PREDICATION AND COMPREHENSION OF RESERVOIR PARAMETERS OF WELL TESTING USING PAN SYSTEM SIMULATOR FOR INDIVIDUAL AND MULTIPLE WELLS

By

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Dissertation submitted to the Petroleum Engineering Programme
in Partial Fulfilment of the Requirements
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CERTIFICATION OF APPROVAL

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
AUGUST, 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

There are many softwares used to perform well test analysis, among which is Pan System. Many simulations have also been done to predicate reservoir parameters using well test analysis. This study aims to shed some light on the ***PREDICATION AND COMPREHENSION OF RESERVOIR PARAMETERS OF WELL TESTING USING PAN SYSTEM SIMULATOR FOR INDIVIDUAL AND MULTIPLE WELLS***. This study is a software simulation research which objective is to correlate pressure and time as a dependant variable in a well test analysis. This simulation will be using the Pan System Simulator which has been developed by Weatherford. The outcome of this simulation would be to demonstrate how well test analysis can be used to predicate reservoir parameters. Also, this study will demonstrate how a computer based well test analysis can be used to overcome the restrictions found on a manual well test analysis. The predicated parameters would then be used to study the effects of interfering wells on predicated parameters and also to classify and characterize the reservoir further. This document is a dissertation report which encompasses a background of the study, a problem statement, the objectives and scope of study, the relevancy and feasibility of study within the scope and time frame, the outline of the research methodology, the equipment involved, a Gantt chart depicting the study planning, the results obtained, discussion, conclusion and recommendation. The experiment was conducted on 7 individual wells where traditional and simulated well testing methods were conducted and also on 6 different cases of multiple well testing. Here, the results have helped comprehend the type of reservoir we are dealing with and what the parameters show. The reservoir dealt with follows a dual porosity flow regime reservoir and mostly parallel and single faulted boundaries. The criteria's of this reservoir together with the predicated parameters have aided in the understanding of the reservoir.

ACKNOWLEDGEMENT

First and foremost, I would like to extend my highest gratitude to my Final Year Project Supervisor, Dr Muhannad Talib Shuker. It is a privilege to be under his supervision. He was always there to provide guidance and support. His motivation urged me to perform better in this project

His guidance in contributing ideas and support has eased my way throughout this project. Although he was very busy, he still managed to attend questions whenever there is doubt. His kindness and unlimited supervision will always be remembered.

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1.0 INTRODUCTION

1.1Background of study

As a petroleum engineer, one of our main tasks is to evaluate, manage and describe a reservoir. Like in medical terms, a medical experiment determines a person's illness, well testing also determines condition of the well with respect to well performance. An excellent way to do this is by conducting well test analysis. A well test analysis can be done using the traditional way of plotting graphs and matching type curves using tracing papers. However, with the advancements in technology these days, many softwares have been developed to aid in well test analysis. One of these softwares is Pan System that has been developed by Weatherford.

Pan System is a software that can be used to predicate reservoir parameters using well test analysis. This software provides a system to enable users to perform efficiently all tasks in regard with preparation, analysis, simulation of well test data and design of well test. The benefit of this software is that it is able to conduct a pressure decline analysis, able to estimate hydrocarbon in place, estimate remote boundaries and also obtain pressure support. This software also allows matching of transient data and what it inputs. (www.ep-solutions.com; 2011)

According to (Roland N.Horne, 1995), a well test is able to provide various reservoir parameters such as reservoir conductivity, initial reservoir pressure, reservoir boundaries, skin and well storage effect. However, a traditional well test analysis has proven to have many restrictions when it comes to conducting a well test. For example, a reservoir boundary or flow regime cannot be easily determined using a traditional well test. (www.ep-solutions.com; 2011)

Pan System on the other hand, is just software where the accuracy of the simulation is still questionable. Hence, this method can help identify the degree of accuracy in a well test analysis using Pan System.

Well data can also be problematic in terms of having well data that cannot be interpreted, missing or negatively affected well data and also noisy and low quality data. Hence, by conducting this study, how these problems identified in well data can also be discussed and overcome. This is hence important for better reservoir modelling and management.

Hence, the purpose of this project is to study the software called Pan System and understand its advantages and disadvantages in predicating reservoir parameters. This would be done by comparing the predicated results obtained via Pan System simulation and the predicated results obtained from manual well testing. This study is also to prove how a computer aided well test analysis can aid in multiple well testing. The interference among two producing wells in predicating reservoir parameters can also be analysed. After that, the predicated parameters between the two interfering wells can be used to further characterise and understand the particular reservoir itself. Besides that, this study would also further enhance my understanding of this software and how the transient well test readings from this software is able to provide a proper understanding of the reservoir and is able to extend the restrictions in a traditional well test.

1.2 Problem Statement

Reservoir parameters can be predicated manually using actual calculation for well testing. Also, there are many softwares such as Fast, Pan System and Sapphire which can be used to predicate reservoir parameters using well testing. However, all these softwares differ in terms of accuracy and ability to predicate reservoir parameters.

Besides that, inefficiency in traditional well testing can also contribute to discrepancies in reservoir parameters predicated. The problem will then continue to persist when these parameters are used in further studies such as nodal analysis and so on. Restrictions of traditional methods include inability to handle continuously varying rates, multiple well tests, complex geometries, down hole measurements of state and indefinite initial pressures. (Roland N. Horne, 1995)

A good well test would also provide excellent permeability readings, data on completion efficiency, reservoir pressure readings, nature of pressure support, drainage area, connected pore volume and initial hydrocarbon in place. (Roland N. Horne, 1995)

Characterisation of reservoir parameters is also vaguely described in literature. How the different parameters, flow regimes and boundaries connect and give a proper understanding of the reservoir is not properly documented.

1.3 Objective & Scope of Study

The objective of this study is to:

a. Use simulation to interpret readings on permeability, completion efficiency, reservoir drainage area and so on.
b. Understand how well storage factors and fractures in reservoirs can affect the well test analysis of a well.
c. Understand how Pan System can be used to increase accuracy on transient well testing, speed up traditional graphical techniques by allowing rapid presentation of graphs
d. Extend the analysis beyond the restrictions or situations that cannot be handled by traditional methods such as continuously varying rate, multiple wells, complex geometry, down hole measurement of flow rate and indefinite initial pressure
e. Comprehend and document the reservoir characteristics based on well tests and obtain a complete understanding of reservoir and what each predicated parameter means and each log curve means.

1.4 RELEVENCY OF STUDY

This study will produce a proper understanding of the software called Pan System and its usage in well test analysis. It will provide a deeper insight on how this software can be used to predicate reservoir parameters. Besides that, it will showcase how the predication of reservoir parameters can be extended with the use of softwares compared to manual methods of well testing by testing wells in response to another producing well. This study would then be used to not only predicate but characterise and obtain a further and more in depth understanding of the reservoir itself. It will also demonstrate the effect of diffusivity and productivity of reservoir using well test analysis.

1.5 FEASIBILITY OF STUDY WITHIN SCOPE AND TIME FRAME

Many softwares are available these days to conduct well test analysis such as Saphire, Pan System and Fast. The purpose these softwares are used is to take the method of well testing one step higher from traditional well testing where the restrictions of traditional well testing can be overcome.

Well testing can be used to predicate reservoir parameters. The benefits of using a software to predicate would be that the predicated parameters can be the result of interference between multiple wells that are located close by. The difference in parameters of interfering wells can also be studied and analysed compared to conducting a well test for each well individually. Also, the predicated parameters can then be used to study and increase further our understanding of the particular reservoir by classification and characterisation of reservoir parameters. The geological fractures in a reservoir field can also be identified and located. Through well testing, seismic and sub seismic faults can also be identified. This is important in cases of multilateral and horizontal wells.

The study is expected to be feasible after much deliberation based on the below:

1. There is only one equipment required for this study which is Pan System Software and this equipment is readily available in the lab.
2. The raw data from this software can be obtained from companies or even from literature reviews available online.
3. The form of this study is straight forward software simulation research; hence should be simple to conduct.

From the result of this study, the knowledge of reservoir comprehension and characterisation can help engineers maximise the performance and the production of the well or the reservoir. The literature review will be covered in the next section, followed by the description of the experimental methodology in the following part. The results will be then discussed. The conclusions of the study are summarized in the last section.

2.0 LITERATURE REVIEW

2.1 Transient Well Testing

Transient well testing is generally used for determining reservoir rock properties and producing formation limits. Detailed reservoir information is important for petroleum engineers to analyse the current behaviour and future performance of the reservoir. With pressure transient testing, engineers will be provided with a quantitative analysis of the reservoir characteristics. This is usually done by creating a pressure disturbance in the reservoir and recording the pressure response at the wellbore as a function of time. A well test can be used to determine reservoir conductivity in terms of permeability thickness, initial reservoir pressure, reservoir boundaries, skin effect and also wellbore storage. (Roland N. Horne, 1995)

When conducting a well test, several assumptions are made such as:

a) Darcy's Law is applied
b) Porosity, permeability and viscosity is constant
c) Fluid compressibility is small
d) Pressure gradient is small
e) Flow single phase
f) Gravity and thermal effect negligible

2.2 Types of Well Test Analysis

According to (Roland N. Horne; 1995) different well test analysis are able to provide different reservoir parameters:

a) Drawdown test

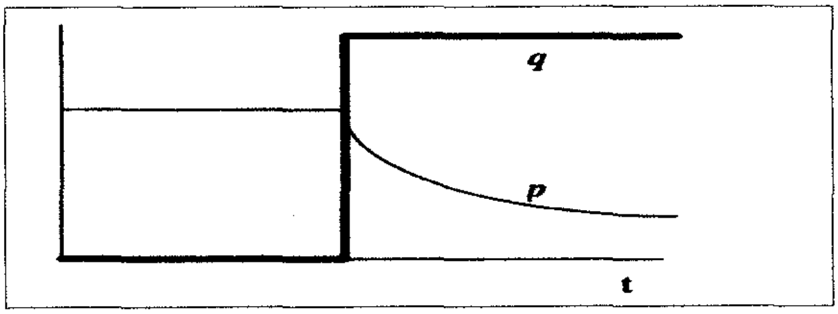

Figure 1: Pressure and flow rate vs. time on a drawdown test

This test provides pressure profile, reservoir behaviour, permeability, skin, fracture length, reservoir limit and shape. This test is done when well is stable, static and shut in before it is allowed to flow. The disadvantage of this test is that it is difficult to make wells flow at a constant rate and well conditions may be not initially be stable.

b) Buildup test

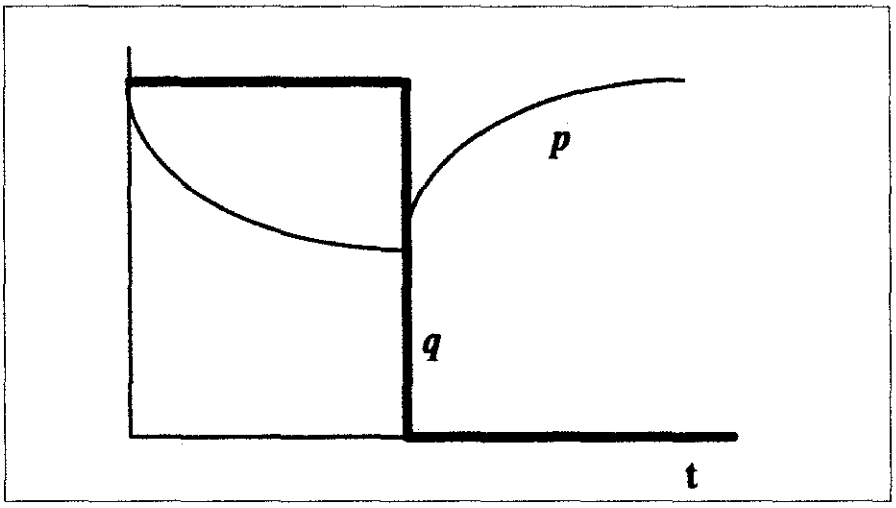

Figure 2: Pressure and flow rate vs. time on a build up test

This test provides information on reservoir behaviour, permeability, fracture length, skin, reservoir pressure and boundaries. This type of test is done on wells that are initially flowing and is shut in thereafter. The down hole pressure of the well is measured and pressure is built up. The advantage of this method is that constant flow rate condition is more easily achieved. The disadvantage of this method is that production can be lost when well is shut in, well might have to be closed in briefly and it is difficult to achieve constant production rate prior to shut in. (Roland N. Horne, 1995)

c) Interference and pulse test

This test provides communication between wells, reservoir type behaviour, porosity, inter well permeability and also vertical permeability. This test is done by pressure monitoring in a different well when another well is producing. (Roland N. Horne, 1995)

d) Injection Test

Injection tests are similar to drawdown tests just that flow of fluid is inward and not outward. The disadvantage of this test is that the results can be complicated if injected fluid is not same as original reservoir fluid. (Roland N. Horne, 1995)

2.3 Functions of Well Test

2.3.1 Skin Effect

One of the reservoir parameters that can be obtained when conducting a well test analysis is skin effect. This refers to the zone around a well that is infiltrated by mud or cement during drilling or completion. This zone might have lower permeability than reservoir, hence it acts as a skin causing pressure to drop. (Roland N. Horne, 1995)

The formula used to calculate skin is as below:

$$S = 1.151[(P_i - P_{1hr})/m - \log(k/\phi\mu c_t r_w^2) + 3.23]$$

2.3.2 Wellbore storage effect

When conducting a well test analysis, one of the factors that can influence a well test result and must be taken into account is the wellbore storage of a well. The wellbore storage effect takes place if flow rate is constant at wellhead, it does not necessarily mean that flow is constant when flowing from reservoir to wellbore. Wellbore storage is affected by fluid expansion and changing liquid levels. When a well test plot is done, the early transient response of a semi log curve does not represent the reservoir; it only represents the wellbore. Hence, a well test must be conducted of a sufficient duration of time so that the wellbore storage is over and the reservoir parameters can be predicated. The wellbore storage effect can be a nuisance and has to be dealt with when conducting a well test analysis. (Roland N. Horne, 1995)

2.4 Radius of Investigation

The pressure response follows the theory that the pressure change in a well would be felt everywhere in the reservoir. However logically speaking, there will be a point in the well where the pressure response is so small and undetectable. The closest such points defines the region of the reservoir that has been tested during the well test. The distance to this point is defined as radius of investigation. This concept is vague and is usually depends on "undetectable" pressure conditions. (Dominique Boudet, 2002)

This would be another parameter that can be predicated from a well test analysis using the formula :

$$r_i = \sqrt{\frac{k\Delta t}{948\phi\mu c_t}}$$

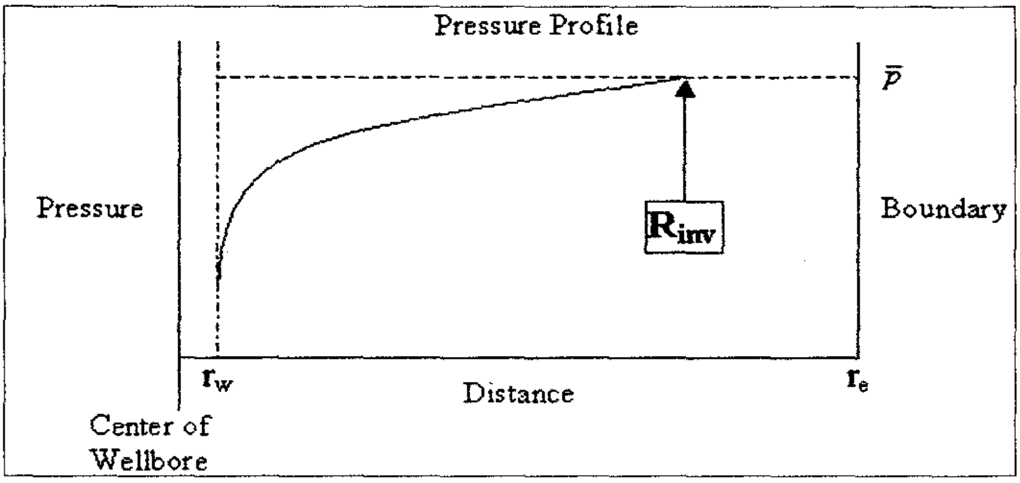

Figure 3: Diagram shows concept of radius of investigation using a plot of pressure versus time. (www.fekete.com)

This figure basically describes the distance the pressure transient has moved into the formation. This radius of investigation is independent of flow rate of well. (Dominique Bourdet, 2002)

2.5 Effect on Reservoir Heterogeneities on Well Responses

Reservoir heterogeneities have been highlighted in recent years due to the development in computerised log- log analysis methods where high accuracy pressure measurements can be computed. Three basic reservoir models are double porosity models, double permeability models and composite systems. (Dominique Bourdet, 2002)

2.5.1 Double porosity models

Fissured reservoirs describe the region of high conductivity while low conductivity regions in a reservoir are called matrix blocks as shown in Figure 4 below. Fissured reservoirs are complex where the density of the fissure network can vary with the position in the reservoir, as a function of the rock stresses due to curvature of the formation. The parameters resulting from the interpretation describe the ideal model but they do not describe the geological configurations in detail.

