2310999.62
35	1050	47995	1600	2274894	0.0007	0.87	1268.94	38068.30	2349067.92
36	1080	43215	1441	2318109	0.0006	0.85	1246.68	37400.29	2386468.21
37	1110	42290	1410	2360399	0.0006	0.84	1225.31	36759.30	2423227.51
38	1140	38981	1299	2399380	0.0005	0.82	1204.79	36143.61	2459371.12
39	1170	38422	1281	2437802	0.0005	0.81	1185.06	35551.68	2494922.80
40	1200	38034	1268	2475836	0.0005	0.80	1166.07	34982.07	2529904.88
41	1230	32816	1094	2508652	0.0004	0.78	1147.78	34433.47	2564338.35
42	1260	35300	1177	2543952	0.0005	0.77	1130.16	33904.68	2598243.03
43	1290	34784	1159	2578736	0.0004	0.76	1113.15	33394.57	2631637.60
44	1320	34740	1158	2613476	0.0004	0.75	1096.74	32902.12	2664539.72
45	1350	33608	1120	2647084	0.0004	0.74	1080.88	32426.37	2696966.09
46	1380	29345	978	2676429	0.0004	0.72	1065.55	31966.45	2728932.54
47	1410	30133	1004	2706562	0.0004	0.71	1050.72	31521.53	2760454.07
48	1440	29324	977	2735886	0.0004	0.70	1036.36	31090.85	2791544.92
49	1470	30641	1021	2766527	0.0004	0.69	1022.46	30673.69	2822218.61
50	1500	28732	958	2795259	0.0003	0.68	1008.98	30269.41	2852488.01
51	1530	28764	959	2824023	0.0003	0.68	995.91	29877.37	2882365.38
52	1560	27657	922	2851680	0.0003	0.67	983.23	29497.00	2911862.38
53	1590	27322	911	2879002	0.0003	0.66	970.93	29127.76	2940990.13
54	1620	25858	862	2904860	0.0003	0.65	958.97	28769.14	2969759.27
55	1650	25081	836	2929941	0.0003	0.64	947.36	28420.66	2998179.93
56	1680	25429	848	2955370	0.0003	0.63	936.06	28081.89	3026261.82
57	1710	25652	855	2981022	0.0003	0.63	925.08	27752.39	3054014.22
58	1740	23435	781	3004457	0.0003	0.62	914.39	27431.78	3081445.99
59	1770	26241	875	3030698	0.0003	0.61	903.99	27119.67	3108565.67
60	1800	25197	840	3055895	0.0003	0.60	893.86	26815.72	3135381.39
61	1830	23809	794	3079704	0.0003	0.60	883.99	26519.60	3161900.99
62	1860	17956	599	3097660	0.0002	0.59	874.37	26230.99	3188131.98
63	1890	24069	802	3121729	0.0003	0.58	864.99	25949.60	3214081.58
64	1920	23127	771	3144856	0.0002	0.58	855.84	25675.14	3239756.72
65	1950	20766	692	3165622	0.0002	0.57	846.91	25407.35	3265164.06
66	1980	23203	773	3188825	0.0002	0.56	838.20	25145.97	3290310.04
67	2010	21304	710	3210129	0.0002	0.56	829.69	24890.77	3315200.81
68	2040	23006	767	3233135	0.0002	0.55	821.38	24641.53	3339842.33
69	2070	25986	866	3259121	0.0003	0.55	813.27	24398.01	3364240.35
70	2100	19497	650	3278618	0.0002	0.54	805.33	24160.03	3388400.37
71	2130	20433	681	3299051	0.0002	0.54	797.58	23927.38	3412327.75
72	2160	18257	609	3317308	0.0002	0.53	790.00	23699.87	3436027.62
73	2190	16958	565	3334266	0.0002	0.52	782.58	23477.34	3459504.97

74	2220	19084	636	3353350	0.0002	0.52	775.32	23259.61	3482764.58
75	2250	21110	704	3374460	0.0002	0.51	768.22	23046.52	3505811.10
76	2280	20551	685	3395011	0.0002	0.51	761.26	22837.92	3528649.02
77	2310	18159	605	3413170	0.0002	0.50	754.46	22633.65	3551282.67
78	2340	20413	680	3433583	0.0002	0.50	747.79	22433.59	3573716.26
79	2370	18643	621	3452226	0.0002	0.50	741.25	22237.59	3595953.85
80	2400	17841	595	3470067	0.0002	0.49	734.85	22045.53	3617999.39
