DETERMINATION OF RESERVOIR PROPERTIES OF A GAS FIELD BY ADVANCED DECLINE ANALYSIS AND PRESSURE BUILD-UP TEST.

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DETERMINATION OF RESERVOIR PROPERTIES OF A GAS FIELD BY ADVANCED DECLINE ANALYSIS AND PRESSURE BUILD-UP TEST.

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By

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CANDIDATE'S DECLARATION

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma

Signature of the Candidate

………………………………

(Md. Latifur Rahman)

RECOMMENDATION OF THE BOARD OF EXAMINERS

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ABSTRACT

Estimating reservoir properties has long been a challenge. Traditionally pressure survey or well testing is conducted to estimate the reservoir properties, which is expensive; also production loss is associated with pressure survey. The importance of performing accurate analysis and interpretation of reservoir behavior using only rate and pressure data as a function of time is fundamental to assessing reservoir properties such as permeability, skin and reservoir drainage area.

The equations used for well test analysis are derived from the constant terminal rate solution of the radial diffusivity equation (RDE). Conventional Decline Curve Analysis normally used to estimate original gas in place and gas reserves. The development of modern Decline Curve Analysis began in 1944. This technique used to analyze and interpret production data and pressure data from gas wells using Type Curves. This technique is also used to estimate Skin Factor for near wellbore drainage area, Formation Permeability, Reservoir Drainage Area and gas in place. As opposed to well test analysis, the equations used for modern decline analysis attempt to plot rate versus time with different transformations.

Therefore theoretically these two independent methods should yield same results. It is of interest to investigate whether in real case two opposite approaches can be used to obtain sufficiently close results of the same properties such as skin, permeability etc.

In this study two real cases were analyzed using both well testing and decline analysis. Commercial software Ecrin v4.20 (Saphir and Topaze) was used to carry out this work. It is

found that the data quality is the greatest challenge with well testing data is obtained from a relatively short period of time in a controlled environment. If properly done, the data quality is good and results obtained can be reliable. However well testing is done only occasionally in Bangladesh, then developing a good understanding of the reservoir from well testing alone is often difficult. On the other hand decline analysis uses well pressure and production data which is usually available for the entire operational life of a well. Despite the volume of the data it is usually full of noise and difficult to discern the true reservoir signal from the dataset. However, sufficiently close results were obtained from the two approaches.

For Well # 4, k was 19.4 from DCA and 25.1 from PBU respectively; S was 0.996 for DCA and 0.64 for PBU. For well A#3, k was 52.53 from DCA and 83 from PBU respectively, S was 1.504 for DCA and 2.97 for PBU.

For DCA, two separate techniques (Fetkovich and Blasingame) were applied. They also showed reasonably close estimate of k (15.8 and 18.9) respectably and STGIIP (82.7 and 76.4 bscf).

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NOMENCLATURE

ABC	Name of the Gas field in study.
BB	Bocka bill formation
BH	Bhubon formation
BCF	Billion Cubic Feet
GOR	Gas Oil Ratio
SCF	Standard Cubic Feet
BBLS	Barrels
MMSCFD	Million Standard Cubic Feet per Day
MSCFD	Thousand Standard Cubic Feet per Day
STGIIP	Gas Initially in Place
STGIP	Gas in Place
OIGP	Original Gas in Place
PMRE	Petroleum and Mineral Resources Engineering
PSIA	Pounds per Square Inch in Absolute
PSIG	Pounds per Square Inch in Gauge
h	Pay zone/Reservoir Thickness, ft
k	Permeability, milli dercy
ϕ	Porosity
m	Slope of the Middle time region
p	Pressure, psia
p_i	Initial reservoir pressure, psia
r_e	Reservoir radius, ft
r_{wa}	Well bore radius, ft
s	Skin factor

Sw	Water saturation, fraction of pore space %.
Sg	Gas Saturation, fraction of pore space %.
B_g	Gas formation volume factor, cu.ft/Mscf.
q	Gas flow rate, Mscfd.
$\boldsymbol{t}$	Time, hours
$\boldsymbol{\mu}$	Viscosity, cp
ρ	Density
T	Temperature

Chapter 1: Introduction

Fluid flow through porous medium is mathematically modeled by the diffusivity equation. When it comes to flow around the wellbore, the radial form of the said equation is used. Commonly known as the radial diffusivity equations (RDE), shown bellow-

$$\frac{1}{r} * \frac{\delta p}{\delta r} + \frac{\delta^2 p}{\delta r^2} = \frac{\emptyset \ c_t}{k} * \frac{\delta p}{\delta t} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (1.1)$$

This equation can be solved by two main approaches. One is the constant terminal rate solution (CTR). All equations used for pressure transient analysis (PTA) are derived for the CTR solution with different boundary conditions. There are a number of standard well testing methods such as pressure built up (PBU), pressure drawdown (PDD) etc. This involves producing well at a constant rate for a certain time and record the pressure vs. time data. This data can be interpreted by various methods such as Horner, MBH, Type curve etc, to obtain permeability (k), Skin (s), distance to fault body, drainage area etc. Data is collected under controlled environment for relatively short period of time, if properly done and data quality is good, reliable results can be obtained.

Decline analysis on the other hand, takes the opposite approach. Here the flow rate versus time is recorded usually over a long period of time. Classical decline analysis, also known as Arps analysis, is established through empirical observation. The basic philosophy is that, if a producing well shows gradual decline naturally without external intervention, decline rate follows a certain pattern such as exponential, hyperbolic or harmonic. From this observation GIIP and reserves can be estimated. Arps methods are based on empirical observation.

Modern decline curve analysis, also sometimes referred to rate transient analysis (RTA), is based on solid theoretical foundation. Originally proposed by Fetkovich, latter expanded by other researcher (Blasingame, Agarwal etc). They have produced type curves which are graphical representation of their solutions. It consists of finding the theoretical type curve that “matches” the actual response from a tested well and the reservoir when subjected to changes in production rates. It uses dimensionless variables rather than real variables. This technique is used to estimate reservoir properties, such as k, kh, s, drainage area etc.

The main advantage of RTA is that no special arrangement for costly testing is necessary, well pressure and production data are usually recorded throughout the operational life of a well. Thus while PTA deals with relatively short time data, RTA deals with data over a long period of time. However, the data is usually full of noise because well pressure and flow rates are often manipulated according to operational necessity; the condition for any decline curve analysis is, no major change of operational parameters is allowed. It is worth investigating whether in real case the two opposite approaches will yield close results.

This project will attempt to apply both of these techniques (Advanced Decline Analysis and Pressure Build-up test analysis) to a producing gas field in Bangladesh, using the historical production data and well test data, to estimate the reservoir and well parameters of the Gas Field in question.

1.1 Objectives

- To investigate whether the two independent methods (advance decline curve analysis and pressure built up test analysis) yield close results on reservoir properties such as permeability (k), skin (s), drainage area etc.
- To investigate whether different advance decline analysis techniques such as Fetkovich, Blasingame etc yield close results.
- To compare the results to see whether decline analysis is a reliable substitute for well testing.
- To estimate GIIP from Material balance and Decline Analysis.

1.2 Methodology

- Gather historical data (pressure, rate for producing time) of well A # 4 and A # 3 production well.
- Check the noise in the data, data quality, look for anomalies and find out the causes. Filter out the anomalies and noises.
- Carryout production data analysis (mainly decline curve analysis) on well A # 4 and A # 3 production well and by type curve matching (Fetkovich type curves, Blasingame type curves) determines the reservoir properties (Permeability, skin factor, boundary of drainage area). Commercial software Ecrin (Topaze) will be used for this work.
- Gather well test data (bottom-hole pressure survey) of A # 4 and A # 3 well.
- Determine Permeability, skin factor, boundary of drainage area by PBU analysis using commercial software Ecrin (Saphir).
- Estimate GIIP from Material Balance.
- Estimate GIIP from Arps Decline Curve Analysis.
- Carry out a comparative analysis of the results.

Chapter-2: Literature Review

This chapter discusses the theory part of the advance decline curves analysis mainly the type curves proposed by Fetkovich and Blasingame. The well test is also included later part of this chapter.

2.1 Decline curve analysis

Decline curve analysis is the most common technique for preparing economic forecasts and reserve estimates. Production-decline analysis is the analysis of past trends of declining production performance, that is, rate versus time and rate versus cumulative production plots, for wells and reservoirs. From about 1975 to 2005, various methods have been developed for estimating reserves in tight gas reservoirs. These methods range from the basic material balance equation to decline- and type-curve analysis techniques. There are two kinds of decline-curve analysis techniques, namely,

- Traditional (The classical curve fit of historical production data) decline curve analysis by Arps from 1945.
- Modern (The type-curve matching technique) decline curve analysis from 1980.

Traditional approach: Using production rate (history trend) only production forecast and recoverable reserves can be estimated under current condition using Arps method[1,2].

Modern approach: Using both production rate and flowing pressure, based on physics, reservoir characterization is possible. OGIP / OOIP and Reserves, Permeability and skin, Drainage area and shape, production optimization screening, Infill potential can be estimated. The power of modern decline curve analysis was investigated by M. Ebrahimi[3].

Type Curve is a dimensionless-variables approach to determine reserves and to describe the recovery performance of hydrocarbon systems with time. This study mainly focused on the following two type curves-

Fetkovich (1980) and Palacio and Blasingame (1993).

All the methods are based on defining a set of decline-curve dimensionless variables that includes:

• Decline-curve dimensionless rate, q_{Dd}.

• Decline-curve dimensionless cumulative production, Q_{Dd}

• Decline-curve dimensionless time, $t_{Dd.}$

The diffusivity equation in dimensionless form become

$$\frac{\partial^2 p_D}{\partial r_D^2}+\frac{1}{r_D}\frac{\partial p_D}{\partial r_D}=\frac{\partial p_D}{\partial t_D} \qquad \text{(2.1)}$$

2.2 Fetkovich Type Curve

Fetkovich in 1980 proposed that the concept of the dimensionless-variables approach can be extended for use in decline-curve analysis to simplify the calculations [4-9]. He introduced the variables for decline-curve dimensionless flow rate, q_{Dd}, and decline-curve dimensionless time, t_{Dd}, that are used in all decline-curve and type-curve analysis techniques [4-6].

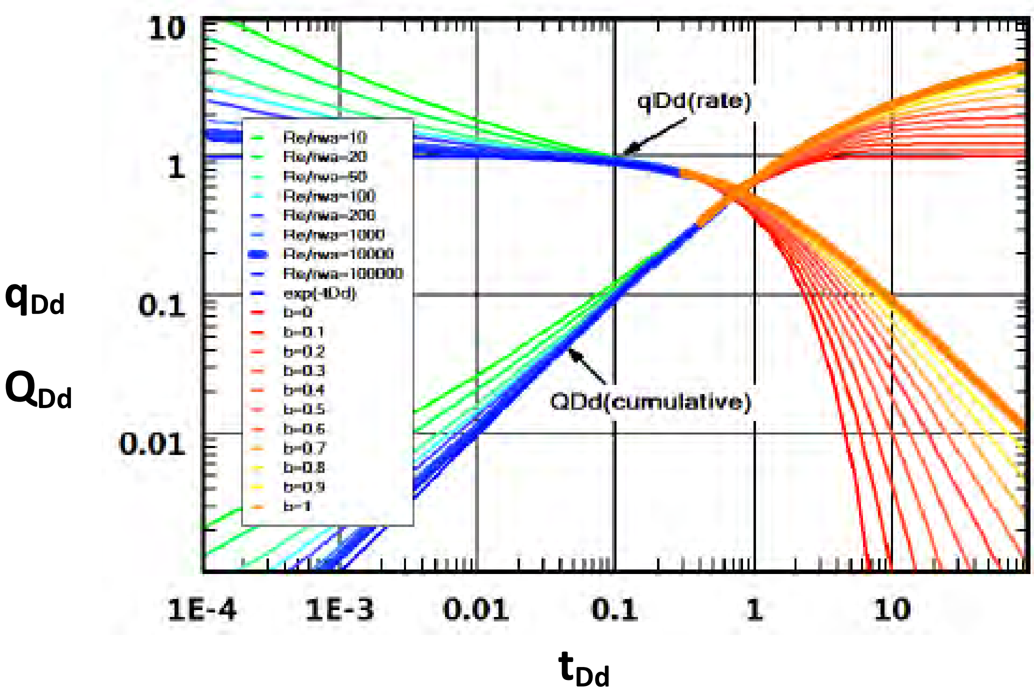


Figure 2.1: Fetkovich Type curve

In Figure 2.2 the left region of the curves (green to blue) corresponds to the transient part of the response. On the right hand side are the Arps decline curves (red to yellow). Note the legend on the left: the red Arps curve is for an exponential decline (b=0), the last yellow curve is for harmonic decline (b=0).

The Fetkovich type-curve displays dimensionless values q_{Dd}, Q_{Dd} versus t_{Dd}.

Where q_{Dd}, Q_{Dd} and t_{Dd} are the decline-curve dimensionless variables,

- **Hyperbolic**: $\frac{q_t}{q_i} = \frac{1}{\left[1 + b D_i t\right]^{1/b}}$

In a dimensionless form:

$$q_{Dd} = \frac{1}{\left[1 + b t_{Dd}\right]^{1/b}} \quad \text{................................(2.2)}$$

$$q_{Dd} = \frac{q_t}{q_i}$$

$$t_{Dd} = D_i t$$

- **Exponential**: $\frac{q_t}{q_i} = \frac{1}{\exp\left[D_i t\right]}$

Similarly, $q_{Dd} = \frac{1}{\exp\left[t_{Dd}\right]}$

- **Harmonic**: $\frac{q_t}{q_i} = \frac{1}{1 + D_i t}$

or $q_{Dd} = \frac{1}{1 + t_{Dd}}$

The Fetkovich analytical type curves can be used to calculate three parameters: permeability, skin and reservoir radius using the following equations.

$$k = \frac{141.2\mu B}{h(p_i - p_{wf})}\left[\ln\left(\frac{r_e}{r_{wa}}\right) - \frac{1}{2}\right]\frac{q}{q_{Dd}}_{match}$$ ....(2.3)

$$r_{wa} = \sqrt{\frac{0.00634k}{\phi\mu c_t}\frac{1}{\frac{1}{2}\left[\ln\left(\frac{r_e}{r_{wa}}\right) - \frac{1}{2}\right]\left[\left(\frac{r_e}{r_{wa}}\right)^2 - 1\right]}\frac{t}{t_{Dd}}}_{match} \qquad s = \ln\left(\frac{r_w}{r_{wa}}\right)$$ ....(2.4)

$$r_e = \sqrt{2\frac{141.2B}{h(p_i - p_{wf})}\frac{0.00634}{\phi c_t}\frac{q}{q_{Dd}}_{match}\frac{t}{t_{Dd}}_{match}}$$ ....(2.5)

The ratio re/rwa is commonly referred to as the dimensionless drainage radius r_D.

2.3 Blasingame Type curve

Blasingame has developed an improved type curve analysis to incorporate reservoir conditions, material balance, rate and pressure information to analyze wells. Provided sufficient rate and pressure data is available and the well meets certain boundary conditions, Blasingame analysis provide OGIP, Permeability, skin factor, drainage area and initial pressure (assuming it is not known)[7].

Blasingame type curves have identical format to those of Fetkovich. However, there are three important differences in presentation:

1. Models are based on constant RATE solution instead of constant pressure
2. Exponential and Hyperbolic stems are absent, only Harmonic stem is plotted
3. Rate Integral and Rate Integral - Derivative type curves are used (simultaneous type curve match) Data plotted on Blasingame type curves make use of modern decline curve analysis. methods:

- Material balance time/Pseudo time.
- Normalized Rate ($q/\Delta p$).

The Blasingame plot contains three curves, which plotted on log vs log scales. The X axis is material balance time with hours as a unit. The calculations for the material balance time is

$$t_e = \frac{Q(t)}{q(t)} \qquad \text{.................... (2.6)}$$

The first Blasingame curve is normalized rate curve which is defined by

$$PI(t) = \frac{q(t)}{p_i - p_w(t)} \qquad \text{.................... (2.7)}$$

The second Blasingame curve is normalized rate integral curve which is defined by

$$PI\,Int. = \frac{1}{t_e}\int_0^{t_e} PI(\tau)d\tau = \frac{1}{t_e}\int_o^{t_e} \frac{q(\tau)}{p_i - p_w(\tau)}d\tau \qquad \text{.................... (2.8)}$$

The third Blasingame curve is normalized rate integral derivative curve which is defined by

$$PI\,Int.\,Derivative = \frac{\partial(PI\,Int)}{\partial \ln(t_e)} \qquad \text{............................ (2.9)}$$

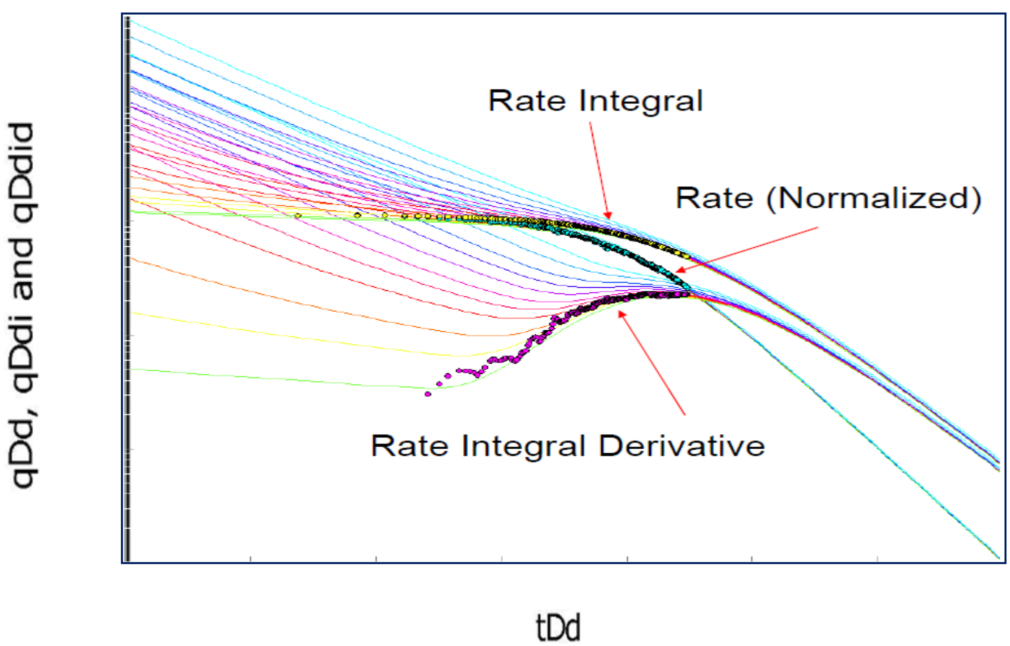


Figure 1.2: Blasingame Type curve

The Blasingame analytical type curves can be used to calculate OIGP, reservoir radius, Skin and permeability using the following equations-

- $$G = \frac{1}{c_{ti}}\left[\frac{t_a}{t_{Dd}}\right]_{mp}\left[\frac{(q_{Dd})_i}{q_{Dd}}\right]_{mp}$$ ………………………. ……..(2.10)
- $$A = \frac{5.615\, G\, B_{gi}}{h\,\phi(1 - S_{wi})}$$ ……………………………….(2.12)
- $$r_e = \sqrt{\frac{A}{\pi}}$$ ……………………………….(2.13)
- $$r_{wa} = \frac{r_e}{r_{eD}}$$ ……………………………….(2.14)
- $$s = -\ln\left(\frac{r_{wa}}{r_w}\right)$$ ……………………………….(2.15)
- $$k = \frac{141.2\, B_{gi}\mu_{gi}}{h}\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2}\right]\left[\frac{(q_{Dd})_i}{q_{Dd}}\right]_{mp}$$ ……………………………….(2.16)

where G = gas-in-place, Mscf
B_{gi} = gas formation volume factor at p_i, bbl/Mscf
A = drainage area, ft^2
s = skin factor
r_{eD} = dimensionless drainage radius
S_{wi} = connate-water saturation
c_{ti} = total system compressibility at P_i, psi^{-1}

2.4 Material Balance

Material balance is a useful engineering method for understanding a reservoir's past performance and predicting its future potential. It determines original oil and gas in place in the reservoir, original water in place in the aquifer, estimate expected oil and gas recoveries as a function of pressure decline in a closed reservoir producing by depletion drive, or as a function of water influx in a water-drive reservoir, it predicts future behavior of a reservoir (production rates, pressure decline, and water influx), it verifies volumetric estimates of original fluids in place and verifies future production rates and recoveries predicted by decline-curve analysis[2,7,8].

It is the application of the law of conservation of mass to oil, gas reservoirs and aquifers. It is based on the premise that reservoir space voided by production is immediately and completely filled by the expansion of remaining fluids and rock.

The general material-balance equation for a pseudo-steady state gas reservoir, neglecting water and formation compressibility's is expressed by:

$$\frac{p}{z} = \frac{p_i}{z_i}\left(1 - \frac{G_p}{G}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.17)$$

It is one of the most often used relationships in gas reservoir engineering. It is usually valid enough to provide excellent estimates of original gas-in-place based on observed production, pressure, and PVT data.