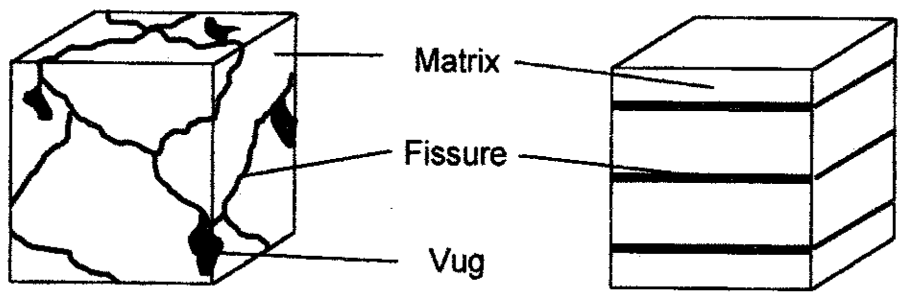

Figure 4: Example of fissured reservoir

Basic assumptions used in double porosity models:

1. The dimensions of the matrix blocks are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with two pressures; the pressure of fluid in the fissures and the pressure of fluid in the matrixes pore volume.
2. The fluid flows to the well through the fissured system only, the matrix blocks are not connected. The radial permeability of the matrix system is negligible.
3. Reservoir fluid is mostly stored in the matrix block porosity, while the fissured reservoir only stores a small portion of the total reservoir storage.

Behaviour of double porosity models:

In a fissured reservoir, a rapid pressure response occurs in the fissure networks due to its high diffusivity when a well is opened. Pressure difference is created between matrix and fissures and the matrix blocks start to produce into the fissures. The pressure of the matrix blocks will decline and slowly equalise with the fissure pressure. (Dominique Bourdet, 2002)

2.5.2 Double permeability model

This behaviour is generally observed in stratified reservoirs, when the permeability of different layers is participating to the response, or in fissured reservoirs where the matrix blocks are connected. The parameters that result from this interpretation define the idealised mathematical model that is used for the description of the layered reservoir. (Dominique Bourdet, 2002)

Basic assumptions used in a double permeability reservoir:

1. The well, intercepting two homogenous layers is affected by wellbore storage. A skin defines the communication between the well and formation in each layer.
2. The initial pressure is the same in the two layers.
3. After producing for a while, the difference is pressure is established between the two layers and a cross flow is taken place in the reservoir.

2.5.3 Composite Reservoirs.

The composite reservoir considers two distinct media in the reservoir. Each component is defined by a porosity and permeability and is located in different reservoir regions. A few assumptions are made in regard to composite reservoirs. A discontinuity defines two distinct homogenous regions in the infinite reservoir. The mobility and storativity ratio are different on either side but the reservoir thickness is constant. The change of the reservoir properties is abrupt and there is no resistance to flow between the two reservoir regions.(Dominique Bourdet, 2002)

2.6 Reservoir Boundary Response

Eventually, the reservoir boundary effects will be felt at the well being tested. The time when the boundary is noticed is dependant on two factors including the distance to the boundary and the properties of the permeable formation and the fluid that fills it. Two types of most commonly found reservoir boundaries are impermeable and constant pressure. These boundaries can be predicated when conducting a well test analysis. (Dominique Bourdet, 2002)

2.6.1 Closed Boundaries

When a reservoir is closed on all sides, the pressure transient will be transmitted outwards until it reaches all sides where the depletion will enter a state known as pseudo steady state. Hence, the pressure in this reservoir will decline at the same rate everywhere in the reservoir. The condition of the reservoir during this state is given by the equation of compressibility:

$$\beta = -\frac{1}{V}\frac{\partial V}{\partial p}$$

From this equation, we can know that the pressure drop is directly proportional to time and that the pressure drop is very useful to determine reservoir drainage area as it is very much dependant on the size of the reservoir. (Dominique Bourdet, 2002)

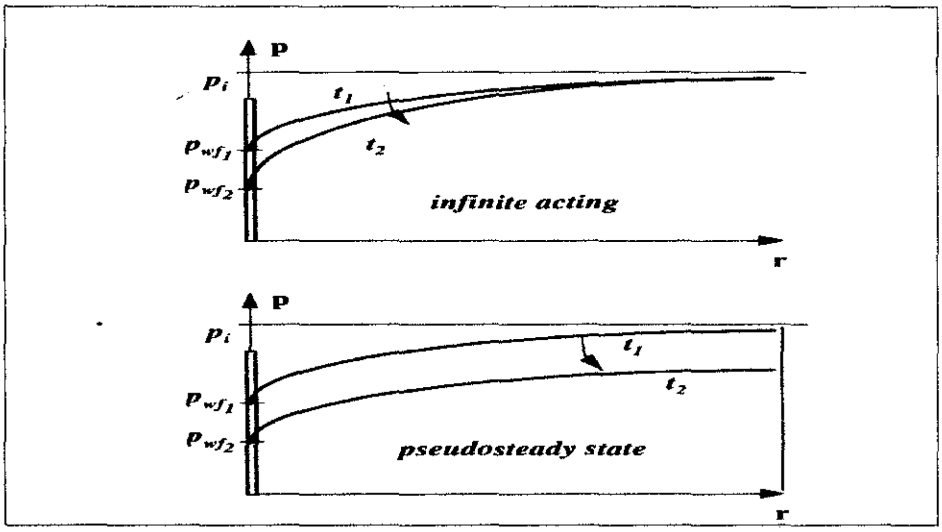

Figure 5: Pressure transient on closed boundaries

2.6.2 Fault Boundaries

This boundary acts as an impermeable barrier and hence the pressure response of a well close to a single linear fault can begin to look like the response of a closed reservoir. The effect is different as the well only responds to one boundary and does not create a pseudo steady state effect. The well will undergo a doubling in slope at the time the boundary effect is felt. Hence, from this, we will be able to determine if a fault is present in the reservoir. Parameters such as the distance from the well to the fault can be predicated from this observation. (Dominique Bourdet, 2002)

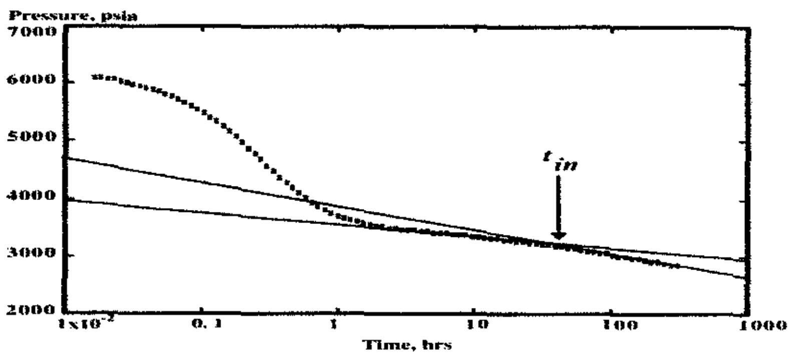

Figure 6: Diagram showing fault distance estimation point

2.6.3 Constant Pressure Boundaries

This occurs when the reservoir is supported by fluid encroachment either due to natural influxes from an aquifer or gas cap. This effect will cause the well pressure to achieve steady state where the well pressure will be the same constant pressure as the boundary as below:

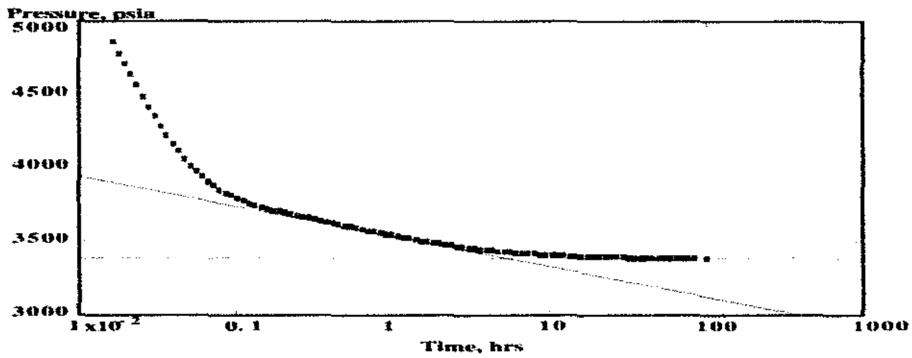

Figure 7: Pressure transient showing constant pressure at boundary

These boundary types can be easily determined from well test analysis and also following parameters such as the distance from the faults and also the drainage area of the wells. The parameters obtained from the well test can then be used to characterize the well according to the type of geological feature and so on. (R. AL-Obaid)

2.7 Effect of Reservoir Boundaries on Well Responses

Nowadays, complex boundary systems are used in well test interpretation with sealing or constant pressure conditions.

2.7.1 Single Sealing Fault In A Homogenous Reservoir

With this model, a linear no flow boundary closes the reservoir in one section. This configuration is encountered in faulted reservoirs but may also be an extension of the linear flow composite solution when the reservoir flow capacity becomes zero. A pinch out is sometimes analysed using this solution. A typical drawdown response is shown as in Figure 8. Here, the early time part of the well response is corresponded to the infinite reservoir behaviour. During radial flow, the pressure response follows the first semi-log straight line. However, when the influence of the sealing fault is felt, the flow becomes hemi-radial and the apparent mobility is reduced by a factor of two. (Dominique Bourdet, 2002)

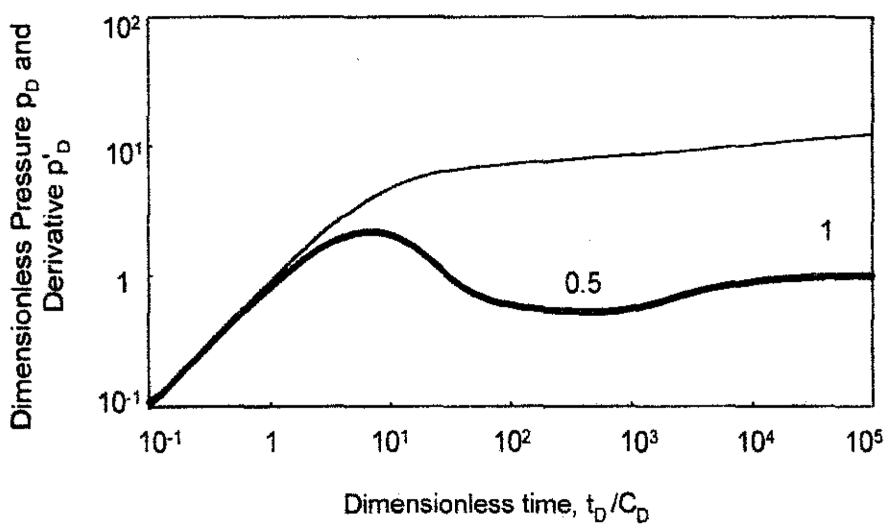

Figure 8: Pressure and derivative response for a well with wellbore storage near one sealing fault.

2.7.2 Two Parallel Sealing Faults in Homogenous Reservoir

With this solution, the well is located between two parallel sealing faults. Even though this type of configuration is encountered in faulted systems, frequently it corresponds to long, narrow reservoirs such as channel sands. Figure 9 below describes an example of parallel sealing faults. On the log-log plot below, the derivative first describes the wellbore storage effect. When the reservoir boundaries have been reached, the flow lines become parallel to the reservoir limits, and a linear flow regime is established. Here, the shape of the transition between radial and linear flow regimes is short if the well is equidistant from the two boundaries. When the well is closer to one of the two boundaries, the characteristic behaviour of one sealing fault is seen before the linear flow. (Dominique Bourdet, 2002)

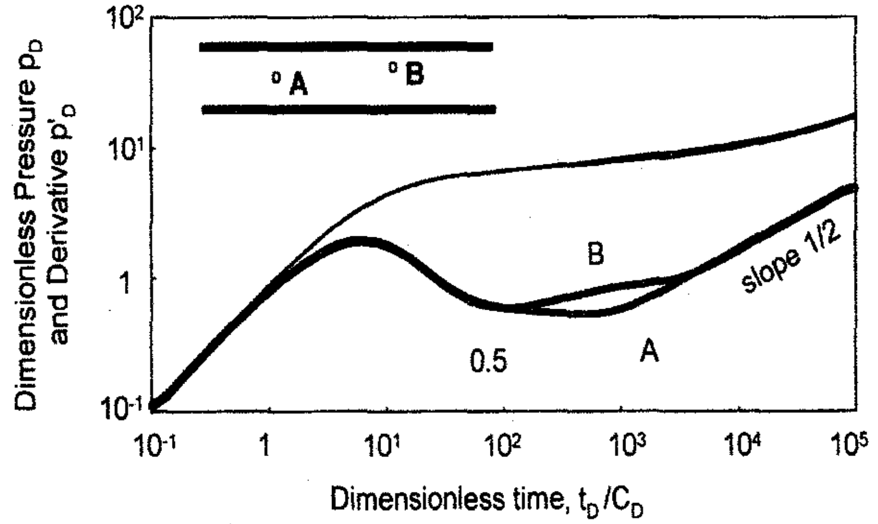

Figure 9: Pressure and derivative response for a well with wellbore storage in a homogenous reservoir limited by two parallel sealing faults.

2.7.3 Two Intersecting Sealing Faults In Homogenous Reservoir

With the intersecting sealing fault model, two linear flow no-boundaries limit the reservoir drainage area, the wedge is otherwise of infinite extension. The angle of the intersection between the two faults can take any value smaller than 180°. The effect of intersecting sealing faults for a well with wellbore storage and skin in a homogenous reservoir is shown in Figure 10. Here, the angle between the faults is about 60°. The response first describes the infinite behaviour. When the two faults are reached, the fraction of radial flow is limited by the wedge. The shape of the transition between the two derivative planes depend upon the location of the well in the angle. If the well is located on the bisector and the two boundaries are equidistant from the well and the derivative transition follows a half a unit straight line. (Dominique Bourdet, 2002)

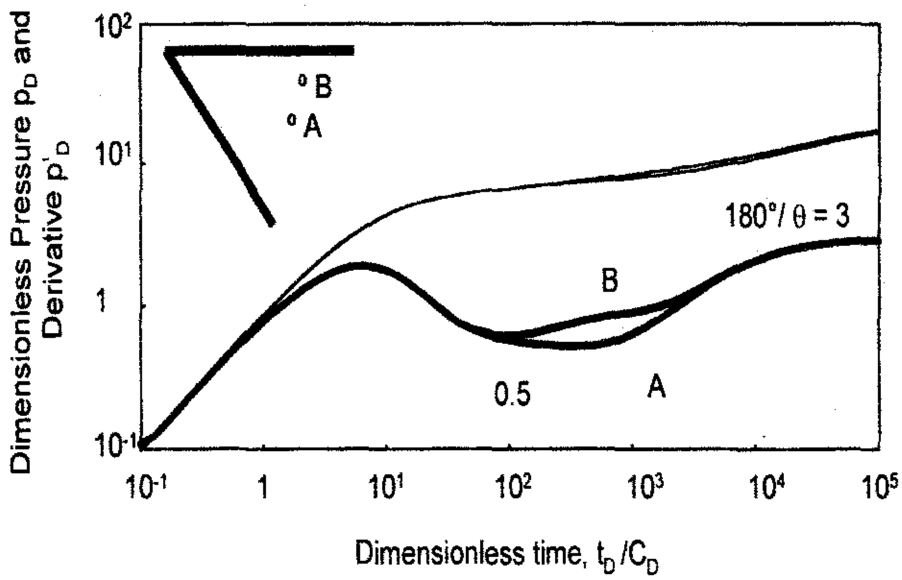

Figure 10: Pressure and derivative responses for a well with wellbore storage in a homogenous reservoir limited by two intersecting faults.