81	2430	17827	594	3487894	0.0002	0.49	728.58	21857.28	3639856.67
82	2460	16309	544	3504203	0.0002	0.48	722.42	21672.73	3661529.40
83	2490	20280	676	3524483	0.0002	0.48	716.39	21491.77	3683021.17
84	2520	21320	711	3545803	0.0002	0.47	710.48	21314.28	3704335.45
85	2550	18637	621	3564440	0.0002	0.47	704.67	21140.16	3725475.60
86	2580	17431	581	3581871	0.0002	0.47	698.98	20969.31	3746444.91
87	2610	15456	515	3597327	0.0001	0.46	693.39	20801.64	3767246.55
88	2640	14987	500	3612314	0.0001	0.46	687.90	20637.05	3787883.61
89	2670	14257	475	3626571	0.0001	0.45	682.52	20475.46	3808359.07
90	2700	13557	452	3640128	0.0001	0.45	677.23	20316.79	3828675.86
91	2730	13851	462	3653979	0.0001	0.45	672.03	20160.94	3848836.80
92	2760	16898	563	3670877	0.0002	0.44	666.93	20007.85	3868844.65
93	2790	15711	524	3686588	0.0001	0.44	661.91	19857.43	3888702.09
94	2820	17055	569	3703643	0.0002	0.44	656.99	19709.62	3908411.71
95	2850	13931	464	3717574	0.0001	0.43	652.14	19564.34	3927976.05
96	2880	14271	476	3731845	0.0001	0.43	647.38	19421.53	3947397.58
97	2910	13153	438	3744998	0.0001	0.43	642.70	19281.12	3966678.71
98	2940	11133	371	3756131	0.0001	0.42	638.10	19143.05	3985821.76
99	2970	14595	487	3770726	0.0001	0.42	633.58	19007.26	4004829.02
100	3000	13221	441	3783947	0.0001	0.42	629.12	18873.69	4023702.71
101	3030	12720	424	3796667	0.0001	0.41	624.74	18742.28	4042444.99
102	3060	15617	521	3812284	0.0001	0.41	620.43	18612.98	4061057.97
103	3090	15921	531	3828205	0.0001	0.41	616.19	18485.74	4079543.72
104	3120	14757	492	3842962	0.0001	0.40	612.02	18360.51	4097904.23
105	3150	13796	460	3856758	0.0001	0.40	607.91	18237.23	4116141.46
106	3180	13553	452	3870311	0.0001	0.40	603.86	18115.87	4134257.33
107	3210	13822	461	3884133	0.0001	0.40	599.88	17996.36	4152253.69
108	3240	14266	476	3898399	0.0001	0.39	595.96	17878.68	4170132.37
109	3270	14104	470	3912503	0.0001	0.39	592.09	17762.77	4187895.14
110	3300	15514	517	3928017	0.0001	0.39	588.29	17648.60	4205543.74
111	3330	16713	557	3944730	0.0001	0.38	584.54	17536.12	4223079.86
112	3360	16966	566	3961696	0.0001	0.38	580.84	17425.30	4240505.16
113	3390	17365	579	3979061	0.0001	0.38	577.20	17316.10	4257821.26

114	3420	15965	532	3995026	0.0001	0.38	573.62	17208.48	4275029.73
115	3450	16133	538	4011159	0.0001	0.37	570.08	17102.40	4292132.13
116	3450	16133	538	4027292	0.0001	0.37	570.08	17102.40	4309234.53
117	3450	16133	538	4043425	0.0001	0.37	570.08	17102.40	4326336.93
118	3450	16133	538	4059558	0.0001	0.37	570.08	17102.40	4343439.33
119	3450	16133	538	4075691	0.0001	0.37	570.08	17102.40	4360541.73
120	3450	16133	538	4091824	0.0001	0.37	570.08	17102.40	4377644.13
121	3450	16133	538	4107957	0.0001	0.37	570.08	17102.40	4394746.53
122	3450	16133	538	4124090	0.0001	0.37	570.08	17102.40	4411848.92
123	3450	16133	538	4140223	0.0001	0.37	570.08	17102.40	4428951.32

Well No. 4H Calculations (Duong Model)

Time		Flow Rate							
Month	Days	Mscf/Month	q (Mscf/d)	Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	37,032	1234.40	37032	0.0333	13.8020	2437.90	73136.92	73136.92