The Flowing Material Balance uses the concept of stabilized or "pseudo-steady-state" flow to evaluate total in-place fluid volumes. In a conventional material-balance calculation, reservoir pressure is measured or extrapolated based on stabilized shut-in pressures at the well. In a flowing situation, the average reservoir pressure clearly cannot be measured. However, in a stabilized flow situation, there is very close connectivity between well flowing pressures (which can be measured) and the average reservoir pressure. The pressure drop measured at the wellbore while the well is flowing at a CONSTANT rate is the same as the pressure drop that would be observed anywhere in the reservoir, including the location which represents average reservoir pressure. This is true only if pseudo-steady-state conditions are present. The conventional p/z plot uses the extrapolated straight-line trend of measured shut-in pressures (for gas reservoirs) to predict OGIP [10].

$$\frac{p}{z} = \frac{p_i}{z_i} - \frac{p_i}{z_i}\frac{G_p}{G} \qquad (2.18)$$

2.5 Well Test/Pressure built-up Test

Pressure buildup analysis is the most widely used form of transient well testing technique.
It has been extensively used in the petroleum industry. Pressure buildup testing is done by shutting in a producing well and recording the closed-in bottom-hole pressure as a function of time. The most common and simplest analysis techniques require that the well produce at a constant rate, either from start-up or long enough to establish a stabilized pressure distribution before shut-in. The flowing bottom-hole pressure prior to shut-in should also be recorded to estimate the skin [7, 10-13].

The following figures schematically shows flow-rate and bottom-hole pressure behavior for an Ideal pressure build-up test.

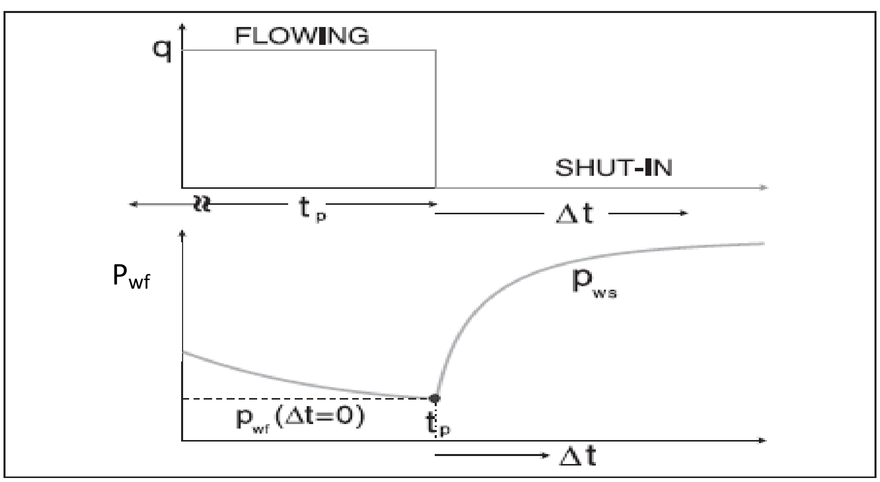


Figure2.3: Schematic flow-rate and pressure behavior for an ideal buildup

Short-time pressure observations are usually necessary for complete delineation of wellbore storage effects. Stabilizing the well at a constant rate before testing is an important part of a pressure buildup test.

There are several ways for analyzing the results of a build-up test, the most popular being the Horner method, which is based on the supposition that the reservoir is infinite in extent and a negligible amount of fluid is removed from the system during the production period prior to closure. This case corresponds to an initial well test conducted in a virgin reservoir.

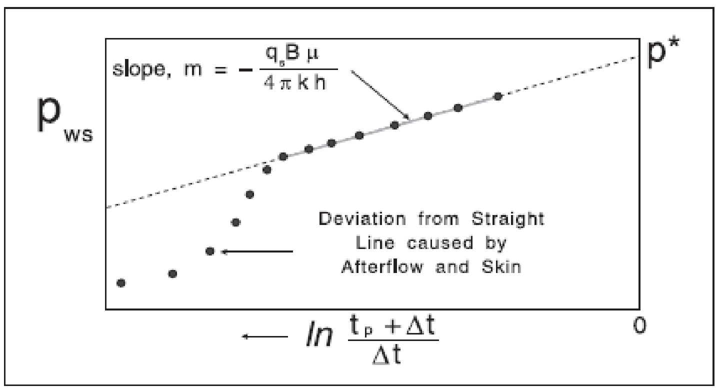


Figure2.4: Horner plot for a buildup

Equation:

$$p_{ws}(\Delta t) = p_i - \frac{q_S B\mu}{4\pi kh} \ln \frac{t_p + \Delta t}{\Delta t} \qquad (2.17)$$

This is the Horner buildup equation that predicts a linear relationship between p_{ws} and ln((tp + Δt)/Δt), which describes a straight line, with the straight line slope m, p_i can be calculated.

$$\overline{p} = p_i = p^* \qquad (2.18)$$

If the net pay h is known and the field unit is used then from this plot, the reservoir average permeability the investigated area can be obtained by equation-

$$kh = -\frac{162.6 q_S B\mu}{m} \text{ (log base 10)} \quad \text{.......................... (2.19)}$$

The determination of the permeability is the most significant result to be obtained from an initial test on a reservoir simply because, under these circumstances, the initial pressure could be obtained from a spot measurement prior to opening the well in the first place.

The skin factor when using field units can be obtained from the following equation-

$$S = 1.1513\left[\frac{p_{wf}(\Delta t = 0) - p^*}{m} - \log_{10}\frac{k t_p}{\phi \mu c_t r_w^2} + 3.2275\right] \quad \text{....................(2.20)}$$

When semi log graph paper with a limited number of cycles is being employed, it may be Inconvenient to extrapolate the straight-line portion of the Horner plot sufficiently far to obtain p* directly. However, it is always possible to determine the pressure on the straight line 1 h after shut-in; this is denoted pws (Δt = 1) or more simply p1hr.

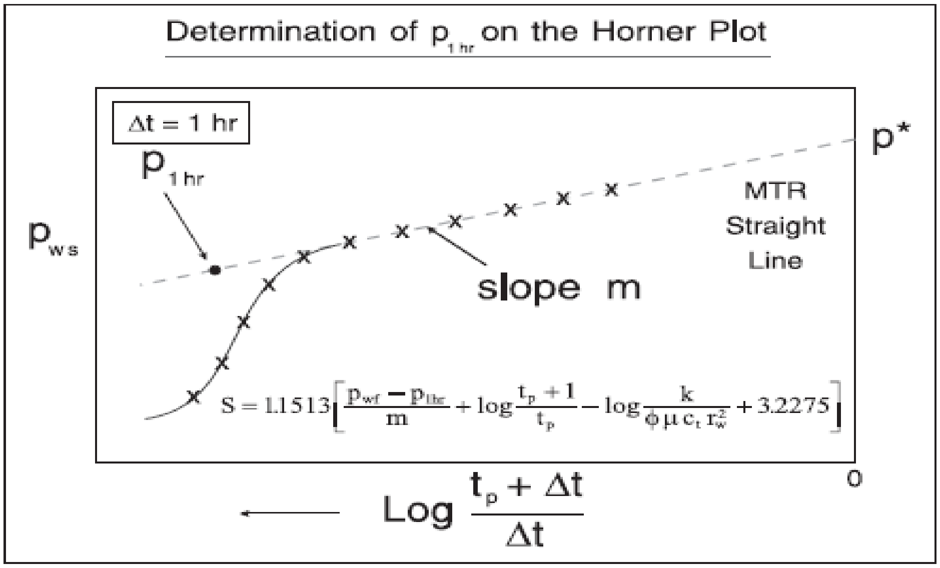


Figure2.5: Procedure for finding the MTR pressure at 1 hour

The skin factor then can be obtained using the following equation-

$$S = 1.1513\left[\frac{p_{wf}(\Delta t = 0) - p_{1hr}}{m} + \log\frac{t_p + 1}{t_p} - \log\frac{k}{\phi \mu c_t r_w^2} + 3.2275\right] \qquad \text{....................(2.21)}$$

2.6 Composite Bi-logarithmic Type Curve

The well test data analysis has kept in close contact with the graphic analysis since the self-recording pressure gauge was used for studying the change of transient pressure in the 1940s. In the 1950s, Horner found that the radial flow in a reservoir corresponds to the linear portion on a semi logarithmic data plot, and he presented the idea that this linear portion can be used for obtaining the value of reservoir permeability. This is a good application of graphic analysis. The bi-logarithmic type curve match method was presented by Agarwal et al. in the 1960s and then developed by Gringarten et al., thus forming the current type curve match method of obtaining the values of parameters [15]. The pressure derivative is also plotted only same figure, which was introducing by

Bourdet et at [16]. Thus this composite type curve is also referred to as the Bourdet Gringerton type curve.

The composite bi-logarithmic graph is a typical characteristic graph used for identifying a homogeneous reservoir. It has the shape of a two-tooth fork and can be divided into three portions for analyzing

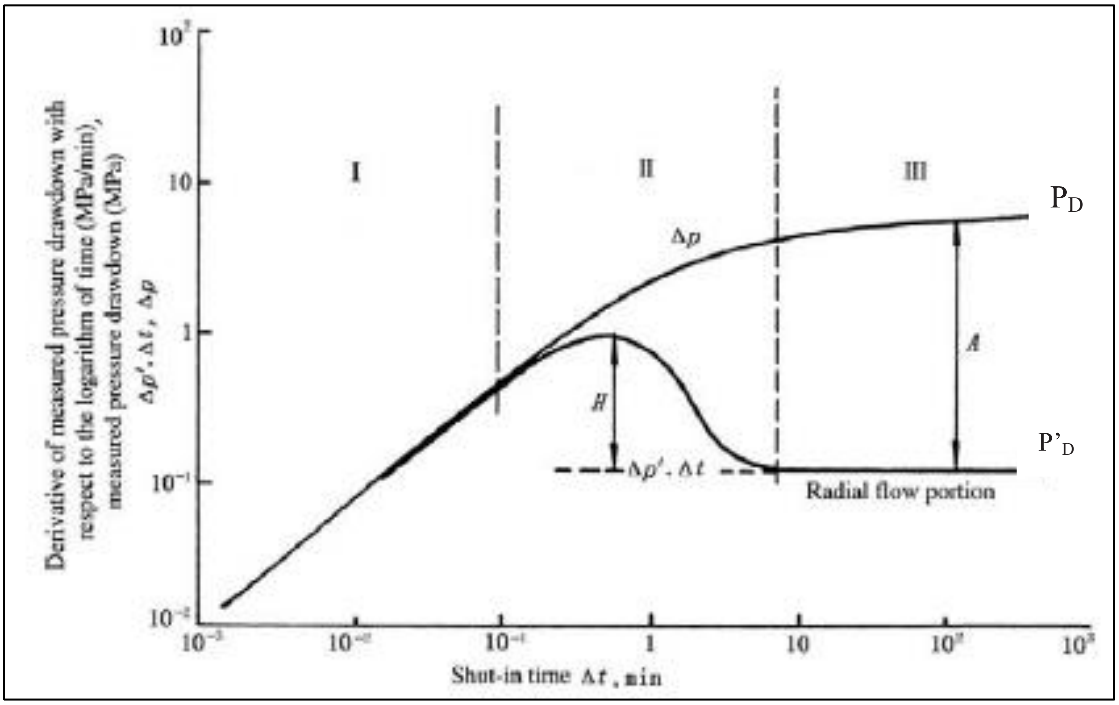


Figure2.6: Composite Bi-logarithmic plot.

The first portion has the shape of the handle of the fork. Both pressure and derivative curves join together and become a 45^{o} straight line, which indicates an after flow effect, that is, the effect of wellbore storage.

The second portion is the transition portion. The derivative curve slopes downward after the peak appears. The value of the peak is dependent on the value of parameter C_De^{2S} where CD is dimensionless wellbore storage coefficient and S is skin factor. The value of S has a greater effect due to its exponential position.

The third portion is a horizontal portion, which is the typical characteristic of radial flow. In the dimensionless coordinate system, the ordinate value of the horizontal line is 0.5, which can be used for confirming the radial flow straight-line portion on the semi-logarithmic plot, such as Horner graph, MDH graph, and superposition function plot. Before the horizontal portion of the derivative curve appears, both pressure and derivative curves have separated from each other and form a forked shape.

There are some typical shapes for different reservoir/Well configurations that can be seen on the type curves [16].

Chpter-3: Overview of ABC Gas field

3.1 ABC gas field

ABC gas field is located in northeastern Bangladesh in Block 14, 170 km northeast of Dhaka. Currently this particular Gas Field is producing from six gas wells, namely A#2, A#3, A#4 and A#6), A-7 and A-9. This Gas Field started its first production on 28th march 2005 with 73 MMscfd from two production wells (A#2 and 3). On 23 July 2005, another gas well (A#4) started producing which added 32 MMscfd to the total production. On 30 July 2005, well A#6 started producing which added further 2.5 MMscfd to the total production. Gradually the production increased to its maximum level at 113 MMscfd on 4 September 2006. Production rate decreased in all producing wells over the following years. In 2010 the total production of the gas field got down to around 60 MMscfd. In 2011 two wells A # 7 and A#9 was drilled and was put online from July 2012 and August 2012 respectively, which added another 20 MMscfd to total production to the Gas field. Currently the gas field is producing at 80MMscfd.

In the past, the well A#4 had the production rate at 32 MMscfd with flowing tubing head pressure of 2050 psi. As of 2012 it came down to around 5 MMscfd with flowing tubing head pressure of 1200 psi and water production has increased due to increasing water loaded to the wellbore of A#4, in March 2013 the producing zone was plugged back and re-perforated to the new upper zone in BB-60. The well A#3 had production rate of 60MMscfd, as of 2013 March its producing at 28 MMscfd.

One pressure survey was conducted in March 2008 in well A#4. Another survey was conducted in April 2010. In well A#3 the last pressure survey was conducted in 2011.

Table-3.1: Current production Scenario of ABC field as of March 2013-

Well (drilled in year)	Production Rate (MMscfd)	Perforated interval in measured depth	Producing Zone (Sand)
A#2 (2004)	7	1880m to 1860m	BB-60
A#3 (2004)	28	2216m to 1860m	BB-70
A#4 (2005)	10	2295m to 2260m	BB-70 (Previously produced from BB-80)
A#5 (2005)	0	No information	Abandoned due to high water production
A#6 (2005)	3	1880m to 1860m	BB-60
A#7 (2011)	5	2180m to 2150m	BB -60
A#9 (2011)	20	2650m to 2600m 2745m to 2725m	BB-45 and 48

3.2 Overview of Well A-4

The A-4 well is a deviated well to a crestal position of the ABC Field which is located in Block 14 in the Surma Basin. The structure is a compressional fold, elongated in the north-south direction, and fault bounded on the east with dip on the flanks of 10 to 15 degrees. The feature is 60-80 kilometers along the north-south axis and 12-15 kilometers along east-west axis [18].

The reservoir is Middle Miocene-Early Pliocene sandstone of the Boka Bil Formation and Middle Miocene sandstone of the Bhuban Formation. The sands are fine to medium grained and were deposited in a shallow marine-deltaic to fluvial environment with decreasing marine influence from older Bhuban Formation to the younger Boka Bil Formation. The primary source rock is believed to be the late Eocene to Oligocene Kopili and Jenum shales.

From side wall core analysis data it was found the sandstone is poorly consolidated, very light grey, firm, friable, very fine to fine (lower) sand grading to silt; sub-angular to rounded, well sorted, clear to translucent quartz; mottled with abundant dark grey, green grey fine to medium, rare orange brown, chart fragments; trace light grey green, chlorite, slight off white argillaceous matrix [18].

The perforated interval for this well is 35m (measured depths from 2295m up to 2260m). The gross thickness of the reservoir is 50m.

Permeability and Skin is 25 and 1.00 respectively from the Well Test study in 2011 by PE of the Operator Company. The gas in place for BB80 was estimated through material balance by the petroleum engineers as 180, 150, 120, 130 and 72 BCF in year 2006, 2007, 2009, 2010 and 2011 respectively and it was measured as 185 BCF by volumetric method [18].

Table-3.2: Initial Gas in place and other parameter for well A#4 as of 2005.

Reservoir	Gross Interval (m)	Porosity (%)	Water saturation (%)	Gas Formation Volume Factor B_g cu.ft/Mscf.	Initial gas- in-place (BCF)
BB80	36	18.0	53	202.8	180
BB70	60	20.0	50	202.8	80

In Figure 3.1 from the production history plot, it is clearly seen that there is decline in production rate and pressure. So decline curve analysis is applicable to this well.

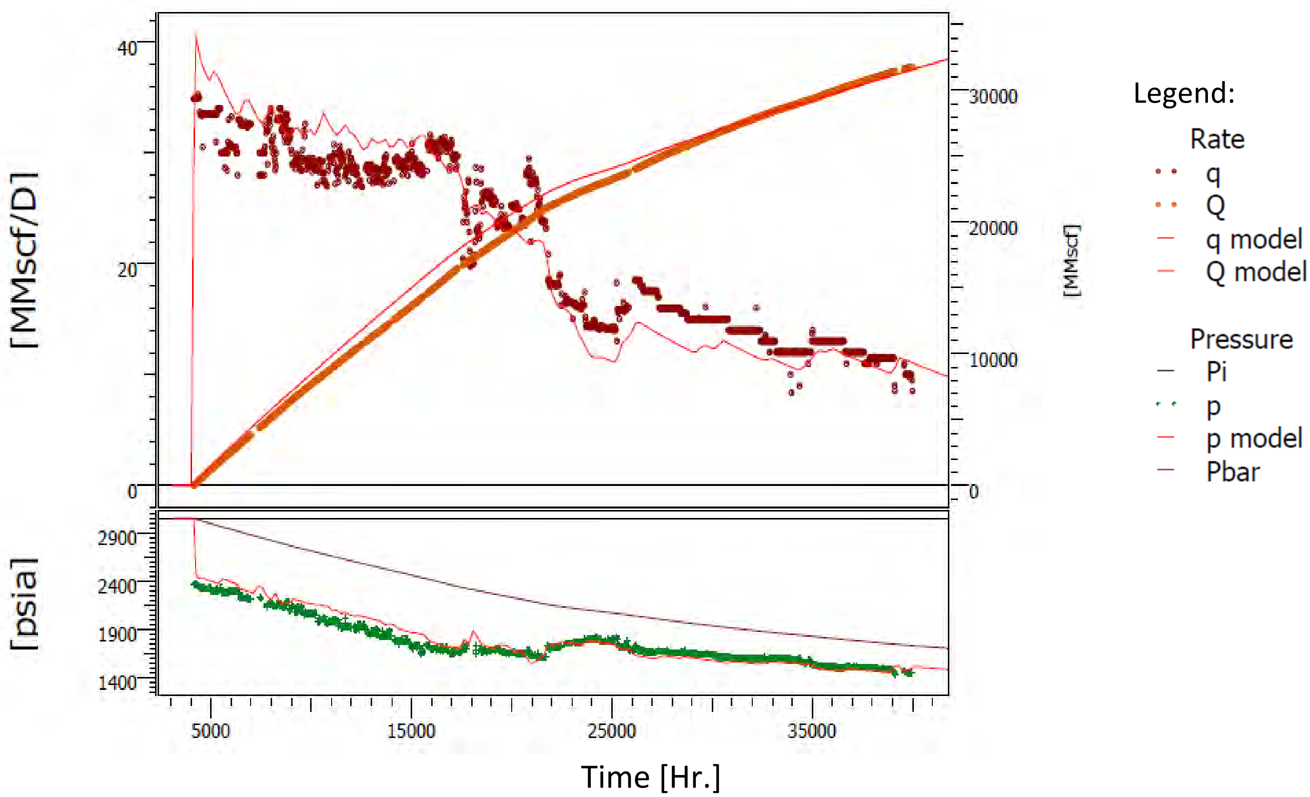


Figure 3.1: Production History of A#4.

3.3 Overview of Well A-3

Well MB-3 was drilled to the Middle Miocene sandstones of the Lower Boka Bil Formation (BB50-BB70) and the Early to Middle Miocene sandstones of the Bhuban Formation (BH10-BH60). The Boka Bil BB70 consists of sandstone with thin interbeds of claystone and siltstone in the upper section, and dominantly claystone with minor thin siltstone interbeds in the lower section. The sandstone is cemented with both silica and calcite cement, and exhibits poor to fair intergranular porosity. The primary source rocks are believed to be the Late Eocene to Oligocene, Kopili and Jenam shales. Vertical migration and leakage along the bounding thrust faults into the overlying Bhuban and Boka Bil reservoirs is the assumed migration pathway [18].

From side wall core analysis data it was found the sandstone is consolidated, very light grey, firm, friable, very fine to fine (lower) sand grading to silt; sub-angular to rounded, well sorted, clear to translucent quartz; mottled with abundant dark grey, green grey fine to medium, rare orange brown, chart fragments; trace light grey green, chlorite, slight off white argillaceous matrix [18].

The perforated interval for this well is 30m (measured depths from 2216m up to 21860m). The gross thickness of the reservoir is 44m.

Permeability and Skin is 65 and 2.00 respectively from the Well Test study in 2011 by PE of the Operator Company. The gas in place for BB80 was estimated through material balance by the petroleum engineers as 135, 130, 115, 105 and 100 BCF in year 2006, 2007, 2009, 2010 and 2011 respectively and it was measured as 145 BCF by volumetric method [18].