2.7.4 Closed Homogenous Reservoir

A closed system behaviour is characteristic of limited reservoirs but it can be encountered in developed fields where a few wells are producing but each well only drains a certain volume. During pressure build up, the pressure starts to build up during the initial infinite regime after shut in but later it stabilizes and tends towards to average reservoir pressure. This shows the particular behaviour of a closed system where the drawdown and build up curves have totally different late time responses. Due to the presence of two boundaries close to the well, the derivative response also show a curve that is oscillating. (Dominique Bourdet, 2002)

2.7.5 Constant Pressure Boundary

This type of boundary describes the influence of a linear change of fluid properties such as the presence of gas or water contact some distance away from an oil well. Figure 11 demonstrates the influence of a linear constant boundary for a well with wellbore storage and skin in a homogenous reservoir. Here, during drawdown and shut-in periods, the pressure stabilizes and the derivative tends to zero when the influence of the constant pressure boundaries is felt. The rate of decline of the derivative response gives an indication of the geometry of the constant pressure boundaries. When several constant pressure boundaries are reached, the shape of the responds starts to be similar to that of a build-up curve in a bounded system with a constant pressure boundary. (Dominique Bourdet, 2002)

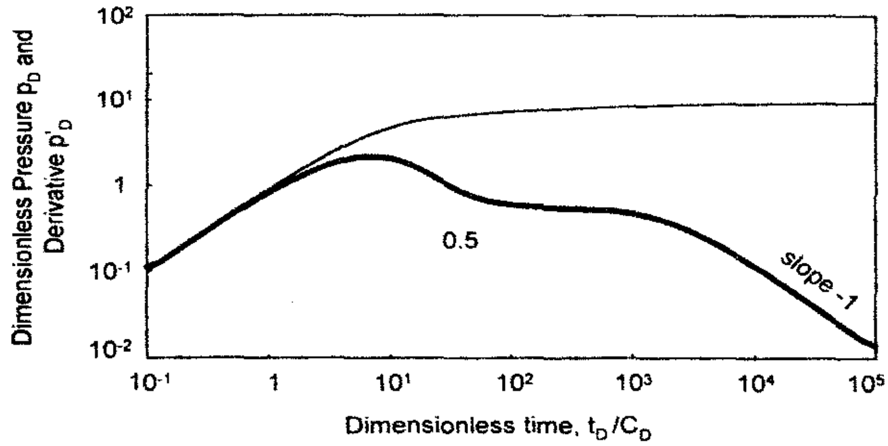

Figure 11: Pressure and derivative response for a well with wellbore storage near one constant pressure linear boundary in a homogenous reservoir.

2.7.6 Communicating Fault

Generally in a hydrocarbon reservoir, faults are non sealing and allow communication between two reservoir regions. If the particular fault shows an infinite conductivity behaviour, a flux parallel to the fault plane is established, hence improving the drainage in a reservoir region. Intermediate well behaviours include partially communicating and finite conductivity faults. The former describes a reduction of permeability in the vertical plane model while the latter describes the fault permeability which is larger than the formation permeability. (Dominique Bourdet, 2002)

This effect of reservoir boundaries can be easily identified in homogenous systems. Specific pressure behaviour, well evidenced with the derivative presentation help categorize reservoir boundaries. In heterogeneous systems however, the effect of boundaries can appear on the early time response even when the boundaries are far from the producing wells. (Dominique Bourdet, 2002)

2.8 Summary of Response in Time Sequence

A well test behaviour would have different behaviours at different times. A summary of those responses is as below(Roland N.Horne, 1995):

	Early Time	Intermediate Time	Late Time
Radial flow	Storage	Infinite-acting radial flow	Closed boundary Sealing fault Constant pressure
Fractures	Storage bilinear flow	Radial flow	Closed boundary Sealing fault Constant pressure
Dual porosity	Storage	Dual porosity behaviour Transition Radial Flow	Closed boundary Sealing fault Constant pressure

Table 1: Table showing summary of responses in time sequence

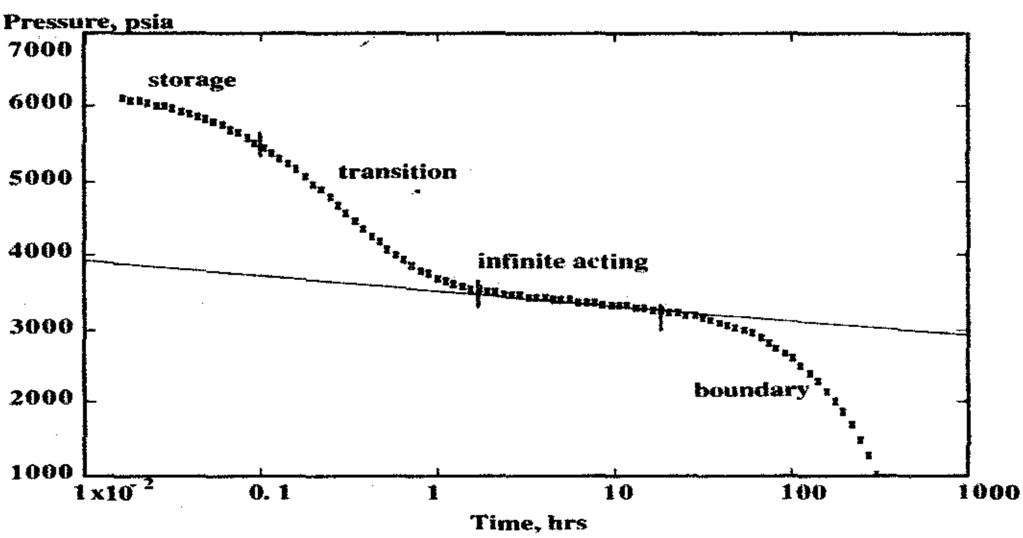

Figure 12: Combination of response gives a rise to an overall transient response

2.9 Superposition

The superposition approach makes it possible to construct reservoir response functions in complex situations using only simple basic models. This method is useful in well test analysis as we can use to represent the response due to several wells by adding up individual well responses. Various reservoir boundaries can also be represented by appropriate choice of flow rate and well location. A second important use of superposition is to add together the effects of wells at different times. This response can be used for any number of wells each with constant flow rates starting at different times. Hence, it is possible to generate the reservoir response to a single well flowing at a variable rate using the same constant rate that has already been described. (PA Fokker). Multiphase flow is commonly encountered in reservoirs of interest to petroleum engineers. This method can be modelled using diffusivity equation with p^2 as the dependant variable. This is applied to analyse simulated multiple well tests for a range of PVT properties. The results obtained are then compared to those from the Perrine's method. (Roland N.Horne, 1995)

$$q_o = \frac{k\,h}{141.2\,(\,0.5 \ln t_D + 0.404 + s\,)}\,(\,m\,(p_i\,) - m\,(p_{wf}\,)\,)$$

This approach would lead to absolute permeability and skin estimates. While Perrines method, though widely used can underestimate permeability and overestimate skin. Hence, to overcome this restriction a new approach is taken. Multiphased diffusivity equation in terms of p^2 can be linearised and be solved for any initial and boundary condition. This then leads to this equation below which is similar to Perrine's equation except that $\mu_o B_o$ is measured as well.

$$k_o = \frac{162.6\,q_o\,(\,\mu_o\,B_o\,)_{\frac{p_{1hr}+p_{10hr}}{2}}}{m^*\,h}.$$

Saturation profiles show that the k_o estimated at $(P_{1hr} + P_{10hr}) / 2$ is lesser than k_o at P_i. That is why Perrine's method underestimates permeability. To overcome this, $k_o/\mu_o B_o$ should be calculated at a higher pressure. (AJA Al Khalifa & RN Horne, 1987)

2.10 **Relationship Between Diffusivity and Productivity Index** (SR Shadizadeh, 2007)

The Diffusivity Equation is represented by the following formula:.

$$\eta = \frac{T}{S} = \frac{[kh/\mu]}{[\varphi C_t h]}$$

Transmissibility (T) represents the rate at which a given fluid of a given μ transmitted through cross section of unit. Storage (S) represents the amount of fluid released from reservoir volume of a high *h* and unit base per unit change in pressure.

The Productivity Index is represented by the following formula:

$$PI = \frac{q}{P_{ave} - P_{wf}}$$

The correlation between Productivity Index and Diffusivity Coefficient is defined by the formula below:

$$PI = 0.0002\left(\frac{1}{\eta}\right)^{-0.6563}$$

2.11 Multiple Well Testing

Using multiple well testing, pressure response is measured in an observation well some distance away from the active well that may be producing or an injection well. This would help create a communication and determine average reservoir properties in the area separating the well.

The response of an interference test either corresponds to a production period or an active shut in of the active well. The multiple well test can influence the wellbore storage and skin at the two wells and effects of boundaries and reservoir directional anisotropy.

Due to the availability of high accuracy of pressure data nowadays, multiple well testing is a very powerful testing method that is a lot more sensitive to many types of reservoir heterogeneities compared to a single well test. (Dominique Bourdet, 2002)

2.11 Computer Aided Analysis of a Well Test

Many underlying principles are based on drawdown in single well and constant production rates. The purpose of conducting a well test using a computer aided method is to speed up traditional graphical techniques by allowing quick graph presentations. Besides that, it is also able to extend the analysis beyond the restrictions in traditional methods that cannot be handled at all such as continuous varying rates, multiple wells, complex geometries and indefinite initial pressures.(Roland N.Horne, 1995)

2.11.1 Diagnostic Plot Evaluation

Different parts of a reservoir response are recognizable by their characteristics or particular graphical presentations. This helps engineer's separate one part of the response from another. Since certain specific portions of the response are used to estimate specific reservoir parameters, it is clearly necessary to identify each portion precisely. Through a computer aided well test analysis, these different regions can be analysed separately.(Roland N.Horne, 1995)

2.11.2 Nonlinear Regression

This is one of the most powerful analytical tools of a computer based well test analysis. This method allows automated curve matching that uses mathematical algorithm to match observed data to an unknown reservoir parameter until the model and data fit as closely as possible. This method gives a statistical determination of goodness, hence not only providing a good analysis but an evaluation of how good the answer is. The advantages of using this method would be to analyse multirate or variable tests, avoid inconsistent interpretations, provide confidence estimates on answer and can be used to interpret "uninterpretable" tests. (Roland N.Horne, 1995)

3.0 RESEARCH METHODOLOGY

The main purpose of this research to predicate reservoir parameters of well test analysis using Pan System software.

3.1 Key Milestones

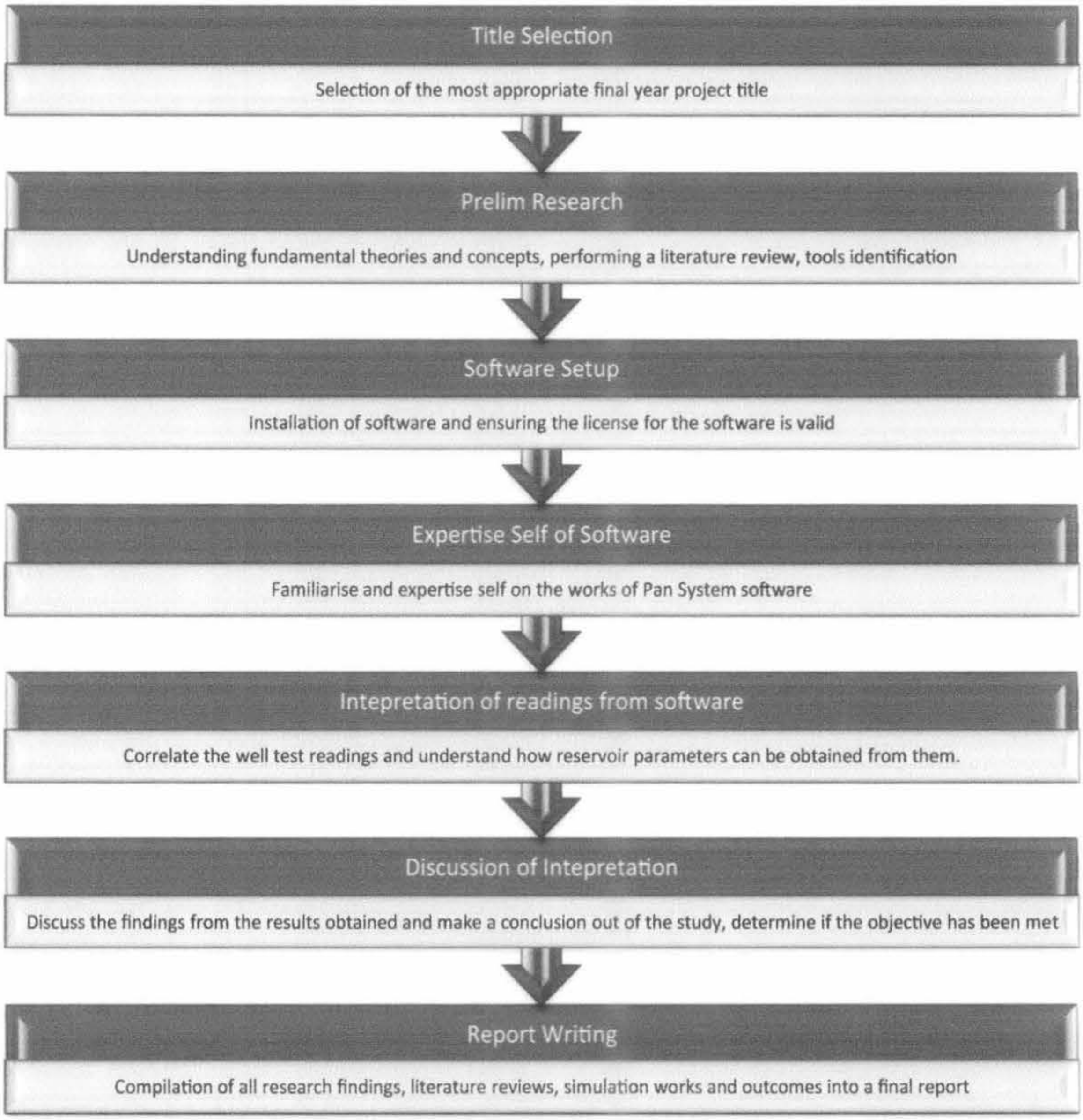

Figure 13: Flow Chart Representing Project Methodology.

Steps	Activity
Title Selection	Selection of the most appropriate final year project title.
Preliminary Research	Performing initial ground work in obtaining information regarding the project and its elements like fundamental theories and concepts, software and other verifications. Also includes critical literature survey to enhance knowledge about advances and previous studies regarding well test analysis and predication of reservoir parameters.
Software Setup	Selection of software and learning how to use software. Involves installation of software, learning the use of software using the instruction manual and also understanding on theory the difference of a computer analysis and traditional well test analysis.
Analysis of Results	The results would involve obtaining the reservoir parameters of Pan System. The analysis would involve comparing the predicated parameters when done on a single well test and from a well test with interfering wells. This would hence prove the benefits of using Pan System to obtain well test results for multiple wells.
Discussion of Analysis	Discussion of the findings from the results obtained. The results obtain which are the predicated parameters would help characterise the reservoir and understand the reservoir.
Report Writing	Compilation of all research findings, literature reviews, software simulation and outcomes into a final report.