2	60	82,849	2761.63	119881	0.0230	14.3221	2528.03	75840.84	148977.76
3	90	77,704	2590.13	197585	0.0131	13.8373	2444.02	73320.51	222298.27
4	120	76,042	2534.73	273627	0.0093	13.1994	2333.47	70004.20	292302.47
5	150	71,697	2389.90	345324	0.0069	12.5706	2224.51	66735.23	359037.70
6	180	68,230	2274.33	413554	0.0055	11.9884	2123.62	63708.65	422746.36
7	210	65,162	2172.07	478716	0.0045	11.4588	2031.85	60955.62	483701.98
8	240	61,609	2053.63	540325	0.0038	10.9789	1948.70	58460.94	542162.92
9	270	64,212	2140.40	604537	0.0035	10.5436	1873.25	56197.52	598360.44
10	300	57,347	1911.57	661884	0.0029	10.1473	1804.58	54137.32	652497.75
11	330	56,201	1873.37	718085	0.0026	9.7852	1741.83	52254.78	704752.53
12	360	52,352	1745.07	770437	0.0023	9.4529	1684.25	50527.63	755280.16
13	390	51,359	1711.97	821796	0.0021	9.1469	1631.23	48936.79	804216.95
14	420	49,412	1647.07	871208	0.0019	8.8640	1582.20	47466.03	851682.97
15	450	43,644	1454.80	914852	0.0016	8.6015	1536.72	46101.51	897784.48
16	480	45,445	1514.83	960297	0.0016	8.3572	1494.38	44831.45	942615.93
17	510	43,723	1457.43	1004020	0.0015	8.1292	1454.86	43645.74	986261.67
18	540	43,848	1461.60	1047868	0.0014	7.9156	1417.86	42535.68	1028797.35
19	570	41,271	1375.70	1089139	0.0013	7.7152	1383.13	41493.75	1070291.10
20	600	41,481	1382.70	1130620	0.0012	7.5266	1350.45	40513.43	1110804.54
21	630	40,164	1338.80	1170784	0.0011	7.3488	1319.63	39589.01	1150393.55
22	660	38,148	1271.60	1208932	0.0011	7.1808	1290.52	38715.50	1189109.05
23	690	38,605	1286.83	1247537	0.0010	7.0217	1262.95	37888.49	1226997.54
24	720	36,131	1204.37	1283668	0.0009	6.8708	1236.80	37104.10	1264101.64
25	750	36,390	1213.00	1320058	0.0009	6.7275	1211.96	36358.86	1300460.50
26	780	32,047	1068.23	1352105	0.0008	6.5911	1188.32	35649.71	1336110.21
27	810	31,288	1042.93	1383393	0.0008	6.4611	1165.80	34973.88	1371084.09
28	840	34,027	1134.23	1417420	0.0008	6.3370	1144.30	34328.91	1405413.00
29	870	32,340	1078.00	1449760	0.0007	6.2185	1123.75	33712.58	1439125.58
30	900	32,546	1084.87	1482306	0.0007	6.1050	1104.10	33122.88	1472248.46
31	930	30,729	1024.30	1513035	0.0007	5.9964	1085.27	32558.00	1504806.46
32	960	31,050	1035.00	1544085	0.0007	5.8922	1067.21	32016.28	1536822.74
33	990	30,303	1010.10	1574388	0.0006	5.7921	1049.87	31496.24	1568318.98

34	1020	28,372	945.73	1602760	0.0006	5.6960	1033.22	30996.49	1599315.47
35	1050	29,436	981.20	1632196	0.0006	5.6035	1017.19	30515.79	1629831.25
36	1080	21,991	733.03	1654187	0.0004	5.5145	1001.77	30052.99	1659884.24
37	1110	29,717	990.57	1683904	0.0006	5.4287	986.90	29607.04	1689491.27
38	1140	26,858	895.27	1710762	0.0005	5.3460	972.57	29176.96	1718668.24
39	1170	22,476	749.20	1733238	0.0004	5.2662	958.73	28761.88	1747430.12
40	1200	25,492	849.73	1758730	0.0005	5.1890	945.37	28360.96	1775791.08
41	1230	22,674	755.80	1781404	0.0004	5.1145	932.45	27973.44	1803764.52
42	1260	21,505	716.83	1802909	0.0004	5.0424	919.95	27598.61	1831363.13
43	1290	24,698	823.27	1827607	0.0005	4.9726	907.86	27235.82	1858598.94
44	1320	24,466	815.53	1852073	0.0004	4.9050	896.15	26884.45	1885483.39