Table-3.3: Initial Gas in place and other parameter for A#3 as of 2005.

Reservoir	Gross Interval (m)	Porosity (%)	Water saturation (%)	Gas Formation Volume Factor B_g cu.ft/Mscf.	Initial gas- in- place (BCF)
BB70	91	21.0	53	202.8	135

In Figure 3.2 from the production history plot, it is clearly seen that there is decline in production rate and pressure. So decline curve analysis is applicable to this well.

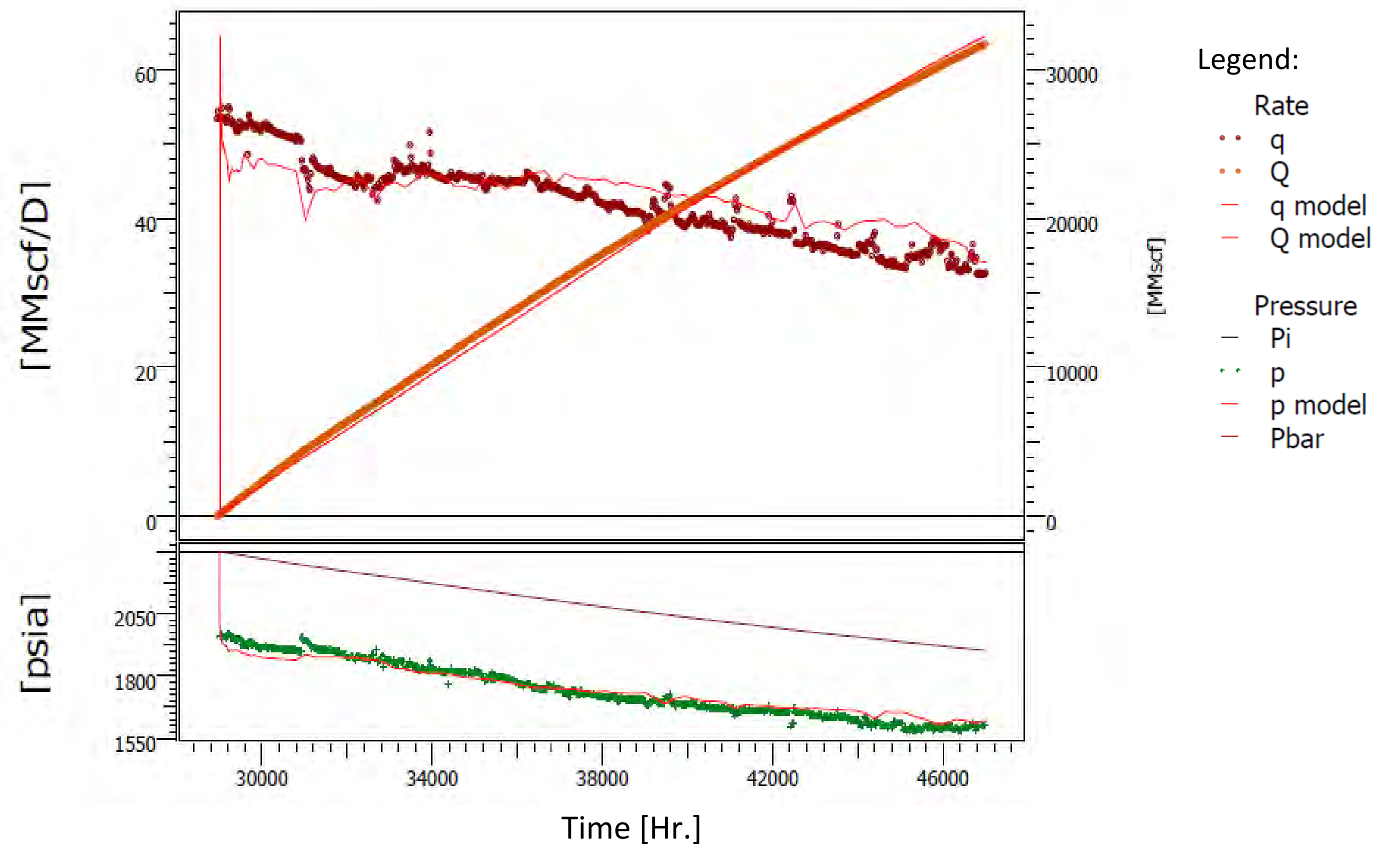


Figure 3.2: Production History of well A # 3.

Chapter-4: Case Studies and Results

This chapter covers all the analysis, plots and results from the analysis and results summary. All these analysis has been done using commercial software Ecrin (Saphir and Topaze).

4.1. Case Study 1: Decline analysis of Well A#4

4.1.1. Fetkovich Type curve plot:

Fetkovich type curve matching is shown in figure 4.1.1. At the boundary dominated flow region it is observed that the decline is completely harmonic, as b=1. As both production and cumulative curves matches to b=1, it gives more confidence to results. The data on the transient region however, doesn't match with any stem.

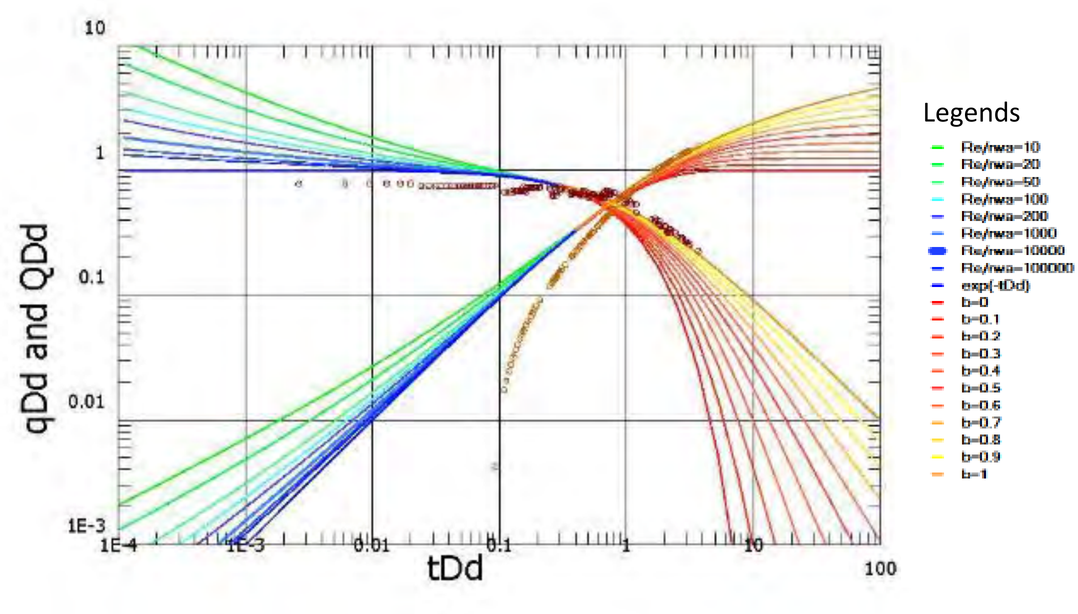


Figure 4.1.1: Fetkovich type curve plot.

The results obtained from this model is shown in Table 4.1.1

Table 4.1.1: Results from Fetkovich type curve

K, average	15.8 md
S, Total Skin	.238
STGIIP	82.70 BCF

STGIP	50.30 BCF

4.1.2. Blasingame Type curve Plot:

Blasingame type curve matching is shown in figure 4.1.2. The ‘rate integral’ and ‘rate integral derivative’ aids more unique match in addition to the normalized rate type curves, this is why Blasingame shows better agreement with the results obtained from well test.

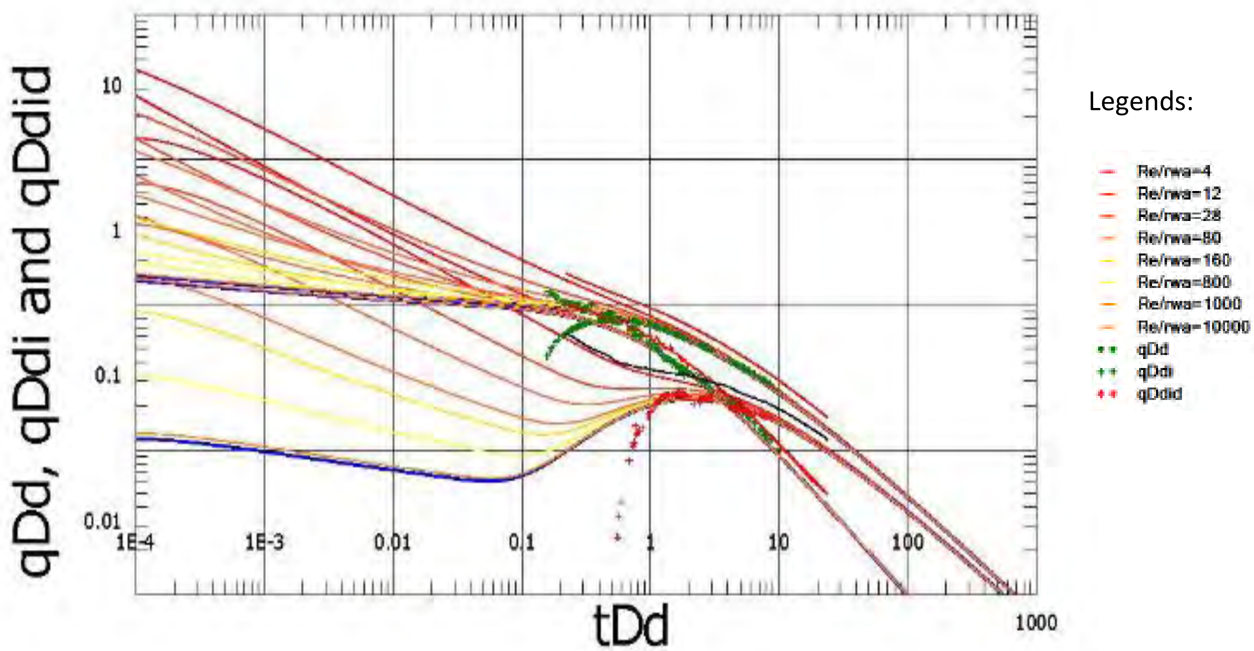


Figure 4.1.2: Blasingame type curve plot.

The results obtained from this model are shown in Table 4.1.2.

Table 4.1.2: Results from Blasingame type curve match

K, average	18.9 md
S, Total Skin	.655
p_i	2650, psia
STGIIP	76.40 BCF
STGIP	13.10 BCF

4.1.3. Arps Plot

Arps plot is shown in figure 4.1.3; a traditional analysis is performed as illustrated in this figure. Having analytical expression of rate and cumulative known, from a given abandonment rate this plot calculates the abandonment time and hence calculates the ultimate recovery.

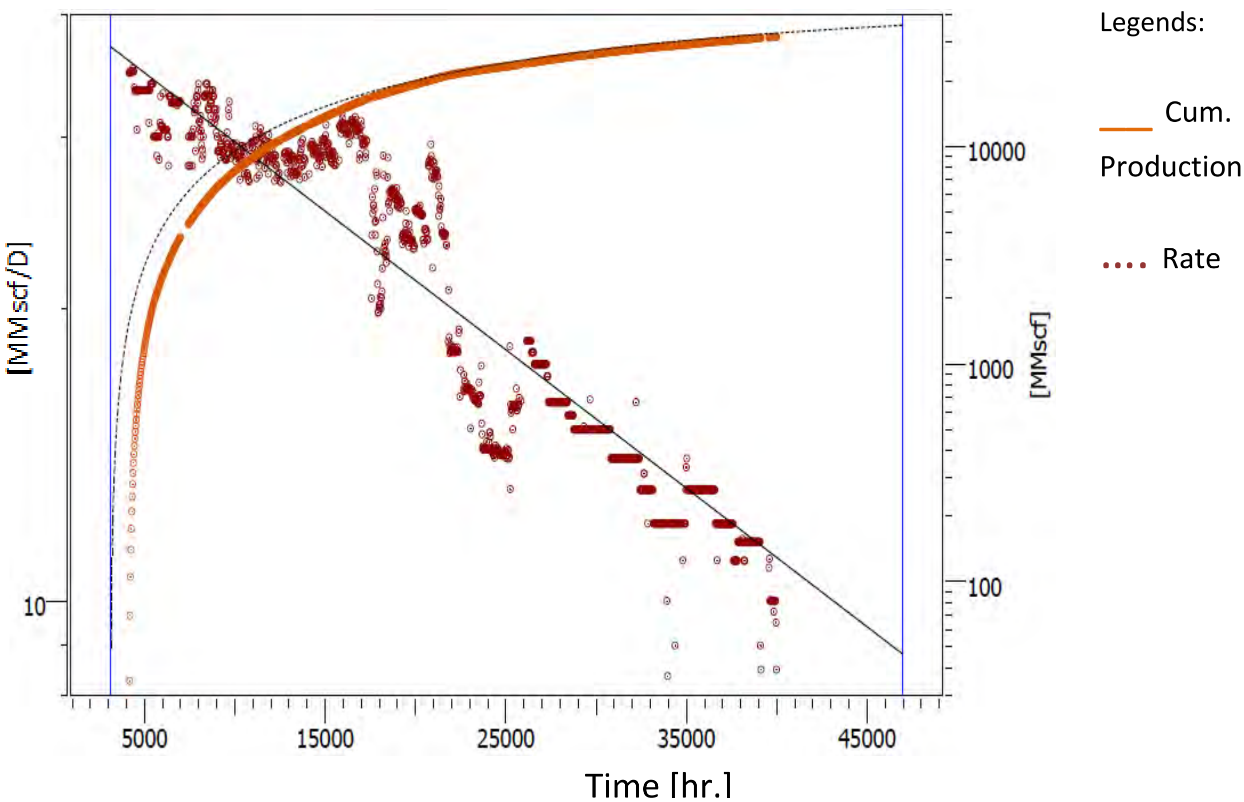


Figure 4.1.3: Arps plot.

The results obtained from this model are shown in Table 4.1.3.

Table 4.1.3: Results from Arps plot

Remaining Reserves	11.2 BCF
UR	65 BCF

4.1.4. P/z Plot (Material Balance):

Flowing material balance, P/z vs. cumulative production (G_P) plot is shown in figure 4.1.4. This analysis was done to verify the results obtained from other methods, and it is found that the results obtained from other methods are close. Flowing material balance is used instead of classical material balance because sufficient number of average reservoir pressure p was not available, which requires Pressure build-up test involving shutting the well for some time.

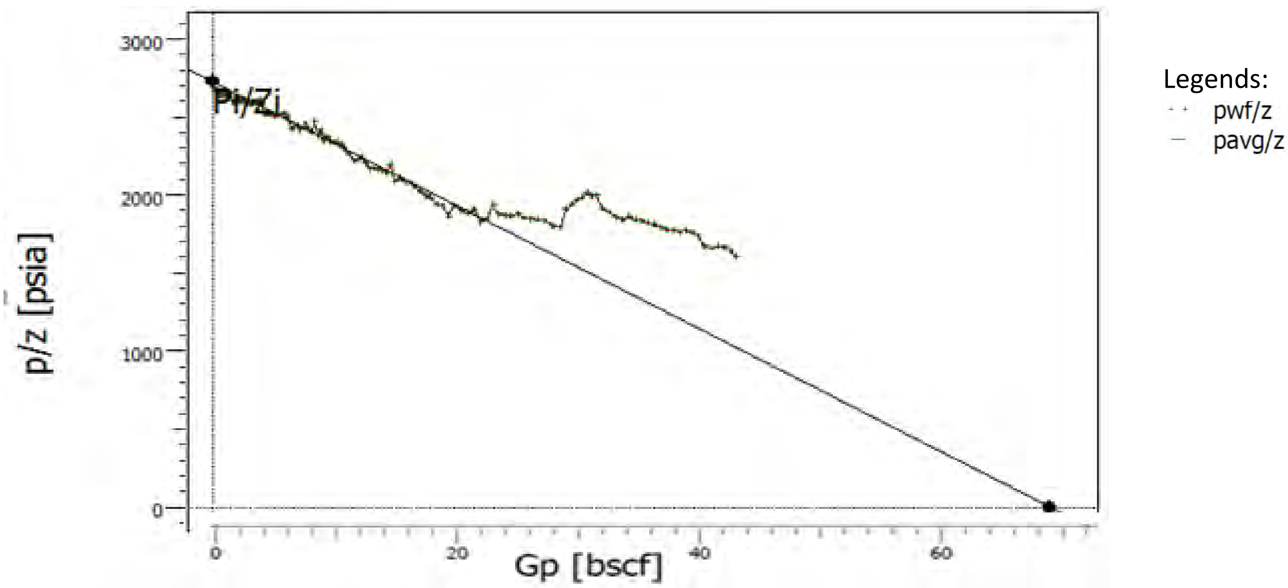


Figure 4.1.5: Arps plot.

The results obtained from this model are shown in Table 4.1.4.

Table 4.1.4: Results from Arps plot

STGIIP	75.50 BCF
STGIP	43.10 BCF
p_i	2668, psia

4.1.5. Production History Plot (Simulation):

The rate and flowing pressure decline history is shown in figure 4.1.5 after filtering the more noisy data, a linear relationship is observed in pressure and rate versus time plot. Decline trend for both rate and pressure are also visible at the very early and late stage of this production history. The models are plotted as continuous lines which jump back and forth when rate and pressure changes, models in the history plot forecast the well performance from the anticipated producing pressure, which eventually integrates skin with time.

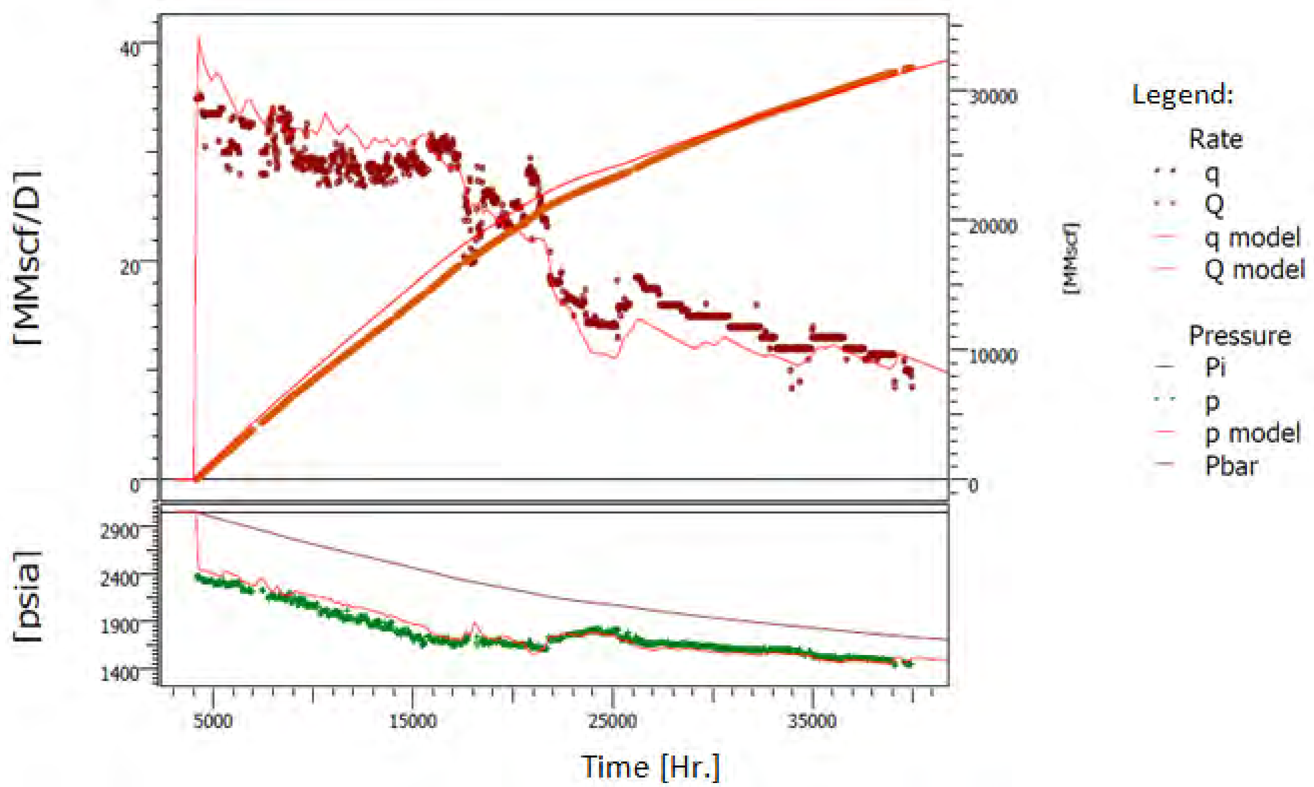


Figure 4.1.5: Production History plot.

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [18]. The well radius, porosity, reservoir thickness, perforation interval value are taken from operator company internal documents, which are input for modeling in this software. For decline analysis homogeneous reservoir with a fault boundary is assumed with vertical well for modeling and a very good model match with the actual plot is obtained as in Figure 4.1.5. The results obtained from this model are shown in Table 4.1.5.