Table 2: Methodology in detail

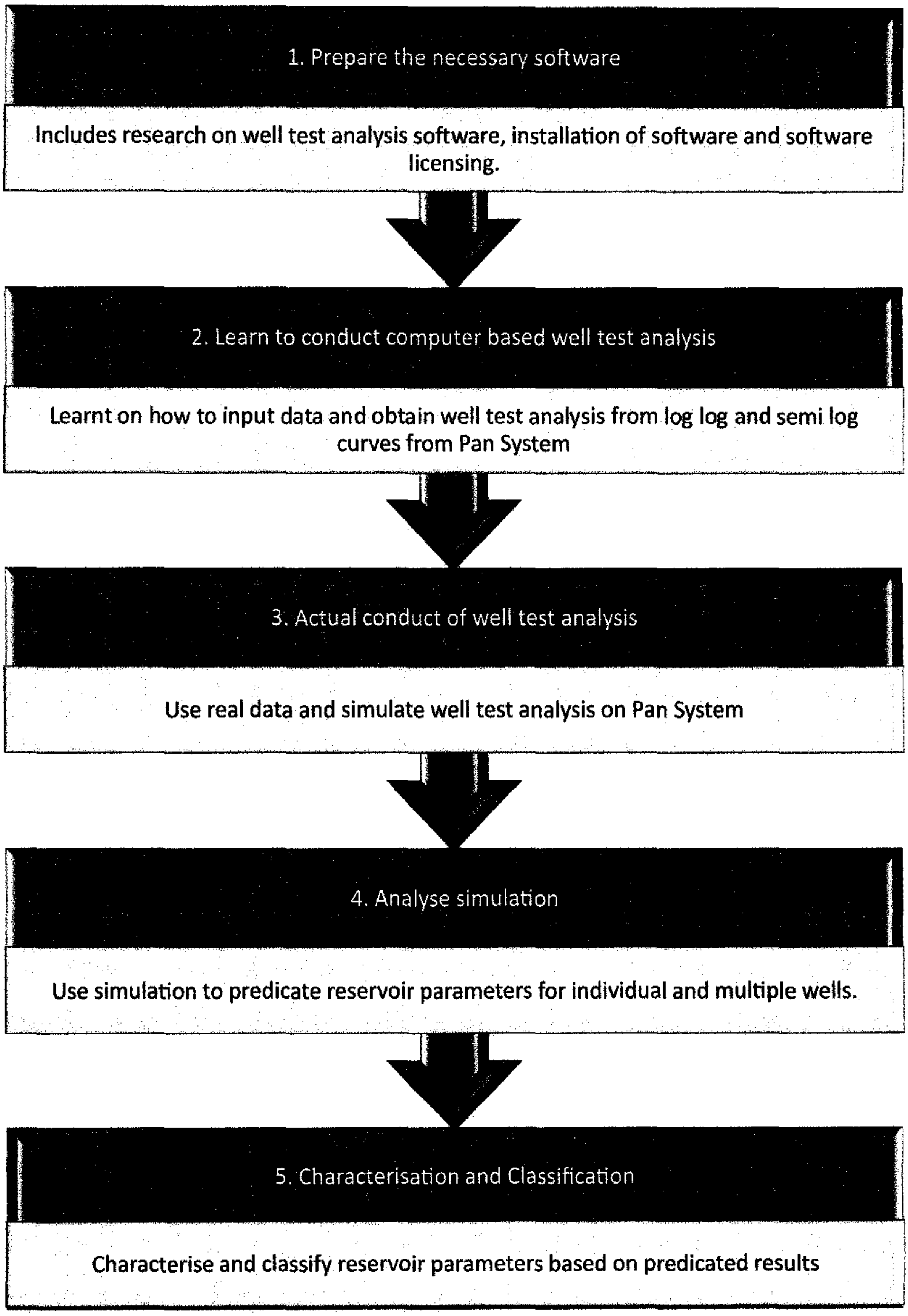

Figure 14: FlowChart Depicting Software Simulation Methodology

3.2 Project Methodology

3.2.1 Manual Well Test Analysis (Semi-Log Curve)

1. Semi log curve of Pressure (psi) versus time (hours) is plotted on a Microsoft Excel Sheet
2. Parameters such as slope; *m*, permeability; k, skin factor; S, compressibility factor, C_t and radius of investigation; r_i is computed using these formulas:

   Permeability

   $K = -162.6\ B\mu/mh$

   Skin Factor

   $S = 1.151[(P_i - P_{1hr})/m - \log(k/\phi\mu c_t r_w^2) + 3.23]$

   Radius of Investigation

   $r_i = ((k\Delta t)/948\phi\mu C_t)$

   Compressibility Factor

   $C_t = c_g S_g + c_o S_o + c_w S_w + c_f$

3.2.2 Individual Well Test Analysis using Pan System

The same manual well test is done computed using Pan System software. The sequence is as below:

1. Pan System software is opened.
2. "**Reservoir Description**" tab is clicked. Here, the parameters for well, layers and fluid is inputted.
3. "**Pressure and Data Preparation**" tab is clicked. Here, the pressure, flow rate and time readings are inputted.
4. A plot of Pressure and Flow Rate vs time is generated. The plot is then edited in case of any discrepancies in data to create a better well test

response. Any unusual data point is removed and mistakes in data input is rechecked.

5. The Log Log Plot icon is then clicked to generate a log log plot.
6. Boundary model and flow regime is then specified according to the shape of the log-log plot generated.
7. Flow regimes are specified and parameters obtained are then confirmed.
8. The data is then simulated. Here, the purpose is to obtain a perfect match. This will help determine that this flow model and combination of model parameters that have been selected adequately describe the reservoir. A theoretical pressure build up response is then generated and compared to the measured data.
9. The model parameters may then be adjusted and the simulation repeated until a good match is achieved.

3.2.3 Multiple Well Test Analysis using Pan System

1. Pan System software is opened.
2. "**Reservoir Description**" tab is clicked. Here, the parameters for well, layers and fluid is inputted.
3. "**Pressure and Data Preparation**" tab is clicked. Here, the pressure, flow rate and time readings are inputted.
4. A plot of Pressure and Flow Rate vs time is generated. The plot is then edited in case of any discrepancies in data to create a better well test response. Any unusual data point is removed and mistakes in data input is rechecked.
5. The Log Log Plot icon is then clicked to generate a log log plot.
6. Boundary model and flow regime is then specified according to the shape of the log-log plot generated.
7. Flow regimes are specified and parameters obtained are then confirmed.
8. The data is then simulated. Here, the purpose is to obtain a perfect match. This will help determine that this flow model and combination of model parameters that have been selected adequately describe the reservoir. A theoretical pressure build up response is then generated and compared to the measured data.

9. Test Design is created for each well in the "**Pressure and Data Preparation**" section. Here, the rate sequence and computation time steps is pre decided by the user.
10. The **Advanced Simulation** tab is clicked and allowed to simulate.
11. Return to Pressure and Data Preparation tab.
12. Plot the simulated plot of Observation Well in response to the Princicple Well selected.
13. Repeat analysis and Simulate via **"Auto Match"** to obtain parameters of area in between observation well and principle well.

3.3 Equipments and Tools

The only equipment that I would need for this project is the Pan System software. This software together with its license is readily available in the computer lab.

Pan System is a software that provides multiple choices for models and analysis. This software provides a way to simplify complex transient well testing through detailed analysis, simulation and reporting. This software would then be able to obtain information within the reservoir with appropriate testing and analysis.

3.4 Gantt Chart

FINAL YEAR 1st SEMESTER (JAN 2011)

No.	Detail/ Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Project title selection and start	■						Mid-semester break								
2.	Preliminary research work		■	■	■	■	■									
3.	Preliminary report submission						■									
4.	Study on fundamental concepts related to the project				■	■	■									
5.	Familiarise self with software				■	■	■		■	■						
7.	Seminar (optional)									■						
8.	Conduct analysis using software									■	■	■	■	■	■	
9.	Preparation of interim report													■	■	
10.	Submission of interim report														■	

Figure 15: The Gantt Chart for the First Semester Project Implementation

FINAL YEAR 2nd SEMESTER (JULY 2011)															
No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Gathering real data and understand significance of provided data														
2.	Understand data input and application of reservoir data														
3.	Conduct manual well test analysis														
4.	Conduct individual well test analysis for all wells														
5.	Conduct multiple well test analysis														
6.	Preparation of progress report														
7.	Submission of progress report														
8.	Intepret predicated parameters														
9.	Discuss and characterise reservoir														
10.	Submission of final report														
11.	EDX														
12.	Oral presentation														
13.	Delivery of Report to External Examiner														

Figure 16: The Gantt Chart for Experimental Work Semester

(Legend: Completed: Ongoing :)

4.0 RESULTS AND DISCUSSION

4.1 Actual Results

4.1.1 Manual Well Test Results

Parameters Obtained

Well	Permeability	Skin	Radius of Investigation
1	1.259	-1.294	46.70084
2	27.308	-8.31	783.4298
3	34.081	-8.826	2417.982
4	130.927	-3.496	7344.826
5	24.414	-1.729	879.3732
6	112.405	-2.64	2774.372
7	31.656	-5.839	999.8421

Table 3: Results for Manual Well Test Analysis using Microsoft Excel

4.1.2 Individual Well Test Results using Pan System Software

Parameters Obtained

Well	K (md)	S	ω	Lam	Cs (bbl/psi)	Cphi (psi)	Tau (hr)	L NF (ft)	Initial Pressure (psia)
1	3.7048	-2.867	0.777	0.0085	0.0439	268.696	1.2147	190.001	1308.58
2	29.847	-2.958	0.398	0.0005	0.0214	324.614	0.2982	250.019	1599.01
3	394.13	-1.165	0.031	0.00004	0.069	34.5568	0.4347	625.998	1404.17
4	252.078	-1.591	0.196	0.0011	0.0549	100.164	0.0847	36.2604	1564.69

5	30.83	-1.343	0.029	0.01	0.501	168.211	0.0018	10.5488	1021.653
6	445.707	2.519	NA	NA	0.1055	507.941	200	NA	1255.545
7	255.991	-2.949	0.004	0.000033	0.2053	70.7275	0.0002	1446.24	1383.55

Table 4: Predicated Parameters for Individual Wells using Pan System

Flow Regimes & Boundary Models

Well	Flow Regime	Boundary Model
1	Dual Porosity (Pseudo Steady State)	U-shaped faults (L:10L:L)
2	Dual Porosity (Pseudo Steady State)	U-shaped faults (L:10L:L)
3	Dual Porosity (Pseudo Steady State)	Parallel faults (L:L)
4	Dual Porosity (Pseudo Steady State)	Parallel faults (L:L)
5	Dual Porosity (Pseudo Steady State)	U-shaped faults (L:10L:L)
6	Radial Homogenous	Infinitely Acting
7	Dual Porosity (Pseudo Steady State)	Parallel faults

Table 5: Flow Regimes and Boundary Models for Individual Wells using Pan System

4.1.3 Multiple Well Test Analysis Results using Pan System Software

Parameters Obtained

Principle Well & Obsv. Well	K (md)	S	ω	Lam	Cs (bbl/psi)	Cphi (psi)	Tau (hr)	L NF (ft)	Initial Pressur (psia)
2 & 7	112.45	0.0943	0.1	0.0009	0.0003	9481.3	0.3403	25801.4	1785.5
2 & 4	46.425	11.34	0.03	0.01	0.0000022	0.000001	0.8012	566.393	1791.5
3 & 7	688.50	-1.155	0.62	1.128e-	0.0619	0.0281	16.263	702.872	1720.8

				009					
4 & 7	3004.1	0.689	0.40	0.0002	0.0387	217.254	0.2523	100.5	1577.8
4 & 2	208.75	-3.5604	0.40	0.0002	0.044	217.79	0.2517	58.7055	1598.1
7 & 3	266.86	-5.202	0.04	2.6e-006	0.0537	35.011	0.0415	1096.32	1064.3

Table 6: Predicated Parameters for Individual Wells using Pan System

Flow Regimes & Boundary Models

Principle Well & Obsv. Well	Flow Regime	Boundary Model
2 & 7	Dual Porosity (Pseudo Steady State)	Single Fault
2 & 4	Dual Porosity (Pseudo Steady State)	Single Fault
3 & 7	Dual Porosity (Pseudo Steady State)	Single Fault
4 & 7	Dual Porosity (Pseudo Steady State)	Parallel Faults
4 & 2	Dual Porosity (Pseudo Steady State)	Single Fault
7 & 3	Dual Porosity (Pseudo Steady State)	U-Shaped Faults (L:L:L)

Table 7: Flow Regimes and Boundary Models for Individual Wells using Pan System

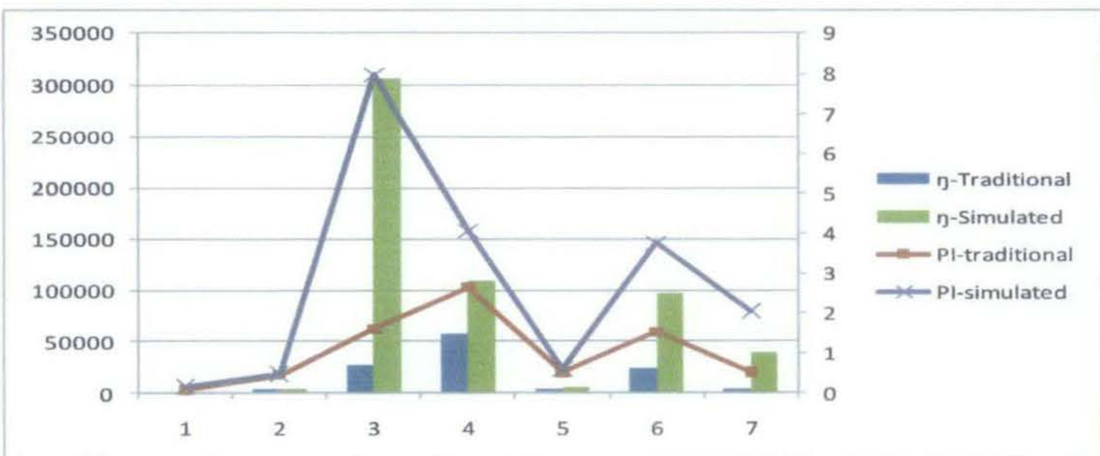

Figure 17: Graph showing diffusivity versus Productivity Index for Traditional and Multiple Well Test Analysis.

4.2 Discussion

4.2.1 Analysis and Interpretation of Individual Wells

WELL 1

From the parameters obtained, the diffusivity and productivity of the reservoir area around the well is low for both traditional and computer aided well test. Well is vertical and able to penetrate complete vertical thickness. The wellbore storage effect and skin are both present. The reservoir in this region has low permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as permeability and viscosity of well is low. This section of the reservoir has a horizontal permeability anisotropy, hence its able to generate a small amount of negative skin on the test responses. Wellbore storage coefficient is low, hence homogenous reservoir model is not applicable. Distance to nearest fault is 190 ft from well.

Well 1 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 1, long transition regimes correspond to shallow valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the larger the value, the earlier the start of the total system flow as found in Well 1. The pressure curves will occur at a lower amplitude and the derivative response valley is displaced towards earlier times. (Dominique Bourdet, 2002)

This well is located at a U-Shaped Fault or also known as limited channel. Limited channel is a special case of infinite acting reservoir where the parallel faults are limited on one side of the well. The channel is infinite acting only on one side of the well. This well is known as a U-shaped fault or limited channel as it is located between three intersecting faults and does not sense a fourth boundary. The well starts producing as an infinite reservoir until it feels presence of boundary. If boundary limiting the channel is further than the distance of well from channel, channel response is seen till the boundary is felt. In this case where the well is not equidistance from all the boundaries; L:10L:L, the well goes into unlimited channel linear flow. The well response deviates from infinite acting radial flow when channel response is seen by pressure. The late time slope of derivative will be similar to infinite channel but shifted upwards by a factor of two as a U-Shaped channel, only half of the reservoir is available to flow. (Resolve™, 2008)

In order to obtain the above results, the analysed period had to be long enough to show the total system flow.

WELL 2

From the parameters obtained, the diffusivity and productivity of the reservoir area around the well is low for both traditional and computer aided well test. The wellbore storage effect and skin are both present. The reservoir in this region has low permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as permeability of zone is low. Wellbore storage coefficient is low, hence homogenous reservoir model is not applicable. Distance to nearest fault is 250 ft from well.

Well 2 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 2, long transition regimes correspond to shallow valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the smaller the value, the later the start of the total system flow as found in Well 2. The pressure curves will occur at a higher amplitude and the derivative response is displaced towards later times. (Dominique Bourdet, 2002)

This well is located at a U-Shaped Fault or also known as limited channel. Limited channel is a special case of infinite acting reservoir where the parallel faults are limited on one side of the well. The channel is infinite acting only on one side of the well. This well is known as a U-shaped fault or limited channel as it is located between three intersecting faults and does not sense a fourth boundary. The well starts producing as an infinite reservoir until it feels presence of boundary. If boundary limiting the channel is further than the distance of well from channel, channel response is seen till the boundary is felt. In this case where the well is equidistance from all the boundaries; L:L:L, the well goes into limited channel linear flow. The well response deviates from infinite acting radial flow when channel response is seen by pressure. The late time slope of derivative will be similar to infinite channel but shifted upwards by a factor of two as a U-Shaped channel, only half of the reservoir is available to flow. In order to obtain the above results, the analysed period had to be long enough to show the total system flow since it's a late start of system flow. (Resolve™, 2008)

WELL 3

From the parameters obtained, the diffusivity and productivity of the reservoir area around the well is high for both traditional and computer aided well test. The wellbore storage effect and skin are both present. The reservoir in this region has high permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as viscosity of producing fluid is low. Wellbore storage coefficient is low, hence homogenous reservoir model is not applicable. Distance to nearest fault is 626 ft from well.