45	1350	22,864	762.13	1874937	0.0004	4.8395	884.80	26543.94	1912027.33
46	1380	22,315	743.83	1897252	0.0004	4.7760	873.79	26213.76	1938241.08
47	1410	19,978	665.93	1917230	0.0003	4.7144	863.11	25893.41	1964134.49
48	1440	24,971	832.37	1942201	0.0004	4.6546	852.75	25582.43	1989716.92
49	1470	9,322	310.73	1951523	0.0002	4.5965	842.68	25280.40	2014997.32
50	1500	23,565	785.50	1975088	0.0004	4.5400	832.90	24986.89	2039984.21
51	1530	48,351	1611.70	2023439	0.0008	4.4851	823.38	24701.54	2064685.75
52	1560	37,557	1251.90	2060996	0.0006	4.4317	814.13	24423.99	2089109.74
53	1590	31,858	1061.93	2092854	0.0005	4.3798	805.13	24153.89	2113263.63
54	1620	26,764	892.13	2119618	0.0004	4.3292	796.36	23890.94	2137154.58
55	1650	25,562	852.07	2145180	0.0004	4.2799	787.83	23634.84	2160789.41
56	1680	25,062	835.40	2170242	0.0004	4.2319	779.51	23385.30	2184174.71
57	1710	14,130	471.00	2184372	0.0002	4.1852	771.40	23142.06	2207316.78
58	1740	44,225	1474.17	2228597	0.0007	4.1395	763.50	22904.87	2230221.65
59	1770	32,789	1092.97	2261386	0.0005	4.0950	755.78	22673.49	2252895.14
60	1800	25,795	859.83	2287181	0.0004	4.0516	748.26	22447.70	2275342.84
61	1830	23,834	794.47	2311015	0.0003	4.0092	740.91	22227.29	2297570.13
62	1860	20,447	681.57	2331462	0.0003	3.9678	733.73	22012.05	2319582.18
63	1890	22,173	739.10	2353635	0.0003	3.9273	726.73	21801.79	2341383.96
64	1920	18,936	631.20	2372571	0.0003	3.8878	719.88	21596.33	2362980.29
65	1950	19,175	639.17	2391746	0.0003	3.8492	713.18	21395.50	2384375.79
66	1980	18,126	604.20	2409872	0.0003	3.8114	706.64	21199.13	2405574.93
67	2010	20,781	692.70	2430653	0.0003	3.7745	700.24	21007.08	2426582.00
68	2040	20,785	692.83	2451438	0.0003	3.7383	693.97	20819.18	2447401.18
69	2070	16,646	554.87	2468084	0.0002	3.7030	687.84	20635.30	2468036.48

Well No. 6H Calculations (Duong Model)

Time		Flow Rate							
Month	Days	Mscf/Month	q (Mscf/d)	Gp (Mscf)	(q/Gp) (1/day)	t(a,m)	q-Duong (Mscf/d)	q-Duong (Mscf/m)	Gp_Duong (Mscf)
1	30	22,174	739.13	22174	0.0333	5.3750	1476.23	44286.79	44286.79
2	60	44,127	1470.90	66301	0.0222	5.2323	1437.19	43115.80	87402.59
3	90	42,766	1425.53	109067	0.0131	4.9302	1354.52	40635.52	128038.11
4	120	42,256	1408.53	151323	0.0093	4.6422	1275.68	38270.53	166308.64
5	150	39,435	1314.50	190758	0.0069	4.3874	1205.97	36179.06	202487.70
6	180	34,535	1151.17	225293	0.0051	4.1643	1144.93	34347.87	236835.56
7	210	28,721	957.37	254014	0.0038	3.9683	1091.27	32738.21	269573.78
8	240	28,523	950.77	282537	0.0034	3.7947	1043.76	31312.89	300886.67
9	270	34,379	1145.97	316916	0.0036	3.6397	1001.36	30040.92	330927.58
10	300	28,047	934.90	344963	0.0027	3.5005	963.25	28897.39	359824.97
11	330	23,798	793.27	368761	0.0022	3.3744	928.75	27862.39	387687.35
12	360	26,677	889.23	395438	0.0022	3.2596	897.33	26919.93	414607.29
13	390	29,117	970.57	424555	0.0023	3.1545	868.57	26057.09	440664.38
14	420	24,991	833.03	449546	0.0019	3.0578	842.11	25263.29	465927.67
15	450	23,080	769.33	472626	0.0016	2.9685	817.66	24529.80	490457.47
16	480	24,152	805.07	496778	0.0016	2.8856	794.98	23849.38	514306.85