Table 4.1.5: Results from history plot

K, average	19.4 md
S, Total Skin	.966
p_i	3050 psia
STGIIP	72.30 BCF
STGIP	41.72 BCF
L-no flow	2770 ft

4.2. Case study 1: Well test analysis of Well A#4

4.2.1. Log-Log / Type Curve

Log-Log plot is shown is Figure 4.2.1. From the figure radial flow is clearly seen in the dt [hr] range of 0.1 to 0.6. After 13hrs the boundary dominated flow observed for this well. Very low skin resulted from the lower magnitude of the hump of the derivative curve. Permeability is found 24 mD, as the derivative responses neither faster nor slower.

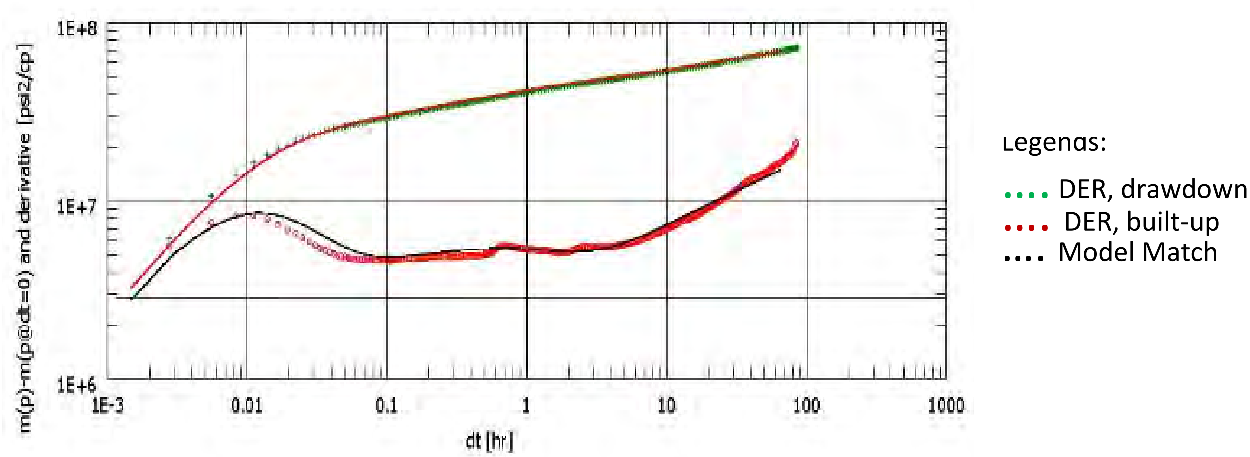


Figure4.2. 1: Log-Log plot

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [18]. The results obtained from this log-log plot are shown in Figure 4.2.1.

Table 4.2.1: Results from Type curve

K	25.1 md
S, Total Skin	.640
p_i	2118.30 psia
L-no flow	1973.00 ft

4.2.2. Horner Plot

Horner plot is shown is figure 4.2.2. From the figure p_{1hr} is 1903.00psia and p_i is 2118psia.

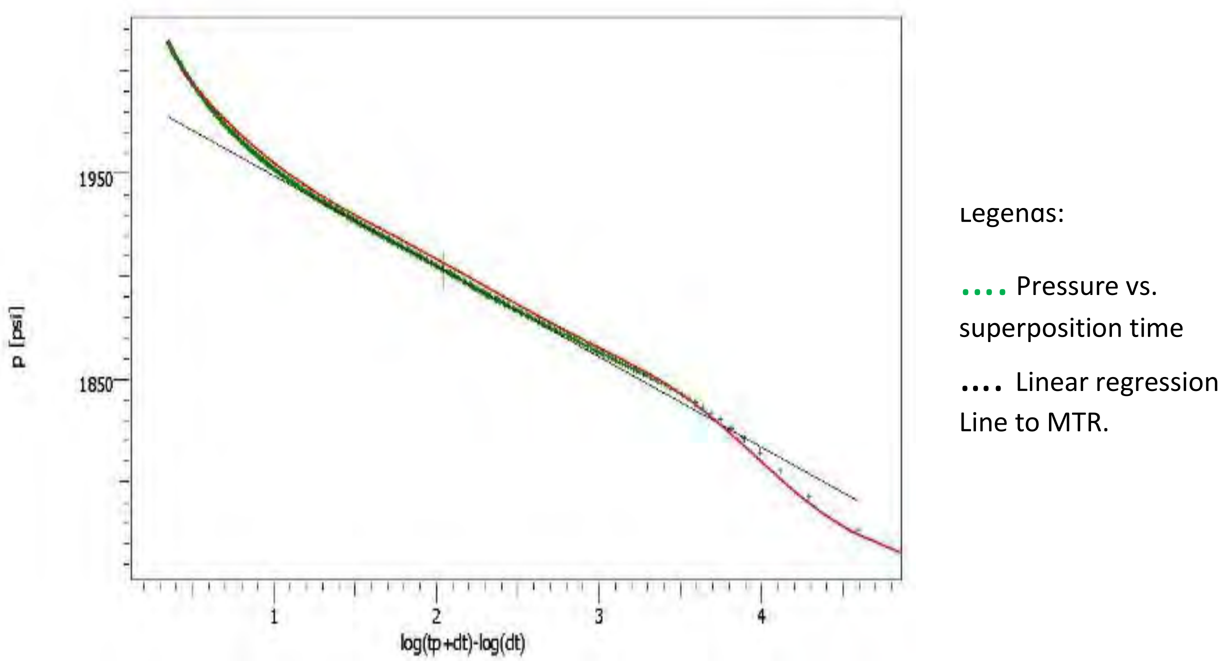


Figure4.2. 2: Horner plot

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [16].

Table 4.2.2: Results from Horner Plot.

K	16.50 md
S, Total Skin	1.27
p_i	2118 psia
p	1980 psi

4.2.3. Semi-log plot

Semi log plot is shown is figure 4.2.3. From the figure p^* is 1982.0psia.

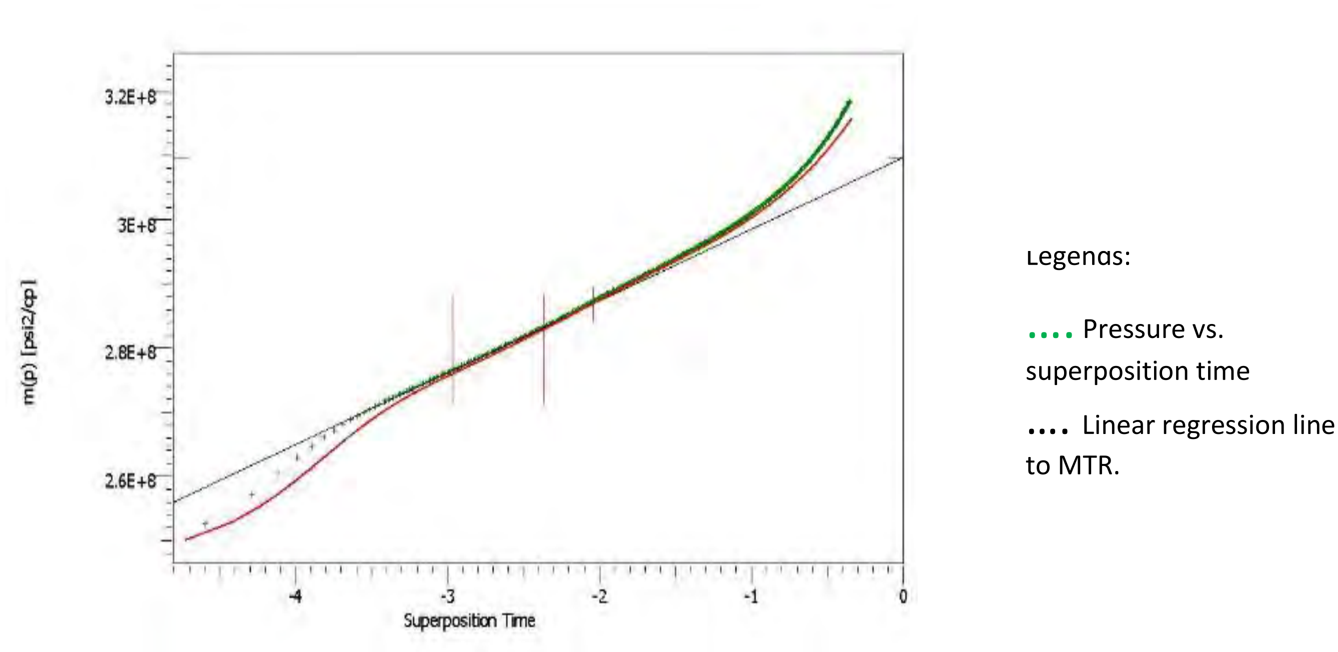


Figure4.2.3: Semi-log Plot

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [16].

Table 4.2.3: Results from Semi-log Plot.

K	25.1 md
S, Total Skin	-0.30
p_i	2118 psia

4.2.4. History plot (Simulation):

History plot with of flow after flow and pressure built up test is shown is figure 4.2.4. From the figure it is observed that the model did match with the actual test in the pressure built-up section but quite didn't match with the actual plot because of

non-dercy effect near wellbore.

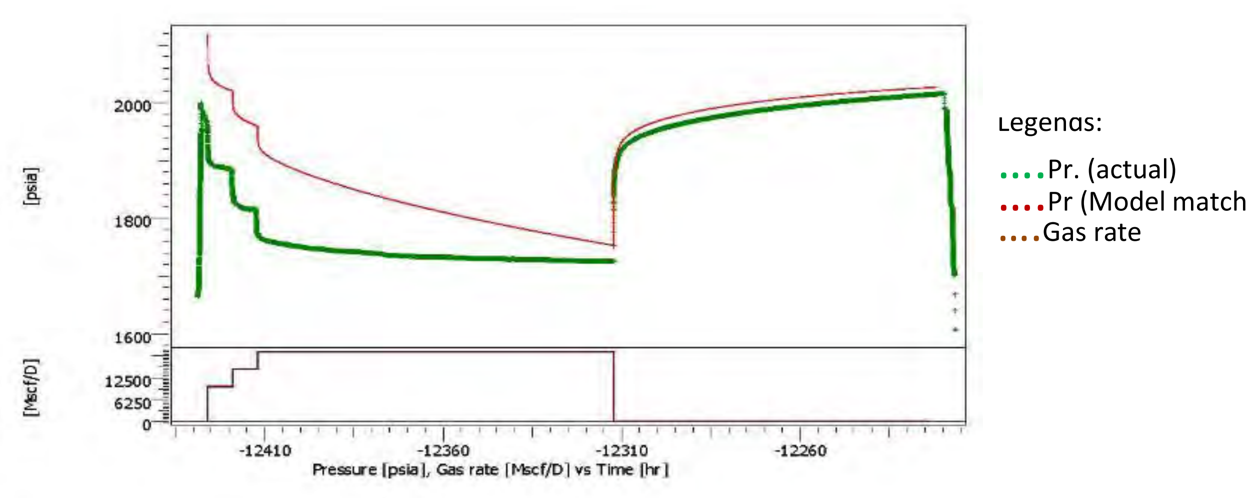


Figure4.2.4 History plot

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [16]. Homogeneous reservoir with a fault boundary is assumed with vertical well for modeling and a very good model match in the built-up region with the actual plot is obtained. The results obtained from this model are shown in Figure 4.2.4.

Table 4.2.4: Results from History plot

K	25.1 md
S, Total Skin	.64
p_i	2118.30 psia
L-no flow	1913.00 ft

4.3. Comparison of Results from Case Study 1:

The following table summarizes the results from deferent methods applied to estimate the reservoir properties.

Table 4.3: Results from DCA and Well Testing for case study 1:

Properties	DCA		Flowing MB	Well Testing		
	Fetkovich	Blasingame	P/z Plot	Log-Log/ Type curve	Horner Plot	Semi-log Plot
K, average	15.8	18.9 md	--	25.1 md	16.50 md	25.1 md
S, Total Skin	.238	.655	--	.640	1.27	-0.30
p_i	--	2650, psia	2668, psia	2118.30 psia	2118 psia	2118 psia
STGIIP	82.70	76.40 BCF	75.50 BCF	--	--	--
STGIP	50.30	13.10 BCF	43.10 BCF	--	--	--
L-no flow	--	--	--	1973.00 ft	--	--

Fetkovich and Blasingame, both methods have given relatively close results for permeability (15.8 md and 18.9 md) and skin (.238 and .655) as in table 4.3. The Gas initially in place obtained from decline curve analysis (Fetkovich and Blasingame) and traditional material balance are very close, so DCA are reliable means of calculating Gas in place. The remaining reserves from Fetkovich and material balance are close but Blasingame shows very low remaining reserves as in Table 4.3, this is due to rate-integral-derivative pattern recognition error as in Figure 4.1.2; this is a limitation of modern DCA. Gas initially in place was measured as 185 BCF by volumetric method is higher than the total reserves (gas initially in place and remaining reserves), this is probably due to seismic survey measurement error.

Traditionally well testing is reliable means of estimating permeability and skin. Permeability obtained from log-log plot, semi-log and Horner plot ranges from 16.50 md to 25.1 md, skin ranges -0.30 to 1.27. The permeability and Skin value obtained from DCA are within this range.

4.4. Case Study 2: Decline analysis of Well A#3

4.4.1. Fetkovich Type curve plot:

Fetkovich type curve matching is shown in figure 4.4.1. Complete boundary dominated flow regime is not established yet for this well. The permeability value obtained from Fetkovich analysis is not close to the value obtained from well test which is more reliable. However, the straight line in the transient region represents strong reservoir.

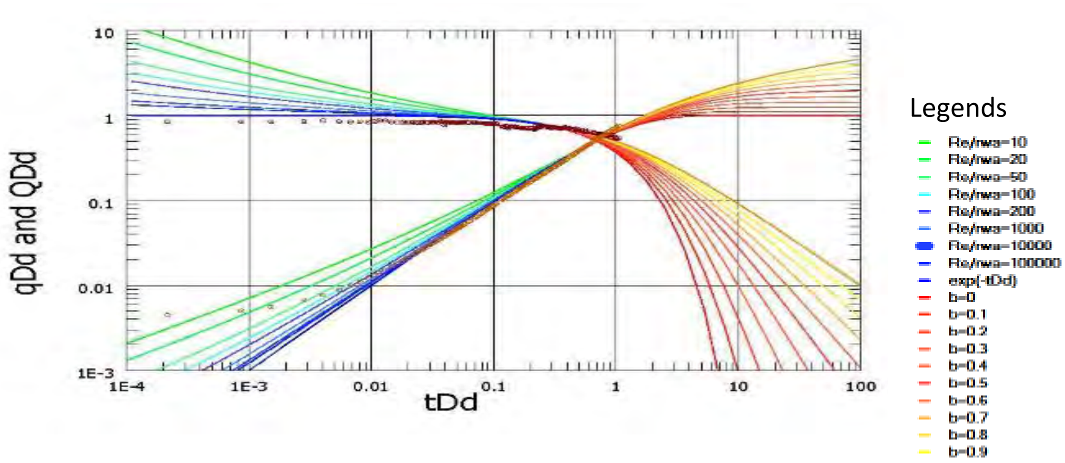


Figure 4.4.1: Fetkovich type curve plot.

The results obtained from this model are shown in Table 4.4.1.

Table 4.4.1: Results from Fetkovich type curve

K, average	36.9 md
S, Total Skin	1.737

STGIIP	131 BCF
STGIP	99.8 BCF

4.4.2. Blasingame Type curve Plot:

Blasingame type curve matching is shown in figure 4.4.2. . The ‘rate integral’ and ‘rate integral derivative’ aids more unique match in addition to the normalized rate type curves, this is why Blasingame shows better agreement with the results obtained from well test.

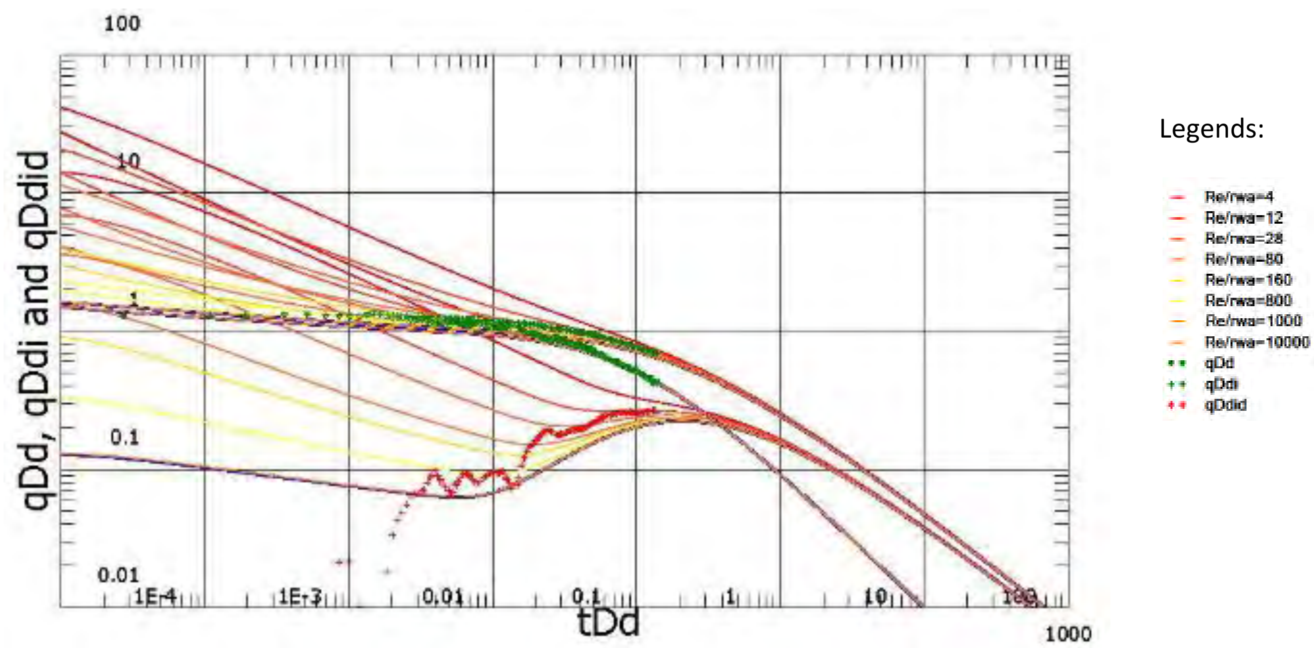


Figure 4.4.2: Blasingame type curve plot.

The results obtained from this model are shown in Table 4.3.2.

Table 4.4.2: Results from Blasingame type curve match.

K, average	51 md
S, Total Skin	1.215
p_i	2300, psia
STGIIP	175 BCF
STGIP	144 BCF

4.4.3. Arps Plot

Arps plot is shown in figure 4.4.3; a traditional analysis is performed as illustrated in this figure. Having analytical expression of rate and cumulative known, from a given abandonment rate this plot calculates the abandonment time and hence calculates the ultimate recovery.

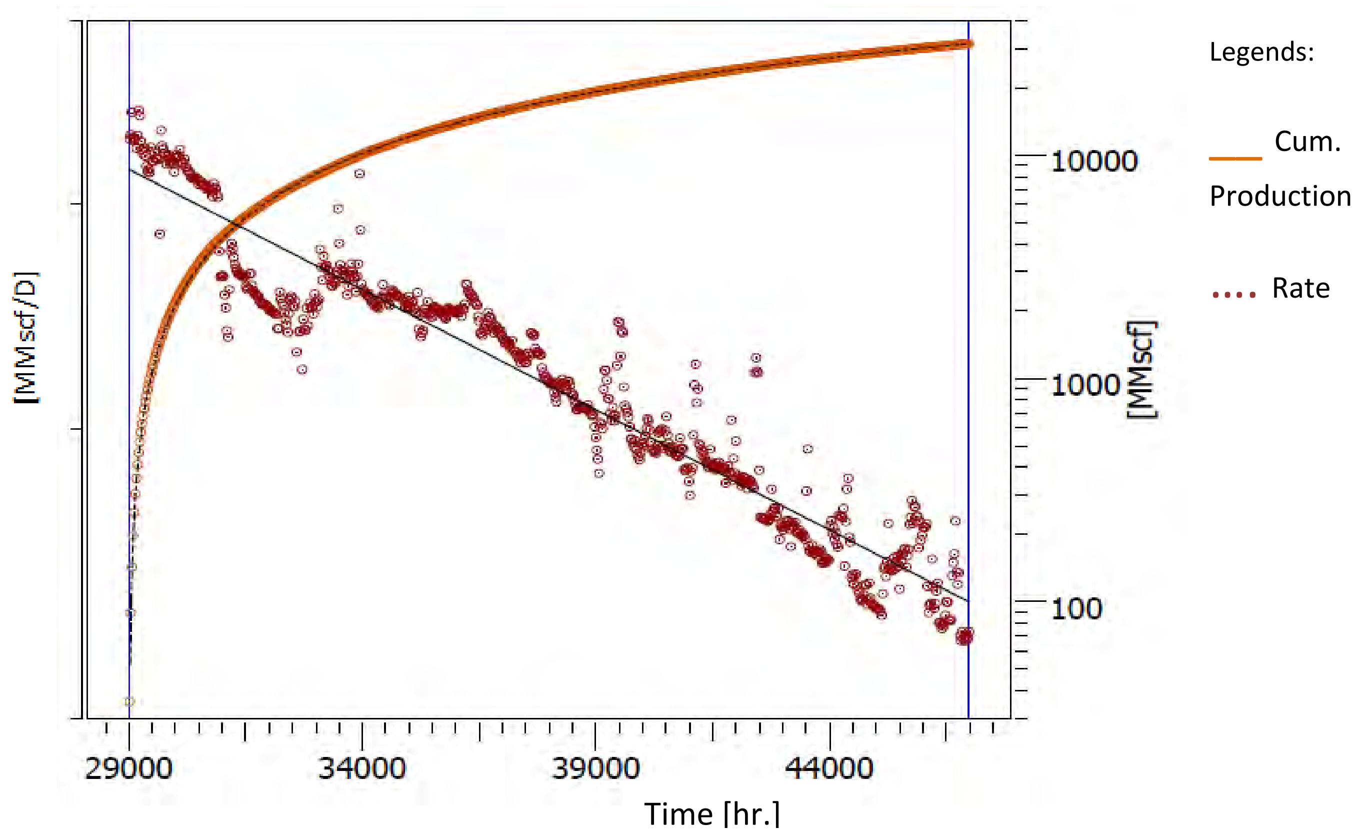


Figure 4.3.4: Arps plot.