Well 3 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. Usually, for small values of ω such as for Well 3, small transition regimes correspond to an increase in the fissure curve parameter. The Lam value defines the interporosity flow parameter. Here, the smaller the value, the later the start of the total system flow as found in Well 3. The pressure curves will occur at a higher amplitude and the derivative response is displaced towards later times. (Dominique Bourdet, 2002)

This well has a parallel fault boundary where the well is located between two parallel sealing faults. Although this configuration refers to faulted systems, it also corresponds to long narrow reservoirs such as channel sands. On the plot above, it can be observed that when the two reservoir boundaries have reached, the flow lines become parallel to reservoir limits and a linear flow regime is met. The shape of the transition between radial and linear flow in the plot above is a function of the well location in the channel. Well 3 is located at an equal distance from the two boundaries. That is why, the transition between radial and linear flow regime is short. In order to obtain the above results, the analysed period had to be long enough to show the total system flow. (Dominique Bourdet, 2002)

WELL 4

From the parameters obtained, the diffusivity and productivity of the reservoir area around the well is high for both traditional and computer aided well test. The wellbore storage effect and skin are both present. The reservoir in this region has high permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as viscosity of producing fluid is low. Wellbore storage coefficient is low, hence homogenous reservoir model is not applicable. Distance to nearest fault is 626 ft from well.

Well 4 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 4, long transition regimes correspond to very shallow valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter. Here, the larger the value, the earlier the start of the total system flow as found in Well 4. The pressure curves will occur at a lower amplitude and the derivative response is displaced towards earlier times. (Dominique Bourdet, 2002)

This well has a parallel fault boundary where the well is located between two parallel sealing faults. Although this configuration refers to faulted systems, it also corresponds to long narrow reservoirs such as channel sands. On the plot above, it can be observed that when the two reservoir boundaries have reached, the flow lines become parallel to reservoir limits and a linear flow regime is met. The shape of the transition between radial and linear flow in the plot above is a function of the well location in the channel. Well 4 is located closer to one of the boundaries, hence the characteristic behaviour of one sealing fault is seen before the other. The derivative fist stabilizes at 0.5 and finally it reaches the half unit slope straight line that represents the fault. (Dominique Bourdet, 2002)

In order to obtain the above results, the analysed period had to be long enough to show the total system flow.

WELL 5

From the parameters obtained, the diffusivity and productivity of the reservoir area around the well is low for both traditional and computer aided well test. The wellbore storage effect and skin are both present. The reservoir in this region has low permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as permeability and viscosity of producing fluid is low. Wellbore storage coefficient is high; a homogenous reservoir model would also be applicable.

Well 5 represents a dual porosity model. This model categorizes the reservoir in several ways. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For small values of ω such as for Well 5, long transition regimes correspond to deeper valleys on the derivative and an increase in the fissure curve parameter. The Lam value defines the interporosity flow parameter. Here, the smaller the value, the later the start of the total system flow as found in Well 5. The pressure curves will occur at a higher amplitude and the derivative response is displaced towards earlier times. (Dominique Bourdet, 2002)

This well is located at a U-Shaped Fault or also known as limited channel. Limited channel is a special case of infinite acting reservoir where the parallel faults are limited on one side of the well. The channel is infinite acting only on one side of the well. This well is known as a U-shaped fault or limited channel as it is located between three intersecting faults and does not sense a fourth boundary. The well starts producing as an infinite reservoir until it feels presence of boundary. If boundary limiting the channel is further than the distance of well from channel, channel response is seen till the boundary is felt. In this case where the well is equidistance from all the boundaries; L:L:L, the well goes into limited channel linear flow. The well response deviates from infinite acting radial flow when channel response is seen by pressure. The late time slope of derivative will be similar to infinite channel but shifted upwards by a factor of two as a U-Shaped channel, only half of the reservoir is available to flow. In order to obtain the above results, the analysed period had to be long enough to show the total system flow since it's a late start of system flow. (Resolve™, 2008)

In order to obtain the above results, the analysed period had to be long enough to show the total system flow.

WELL 6

From the parameters obtained, the diffusivity and productivity of the reservoir area around the well is high for computer aided well test and low for traditional well test. The wellbore storage effect and skin are both present. The reservoir in this region has high permeability when calculated. Due to the radial composite reservoir condition, negative skin is observed from the traditional well test. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is high as permeability and viscosity of producing fluid is high. However, when tested using Pansystem, the skin obtained was positive. This shows that there is poor contact between the well and the reservoir. Wellbore storage coefficient is high; a homogenous reservoir model is applicable. (Dominique Bourdet, 2002)

Well 6 represents a radial homogenous infinitely acting model. This model categorizes the reservoir in several ways. The well is assumed to be vertical and to be able to penetrate the complete reservoir thickness. An infinitesimal skin and wellbore storage effect is present. (Dominique Bourdet, 2002)

In order to obtain the above results, the analysed period had to be long enough to show the total system flow. The drastic differences in traditional and computer aided well test analysis found for this well can happen due to the quest to find the exact match between the analytical solution and tested data. A perfect matched data with the wrong model is completely useless. A full study for this part of the reservoir should be done in order to obtain the correct model. Well testing as demonstrated above, can provide multiple models and parameters with ranges of values. The uncertainty in this simulation can be reduced when integrated with other data such as log readings. (Dominique Bourdet, 2002)

WELL 7

From the parameters obtained, the diffusivity and productivity of the reservoir area around the well is low for traditional well test and high for computer aided well test. The wellbore storage effect and skin are both present. The reservoir in this region has high permeability when calculated using Pan System software and low permeability when calculated using traditional well testing methods. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as viscosity of producing fluid is low. Wellbore storage coefficient is high; a homogenous reservoir model would also be applicable.

Well 7 represents a dual porosity model. This model categorizes the reservoir in several ways. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For small values of ω such as for Well 7, long transition regimes correspond to deeper valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter. Here, the smaller the value, the later the start of the total system flow as found in Well 7. The pressure curves will occur at a higher amplitude and the derivative response is displaced towards later times. (Dominique Bourdet, 2002)

In order to obtain the above results, the analysed period had to be long enough to show the total system flow. The drastic differences in traditional and computer aided well test analysis found for this well can happen due to the quest to find the exact match between the analytical solution and tested data. A perfect matched data with the wrong model is completely useless. A full study for this part of the reservoir should be done in order to obtain the correct model. Well testing as demonstrated above, can provide multiple models and parameters with ranges of values. The uncertainty in this simulation can be reduced when integrated with other data such as log readings. (Dominique Bourdet, 2002)

This well has a parallel fault boundary where the well is located between two parallel sealing faults. Although this configuration refers to faulted systems, it also corresponds to long narrow reservoirs such as channel sands. On the plot above, it can be observed that when the two reservoir boundaries have reached, the flow lines become parallel to reservoir limits and a linear flow regime is met. The shape of the transition between radial and linear flow in the plot above is a function of the well location in the channel. Well 3 is located at an equal distance from the two boundaries. That is why, the transition between radial and linear flow regime is short. In order to obtain the above results, the analysed period had to be long enough to show the total system flow. (Dominique Bourdet, 2002)

4.2.2 Analysis and Interpretation of Multiple Wells

CASE 1: Pressure response at Well 2 when observed from Well 7

This case represents the pressure response at Well 2 when observed from Well 7. This test also describes the reservoir region between Well 2 and Well 7. The reservoir in this region has high permeability. Well 2 shows a positive skin response due to damaged well conditions. This is due to poor contact between well and the reservoir or invaded zone. Wellbore storage coefficient is low, hence homogenous reservoir model is not applicable.

The area between Well 2 and Well 7 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 2, long transition regimes correspond to shallow valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the smaller the value, the later the start of the total system flow as found in Well 2. The pressure curves will occur at a higher amplitude and the derivative response valley is displaced towards later times. (Dominique Bourdet, 2002)

Well 2 has a single sealing fault model when observed from Well 7. Here, a linear no-flow boundary closes the reservoir in one direction. The early time part of the well responds to infinite reservoir behaviour. When the influence of the sealing fault is felt, the flow becomes hemi-radial and the mobility is reduced by a factor of 2. (Dominique Bourdet, 2002)

CASE 2: Pressure response at Well 2 when observed from Well 4

This case represents the pressure response at Well 2 when observed from Well 4. This test also describes the reservoir region between Well 2 and Well 4. The reservoir in this region has low permeability. Well 2 shows a positive skin response due to damaged well conditions. This is due to poor contact between well and the reservoir or invaded zone. Wellbore storage coefficient is low, hence homogenous reservoir model is not applicable.

The area between Well 2 and Well 4 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 2, long transition regimes correspond to shallow valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the larger the value, the earlier the start of the total system flow as found in Well 1. The pressure curves will occur at a lower amplitude and the derivative response valley is displaced towards earlier times. (Dominique Bourdet, 2002)

Well 2 has a single sealing fault model when observed from Well 4. Here, a linear no-flow boundary closes the reservoir in one direction. The early time part of the well responds to infinite reservoir behaviour. When the influence of the sealing fault is felt, the flow becomes hemi-radial and the mobility is reduced by a factor of 2. (Dominique Bourdet, 2002)

CASE 3: Pressure response at Well 3 when observed from Well 7

This case represents the pressure response at Well 3 when observed from Well 7. This test also describes the reservoir region between Well 3 and Well 7. The reservoir in this region has high permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as viscosity of producing fluid is low. Wellbore storage coefficient is high; hence homogenous reservoir model can be applied.

The area between Well 3 and Well 7 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 3, long transition regimes correspond to shallow valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the smaller the value, the later the start of the total system flow as found in Well 3. The pressure curves will occur at a higher amplitude and the derivative response valley is displaced towards later times. (Dominique Bourdet, 2002)

Well 3 has a single sealing fault model when observed from Well 7. Here, a linear no-flow boundary closes the reservoir in one direction. The early time part of the well responds to infinite reservoir behaviour. When the influence of the sealing fault is felt, the flow becomes hemi-radial and the mobility is reduced by a factor of 2. (Dominique Bourdet, 2002)

CASE 4: Pressure response at Well 4 when observed from Well 7

This case represents the pressure response at Well 4 when observed from Well 7. This test also describes the reservoir region between Well 4 and Well 7. The reservoir in this region has high permeability. Due to the radial composite reservoir condition, positive skin is observed. Well 4 shows a positive skin response due to damaged well conditions. This is due to poor contact between well and the reservoir or invaded zone. Wellbore storage coefficient is high, hence homogenous reservoir model is applicable.

The area between Well 4 and Well 7 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 4, long transition regimes correspond to shallow valleys on the derivative and a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the smaller the value, the later the start of the total system flow as found in Well 4. The pressure curves will occur at a higher amplitude and the derivative response valley is displaced towards later times. (Dominique Bourdet, 2002)

This well has a parallel fault boundary where the well is located between two parallel sealing faults. Although this configuration refers to faulted systems, it also corresponds to long narrow reservoirs such as channel sands. On the plot above, it can be observed that when the two reservoir boundaries have reached, the flow lines become parallel to reservoir limits and a linear flow regime is met. The shape of the transition between radial and linear flow in the plot above is a function of the well location in the channel. Well 4 is not located at an equal distance from the two boundaries. That is why, the transition between radial and linear flow regime is long. In order to obtain the above results, the analysed period has to be long enough to show the total system flow. (Dominique Bourdet, 2002)

CASE 5: Pressure response at Well 4 when observed from Well 2

This case represents the pressure response at Well 4 when observed from Well 2. This test also describes the reservoir region between Well 4 and Well 2. The reservoir in this region has high permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is low as viscosity of producing fluid is low. Wellbore storage coefficient is high, hence homogenous reservoir model can be applicable. (Dominique Bourdet, 2002)

The area between Well 4 and Well 2 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and p_m, the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 4, long transition regimes correspond to a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the smaller the value, the later the start of the total system flow as found in Well 4. The pressure curves will occur at a higher amplitude and the derivative response valley is displaced towards later times. (Dominique Bourdet, 2002)

Well 4 has a single sealing fault model when observed from Well 2. Here, a linear no-flow boundary closes the reservoir in one direction. The early time part of the well responds to infinite reservoir behaviour. When the influence of the sealing fault is felt, the flow becomes hemi-radial and the mobility is reduced by a factor of 2. (Dominique Bourdet, 2002)

CASE 6: Pressure response at Well 7 When observed from Well 3.

This case represents the pressure response at Well 7 when observed from Well 3. This test also describes the reservoir region between Well 7 and Well 3. The reservoir in this region has high permeability. Due to the radial composite reservoir condition, negative skin is observed. Negative skin behaviour shows surface of contact between well and reservoir has been increased compared to basic well behaviour. Skin damage is high as permeability of producing fluid is high. Wellbore storage coefficient is high, hence homogenous reservoir model can be applicable. (Dominique Bourdet, 2002)

The area between Well 7 and Well 3 represents a dual porosity model. In this model, a few assumptions are made. Based on the assumptions, a few conclusions can be made. The dimensions of the matrix blocks in the reservoir are small compared to the reservoir volume involved in the test. Each point in the reservoir is associated with 2 pressures, which is p_f the pressure of the fluid in fissures, and $p_{m,}$ the pressure of the fluid in the matrix pore volume. The pressure of the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flow through the well is only through the fissured system of the reservoir. This flow is assumed to be pseudo steady state. This assumption is the result of damage at the surface blocks. The fissures in the reservoir are partially plugged by mineral deposition or by chemical precipitation, but they include some channels that allow the fluid to flow to the well. Though the matrix creates these channels, the flow has to first cross through the thin low permeability deposit layer on the wall of the fissures. (Dominique Bourdet, 2002)

The storativity ratio, ω defines the contrast between the fissured regime and total system regime. For large values of ω such as for Well 7, long transition regimes correspond to a decrease in the fissure curve parameter. The Lam value defines the interporosity flow parameter and the ability of the matrix blocks to produce into the fissured system. Here, the smaller the value, the later the start of the total system flow as found in Well 7. The pressure curves will occur at a higher amplitude and the derivative response valley is displaced towards later times. (Dominique Bourdet, 2002)

This well is located at a U-Shaped Fault or also known as limited channel. Limited channel is a special case of infinite acting reservoir where the parallel faults are limited on one side of the well. The channel is infinite acting only on one side of the well. This well is known as a U-shaped fault or limited channel as it is located between three intersecting faults and does not sense a fourth boundary. The well starts producing as an infinite reservoir until it feels presence of boundary. If boundary limiting the channel is further than the distance of well from channel, channel response is seen till the boundary is felt. In this case where the well is equidistance from all the boundaries; L:L:L, the well goes into limited channel linear flow. The well response deviates from infinite acting radial flow when channel response is seen by pressure. The late time slope of derivative will be similar to infinite channel but shifted upwards by a factor of two as a U-Shaped channel, only half of the reservoir is available to flow. In order to obtain the above results, the analysed period had to be long enough to show the total system flow since it's a late start of system flow. (Resolve™, 2008)

5.0 CONCLUSION

This study was able to demonstrate the difference in results for a traditional and simulated well test, difference in reservoir parameters for multiple and individual wells and also able to describe the reservoir precisely based on predicated parameters.