17	510	22,149	738.30	518927	0.0014	2.8084	773.86	23215.92	537522.77
18	540	22,123	737.43	541050	0.0014	2.7364	754.14	22624.28	560147.05
19	570	20,913	697.10	561963	0.0012	2.6688	735.67	22070.05	582217.10
20	600	19,196	639.87	581159	0.0011	2.6054	718.32	21549.47	603766.57
21	630	18,394	613.13	599553	0.0010	2.5457	701.98	21059.27	624825.84
22	660	19,508	650.27	619061	0.0011	2.4894	686.55	20596.62	645422.46
23	690	19,220	640.67	638281	0.0010	2.4361	671.97	20159.04	665581.50
24	720	17,947	598.23	656228	0.0009	2.3856	658.15	19744.37	685325.87
25	750	17,785	592.83	674013	0.0009	2.3376	645.02	19350.67	704676.54
26	780	14,647	488.23	688660	0.0007	2.2920	632.54	18976.26	723652.80
27	810	15,460	515.33	704120	0.0007	2.2486	620.65	18619.62	742272.43
28	840	17,141	571.37	721261	0.0008	2.2071	609.31	18279.41	760551.83
29	870	15,846	528.20	737107	0.0007	2.1675	598.48	17954.40	778506.23
30	900	15,310	510.33	752417	0.0007	2.1297	588.12	17643.50	796149.73
31	930	14,422	480.73	766839	0.0006	2.0934	578.19	17345.75	813495.48
32	960	14,126	470.87	780965	0.0006	2.0586	568.67	17060.24	830555.73
33	990	13,042	434.73	794007	0.0005	2.0252	559.54	16786.18	847341.90

34	1020	12,835	427.83	806842	0.0005	1.9932	550.76	16522.82	863864.72
35	1050	13,497	449.90	820339	0.0005	1.9623	542.32	16269.49	880134.22
36	1080	13,073	435.77	833412	0.0005	1.9326	534.19	16025.59	896159.81
37	1110	13,139	437.97	846551	0.0005	1.9040	526.35	15790.55	911950.36
38	1140	12,893	429.77	859444	0.0005	1.8764	518.80	15563.86	927514.22
39	1170	11,840	394.67	871284	0.0005	1.8497	511.50	15345.04	942859.26
40	1200	12,899	429.97	884183	0.0005	1.8239	504.45	15133.65	957992.90
41	1230	10,913	363.77	895096	0.0004	1.7991	497.64	14929.29	972922.19
42	1260	9,747	324.90	904843	0.0004	1.7750	491.05	14731.58	987653.77
43	1290	13,496	449.87	918339	0.0005	1.7517	484.67	14540.18	1002193.95
44	1320	12,613	420.43	930952	0.0005	1.7291	478.49	14354.77	1016548.72
45	1350	13,379	445.97	944331	0.0005	1.7072	472.50	14175.04	1030723.77
46	1380	11,384	379.47	955715	0.0004	1.6860	466.69	14000.73	1044724.49
47	1410	9,501	316.70	965216	0.0003	1.6653	461.05	13831.55	1058556.05
48	1440	5,899	196.63	971115	0.0002	1.6453	455.58	13667.28	1072223.33
49	1470	4,629	154.30	975744	0.0002	1.6259	450.26	13507.69	1085731.02
50	1500	17,258	575.27	993002	0.0006	1.6070	445.09	13352.56	1099083.58
51	1530	32,735	1091.17	1025737	0.0011	1.5886	440.06	13201.70	1112285.28
52	1560	20,991	699.70	1046728	0.0007	1.5707	435.16	13054.91	1125340.18
53	1590	18,693	623.10	1065421	0.0006	1.5533	430.40	12912.02	1138252.20
54	1620	15,782	526.07	1081203	0.0005	1.5364	425.76	12772.86	1151025.06
55	1650	14,791	493.03	1095994	0.0004	1.5199	421.24	12637.29	1163662.35
56	1680	12,137	404.57	1108131	0.0004	1.5038	416.84	12505.14	1176167.49
57	1710	5,851	195.03	1113982	0.0002	1.4881	412.54	12376.29	1188543.78
58	1740	18,065	602.17	1132047	0.0005	1.4728	408.35	12250.60	1200794.37
59	1770	17,102	570.07	1149149	0.0005	1.4578	404.26	12127.94	1212922.32
60	1800	11,324	377.47	1160473	0.0003	1.4433	400.27	12008.21	1224930.53