The results obtained from this model are shown in Table 4.4.3.

Table 4.4.3: Results from Arps plot

Reserves	130 BCF
UR	180 BCF

4.4.4. P/z Plot

Flowing material balance, P/z vs. cumulative production (G_P) plot is shown in figure 4.4.4. This analysis was done to verify the results obtained from other methods, and it is found that the results obtained from other methods are close. Flowing material balance is used instead of classical material balance not to incur any revenue loss as no shut-in well is required.

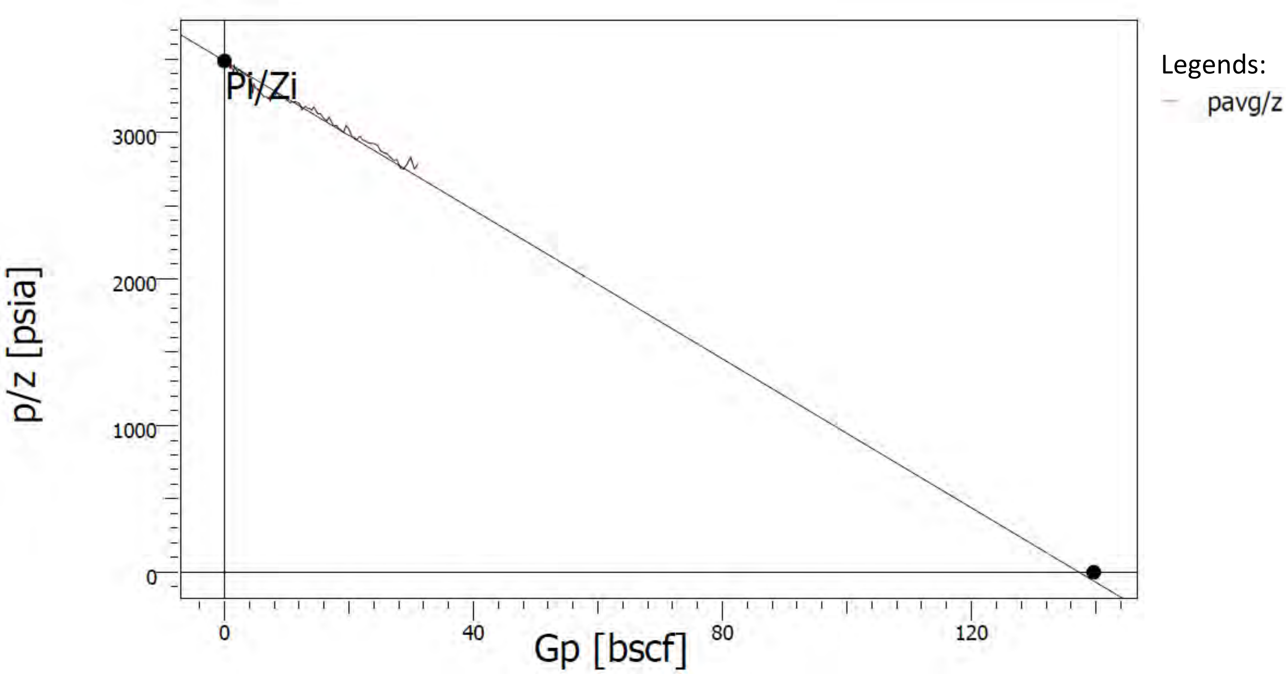


Figure 4.4.4: Arps plot.

The results obtained from this model are in Table 4.3.4.

Table 4.4.4: Results from Arps plot

STGIIP	150 BCF
STGIP	118 BCF
p_i	2300, psia

4.4.5. Production History Plot:

The rate and flowing pressure decline history is shown in figure 4.4.5 after filtering the more noisy data, however clear decline trend for both rate and pressure are visible at the very early and late stage of this production history. Decline trend for both rate and pressure are also visible throughout the production history of this well. The models are plotted as continuous lines which jump back and forth when rate and pressure changes, models in the history plot forecast the well performance from the anticipated producing pressure, which eventually integrates skin with time.

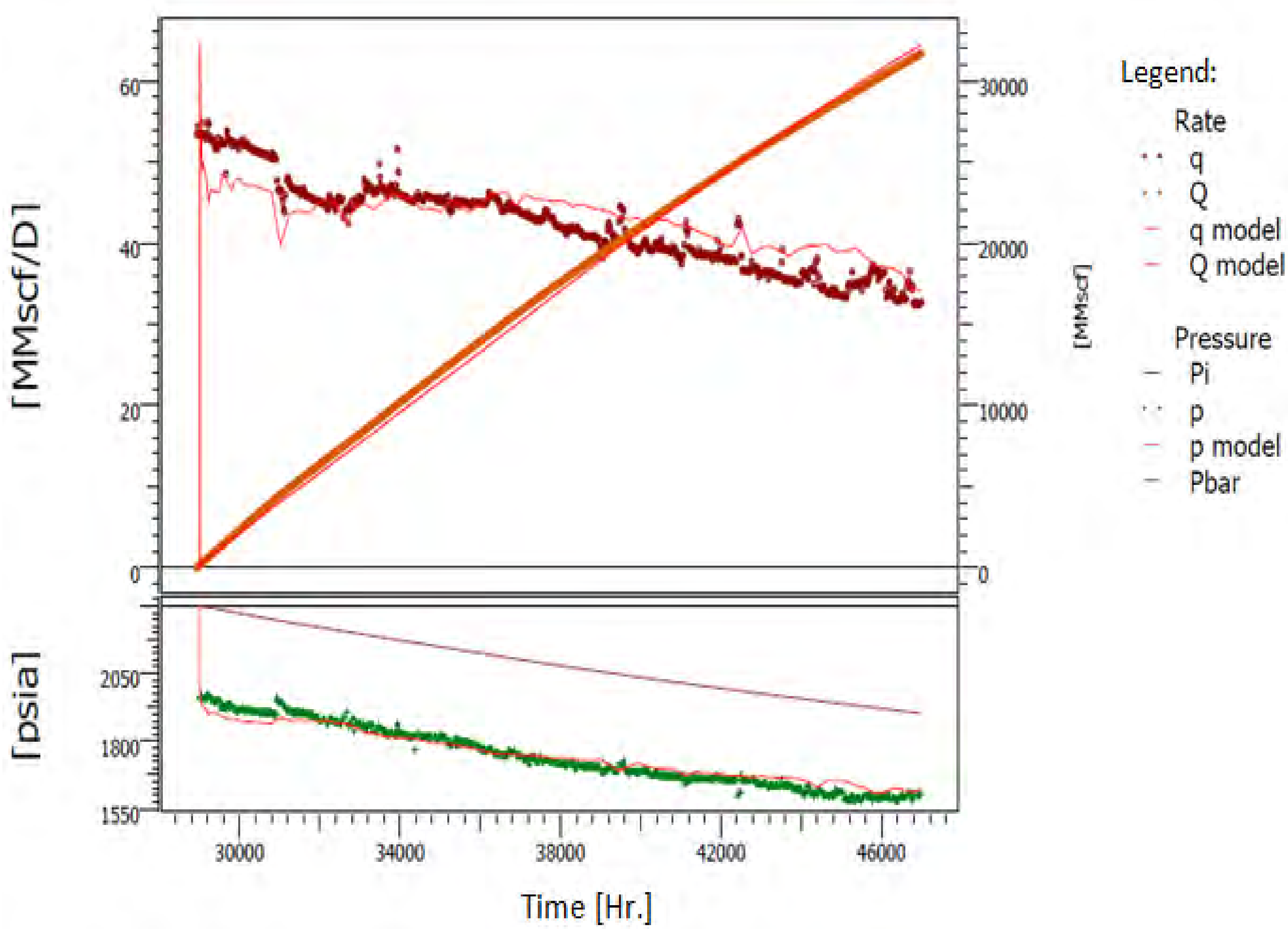


Figure 4.4.5: Production History plot.

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [16]. The well radius, porosity, reservoir thickness, perforation interval value are taken from operator company internal documents, which are input for modeling in this software. For decline analysis, homogeneous reservoir with a fault boundary is assumed with vertical well for modeling and a very good model match with the actual plot is obtained.

The results obtained from this model are shown in Table 4.4.5.

Table 4.4.5: Results from history plot

K, average	32.3 md

S, Total Skin	1.504
p_i	2300 psia
STGIIP	139 BCF
STGIP	118 BCF
L	2290 ft

4.5. Case study 2: Well test analysis of Well A#3

4.5.1. Log-Log / Type Curve

Log-Log plot is shown is figure 4.5.1. From the figure radial flow is clearly seen in the dt [hr] range of 0.2 to 0.6hrs. After 4hrs the boundary dominated flow observed for this well.

Permeability is found 83 mD, as the derivative responses is faster. Very low skin resulted from the lower magnitude of the hump of the derivative curve.

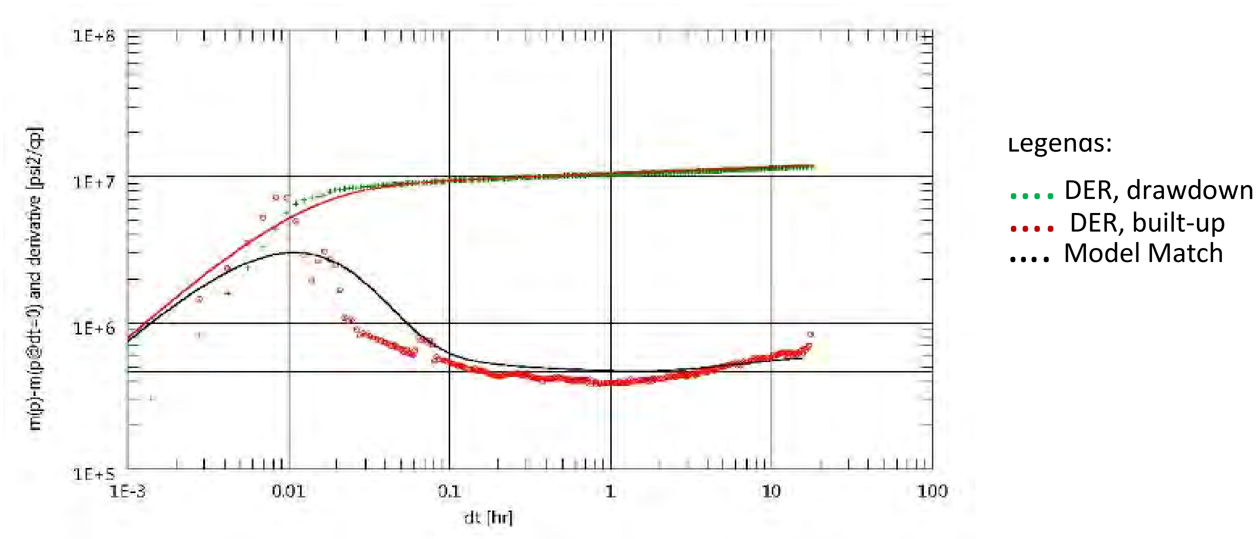


Figure4.5. 1: Log-Log plot

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [16]. The results obtained from this log-log plot are shown in Figure 4.5.1.

Table 4.5.1: Results from Type curve

K	83 md
S, Total Skin	2.97
p_i	1541 psia
L	2930 ft

4.5.2. Horner Plot

Horner plot is shown is figure 4.5.2. From the figure p_{1hr} is 1511psia.

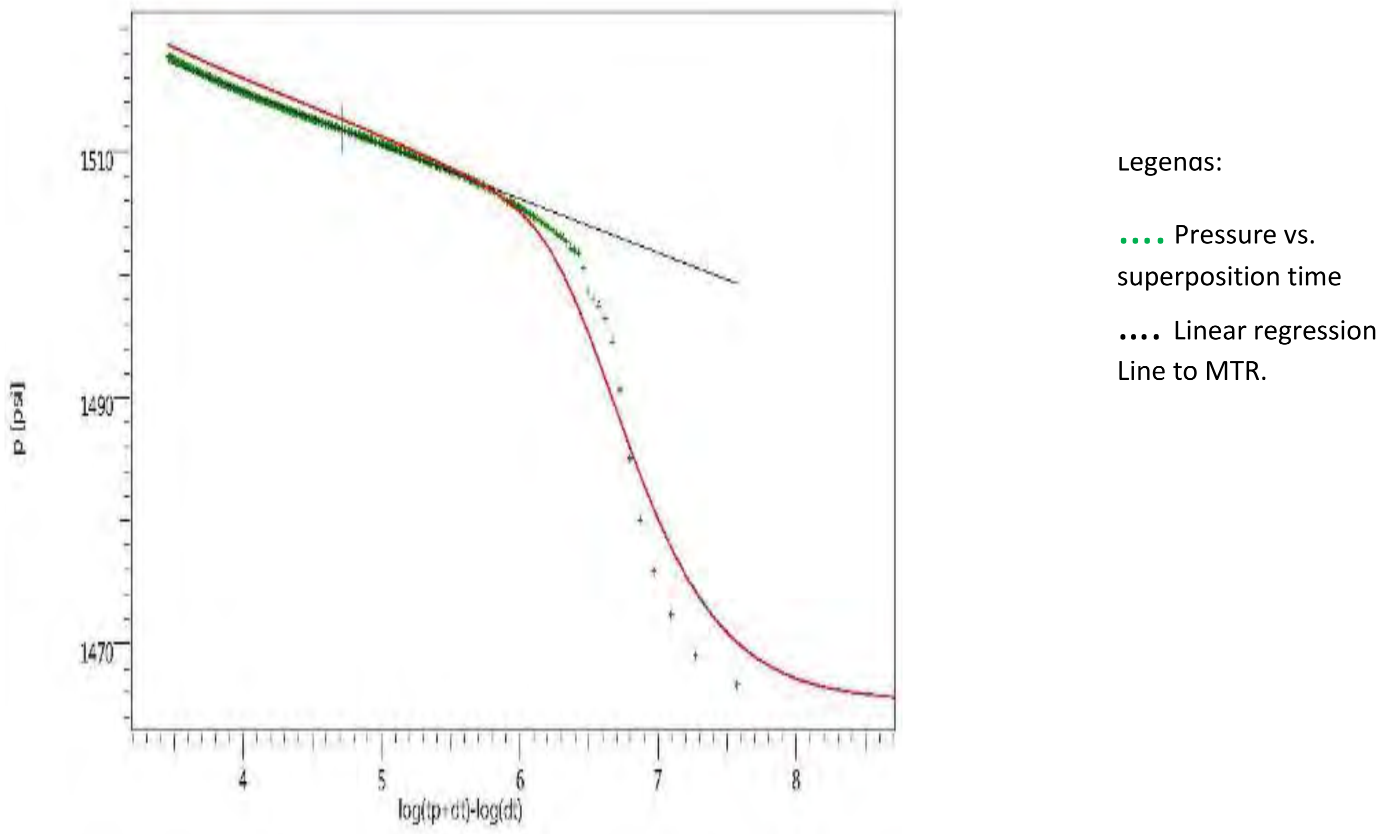


Figure4.5.2: Horner plot

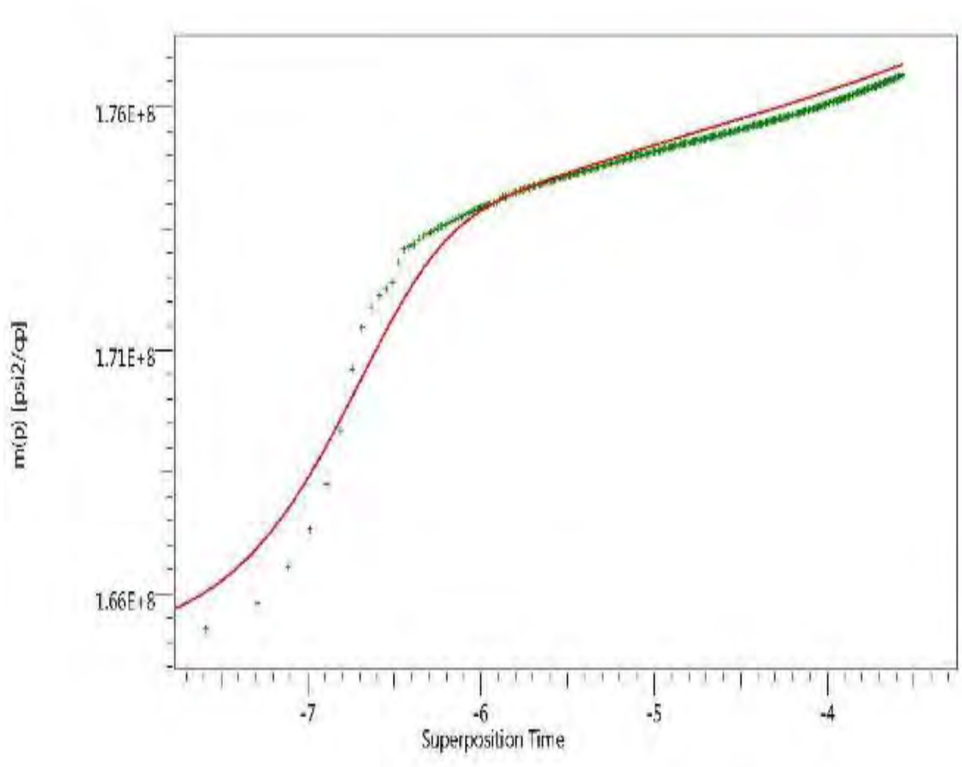
Homogeneous reservoir model with one fault is assumed with vertical well.

Table 4.5.2: Results from Horner Plot.

K	81 md
S, Total Skin	3.02
p_i	1541 psia
p	1480 psi

4.5.3. Semi-log plot

Semi log plot is shown is figure 4.5.3. From the figure p^* is 1982.0psia.



Legends:

.... Pressure vs. superposition time

.... Linear regression line to MTR.

Figure4.5.3: Semi-log Plot

Homogeneous reservoir model with one fault is assumed with vertical well.

Table 4.5.3: Results from Semi-log Plot.

K	93 md
S, Total Skin	2.97
p_i	1541 psia

4.5.4. History plot

History plot with of flow after flow and pressure built up test is shown is figure 4.5.4. From the figure it is observed that the model did match with the actual test in the pressure built-up section and with the draw-down section.

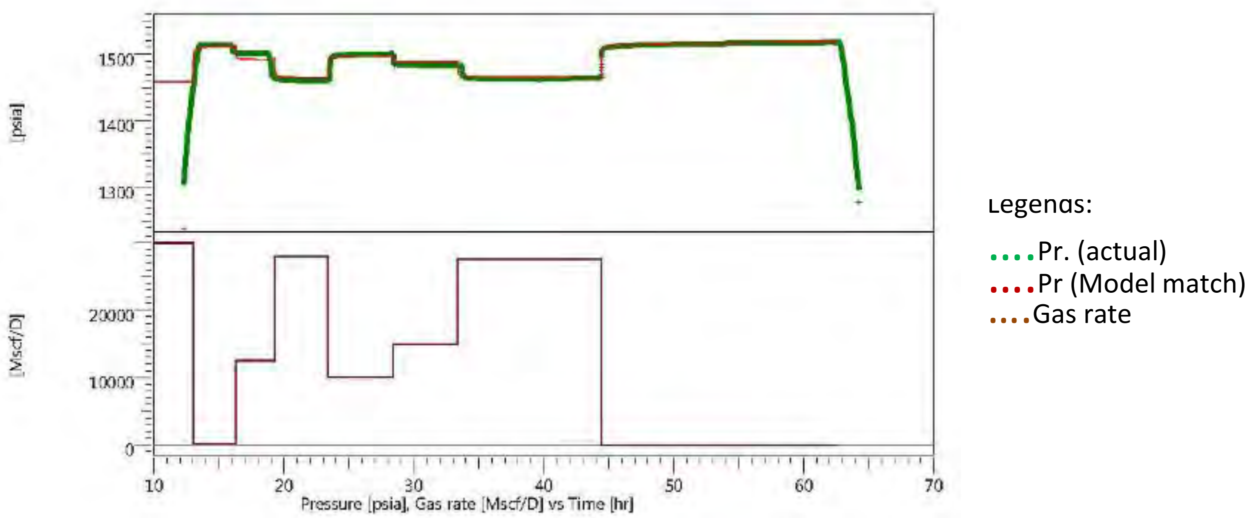


Figure4.5.4 History plot

From seismic surveys a fault clearly seen and the well is vertical as in the well directional report [16]. Homogeneous reservoir with a fault boundary is assumed with vertical well for modeling and a very good model match with the actual plot is obtained.