- In terms of diffusivity and Productivity Index, the relationship between these two parameters have been studied. Well 3, 4 and 6 have high diffusivity and Productivity Index. This shows that these wells have high potential compared to Well 1, 2, 5 and 7.
- The flow regime for all the wells are dual porosity except for Well 6. In this type of model, the matrix blocks in the reservoir surrounding the well are smaller compared to the reservoir volume involved. The pressure in the matrix blocks will decrease as flow progresses and finally equalise with the pressure of the surrounding fissures. The fluid flows only through the fissured system and the flow is pseudo steady state. This shows that this is the result of damage at surface blocks.
- The boundary models for the individual wells are U-Shaped faults for Well 1,2 and 5. This describes a reservoir with a limited channel where the parallel faults are limited to one side of the well. It is known as a U-shaped fault as the channel is located between three intersecting faults. While Well 3, 4 and 7 demonstrate a parallel fault model and Well 6 shows an infinite acting reservoir boundary. The parallel reservoir boundary describes a well that is located between two parallel sealing faults. Based on the derivative curve on the log log plot, the well location whether its equally distant from both the faults or closer to one plot can be determined.
- The storativity ratio and the interporosity flow parameter is beneficial influence the formation of the pressure and derivative curve on the log log plot. Permeability influences the skin value while wellbore storage coefficient describes whether a homogenous reservoir model is applicable or not.
- For multiple wells, the reservoir area between two wells are studied. The reservoir dealt with still shows a dual porosity flow regime for all cases studied. The reservoir boundary however is single fault for Case 1, 2,3 and 5. This type of boundary closes the reservoir in one direction. When the influence of sealing fault is felt, the mobility of flow is reduced and flow becomes hemi-radial.
- The differences between traditional and simulated well test is also studied and the recommendations are included in the following section.

6.0 FUTURE WORK AND RECOMMENDATION

As a recommendation for future work, a simulation study using Pan System should be done for type curves and semi log curves as well. These different curves can prove to have different sensitivities for different predicated parameters. Besides that, when conducting advanced simulation for multiple wells, a type curve analysis will prove to be more accurate in predicating parameters. The shape of transition curves in a type curve and how they can be used to characterise the reservoir would prove to be very important knowledge.

When it comes to well testing, a few important considerations should be taken into account. These considerations when taken into account by engineers can improve the predication of well testing parameters and reservoir characterisation.

- The design, operation and the analysis of the well test should be done by the same team. This was impossible for this study as the analysis I conducted was based on the well test that was designed by a different team. However, this is important as communication within the company is done via people who have insufficient knowledge about the technology. An improved organisation structure would be very much necessary in this case. (SY Zheng and P Corbett, 2005)
- The same test program should also be used for all reservoirs. This will give a generalised rate schedule and test durations for flow and well shut in. this is because reservoirs are all different in terms of rock size and fluid properties. A good test program can help meet all these objectives. (SY Zheng and P Corbett, 2005)
- For a proper build up test, the preceding drawdown also has critical impact on the outcome of the welltest. Hence, disturbances in the drawdown period before a build up should be avoided to prevent a deviation in the well test analysis. This is because the drawdown period can provide useful information for the reservoir in channel and closed reservoir systems. (SY Zheng and P Corbett, 2005)

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20. TLFeBOOK. *Well Test Analysis*