61	1830	13,923	464.10	1174396	0.0004	1.4290	396.38	11891.29	1236821.82
62	1860	12,071	402.37	1186467	0.0003	1.4151	392.57	11777.07	1248598.89
63	1890	13,287	442.90	1199754	0.0004	1.4015	388.85	11665.46	1260264.35
64	1920	9,908	330.27	1209662	0.0003	1.3882	385.21	11556.35	1271820.70
65	1950	14,412	480.40	1224074	0.0004	1.3752	381.66	11449.67	1283270.37
66	1980	10,569	352.30	1234643	0.0003	1.3625	378.18	11345.32	1294615.68
67	2010	11,837	394.57	1246480	0.0003	1.3501	374.77	11243.22	1305858.90
68	2040	14,078	469.27	1260558	0.0004	1.3379	371.44	11143.29	1317002.20
69	2070	7,603	253.43	1268161	0.0002	1.3260	368.18	11045.47	1328047.67

Well No. 1 Calculations (ARP's Model)

	Field	q ^{a-b}	q-ARPs	SD-q	ST-q	Gp-ARPs	SD-Gp	ST-Gp
(DAYS)	q (MSCF/DAY)							
30	1935	0.017507	1389.494	161930.5	836650.8	84759.82	731874680. 3	3.70036E+11
60	1792	0.018619	1345.419	64168.32	520590.4	125122.4	1200804243	3.2256E+11
90	1599	0.019659	1303.46	20222.74	323138.6	164226.2	1514674767	2.79671E+11
120	1446	0.019959	1263.483	20235.14	279332.9	202130.7	1865059221	2.41017E+11
150	1406	0.020615	1225.363	9716.016	199558.3	238891.6	2,129,215,8 55	206,274,258,7 47
180	1324	0.0224	1188.987	2889.415	66574.07	274561.2	1,982,994,7 10	175,146,152,1 93
210	1135	0.021723	1154.247	2242.352	105226.4	309188.6	2111534205	1.47362E+11
240	1202	0.022643	1121.045	67.43633	55516.55	342819.9	2088953810	1.22672E+11
270	1113	0.022893	1089.292	1.227059	45448.35	375498.7	2091992639	1.00849E+11
300	1090	0.022971	1058.903	608.2758	42581.5	407265.8	2160223396	81681661026
330	1084	0.023191	1029.801	1210.988	35113.58	438159.8	2258357672	64977076062
360	1065	0.02353	1001.912	1187.136	25329.63	468217.2	2357668242	50556919622
390	1036	0.024291	975.1693	3.600169	9970.591	497472.3	2363199304	38256849203
420	977	0.024442	949.5103	269.7159	7871.152	525957.6	2411344167	27925174776
450	966	0.02528	924.8765	303.1021	915.2347	553703.9	2360321923	19421760847
480	907	0.024871	901.2133	1161.905	3374.004	580740.3	2460730046	12617035795
510	935	0.025323	878.4697	682.7923	750.0028	607094.3	2539117327	7391096799
540	905	0.02726	856.5982	4542.511	7746.433	632792.3	2339435411	3632900076
570	789	0.026111	835.5541	366.567	506.8721	657858.9	2395328040	1239527354
600	855	0.027246	815.2957	643.2497	7617.884	682317.8	2321429729	115520598.8
630	790	0.027572	795.784	532.8694	10923.14	706191.3	2255176503	172277909.8
660	773	0.027879	776.9822	397.9556	14443.35	729500.8	2198694041	1327504321
690	757	0.036836	758.8558	94221.88	180891.8	752266.4	1419899887	3504711950
720	452	0.026633	741.3726	6816.271	2838.81	774507.6	1612695511	6632764561
750	824	0.027579	724.5021	2287.828	10999.92	796242.7	1730004086	10645462141
780	772	0.028108	708.2156	1402.584	17304.65	817489.1	1824729322	15481161591
810	746	0.029981	692.4861	947.7848	46446.21	838263.7	1746677181	21082430019
840	662	0.029958	677.2883	214.7672	46044.79	858582.4	1710121808	27395727538
870	663	0.030132	662.5981	49.44056	49127.46	878460.3	1692719878	34371116764
900	656	0.031485	648.3929	1938.306	74445.57	897912.1	1585783029	41961996521