The results obtained from this model is tabulated as-

Table 4.4.4: Results from History plot

K	83 md
S, Total Skin	2.97
p_i	1541 psia
L	2930 ft

4.6. Comparison of Results from Case Study 2:

Table 4.6 summarizes the results from deferent methods applied to estimate the reservoir properties. Permeability obtained from Fetkovich type curve is 36.9 md and from Blasingame type curve is 51 md, they are not very close however Blasingame is more reliable, as this method of decline curve analysis is considering bottom hole pressure variation in transient region. Both methods have given relatively close results for skin (1.737 and 1.215) as in table 4.6. The Gas initially in place obtained from Fetkovich type curves (131 BCF) is not consistent with the value Blasingame type curves shows (174 BCF), however traditional material balance shows 150 BCF and is very close to the value from Blasingame type curves. As Blasingame is more reliable than Fetkovich so it is reliable means of calculating Gas in place. The remaining reserves from Fetkovich, Blasingame and material balance are ranges from 99.88 BCF to 144 BCF.

Table 4.6: Results from DCA and Well Testing for case study 2:

Properties	DCA		Flowing MB	Well Testing		
	Fetkovich	Blasingame	P/z Plot	Log-Log/ Type curve	Horner Plot	Semi-log Plot
K, average	36.9	51 md	--	83 md	81 md	93 md
S, Total Skin	1.737	1.215	--	2.97	3.02	2.97
p_i	--	2300, psia	2300 psia	1541 psia	1541 psia	1541 psia
STGIIP	131 BCF	175 BCF	150 BCF	--	--	--
STGIP	99.88 BCF	144 BCF	118 BCF	--	--	--
L-no flow	--	--	--	2930 ft	--	--

Traditionally well testing is reliable means of estimating permeability and skin. Permeability obtained from log-log plot, semi-log and Horner plot ranges from 81 md to 93 md, skin ranges -2.97 to 3.02. The Skin values obtained from DCA (ranges 1.737 to 1.215) are very close to the values obtained from well testing. Permeability value from Blasingame (51 md) is not very close to the permeability value obtained from well testing (83 md); however to some extend DCA can still be used to make assumption on permeability.

Chapter-5: Conclusions and Recommendations

This chapter discusses the summary of the results from deferent methods applied to estimate the reservoir properties, conclusions and recommendations.

5.1 Conclusion

- Decline curve analysis (Fetkovich and Blasingame type curves) is capable of predicting reservoir properties with an acceptable accuracy. The results are validated with the results form well testing (Pressure built up analysis).
- Case study 1 shows, different advance decline curve analysis (Fetkovich and Blasingame) is providing relatively close estimate of k (15.8 from Fetkovich and 18.9 from Blasingame) and STGIIP (82.7 BCF from Fetkovich and 76.4 BCF from Blasingame). STGIIP from MB is 75.50 BCF, which supports results from DCA. The Gas volume initially in place from volumetric method was 185BCF is significantly higher than the total reserves 138 BCF by DCA & 185.60 BCF by MB, this is due to seismic survey data quality issue.
- Case study 1 also shows acceptable degree of reliability and accuracy of decline curve analysis methods in determining reservoir properties. From DCA skin is ranges from 0.238 to 0.655 and from PBU it is ranges from -0.30 to 1.27. Permeability obtained from log-log plot, semi-log and Horner plot ranges from 16.50md to 25.1md, permeability obtained from Fetkovich and Blasingame type curves are within this range.
- From the results obtained from case study 2 (Well A#3) it can be concluded that the decline analysis is still correct to some degree of reliability for a gas well for estimating reservoir properties. Skin from well testing ranges from 2.97 to 3.02 and skin from DCA ranges from 1.215 to 1.737, which is within the range and validate DCA to estimate skin. Permeability values from DCA, however vary significantly from that obtained from PTA. There is not enough information to explain this difference. However, to have more confidence with results core data & geological reports may be helpful. Moreover, DCA can

yield GIIP, Which cannot be obtained from PTA. GIIP then can be checked by Volumetric/MB techniques.

- It can be concluded that if there is less noisy data and decline trend through the well life, DCA can be the reliable means of estimating such reservoir properties, especially when the results of more than one type curves are available.

5.2 Recommendation:

- As pointed out through this project work the degree of reliability of DCA is quite good provided that the data is less noisy, the noise usually results from frequent intervention, not letting the reservoir behavior naturally. Moreover liquid slugging also introduce a lot of noise. Therefore cleaning up the data to discern the true trend of the reservoir is the main challenge. Researcher may be undertaken to find techniques to reduce noise, and to discern the true reservoir trend, so for continuous well surveillance and monitoring it is recommended to use advance decline analysis, this way well testing frequency can be reduced for the said purpose.
- Installation of down-hole pressure and temperature gauge during well completion operation is recommended. This way high frequency down-hole data can be collected and can be used for decline analysis.
- As the skin factors from all analysis are within acceptable range of 0-5, which does not indicate severe damage around wellbore, so no stimulation is recommended.

References:

1. Arps, J. J.: *"Analysis of Decline Curves,"* Trans. AIME., 1945. Volume 160.

2. Ikoku, Chi. U (1984): *"Natural Gas Reservoir Engineering"*. Krieger Publishing Company, Kreiger Drive, Malabar, Florida, USA.

3. M. Ebrahimi; *''Enhenced Estimation of Reservoir Parameters Using Decline Curve Analysis''* SPE 133432, SPE, ACECR-Production Technology Research Institute.

4. Fetkovich, M. J., Vienot, M. E., Bradley, M. D., and Kiesow, U. G., "*Decline Curve Analysis Using Type Curves: Case Histories*," SPE 13169, SPE Formation Evaluation, December 1987.

5. Fetkovich, E. J., Fetkovich, M. J., and Fetkovich, M. D.: "*Useful Concepts for Decline Curve forecasting, Reserve Estimation, and Analysis,*" SPE Reservoir Engineering, February 1996.

6. M.J. Fetkovich. (1980): "*Decline Curve Analysis using Type curve"* SPE-4629-PA.

7. Blasingame, T. A., McCray, T. L., and Lee, W. J., *"Decline Curve Analysis for Variable Pressure Drop/Variable Flow rate Systems*," SPE 21513, SPE Gas Technology Symposium, Houston, TX, January 1991.

8. Ahmed, Terek : "*Reservoir Engineering Handbook''* Elsevier.

9. Satter, Abdus; Iqbal, Ghulam M.: Buchwalter, James L.; *“Practical Enhanced Reservoir Engineering-Assisted with Simulated software, Chapter 12-Material Balance Method and application”* (2008) PennWell.

10. L. Mattar, D.M.Anderson, (2003): *‘’A Systematic and Comprehensive Methodology for Advanced Analysis of Production Data’.* SPE-84472.

11. John Lee (1982): “*Well Testing”*. Society of petroleum engineers of AIME, New York, Dallas, Texas, USA.

12. Chaudhry, Amant U. (2003*):”Gas Well Testing Handbook”* Elsevier.

13. Matthews, C.S and Russell, D.G.(1967): “*Pressure built and flow test in wells, Monograph series”,* SPE, Dallas, Texas, USA.

14. Horner, D.R.: *“Pressure built-up in wells; Proc., Third World Pet. Org*., The Hague (1951) Sec II. 503-523; also “Pressure Analysis Methods, Reprint Series, SPE, Dallas (1967) 9, 25-43.

15. A.C. Gringarten, et al.: *‘’A Comparison between Different Skin and Wellbore Storage Type-Curves for Early-Tome Transient Analysis’’.* Paper SPE 8205,Presented at the 54th Annual Technical Conference and Exhibition of SPE, Las Vegas, Nov., Sept., 23–26 (1979).

16. Bourdet et at: ‘’ Well Testing Analysis – The Use Of Advanced Interpretation Models’’ Elsevier.

17. Horne, R.N.(1995): ‘*Modern Well Test Analysis’’*.

18. RLLCP (recommended location logging and coring plan) and other internal documents of the operator company.

Appendix-A

Production History Listing of Well A#4

History listings | A#4_final

Company | Field ABC

Well A#4 | Test Name / #

qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr
34.9	4152	30	5568	32.6	6960	33.5	8784	28.51	10320
34.9	4176	30	5592	32.6	6984	33	8808	28.32	10368
34.9	4200	30	5616	28	7416	33	8832	29.35	10392
35	4224	30	5640	30	7440	32	8856	29.34	10416
35	4248	30	5664	30	7464	31	8880	29.19	10440
35	4272	28.68	5688	28	7488	32	8904	28.8	10464
35	4296	30	5712	28	7536	31.31	8928	29.21	10488
35	4320	30	5736	30	7560	31.42	8952	27.47	10536
35.28	4344	30.27	5760	30	7584	30.3	8976	28.18	10560
35	4368	30	5784	30	7608	32	9000	29.28	10584
35	4392	28.42	5808	30.28	7632	30	9024	28.27	10608
35	4416	30	5832	28	7656	29.01	9048	28.15	10632
33.7	4440	31	5856	30	7680	29	9072	27.36	10656
33.5	4464	33	5880	30.55	7704	29	9096	27.52	10680
33.5	4488	30.75	5904	32.5	7728	29	9120	27.32	10728
33.5	4512	30.75	5928	31.78	7752	29.01	9144	27.07	10752
33.5	4536	30.75	5952	32	7776	28.58	9192	26.98	10800
33.35	4560	30.75	5976	32	7800	29.5	9216	28.34	10824
30.5	4584	30.75	6000	29	7824	29	9240	28.8	10872
33.5	4608	33.25	6024	32	7848	29.9	9264	29.59	10896
33.5	4632	30.5	6048	33.05	7872	29.5	9288	29.53	10920
33.5	4656	30.5	6072	32.95	7896	29	9312	29.6	10944
33.5	4680	30.5	6096	33	7920	28.9	9336	29.63	10968
33.5	4704	30.5	6120	32.5	7944	28.9	9360	29.24	10992
33.5	4728	30.5	6144	33.5	7968	29.83	9384	29.65	11064
33.5	4752	30.5	6168	34	7992	28.57	9408	29.73	11088
33.5	4776	30.5	6192	31.11	8016	29.05	9432	29.12	11112
33.5	4800	30.5	6216	30.5	8040	28.5	9456	30.77	11136
33.5	4824	30.5	6240	31.08	8064	28.4	9480	29.99	11160
33.5	4848	30	6264	30	8088	28.5	9504	29.76	11184
33.5	4872	30	6288	31.5	8112	28.4	9528	27.2	11208
33.5	4896	30	6312	30.42	8136	29.49	9552	28.32	11232
33.5	4920	28	6336	29.41	8160	30.3	9576	28.43	11256
33.5	4944	33	6360	28.46	8184	29.25	9600	28.51	11280
33.5	4968	33	6384	29.09	8208	29.5	9624	28.64	11304
33.5	4992	33	6408	28.74	8232	32	9648	28	11328
33.5	5016	33	6432	30	8256	31.5	9672	27.39	11352
33.5	5040	33	6456	33	8280	32.6	9696	28.74	11376
33.5	5064	32.5	6480	33	8304	29.2	9720	30.23	11400
33.5	5088	32.5	6504	33.1	8328	28.53	9768	30.6	11424
33.5	5112	32.6	6528	33	8352	29.26	9792	29.53	11448
33.5	5136	32.6	6552	33	8376	29.45	9816	30	11472
33.5	5160	32.6	6576	34	8400	28.72	9840	30.05	11496
33.5	5184	32.5	6600	33.2	8424	28.9	9864	29.23	11520
33.5	5208	32.5	6624	34	8448	28.83	9888	29.86	11544
33.5	5232	32.5	6648	34	8472	29.54	9912	29.44	11568
31	5256	32.5	6672	33	8496	28.99	9936	28.89	11592
33.5	5280	32.79	6696	32	8520	28.99	9960	29.37	11616
33.5	5304	32.5	6720	32.2	8544	28.3	10056	29.72	11640
33.92	5328	32.5	6744	32	8568	28.78	10080	27.88	11664
34	5352	32.5	6768	33	8592	29.5	10104	28.23	11736
34	5376	32.6	6792	33.5	8616	29.31	10128	28.6	11760
34	5400	32.31	6816	32.5	8640	28.64	10152	28.26	11784
34	5424	32.5	6840	31.5	8664	28.94	10176	28.61	11808
34	5448	32.52	6864	31	8688	28.58	10200	28.73	11832
34	5472	32.5	6888	32.5	8712	28.82	10224	27.47	11856
30	5496	32.61	6912	33.5	8736	28.4	10248	30.12	11880
30	5544	32.6	6936	33	8760	27.11	10296	28.71	11904

History listings					A#4_final				
Company	Well A#4				Field ABC	Test Name / #			

qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr
29.53	11928	29.58	13656	28.69	15264	30.86	16824	27.26	18456
29.07	11952	29.13	13680	28.51	15288	30.43	16848	28.55	18480
29.51	11976	27.97	13704	28.49	15312	30.66	16872	25.58	18504
29.52	12000	29.52	13728	28.24	15336	28.43	16896	25.7	18528
28.26	12048	29.8	13752	28.75	15360	28.77	16920	26.34	18552
29.13	12072	28.04	13776	28.25	15384	30.55	16944	25.17	18576
28.42	12096	28.51	13800	28.82	15408	30.05	16968	26.02	18600
28.47	12120	28.47	13824	28.98	15432	31.14	16992	26.31	18624
28.52	12144	28.5	13848	28.88	15456	30.77	17016	26.43	18648
28.74	12168	27.27	13872	28.09	15480	29.81	17040	26.04	18672
27.04	12192	28.35	13896	28.06	15504	29.51	17064	26.51	18696
28.09	12216	27.46	14112	28.53	15528	29.41	17088	26.44	18720
28.71	12240	29.42	14160	28.69	15552	29.51	17112	26.53	18744
28.68	12264	29.21	14184	28.04	15576	29.74	17136	26.16	18768
28.1	12288	29.36	14208	28.36	15768	29.85	17160	26.37	18792
28.01	12312	29.37	14232	30.77	15792	29.55	17184	26.16	18816
27.21	12336	29.34	14256	30.77	15816	29.46	17208	25.97	18840
27.42	12408	29.64	14280	30.61	15840	28.57	17232	25.89	18864
27.52	12456	29.46	14304	30.9	15864	28.86	17256	25.89	18888
27.01	12480	28.86	14328	30.25	15888	29.77	17280	26.23	18912
26.93	12552	29.03	14352	30.94	15912	29.7	17304	26.23	18936
28.53	12720	28.74	14376	31.65	15936	20.46	17568	26.56	18960
28.84	12744	29.34	14400	31.34	15960	23.77	17592	25.45	18984
28.84	12768	29.29	14424	31	15984	26.02	17616	25.48	19008
28.86	12792	29.09	14448	30.92	16008	25.02	17640	25.8	19032
28.94	12816	28.83	14472	30.64	16032	25.51	17664	25.51	19056
28.43	12840	28.75	14496	30.48	16056	25.51	17688	25.36	19080
28.22	12864	28.79	14520	30.55	16080	25.26	17712	25.99	19104
27.54	12912	28.04	14544	30.89	16104	26.51	17736	25.89	19128
28.24	12936	28.92	14568	30.89	16128	24.52	17760	25.79	19152
28.94	12960	29.19	14592	30.16	16152	23.77	17784	25.33	19176
28.79	12984	29.18	14616	30.25	16176	24.58	17808	25.64	19200
28.95	13008	28.46	14640	30.4	16200	27.57	17832	25.64	19224
28.53	13032	28.63	14664	30.44	16224	27.37	17856	23.67	19248
28.43	13056	28.74	14688	30.86	16248	22.87	17880	23.26	19272
27.29	13080	28.33	14712	30.21	16272	21.17	17904	23.8	19296
27.6	13104	28.76	14736	30.25	16296	19.8	17928	23.71	19320
27.76	13128	28.63	14760	29.53	16320	19.8	17952	23.79	19344
28.6	13152	29.38	14784	30.87	16344	20.03	17976	23.5	19368
28.69	13176	29.76	14808	30.6	16368	20.16	18000	23.44	19392
27.38	13200	27.96	14832	30.16	16392	20.01	18024	23.87	19416
28.54	13224	29.62	14856	31.05	16416	20.52	18048	24	19440
28.63	13248	29.83	14880	30.1	16440	20.2	18072	24.42	19464
28.37	13272	28.71	14904	31.23	16464	19.97	18096	25.16	19488
28.27	13296	29.36	14928	31.03	16488	20.5	18120	23.48	19512
27.85	13320	29.78	14952	31.19	16512	20.8	18144	23.87	19536
27.42	13344	29.82	14976	31.03	16536	21.97	18168	23.57	19560
27.65	13368	29.69	15000	30.82	16560	24.78	18192	23.86	19584
27.43	13392	30.1	15024	30.86	16584	28.69	18216	23.76	19608
27.57	13416	30.86	15048	30.75	16608	27.39	18240	23.14	19632
27.53	13440	28.58	15072	31.08	16632	23.05	18264	24.37	19656
27.45	13464	28.9	15096	31.43	16656	22.86	18288	23.93	19680
28.52	13488	29.52	15120	30.91	16680	23.27	18312	23.49	19704
28.42	13512	29.24	15144	30.56	16704	22.59	18336	23.47	19728
27.64	13536	29.38	15168	30.15	16728	22.87	18360	23.42	19752
27.13	13584	29.53	15192	30.38	16752	22.27	18384	23.42	19776
28.71	13608	28.93	15216	30.46	16776	22.6	18408	23.5	19800
28.95	13632	28.73	15240	30.51	16800	23.51	18432	23.53	19824

History listings	A#4_final
Company Well A#4	Test Name / #
Field ABC	

qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr
23.41	19848	27.28	21240	16.62	22872	14.22	24288	15.88	25680
23.01	19872	26.1	21264	16.55	22896	14.12	24312	15.9	25704
23.19	19896	24.87	21288	16.46	22920	14.25	24336	15.9	25728
23.02	19920	26.68	21312	16.55	22944	14.13	24360	16.17	25752
23.18	19944	25.34	21336	16.55	22968	14.04	24384	16.05	25848
25.24	19968	25.24	21360	16.55	22992	14.26	24408	18.51	26160
25.22	19992	25.47	21384	16.5	23016	14.45	24432	18.51	26184
25.13	20016	25.89	21408	15.04	23040	14.25	24456	18.51	26208
25.31	20040	24.25	21432	16.43	23088	14.24	24480	18.51	26232
25.27	20064	23.87	21456	16.33	23112	14.38	24504	18.51	26256
25.03	20088	23.92	21480	16.48	23136	14.25	24528	18.51	26280
25.25	20112	23.91	21504	16.28	23160	14.32	24552	18.51	26304
25.15	20136	23.82	21528	16.18	23184	14.32	24576	18.51	26328
25.2	20160	23.7	21552	16.38	23208	14.26	24600	18.51	26352
25.36	20184	23.88	21576	16.23	23232	14.16	24624	18.51	26376
25.15	20208	23.9	21600	16.1	23256	14.14	24648	18.51	26400
24.99	20232	23.81	21624	16.09	23280	14.12	24672	18.01	26424
25.49	20256	23.72	21648	16.07	23304	14.14	24696	18.01	26448
24.97	20280	23.82	21672	16.13	23328	14.15	24720	18.01	26472
24.89	20304	23.23	21696	16.17	23352	14.15	24744	18.01	26496
25.03	20328	23.19	21720	16.08	23376	14.16	24768	18.01	26520
24.96	20352	18.47	21816	16.02	23400	14.17	24792	18.01	26544
24.89	20376	20.87	21840	16	23424	14.11	24816	17.51	26568
24.95	20400	18.67	21864	15.98	23448	14.12	24840	17.51	26592
23.5	20424	18.27	21888	15.96	23472	14.14	24864	17.51	26616
23.51	20448	17.97	21912	15.93	23496	14.1	24888	17.51	26640
23.3	20472	18.07	21936	16.77	23520	14.26	24912	17.51	26664
24.08	20496	18.33	21960	16.22	23544	14.24	24936	17.51	26688
24.1	20520	18.04	21984	16.27	23568	14.21	24960	17.51	26712
24.12	20544	18.22	22008	16.25	23592	14.22	24984	17.51	26736
24.11	20568	18.11	22032	16.24	23616	14.03	25008	17.51	26760
23.93	20592	18.21	22056	17.44	23640	14.34	25032	17.51	26784
23.97	20616	18.11	22080	15.22	23664	14.22	25056	17.51	26808
23.49	20640	18.05	22104	14.84	23688	14.12	25080	17.51	26832
23.5	20664	18.05	22128	14.35	23712	14.01	25104	17.51	26856
23.56	20688	18.01	22152	14.41	23736	14.3	25128	17.51	26880
28.01	20712	18.22	22176	14.31	23760	14.27	25152	17.51	26904
28.25	20736	18.03	22200	14.32	23784	14.01	25176	17.51	26928
28.33	20760	18.05	22224	14.31	23808	14.05	25200	17.51	26952
27.99	20784	18.03	22248	14.31	23832	18.27	25224	17.51	26976
28.43	20808	18.07	22272	14.37	23856	13.03	25248	17.51	27000
28.2	20832	18.1	22296	14.37	23880	15.91	25272	17.51	27024
29.47	20856	18.23	22320	14.34	23904	15.61	25296	17.51	27048
28.66	20880	18.04	22344	14.34	23928	15.76	25320	17.51	27072
27.24	20904	18.04	22368	14.58	23952	15.7	25344	17.51	27096
27.67	20928	18.86	22392	14.35	23976	15.88	25368	17.51	27120
22	20952	19.01	22416	14.31	24000	15.01	25392	17.51	27144
28.28	20976	16.22	22464	14.32	24024	15.88	25416	17.51	27168
27.14	21000	17.27	22488	14.31	24048	15.87	25440	17.51	27192
27.27	21024	16.51	22656	14.56	24072	15.88	25464	17.51	27216
28.19	21048	17.08	22680	14.89	24096	15.9	25488	17.51	27240
27.37	21072	16.43	22704	14.91	24120	15.88	25512	17.51	27264
27.67	21096	16.82	22728	14.76	24144	15.91	25536	17.01	27288
27.52	21120	16.59	22752	14.34	24168	15.81	25560	17.01	27312
27.34	21144	16.46	22776	14.31	24192	16.53	25584	17.01	27336
27.67	21168	16.53	22800	14.25	24216	15.7	25608	16.01	27360
27.7	21192	16.74	22824	14.35	24240	15.71	25632	16.01	27384
27.34	21216	16.53	22848	14.22	24264	16	25656	16.01	27408