8.0 APPENDIXES

Traditional Analysis and Simulation Graphs for Individual Wells

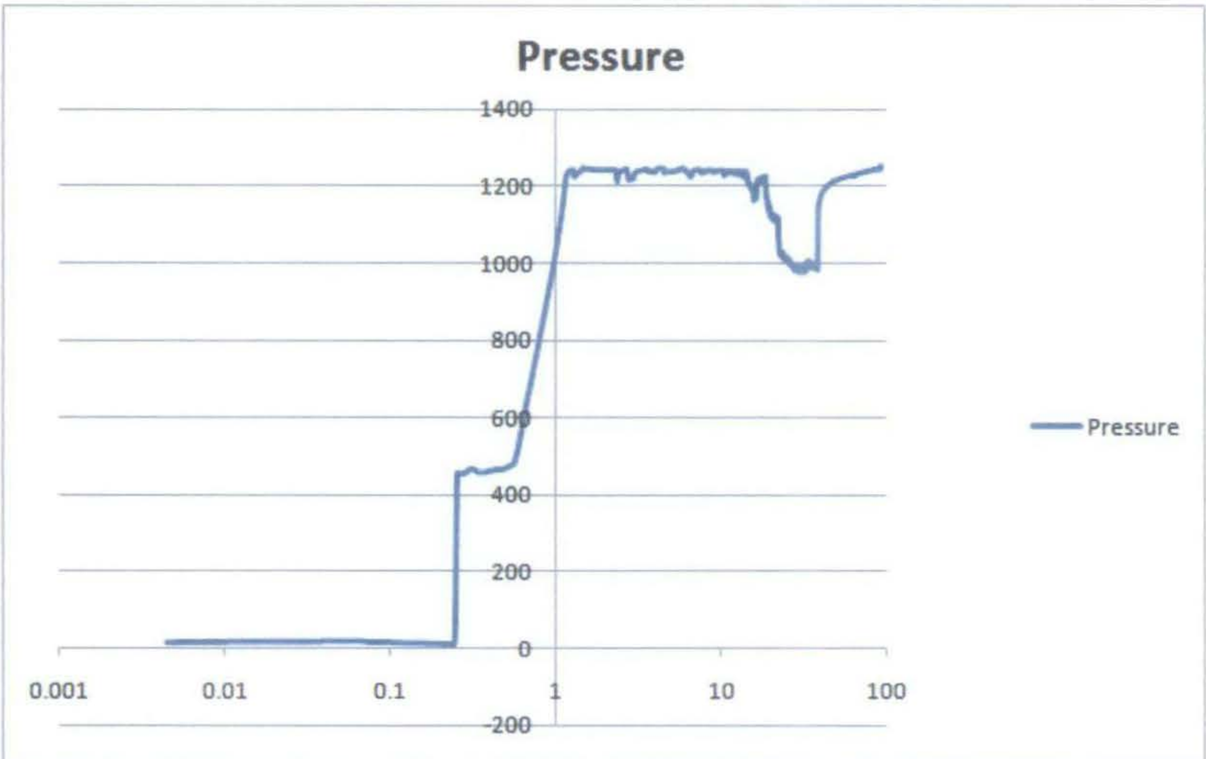

Figure 18: Traditional Well Test Analysis for Well 1 using Semi Log Curve

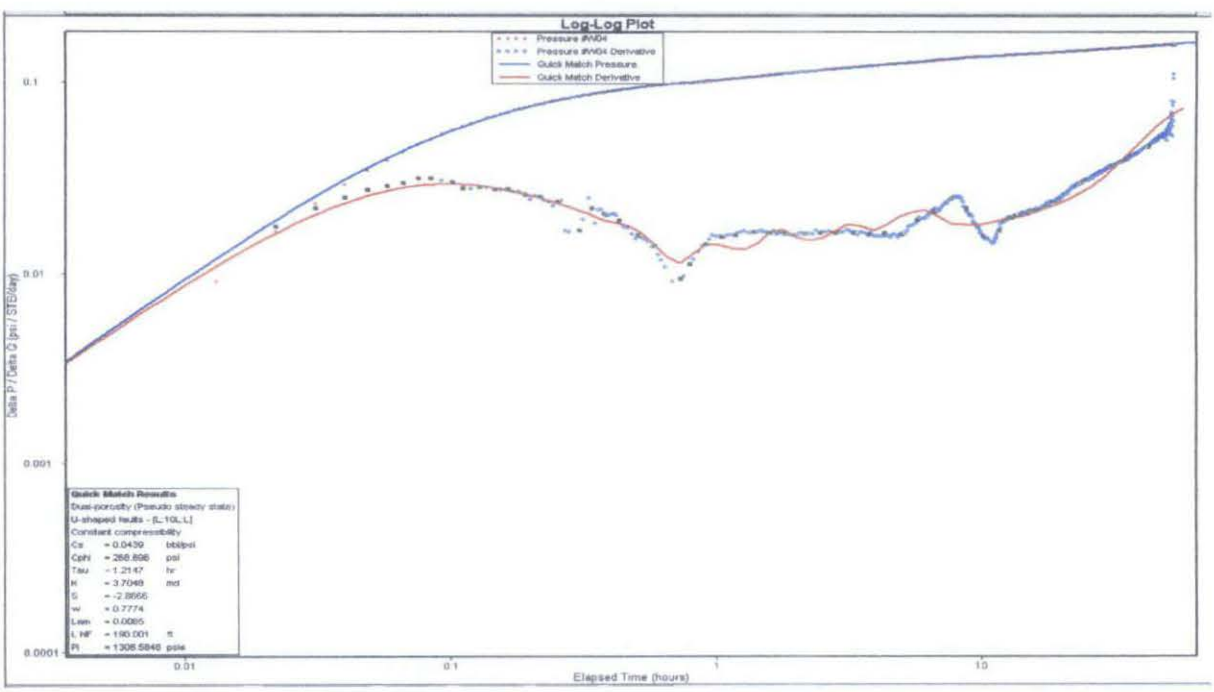

Figure 19: Simulated Well Test Response for Well 1 using Pan Sytem

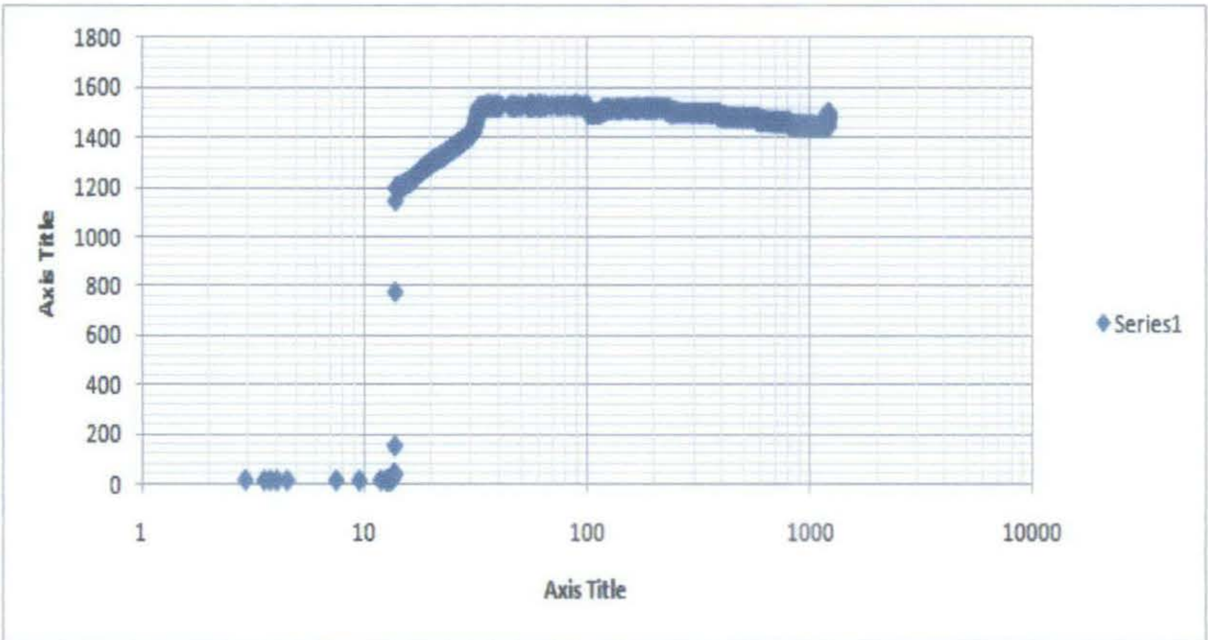

Figure 20: Traditional Well Test Analysis for Well 2 using Semi Log Curve

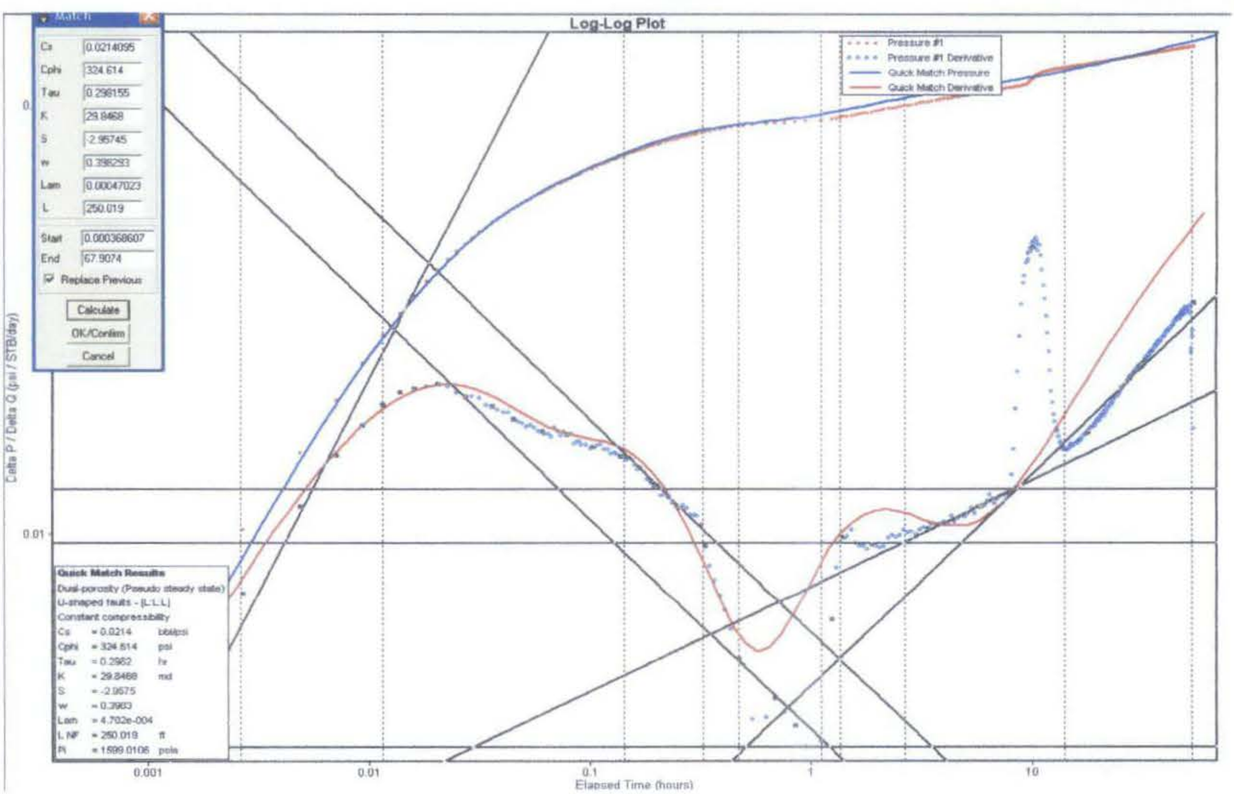

Figure 21: Simulated Well Test Response for Well 2 using Pan Sytem

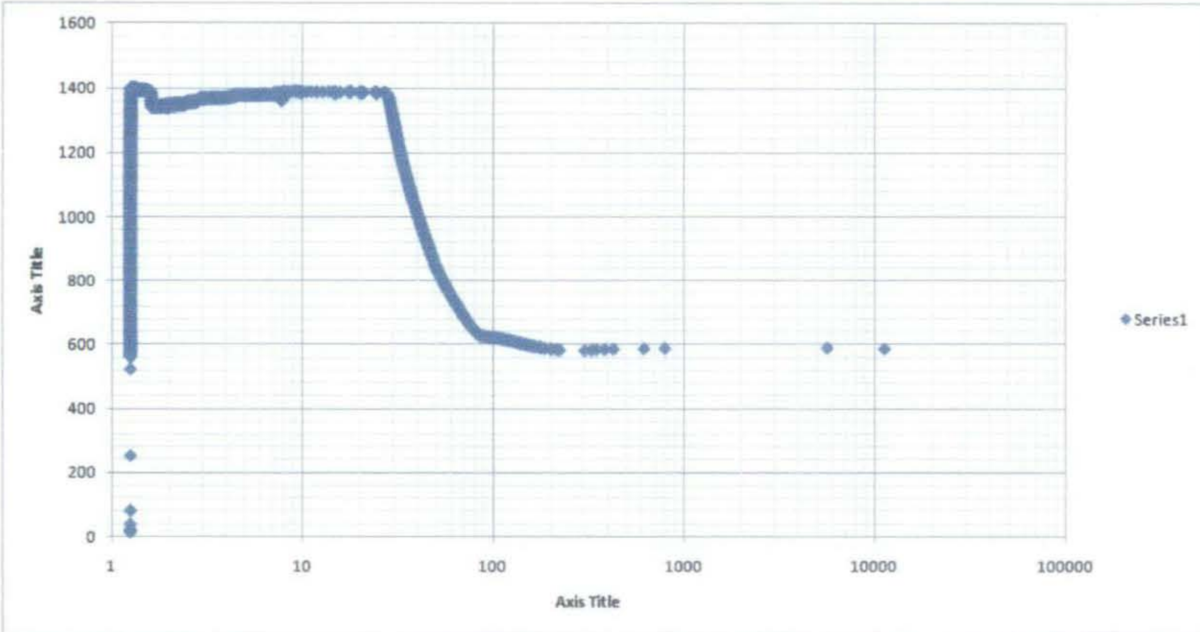

Figure 22: Traditional Well Test Analysis for Well 3 using Semi Log Curve

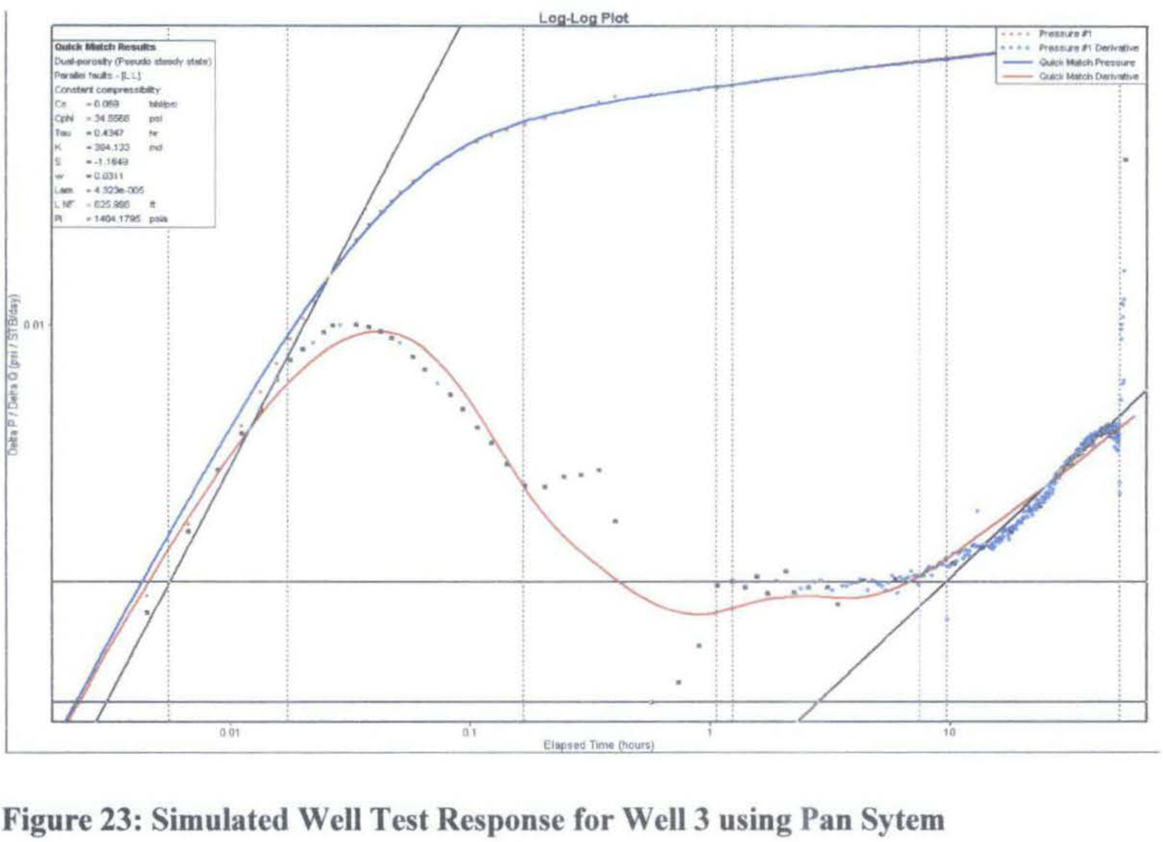

Figure 23: Simulated Well Test Response for Well 3 using Pan Sytem

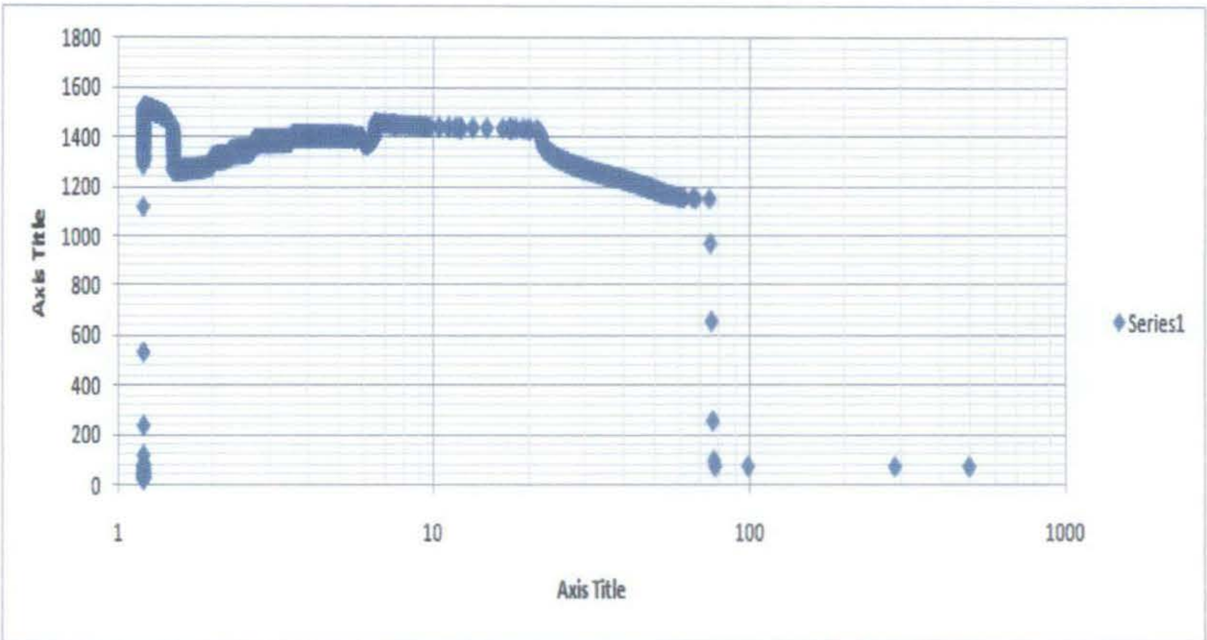

Figure 24: Traditional Well Test Analysis for Well 4 using Semi Log Curve

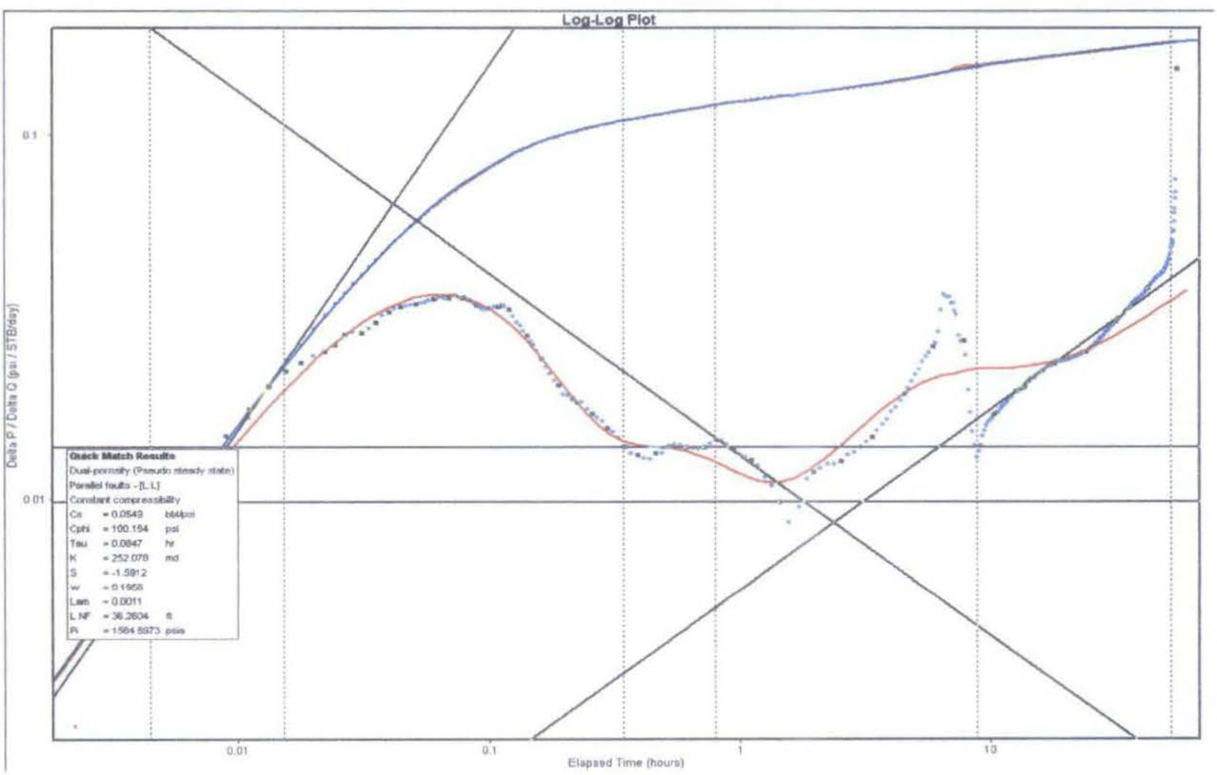

Figure 25: Simulated Well Test Response for Well 4 using Pan Sytem