930	604	0.044155	634.6513	97084.97	307079.1	916951.6	928686198. 1	50124857507
960	323	0.031173	621.3531	33.09819	68441.79	935592.2	918196661	58819057915
990	616	0.025709	608.4792	73524.54	5.854039	953846.6	1477355529	68006617192

1020	880	0.030176	596.0116	3339.5	49913.74	971727	1613631711	77652026309
1050	654	0.03098	583.9331	1505.462	64760.32	989245	1708503140	87722073088
1080	623	0.03219	572.2274	61.45428	88296.43	1006412	1728000192	98185681232
1110	580	0.031184	560.8792	2950.747	68651.24	1023238	1866140222	1.09014E+11
1140	615	0.031803	549.874	1877.146	80663.85	1039734	1980127766	1.20179E+11
1170	593	0.031781	539.1977	2999.635	80228.95	1055910	2129055945	1.31656E+11
1200	594	0.031813	528.8374	4099.741	80853.3	1071775	2310010722	1.43421E+11
1230	593	0.032403	518.7806	2943.364	92525.77	1087339	2469111434	1.55451E+11
1260	573	0.032143	509.0152	5273.394	87367.82	1102609	2690361880	1.67726E+11
1290	582	0.034922	499.5301	0.485439	143171.8	1117595	2688193993	1.80225E+11
1320	499	0.034246	490.3144	724.6279	129586	1132305	2772587337	1.92931E+11
1350	517	0.034836	481.358	391.0633	141436.5	1146745	2835415893	2.05825E+11
1380	501	0.03427	472.6511	1928.578	130066.4	1160925	2977458242	2.18892E+11
1410	517	0.03419	464.1844	2982.868	128460.5	1174850	3158952526	2.32116E+11
1440	519	0.034595	455.949	2667.83	136614.4	1188529	3335534998	2.45484E+11
1470	508	0.035124	447.9364	2079.077	147210.7	1201967	3495410613	2.5898E+11
1500	494	0.035855	440.1387	1219.962	161722.3	1215171	3620409220	2.72594E+11
1530	475	0.035052	432.5481	3954.555	145756.3	1228148	3850996048	2.86313E+11
1560	495	0.03402	425.1572	9690.988	125042.7	1240902	4226258299	3.00125E+11
1590	524	0.03718	417.959	688.5902	187501	1253441	4329233179	3.1402E+11
1620	444	0.034414	410.9468	10326.6	132967.5	1265769	4739703557	3.27989E+11
1650	513	0.034524	404.1141	11113.21	135188.9	1277893	5185163774	3.42023E+11
1680	510	0.033558	397.4549	19482.15	115722.8	1289817	5805744433	3.56111E+11
1710	537	0.036271	390.9631	5486.402	169892.8	1301545	6149311099	3.70247E+11
1740	465	0.036237	384.6332	6593.466	169233.9	1313084	6537296238	3.84423E+11
1770	466	0.03797	378.4597	2378.865	202482.4	1324438	6776048379	3.98631E+11
1800	427	0.03833	372.4376	2246.36	209196.9	1335611	7012158116	4.12865E+11
1830	420	0.037748	366.5617	4269.094	198304.4	1346608	7344280695	4.27118E+11
1860	432	0.038467	360.8274	3162.856	211735.4	1357433	7636305474	4.41384E+11
1890	417	0.037944	355.2301	5261.556	202002.7	1368090	8021361608	4.55658E+11
1920	428	0.038049	349.7654	5750.891	203955	1378583	8434051721	4.69934E+11
1950	426	0.04032	344.4291	1431.685	244972.7	1388916	8643834009	4.84207E+11
1980	382	0.037757	339.2171	8553.088	198482.6	1399092	9167432255	4.98473E+11
2010	432	0.037442	334.1256	10887.06	192499.1	1409116	9776649390	5.12728E+11
2040	438	0.037392	329.1509	12184.29	191564.2	1418991	1044247212 9	5.26967E+11
2070	440	0.037765	324.2893	11501.29	198631.1	1428719	1111036935 3	5.41186E+11
2100	432	0.037202	319.5374	15416.36	187934.2	1438305	1190949121 0	5.55382E+11
2130	444	0.037691	314.8919	13973.16	197237.1	1447752	1269607451 9	5.69551E+11