KAPPA	History listings	A#4_final
	Company Well A#4	Field ABC Test Name / #

qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr
16.01	27432	15.01	28824	15.01	30216	14.01	31608	13.01	33000
16.01	27456	15.01	28848	15.01	30240	14.01	31632	13.01	33024
16.01	27480	15.01	28872	15.01	30264	14.01	31656	13.01	33048
16.01	27504	15.01	28896	15.01	30288	14.01	31680	13.01	33072
16.01	27528	15.01	28920	15.01	30312	14.01	31704	13.01	33096
16.01	27552	15.01	28944	15.01	30336	14.01	31728	13.01	33120
16.01	27576	15.01	28968	15.01	30360	14.01	31752	13.01	33144
16.01	27600	15.01	28992	15.01	30384	14.01	31776	12.01	33168
16.01	27624	15.01	29016	15.01	30408	14.01	31800	12.01	33192
16.01	27648	15.01	29040	15.01	30432	14.01	31824	12.01	33216
16.01	27672	15.01	29064	15.01	30456	14.01	31848	12.01	33240
16.01	27696	15.01	29088	15.01	30480	14.01	31872	12.01	33264
16.01	27720	15.01	29112	15.01	30504	14.01	31896	12.01	33288
16.01	27744	15.01	29136	15.01	30528	14.01	31920	12.01	33312
16.01	27768	15.01	29160	15.01	30552	14.01	31944	12.01	33336
16.01	27792	15.01	29184	15.01	30576	14.01	31968	12.01	33360
16.01	27816	15.01	29208	15.01	30600	14.01	31992	12.01	33384
16.01	27840	15.01	29232	15.01	30624	14.01	32016	12.01	33408
16.01	27864	15.01	29256	15.01	30648	14.01	32040	12.01	33432
16.01	27888	15.01	29280	15.01	30672	14.01	32064	12.01	33456
16.01	27912	15.01	29304	15.01	30696	14.01	32088	12.01	33480
16.01	27936	15.11	29328	15.01	30720	14.01	32112	12.01	33504
16.01	27960	15.01	29352	15.01	30744	14.01	32136	12.01	33528
16.01	27984	15.01	29376	15.01	30768	14.01	32160	12.01	33552
16.01	28008	15.01	29400	15.01	30792	14.01	32184	12.01	33576
16.01	28032	15.01	29424	14.01	30816	16.01	32208	12.01	33600
16.01	28056	15.01	29448	14.01	30840	14.01	32232	12.01	33624
16.01	28080	15.01	29472	14.01	30864	14.01	32256	12.01	33648
16.01	28104	15.01	29496	14.01	30888	14.01	32280	12.01	33672
16.01	28128	15.01	29520	14.01	30912	14.01	32304	12.01	33696
16.01	28152	15.01	29544	14.01	30936	14.01	32328	12.01	33720
16.01	28176	15.01	29568	14.01	30960	14.01	32352	12.01	33744
16.01	28200	15.01	29592	14.01	30984	14.01	32376	12.01	33768
16.01	28224	15.01	29616	14.01	31008	14.01	32400	12.01	33792
16.01	28248	15.01	29640	14.01	31032	13.01	32424	12.01	33816
16.01	28272	16.11	29664	14.01	31056	13.01	32448	12.01	33840
16.01	28296	15.01	29688	14.01	31080	13.01	32472	12.01	33864
16.01	28320	15.01	29712	14.01	31104	13.01	32496	12.01	33888
16.01	28344	15.01	29736	14.01	31128	13.01	32520	10	33912
16.01	28368	15.01	29760	14.01	31152	13.01	32544	8.37	33960
16.01	28392	15.01	29784	14.01	31176	13.01	32568	12.01	33984
16.01	28416	15.01	29808	14.01	31200	13.01	32592	12.01	34008
15.51	28440	15.01	29832	14.01	31224	13.01	32616	12.01	34032
15.51	28464	15.01	29856	14.01	31248	13.52	32640	12.01	34056
15.51	28488	15.01	29880	14.01	31272	13.52	32664	12.01	34080
15.51	28512	15.01	29904	14.01	31296	13.01	32688	12.01	34104
15.51	28536	15.01	29928	14.01	31320	13.01	32712	12.01	34128
15.51	28560	15.01	29952	14.01	31344	13.01	32736	12.01	34152
15.51	28584	15.01	29976	14.01	31368	13.01	32760	12.01	34176
15.51	28608	15.01	30000	14.01	31392	13.01	32784	12.01	34200
15.51	28632	15.01	30024	14.01	31416	13.01	32808	12.01	34224
15.51	28656	15.01	30048	14.01	31440	13.01	32832	12.01	34248
15.51	28680	15.01	30072	14.01	31464	12.01	32856	12.01	34272
15.51	28704	15.01	30096	14.01	31488	13.01	32880	12.01	34296
15.51	28728	15.01	30120	14.01	31512	13.01	32904	12.01	34320
15.01	28752	15.01	30144	14.01	31536	13.01	32928	12.01	34344
15.01	28776	15.01	30168	14.01	31560	13.01	32952	9	34368
15.01	28800	15.01	30192	14.01	31584	13.01	32976	12.01	34392

History listings | A#4_final

Company | Field ABC
Well A#4 | Test Name / #

qg MMscf/D	Time hr
12.01	34416
12.01	34440
12.01	34464
12.01	34488
12.01	34512
12.01	34536
12.01	34560
12.01	34584
12.01	34608
12.01	34632
12.01	34656
12.01	34680
12.01	34704
12.01	34728
12.01	34752
12.01	34776
11.01	34800
12.01	34872
12.01	34896
12.01	34920
12.01	34944
13.01	34968
13.72	34992
14.01	35016
13.02	35040
13.01	35064
13.01	35088
13.01	35112
13.01	35136
13.01	35160
13.01	35184
13.01	35208
13.01	35232
13.01	35256
13.01	35280
13.01	35304
13.01	35328
13.01	35352
13.01	35376
13.01	35400
13.01	35424
13.01	35448
13.01	35472
13.01	35496
13.01	35520
13.01	35544
13.01	35568
13.01	35592
13.01	35616
13.01	35640
13.01	35664
13.01	35688
13.01	35712
13.01	35736
13.01	35760
13.01	35784
13.01	35808
13.01	35832

qg MMscf/D	Time hr
13.01	35856
13.01	35880
13.01	35904
13.01	35928
13.01	35952
13.01	35976
13.01	36000
13.01	36024
13.01	36048
13.01	36072
13.01	36096
13.01	36120
13.01	36144
13.01	36168
13.01	36192
13.01	36216
13.01	36240
13.01	36264
13.01	36288
13.01	36312
13.01	36336
13.01	36360
13.01	36384
13.01	36408
13.01	36432
13.01	36456
13.01	36480
13.01	36504
13.01	36528
13.01	36552
13.01	36576
12.01	36600
12.01	36624
12.01	36648
12.01	36672
11.01	36696
12.01	36720
12.01	36744
12.01	36768
12	36792
12	36816
12	36840
12	36864
12	36888
12	36912
12	36936
12	36960
12	36984
12	37008
12	37032
12	37056
12	37080
12	37104
12	37128
12	37152
12	37176
12	37200
12	37224

qg MMscf/D	Time hr
12	37248
12	37272
12	37296
12	37320
12	37344
12	37368
12	37392
12	37416
12	37440
12	37464
12	37488
12	37512
12	37536
12	37560
12	37584
11	37608
11	37632
11	37656
11	37680
11	37704
11	37728
11	37752
11	37776
11	37800
11	37824
11.5	37848
11.5	37872
11.5	37896
11.5	37920
11.5	37944
11.5	37968
11.5	37992
11.5	38016
11.5	38040
11.5	38064
11.59	38088
11.5	38112
11.5	38136
11.5	38160
11	38184
11	38208
11	38232
11.5	38256
11.5	38280
11.5	38304
11.5	38328
11.5	38352
11.5	38376
11.5	38400
11.5	38424
11.5	38448
11.5	38472
11.5	38496
11.51	38520
11.5	38544
11.5	38568
11.5	38592
11.5	38616

qg MMscf/D	Time hr
11.5	38640
11.5	38664
11.5	38688
11.5	38712
11.5	38736
11.5	38760
11.5	38784
11.5	38808
11.5	38832
11.5	38856
11.5	38880
11.5	38904
11.5	38928
11.5	38952
11.5	38976
11.5	39000
11.5	39024
11.5	39048
11.5	39072
9	39096
8.5	39120
10.82	39576
11.05	39600
10	39624
10	39648
10	39672
10	39696
10.02	39720
10	39744
10	39768
10	39792
10	39816
9.75	39840
10	39864
10	39888
10	39912
10	39936
9.5	39960
8.5	39984

Appendix-B

Production History Listing of Well A # 3

KAPPA — History listings — A_3_FINAL

Company Well A#3 — Field ABC — Test Name / #

qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr
53.36	28944	51.35	30336	45.67	31728	46.96	33192	45.58	34608
54.31	28968	51.35	30360	45.63	31752	47.05	33216	45.92	34632
53.42	28992	51.27	30384	45.6	31776	47.04	33240	45.86	34656
53.33	29016	51.29	30408	45.4	31800	46.81	33264	45.8	34680
53.56	29040	51.35	30432	45.34	31824	46.51	33288	45.74	34704
54.75	29064	51.29	30456	45.27	31848	46.72	33312	45.68	34728
53.4	29088	51.24	30480	45.29	31872	46.13	33336	45.66	34752
53.23	29112	50.98	30504	45.28	31896	46.08	33360	45.57	34776
53.34	29136	51.12	30528	45.23	31920	46.35	33384	45.53	34872
52.85	29160	51.11	30552	45.2	31944	46.3	33408	45.38	34896
53.52	29184	50.95	30576	45.14	31968	46.24	33432	45.1	34920
54.87	29208	50.96	30600	45.1	31992	46.76	33456	45.36	34944
54.58	29232	50.96	30624	44.97	32016	49.77	33480	45.15	34968
53.22	29256	50.75	30648	44.95	32040	48.09	33504	45.61	34992
52.77	29280	50.82	30672	44.96	32064	47.08	33528	45.09	35016
52.55	29304	50.94	30696	44.91	32088	46.81	33552	45.12	35040
52.87	29328	50.73	30720	44.89	32112	46.45	33576	45.34	35064
52.44	29352	50.68	30744	44.82	32136	46.77	33600	45.39	35088
51.93	29376	50.62	30768	44.8	32160	46.64	33624	45.07	35112
51.64	29400	50.38	30792	44.18	32184	46.55	33648	44.88	35136
51.77	29424	51.03	30816	44.19	32208	45.69	33672	44.85	35160
51.6	29448	50.81	30840	45.82	32232	46.1	33696	45.8	35184
52.9	29472	50.76	30864	45.5	32256	46.36	33720	44.16	35208
52.2	29496	50.47	30888	45.32	32280	46.78	33744	44.76	35232
52.15	29520	50.33	30912	45.21	32304	47.13	33768	43.82	35256
52.63	29544	47.71	30936	44.86	32328	46.74	33792	43.98	35280
52.33	29568	46.5	30960	44.6	32352	46.5	33816	44.1	35304
52.33	29592	46.53	30984	44.35	32376	46.48	33840	45.06	35328
52.29	29616	46.57	31008	44.02	32400	45.83	33864	44.84	35352
52.27	29640	46.52	31032	44.84	32424	46.54	33888	45.05	35376
48.53	29664	45.69	31056	45.46	32448	47.12	33912	45.39	35400
53.8	29688	45.1	31080	45.62	32472	51.52	33936	44.81	35424
52.99	29712	44.09	31104	45.54	32496	48.73	33960	44.81	35448
52.81	29736	43.8	31128	45.19	32520	46.19	33984	44.71	35472
52.6	29760	45.93	31152	45.15	32544	45.97	34008	44.7	35496
52.49	29784	47.71	31176	45.4	32568	45.86	34032	45.08	35520
52.01	29808	48.09	31200	43.16	32592	45.79	34056	45.17	35544
52.41	29832	47.83	31224	44.04	32640	45.78	34080	45.09	35568
52.51	29856	47.42	31248	44.07	32664	45.67	34104	45.07	35592
52.05	29880	47.1	31272	42.42	32712	45.63	34128	45.02	35616
52.15	29904	46.92	31296	44.59	32736	45.75	34152	44.96	35640
52.05	29928	46.79	31320	44.15	32760	45.55	34176	44.93	35664
52.02	29952	46.64	31344	44.11	32784	45.37	34200	44.88	35688
51.62	29976	46.69	31368	45.09	32808	45.32	34224	44.79	35712
52.35	30000	46.6	31392	44.31	32832	45.28	34248	44.76	35736
52.53	30024	46.59	31416	45.33	32880	45.2	34272	44.69	35760
52.39	30048	46.52	31440	45.14	32904	45.19	34296	44.62	35784
52.44	30072	46.48	31464	45.1	32928	45.16	34320	45.03	35808
52.78	30096	46.56	31488	44.83	32952	45.07	34344	45.12	35832
52.01	30120	46.06	31512	45.72	32976	45.57	34392	45.04	35856
52.06	30144	45.93	31536	45.35	33000	45.52	34416	44.99	35880
52.09	30168	45.99	31560	45.14	33024	46.15	34440	45	35904
52.29	30192	46.65	31584	45.41	33048	45.71	34464	44.96	35928
51.87	30216	46.67	31608	45.5	33072	45.57	34488	44.9	35952
51.82	30240	46.13	31632	47.79	33096	45.53	34512	44.96	35976
51.66	30264	45.88	31656	46.97	33120	45.42	34536	44.89	36000
51.66	30288	45.8	31680	46.36	33144	45.3	34560	44.84	36024
51.53	30312	45.72	31704	47.47	33168	45.21	34584	44.99	36048

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KAPPA	History listings	A_3_FINAL
	Company Well A#3	Field ABC Test Name / #

qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr
44.89	36072	42.71	37488	40.69	38880	39.15	40272	38.42	41664
45.08	36096	42.7	37512	40.55	38904	39.04	40296	38.46	41688
44.72	36120	43.13	37536	40.55	38928	39.34	40320	38.5	41712
45.05	36144	43.08	37560	40.54	38952	39.84	40344	38.49	41736
45.02	36168	42.99	37584	40.07	38976	39.91	40368	38.4	41760
45.27	36192	43.97	37608	39.65	39000	39.93	40392	37.89	41784
46.18	36216	43.98	37632	39.16	39024	40	40416	38.33	41808
46.15	36240	43.87	37656	38.81	39048	39.33	40440	38.55	41832
45.88	36264	43.9	37680	38.27	39072	39.22	40464	38.31	41856
45.77	36288	43.32	37704	40.24	39096	39.93	40488	38.3	41880
45.74	36312	43.17	37728	40.18	39120	40.49	40512	40.34	41904
45.64	36336	43.13	37752	40	39144	39.74	40536	38	41928
45.63	36360	43.16	37776	41.59	39168	39.42	40560	38.83	41952
45.54	36384	43.07	37800	42.4	39192	39.1	40584	38.29	41976
45.34	36408	43.04	37824	42.38	39216	39.11	40608	39.51	42000
45.27	36432	42.49	37848	41.97	39240	39.21	40632	38.1	42024
45.22	36456	42.29	37872	41.23	39264	39.28	40656	38.17	42048
44.72	36480	42.1	37896	41.21	39288	39.14	40680	38.07	42072
44.51	36504	42.09	37920	40.61	39312	38.99	40704	37.96	42096
43.97	36528	42.13	37944	40.33	39336	38.97	40728	37.8	42120
44.01	36552	42.01	37968	40.86	39360	38.91	40752	37.89	42144
43.88	36576	41.93	37992	40.53	39384	38.93	40776	38.13	42168
44.17	36600	41.82	38016	40.3	39408	39.63	40800	38.08	42192
44.37	36624	41.85	38040	40.54	39432	39.22	40824	37.93	42216
44.35	36648	41.8	38064	42.6	39456	39.24	40848	37.69	42240
44.12	36672	41.88	38088	44.48	39480	39.2	40872	37.93	42264
44.91	36696	41.46	38112	44.43	39504	38.41	40896	38.02	42288
44.69	36720	41.26	38136	42.99	39528	38.36	40920	37.98	42312
44.67	36744	41.07	38160	44.08	39552	38.47	40944	37.92	42336
44.44	36768	41.48	38184	44	39576	38.44	40968	37.79	42360
44.18	36792	41.88	38208	41.69	39600	37.96	40992	37.71	42384
43.99	36816	41.62	38232	40.94	39624	37.44	41016	42.28	42408
44.27	36840	41.79	38256	40.81	39648	38.33	41040	42.92	42432
44.32	36864	42.01	38280	40.66	39672	38.48	41064	42.34	42456
44.15	36888	41.83	38304	40.47	39696	39.75	41088	42.28	42480
44.13	36912	41.74	38328	40.07	39720	41.79	41112	38.38	42504
43.95	36936	41.69	38352	39.59	39744	42.65	41136	36.63	42528
44.1	36960	41.6	38376	39.6	39768	41.04	41160	36.63	42552
43.89	36984	41.92	38400	39.43	39792	41.61	41184	36.59	42576
43.72	37008	41.93	38424	39.29	39816	39.41	41208	36.57	42600
43.72	37032	41.76	38448	39.53	39840	39.35	41232	36.56	42624
43.55	37056	41.46	38472	39.18	39864	39.18	41256	36.59	42648
43.63	37080	41.32	38496	38.98	39888	38.96	41280	36.48	42672
43.61	37104	41.37	38520	38.89	39912	39.11	41304	36.49	42696
43.52	37128	41.12	38544	38.78	39936	38.86	41328	36.56	42720
43.45	37152	40.94	38568	39.06	39960	38.75	41352	36.75	42744
43.29	37176	40.76	38592	39.39	39984	38.65	41376	37.67	42768
43.66	37200	40.77	38616	39.3	40008	38.52	41400	36.84	42792
43.21	37248	40.83	38640	39.45	40032	38.51	41424	36.96	42816
43.19	37272	40.9	38664	39.73	40056	39.19	41448	36.96	42840
43.04	37296	40.88	38688	39.99	40080	38.69	41472	36.67	42864
43.16	37320	40.84	38712	40.39	40104	38.59	41496	36.64	42888
42.9	37344	40.84	38736	40.31	40128	38.56	41520	36.96	42912
43.02	37368	40.8	38760	39.95	40152	38.4	41544	35.84	42936
42.7	37392	40.82	38784	39.47	40176	38.45	41568	36.31	42960
42.93	37416	40.82	38808	39.18	40200	38.65	41592	36.27	42984
42.9	37440	40.95	38832	39.18	40224	38.55	41616	36.17	43008
42.81	37464	40.76	38856	39.09	40248	38.69	41640	36.29	43032

History listings	A_3_FINAL
Company	Field ABC
Well A#3	Test Name / #

qg MMscf/D	Time hr	qg MMscf/D	Time hr	qg MMscf/D	Time hr
36.28	43056	35.74	44448	37.01	45840
36.49	43080	34.51	44472	36.66	45864
36.47	43104	34.6	44496	36.66	45888
36.51	43128	34.28	44520	35.53	45912
36.2	43152	34.56	44544	36.48	45936
35.58	43176	34.63	44568	35.81	45960
36.45	43200	34.23	44592	35.98	45984
36.29	43224	34.07	44616	36.27	46008
36.34	43248	33.97	44640	36.28	46032
36.45	43272	33.8	44664	36.28	46056
36.09	43296	33.71	44688	36.41	46080
36.07	43320	33.77	44712	34.21	46104
36.08	43344	33.92	44736	33.32	46128
36.16	43368	34.27	44760	33.57	46152
36	43392	34.24	44784	33.63	46176
35.95	43416	33.59	44808	35.14	46200
36.03	43440	33.76	44832	34.18	46224
35.95	43464	34.32	44856	33.46	46248
35.84	43488	33.81	44880	33.61	46272
37.6	43512	33.64	44904	34.04	46296
39.2	43536	33.58	44928	34.32	46320
35.61	43560	33.54	44952	32.99	46344
35.44	43584	33.52	44976	33	46368
35.39	43608	33.45	45000	32.93	46392
35.64	43632	33.46	45024	32.8	46416
35.44	43656	33.46	45048	32.89	46440
35.34	43680	33.43	45072	33.03	46464
35.41	43704	33.37	45096	33.23	46488
35.26	43728	33.23	45120	33.69	46512
35.42	43752	33.95	45144	33.67	46536
35.38	43776	34.82	45168	33.08	46560
35.48	43800	34.87	45192	33.06	46584
35.39	43824	34.54	45216	33.08	46608
35	43848	35.06	45240	34.57	46632
35.07	43872	36.41	45264	35.02	46656
35	43896	34.78	45288	35.32	46680
35.19	43920	34.82	45312	36.49	46704
35.07	43944	34.75	45336	34.7	46728
35.15	43968	34.75	45360	34.27	46752
35.1	43992	35.19	45384	34.67	46776
36.35	44016	34.8	45408	32.56	46800
36.51	44040	35.02	45432	32.4	46824
36.05	44064	35.23	45456	32.7	46848
36.27	44088	34.89	45480	32.48	46872
35.85	44112	34.11	45504	32.4	46896
36.07	44136	35.29	45528	32.54	46920
35.66	44160	35.06	45552	32.43	46944
35.56	44184	35.36	45576	32.5	46968
36.71	44208	35.48	45600	32.7	46992
36.68	44232	35.52	45624		
36.65	44256	34.86	45648		
36.62	44280	35.26	45672		
36.95	44304	35.49	45696		
34.9	44328	36.37	45720		
36.47	44352	36.63	45744		
37.67	44376	37.26	45768		
38.08	44400	36.4	45792		
35.92	44424	37.01	45816		

<u>Appendix-C:</u>

Model results of advance decline analysis for A # 4

Main results	A#4_final
Company	Field ABC
Well A#4	Test Name / #

Test date / time
Formation interval
Perforated interval
Gauge type / #
Gauge depth
Analyzed by
Analysis date / time

Porosity Phi (%) 21
Well Radius rw 0.353333 ft
Pay Zone h 120 ft

Fluid type Gas

Gas
Gas Gravity 0.57
Pseudo-Critical P 681.203 psia
Pseudo-Critical T 344.042 °R

Sour gas composition
Hydrogen sulphide 0
Carbon dioxide 0
Nitrogen 0

Water
Salinity, ppm 10000

Temperature 145 °F
Pressure 3100 psia

Properties @ Reservoir T&P

Gas
Z 0.8918
Mug 0.0189688 cp
Bg 0.00491607 cf/scf
cg 2.9026E-4 psi-1
Rhog 0.142009 g/cc

Water
Rsw 15.4709 scf/stb
Bw 1.01319 B/STB
cw 3.16406E-6 psi-1
Muw 0.494417 cp
Rhow 0.994568 g/cc

Total Compr. ct 2.30099E-4 psi-1
Connate Water (%) 22

Selected Model
Model Option Standard Model, Material Balance
Well Vertical
Reservoir Homogeneous
Boundary One Fault

Main Model Parameters
Tmin 3120 hr
Tmax 46968 hr
Total Skin 0.966
k.h, total 2320 md.ft
k, average 19.4 md
Pi 2688.38 psia
STGIIP 67.3 bscf
STGIP 13.72 bscfS

Model Parameters
Well & Wellbore parameters (mb4)
Skin 0.966
Reservoir & Boundary parameters
Pi 2668.38 psia
k.h 2320 md.ft
k 19.4 md
L - No flow 2770.1 ft

Derived & Secondary Parameters
TMatch 3610 1/hr
PMatch 8.85E-4 1/[psi2/cp]
Abandonment
Ab. rate (qa) 0 MMscf/D
Ab. time (ta) 4020 hr
Q(ta) 2.81539E-13 MMscf

Appendix-D

Model Results from PBU test for A # 4

Main results	A#4_final1
Company	Field
Well Tested well	Test Name / #

Test date / time	
Formation interval	
Perforated interval	
Gauge type / #	
Gauge depth	
Analyzed by	
Analysis date / time	
TEST TYPE	Standard
Porosity Phi (%)	22
Well Radius rw	0.34 ft
Pay Zone h	118.11 ft
Form. compr.	3E-6 psi-1
Reservoir T	144 °F
Reservoir P	3070 psia
Fluid type	Gas
Gas Gravity	0.7
Pseudo-Critical P	663.573 psia
Pseudo-Critical T	377.26 °R
Sour gas composition	
Hydrogen sulphide	0
Carbon dioxide	0
Nitrogen	0
Temperature	144 °F
Pressure	3070 psia
Properties	@ Reservoir T&P
Gas	
Z	0.837672
Mug	0.0213341 cp
Bg	0.0046551 cf/scf
cg	2.76284E-4 psi-1
Rhog	0.184174 g/cc
Total Compr. ct	2.79284E-4 psi-1
Connate Water (%)	0
Selected Model	
Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	One fault
Main Model Parameters	
TMatch	429 [hr]-1
PMatch	1.72E-7 [psi2/cp]-1
C	0.0954 bbl/psi
Total Skin	0.64
k.h, total	2960 md.ft
k, average	25.1 md
Pi	2118.3 psia

Model Parameters	
Well & Wellbore parameters (Tested well)	
C	0.0954 bbl/psi
Skin	0.64
Reservoir & Boundary parameters	
Pi	2118.3 psia
k.h	2960 md.ft
k	25.1 md
L - No flow	1913 ft
Derived & Secondary Parameters	
Delta P (Total Skin)	12.5151 psi
Delta P (Geometrical Skin)	2.08175 psi
Delta P Ratio (Total Skin)	0.0458052 Fraction

Appendix-E

Model results of advance decline analysis of Well A # 3

Main results	A_3_FINAL
Company	Field ABC
Well A#3	Test Name / #

Test date / time	
Formation interval	
Perforated interval	
Gauge type / #	
Gauge depth	
Analyzed by	
Analysis date / time	
Porosity Phi (%)	21
Well Radius rw	0.354167 ft
Pay Zone h	100 ft
Fluid type	Gas
Gas	
Gas Gravity	0.57
Pseudo-Critical P	681.203 psia
Pseudo-Critical T	344.042 °R
Sour gas composition	
Hydrogen sulphide	0
Carbon dioxide	0
Nitrogen	0
Water	
Salinity, ppm	10000
Temperature	145 °F
Pressure	3100 psia
Properties	@ Reservoir T&P
Gas	
Z	0.8918
Mug	0.0189688 cp
Bg	0.00491607 cf/scf
cg	2.9026E-4 psi-1
Rhog	0.142009 g/cc
Water	
Rsw	15.4709 scf/stb
Bw	1.01319 B/STB
cw	3.16406E-6 psi-1
Muw	0.494417 cp
Rhow	0.994568 g/cc
Total Compr. ct	1.3234E-4 psi-1
Connate Water (%)	22
Selected Model	
Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	One Fault
STGIIP	140 bscf
STGIP	120 bscf

Main Model Parameters	
Tmin	29000 hr
Tmax	46992 hr
Total Skin	1.504
k.h, total	3230 md.ft
k, average	52.3 md
Pi	2300.02 psia
Model Parameters	
Well & Wellbore parameters (mb3)	
Skin	1.504
Reservoir & Boundary parameters	
Pi	2300.02 psia
k.h	3230 md.ft
k	52.3 md
L - No Flow	454 ft
Derived & Secondary Parameters	
TMatch	3590 1/hr
PMatch	0.00123 1/[psi2/cp]
Abandonment	
Ab. rate (qa)	0 MMscf/D
Ab. time (ta)	29014.3 hr
Q(ta)	125.492 MMscf

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Appendix-F

Model Results from PBU test for Well A # 3

Main results	A-3 Final
Company	Field
Well Tested well	Test Name / #

Test date / time	
Formation interval	
Perforated interval	
Gauge type / #	
Gauge depth	
Analyzed by	
Analysis date / time	
TEST TYPE	Standard
Porosity Phi (%)	21
Well Radius rw	0.458333 ft
Pay Zone h	229.659 ft
Form. compr.	3E-6 psi-1
Water Salt (ppm)	10000
Reservoir T	147 °F
Reservoir P	3100 psia
Fluid type	Gas
Gas	
Gas Gravity	0.57
Pseudo-Critical P	681.203 psia
Pseudo-Critical T	344.042 °R
Sour gas composition	
Hydrogen sulphide	0
Carbon dioxide	0
Nitrogen	0
Water	
Salinity, ppm	10000
Temperature	147 °F
Pressure	3100 psia
Properties	@ Reservoir T&P
Gas	
Z	0.893569
Mug	0.0189547 cp
Bg	0.00494212 cf/scf
cg	2.90528E-4 psi-1
Rhog	0.141261 g/cc
Water	
Rsw	15.4078 scf/stb
Bw	1.01378 B/STB
cw	3.16752E-6 psi-1
Muw	0.485592 cp
Rhow	0.993995 g/cc

Total Compr. ct	1.78584E-4 psi-1
Connate Water (%)	40
Selected Model	
Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	One Fault
Main Model Parameters	
TMatch	912 [hr]-1
PMatch	1.09E-6 [psi2/cp]-1
C	0.443 bbl/psi
Total Skin	2.97
k.h, total	25900 md.ft
k, average	83 md
Pi	1541.01 psia
Model Parameters	
Well & Wellbore parameters (Tested well)	
C	0.443 bbl/psi
Skin	2.97
Reservoir & Boundary parameters	
Pi	1541.01 psia
k.h	25900 md.ft
k	83 md
L-No Flow	559 ft
Derived & Secondary Parameters	
Delta P (Total Skin)	19.9819 psi
Delta P Ratio (Total Skin)	0.374014 Fraction

Appendix-G

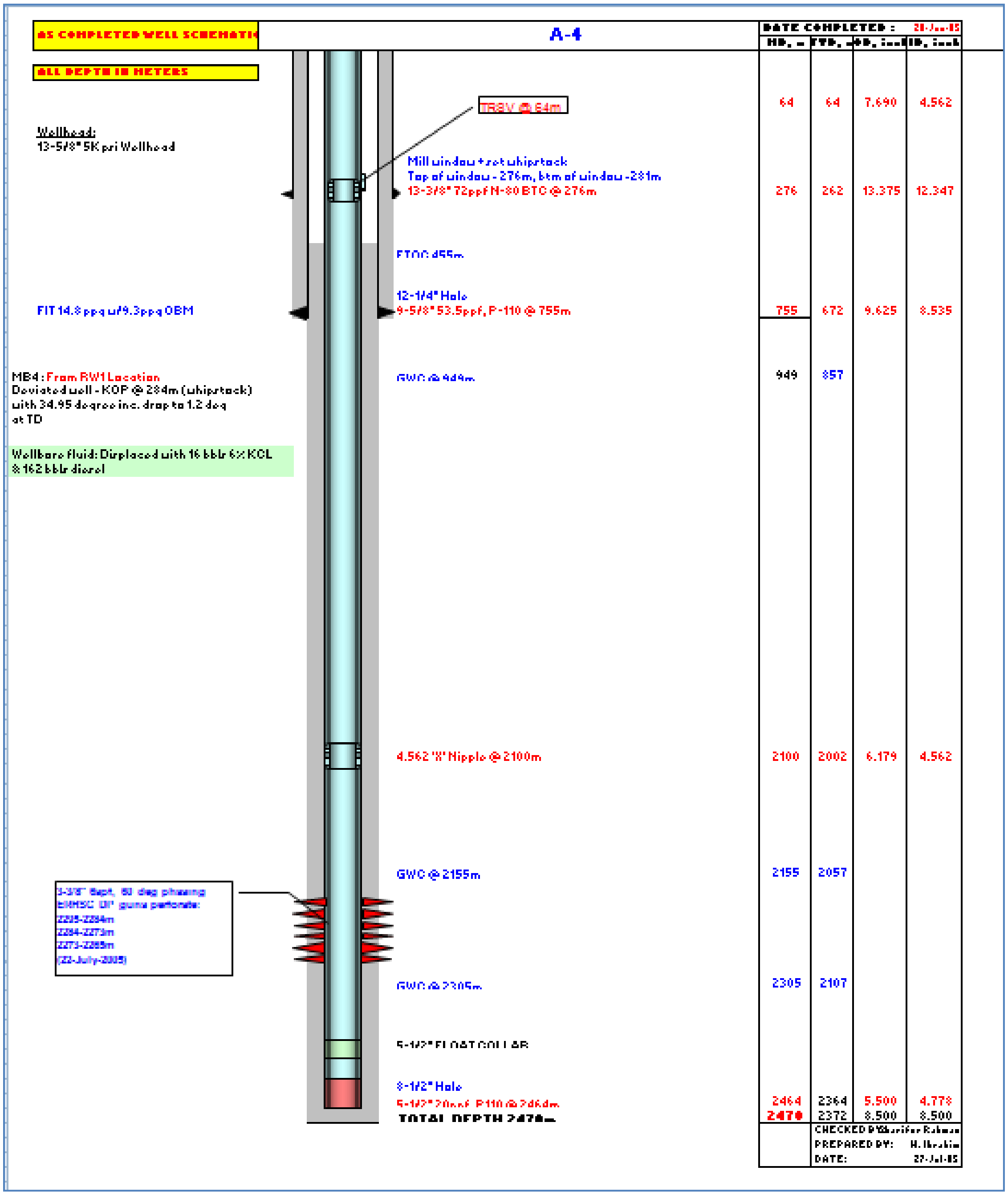

Figure 5.1: Well A#4 Schematic

Appendix-H

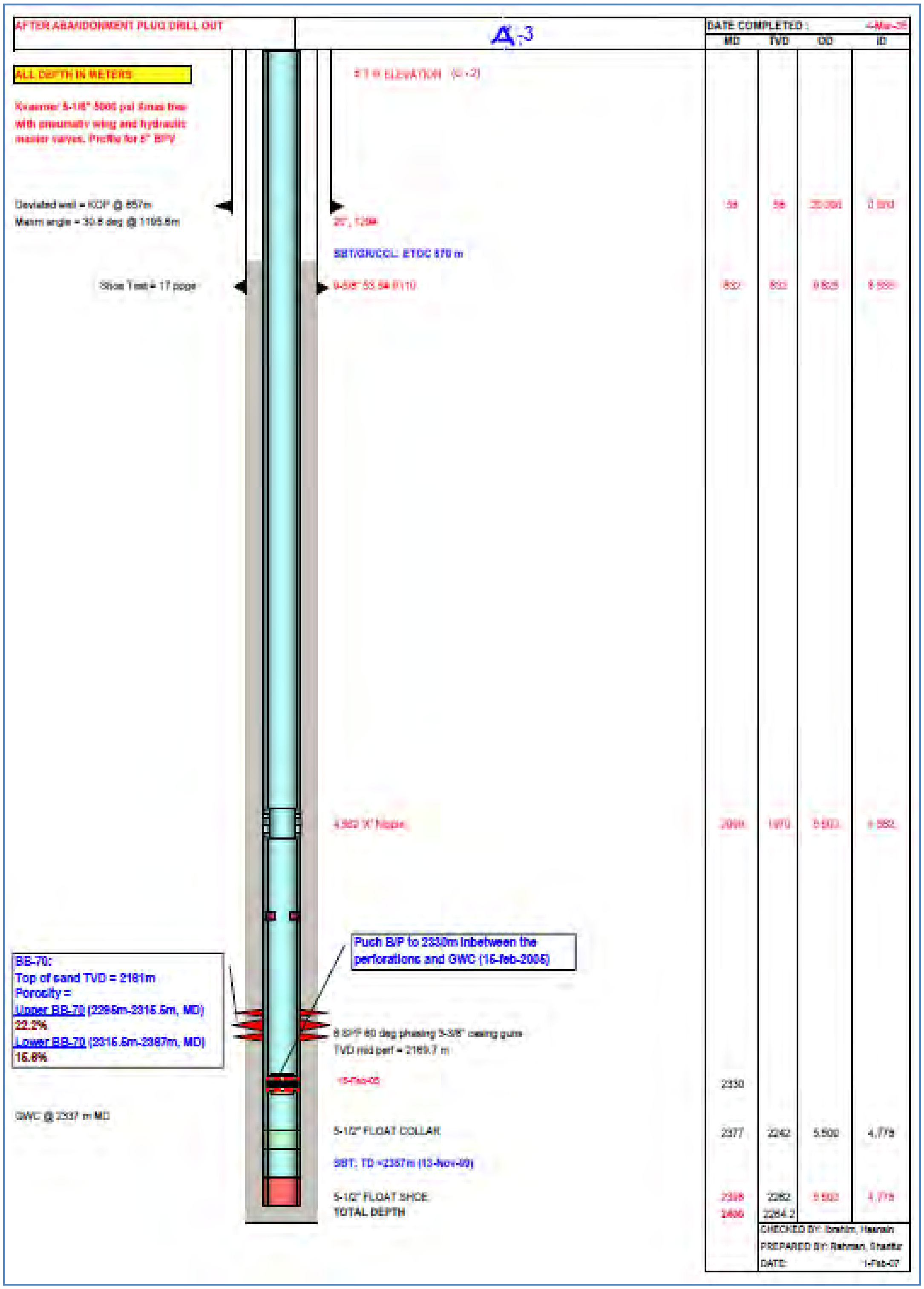

Figure 5.2: Well A#3 Schematic

Appendix-I

Reservoir cross-section with fault

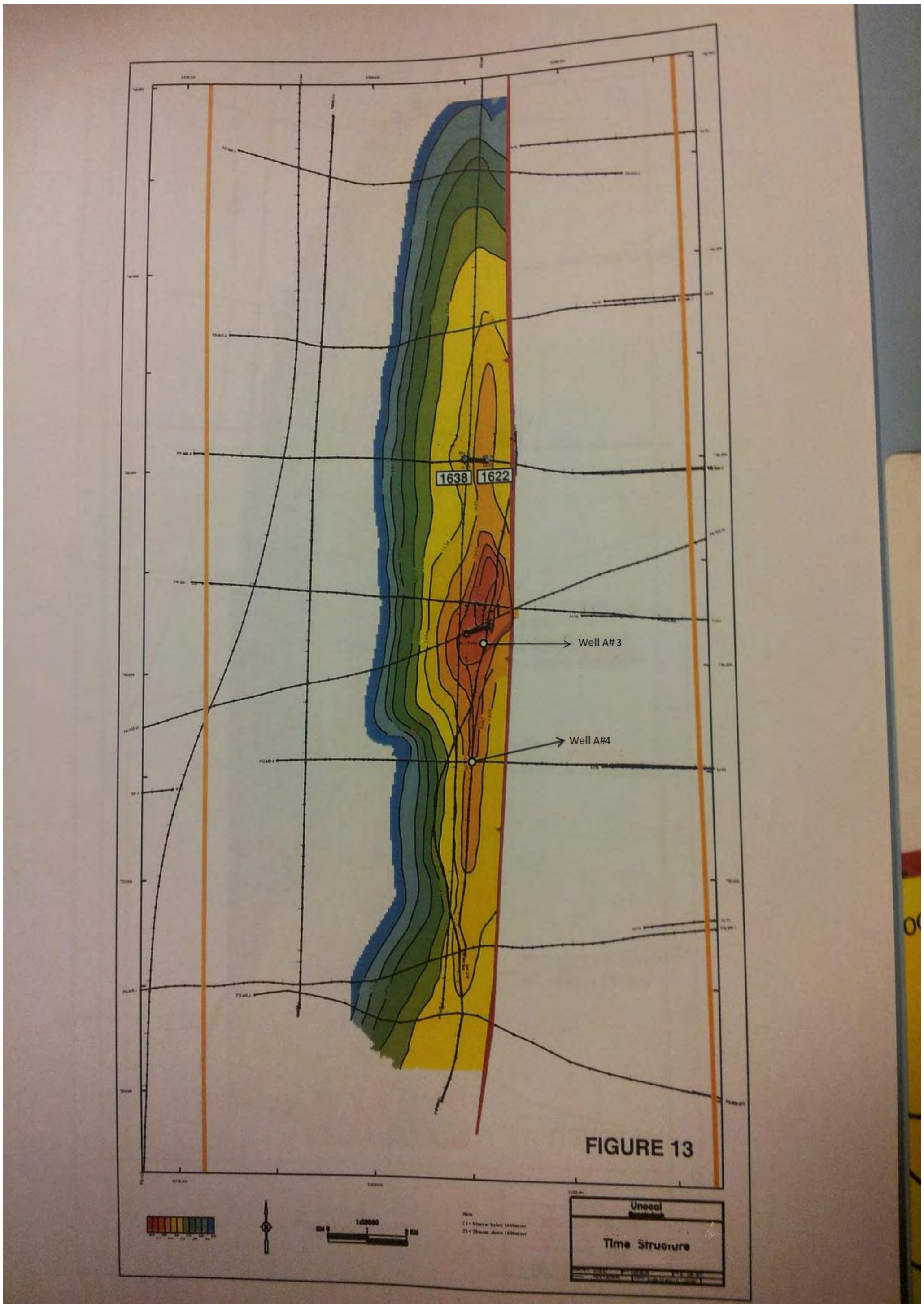

Figure 5.3: Reservoir