2160	433	0.038374	310.3496	11790.43	210021	1457063	1344077845 9	5.83691E+11
2190	419	0.037862	305.9074	15275.13	200447.7	1466240	1431424385 1	5.97798E+11
2220	430	0.038514	301.5624	13126.5	212595.2	1475287	1514850848 7	6.1187E+11
2250	416	0.038469	297.3117	14333.27	211766.1	1484206	1604552352 7	6.25903E+11
2280	417	0.039609	293.1526	10386.48	232465.9	1493001	1682944443 3	6.39896E+11
2310	395	0.043269	289.0824	2148.41	293526.1	1501673	1719215985 9	6.53846E+11
2340	335	0.039345	285.0986	13202.34	227733	1510226	1810798665 8	6.67751E+11
2370	400	0.040318	281.1987	10221.47	244939.7	1518662	1893347341 4	6.81609E+11
2400	382	0.039599	277.3804	13897.18	232273.1	1526983	1991924291 3	6.95419E+11
2430	395	0.039829	273.6413	13780.89	236371.5	1535193	2092573721 8	7.09178E+11
2460	391	0.039355	269.9793	16853.42	227924	1543292	2206767638 3	7.22885E+11
2490	400	0.039958	266.3922	14959.2	238645.8	1551284	2317128343 1	7.36538E+11
2520	389	0.040797	262.878	12355.52	253190.6	1559170	2419761534 7	7.50137E+11
2550	374	0.040003	259.4346	16503.35	239428	1566953	2541148043 9	7.63679E+11
2580	388	0.041761	256.0603	10432.52	269375.3	1574635	2639779387 9	7.77164E+11
2610	358	0.04147	252.7531	12125.01	264553	1582218	2748214221 0	7.90591E+11
2640	363	0.028799	249.5111	214698.3	27009.99	1589703	3228420282 7	8.03958E+11
2670	713	0.029112	246.3328	204666.2	31855.28	1597093	3734558897 1	8.17265E+11
2700	699	0.027824	243.2164	266858.6	13786.01	1604389	4357555027 9	8.30511E+11
2730	760	0.02868	240.1603	228649.4	25243.01	1611594	4977038188 4	8.43694E+11
2760	718	0.0278	237.163	274405.2	13505.65	1618709	5702920136 4	8.56816E+11
2790	761	0.041913	234.2229	14781	271872.4	1625736	5878451890 0	8.69873E+11
2820	356	0.04228	231.3385	14104.29	277849	1632676	6052487334 4	8.82867E+11
2850	350	0.043158	228.5085	11777.65	291795	1639531	6213741770 4	8.95797E+11
2880	337	0.043158	225.7314	12388.12	291795	1646303	6381324621 5	9.08661E+11

2910	337	0.041337	223.006	20171.77	262328.9	1652993	6598407689 9	9.21461E+11
2940	365	0.042601	220.3309	15600.62	283003.2	1659603	6792316631 2	9.34195E+11
2970	345	0.043357	217.7049	13563.34	294900.2	1666134	6975651425 7	9.46862E+11
3000	334	0.044242	215.1268	11400.51	308373.4	1672588	7145879605 7	9.59464E+11
3030	322	0.04523	212.5954	9293.839	322866.9	1678966	7301339971 5	9.71999E+11
3060	309	0.043273	210.1096	15689.32	293598.3	1685269	7505826148 2	9.84468E+11
3090	335	0.049986	207.6683	2410.647	384954.7	1691499	7586751235 4	9.9687E+11
3120	257	0.05294	205.2704	655.1675	417764.6	1697658	7629111658 6	1.0092E+12
3150	231	0.043086	202.9149	18266	290679.7	1703745	7854735972 3	1.02147E+12
3180	338	0.085286	200.6007	11053.17	611128.6	1709763	7678939598 2	1.03367E+12
3210	95	0.065885	198.327	1967.837	523086.4	1715713	7605360853 6	1.04581E+12
3240	154	0.043441	196.0927	18734.49	296205	1721596	7833528143 2	1.05787E+12
3270	333	0.047686	193.8969	7442.476	356465.3	1727412	7979071375 9	1.06987E+12
3300	280	0.057104	191.7387	79.70803	457716.1	1733165	7994209926 7	1.08181E+12
3330	201							