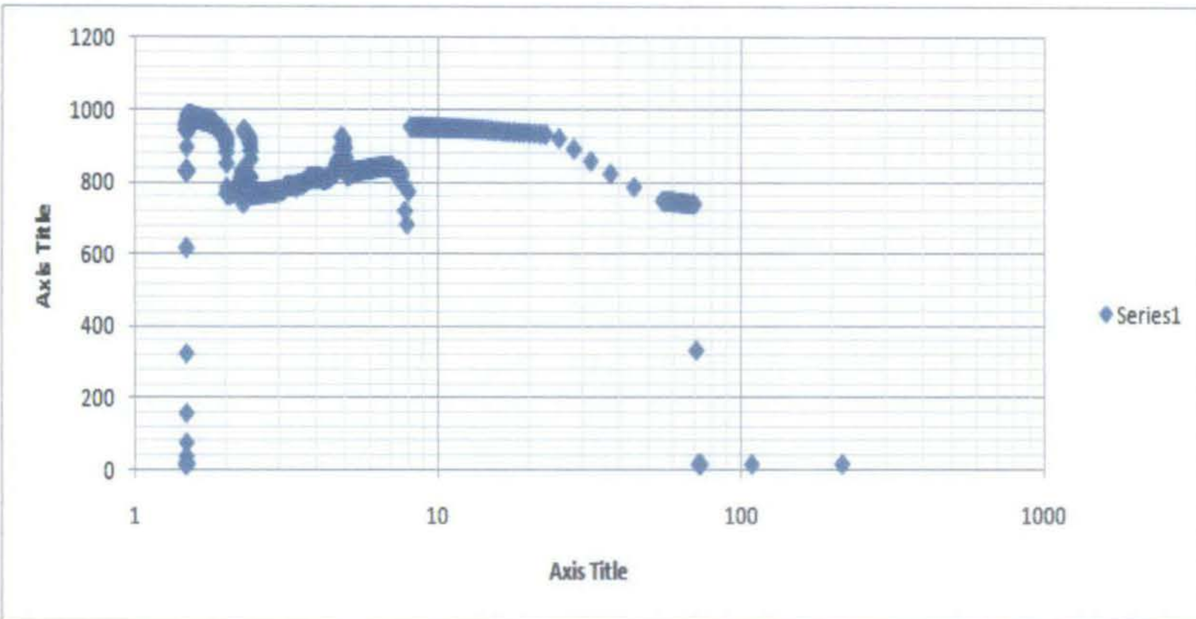

Figure 26: Traditional Well Test Analysis for Well 5 using Semi Log Curve

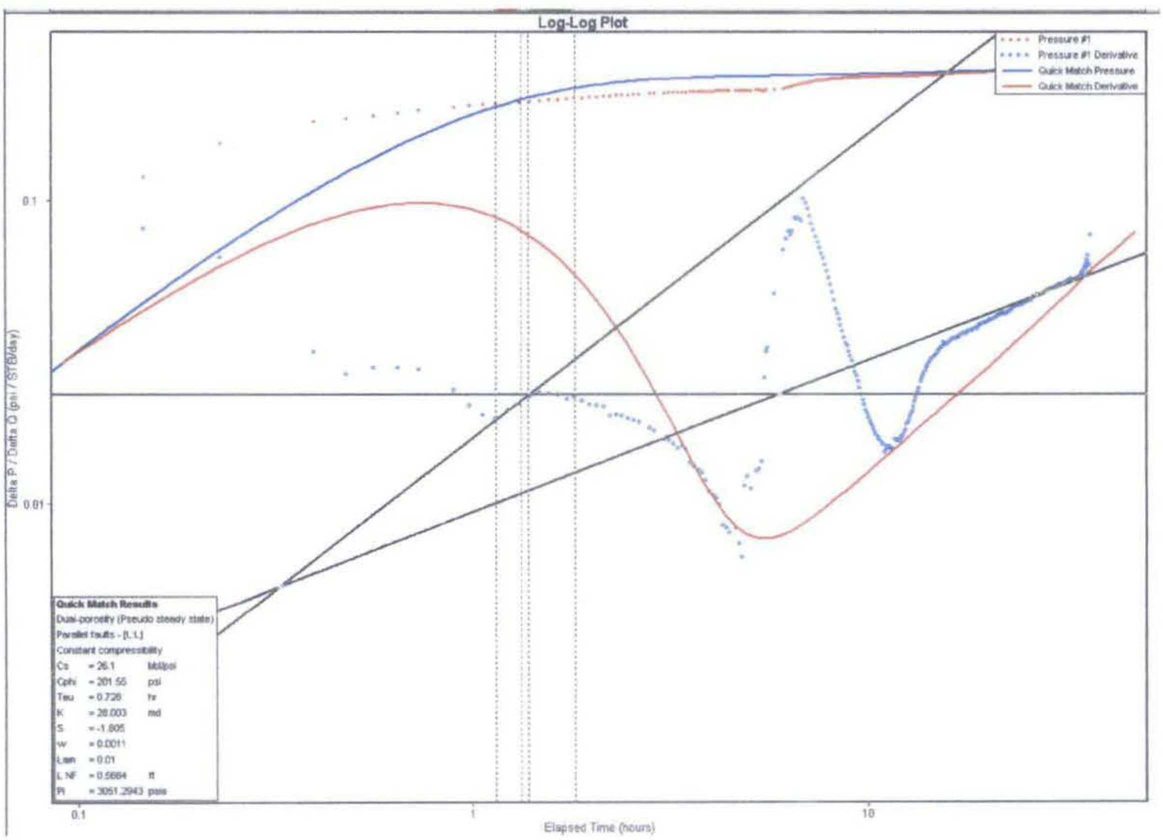

Figure 27: Simulated Well Test Response for Well 5 using Pan Sytem

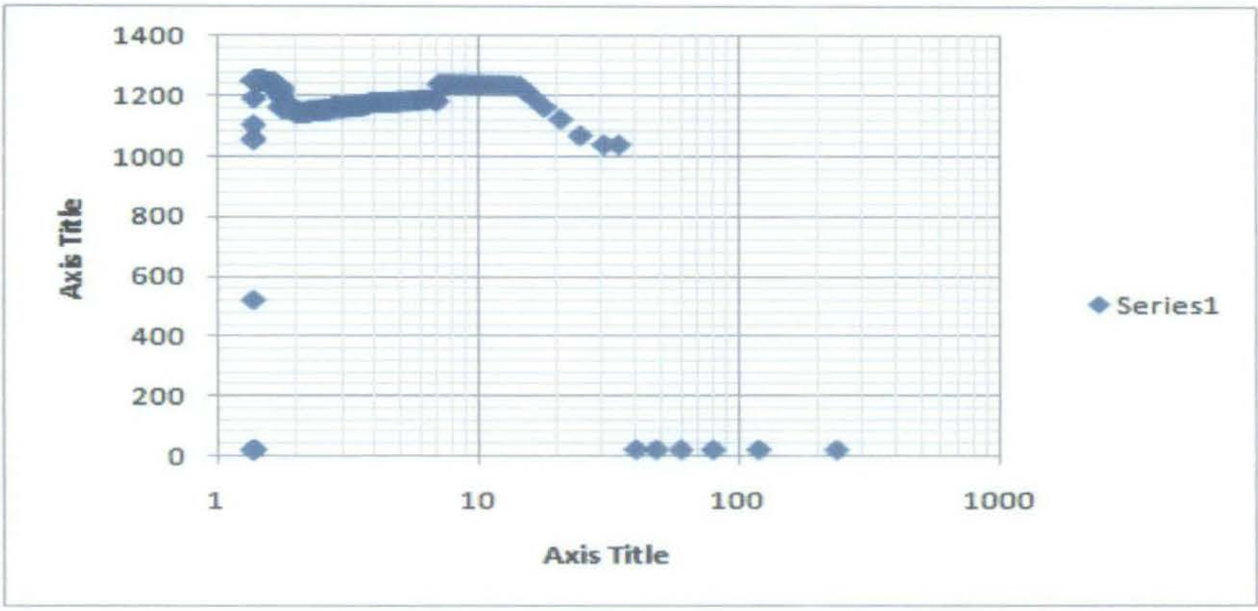

Figure 28: Traditional Well Test Analysis for Well 6 using Semi Log Curve

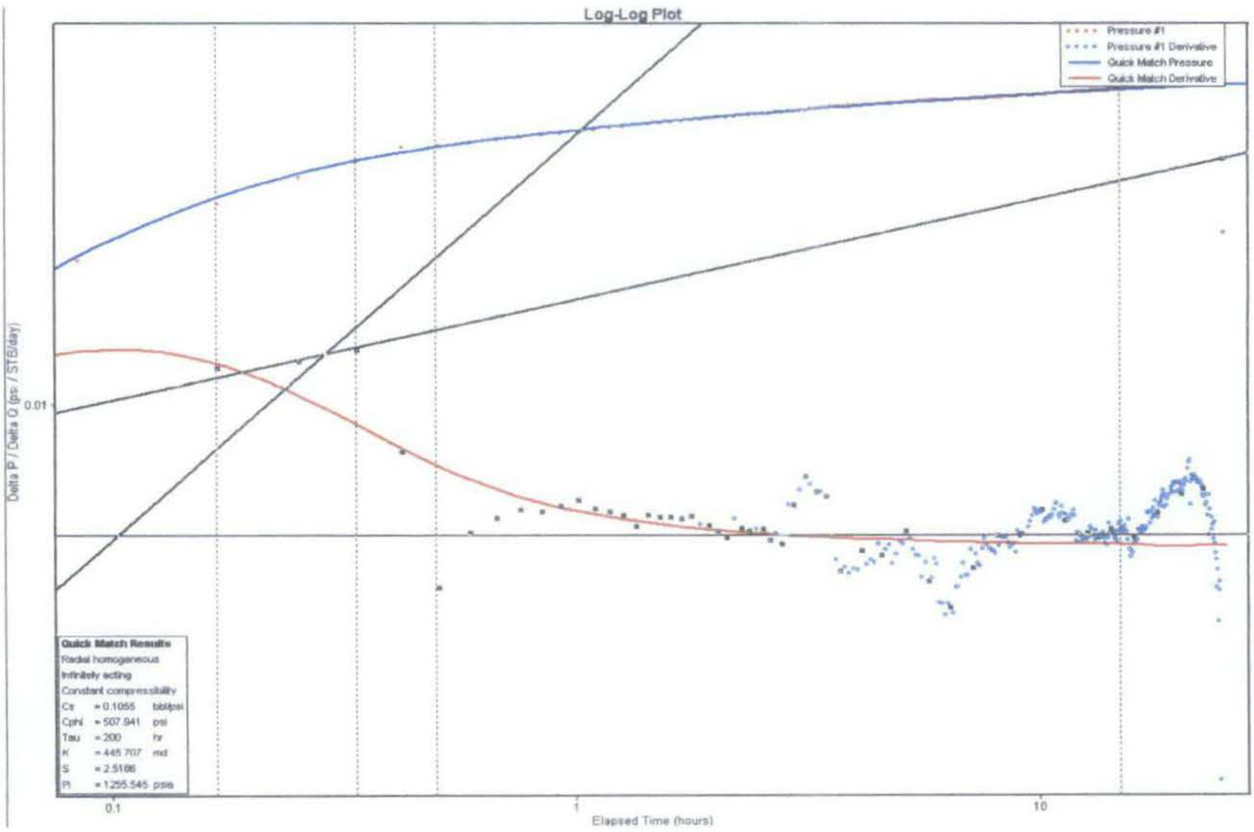

Figure 29: Simulated Well Test Response for Well 6 using Pan Sytem

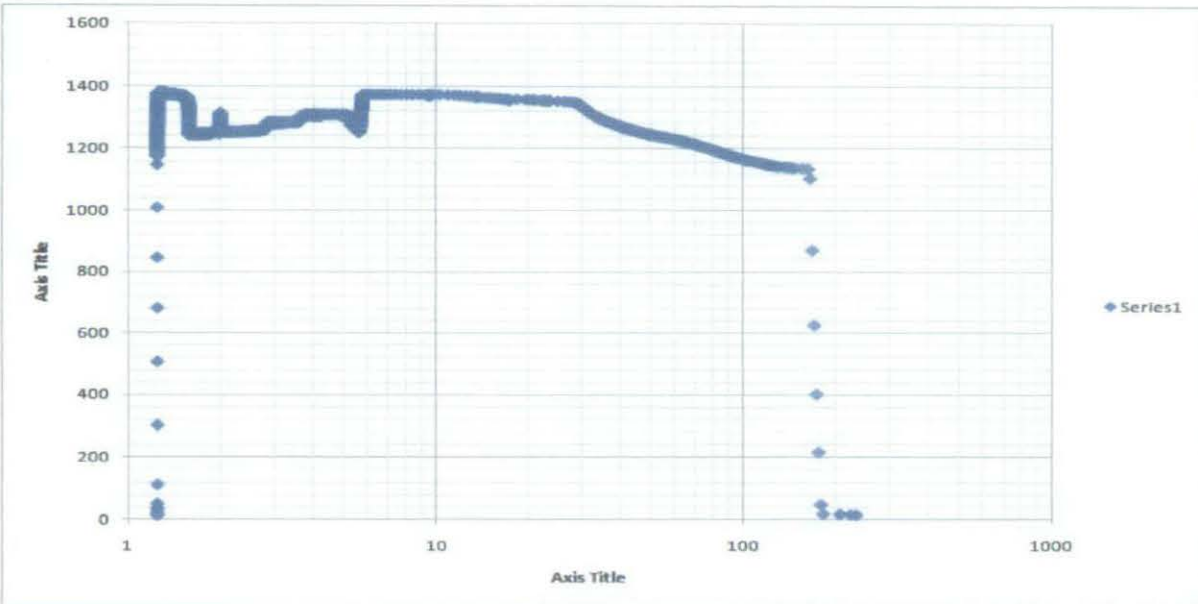

Figure 30: Traditional Well Test Analysis for Well 7 using Semi Log Curve

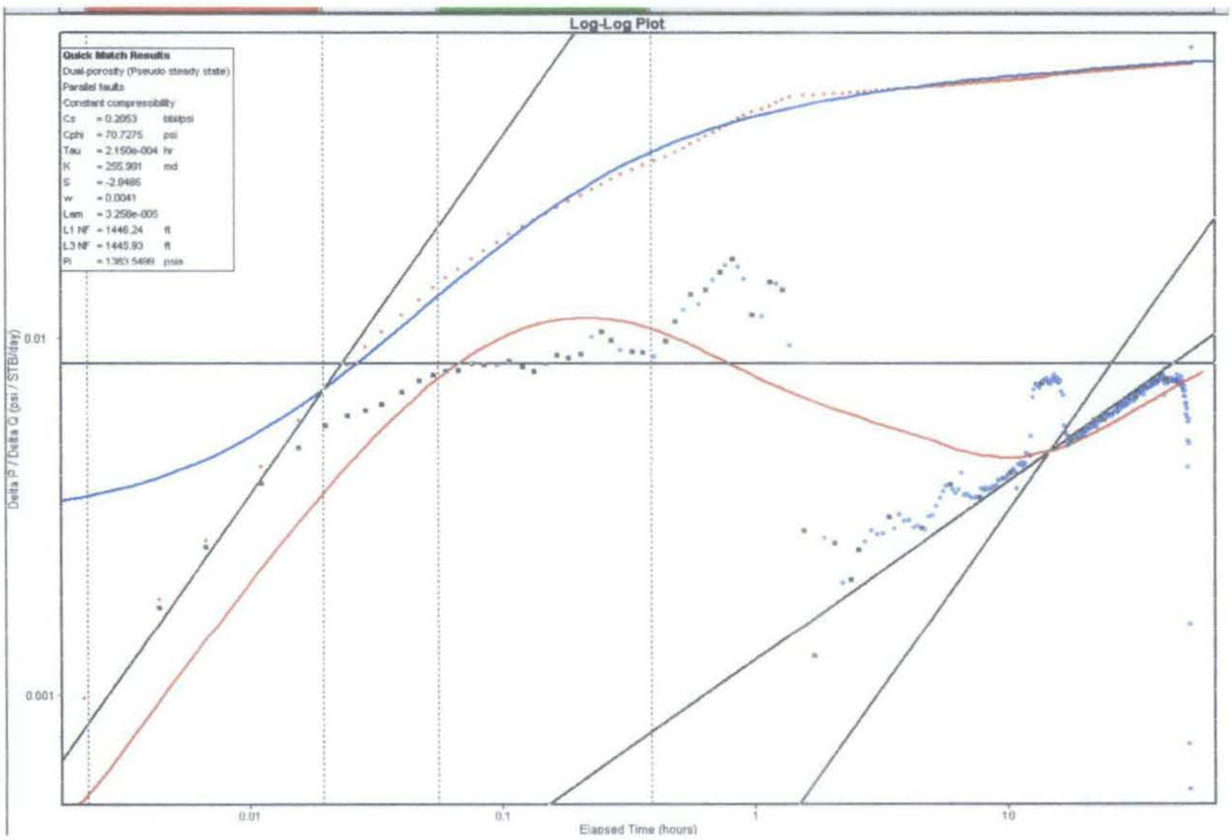

Figure 31: Simulated Well Test Response for Well 7 using Pan Sytem

Simulation Graphs for Multiple Wells

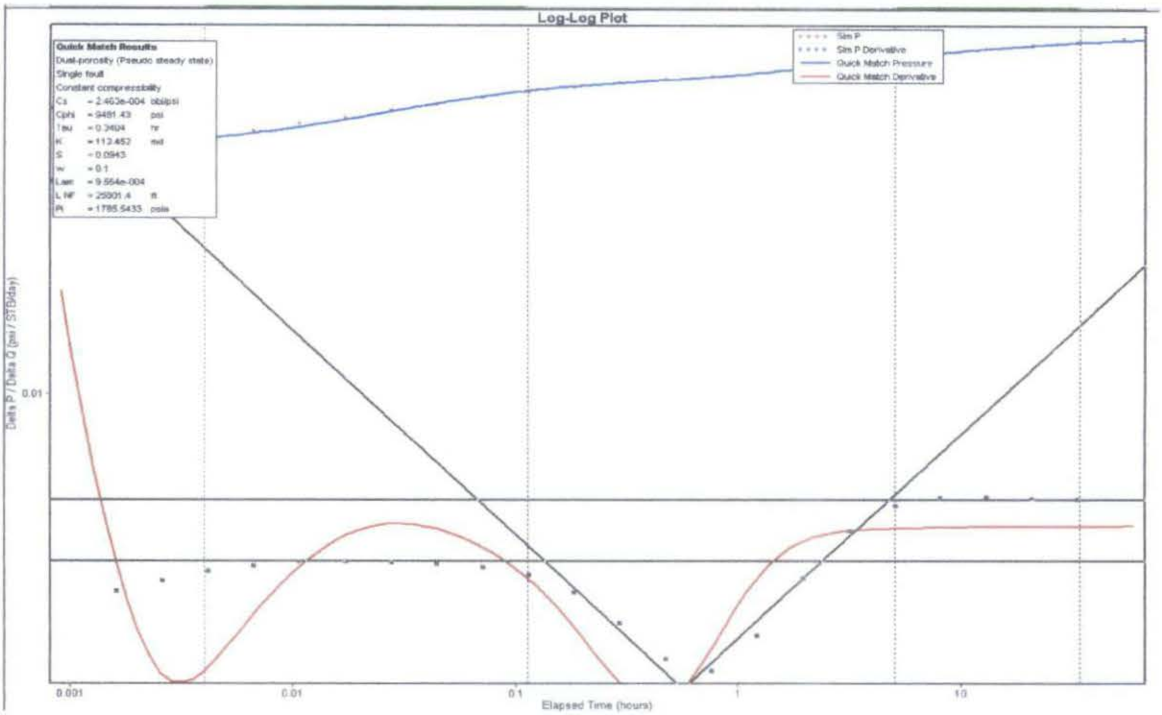

Figure 32: CASE 1- Simulated well test analysis response at Well 2 when observed from Well 7

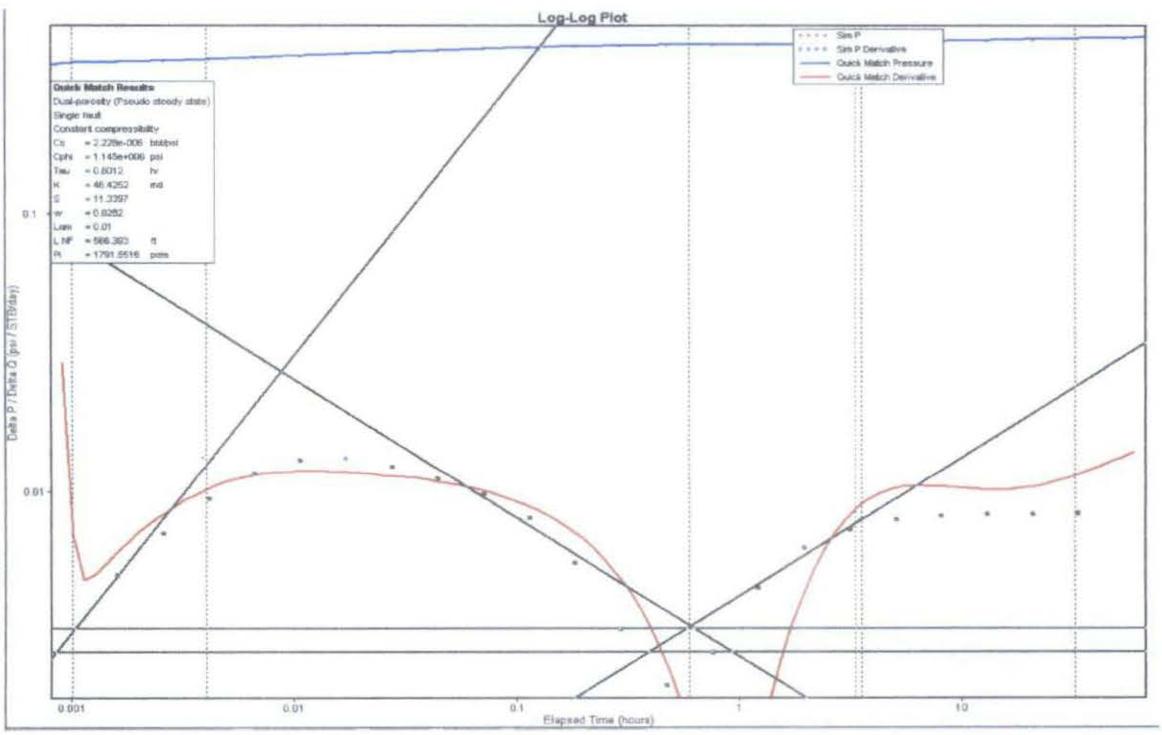

Figure 33: CASE 2- Simulated well test analysis response at Well 2 when observed from Well 4

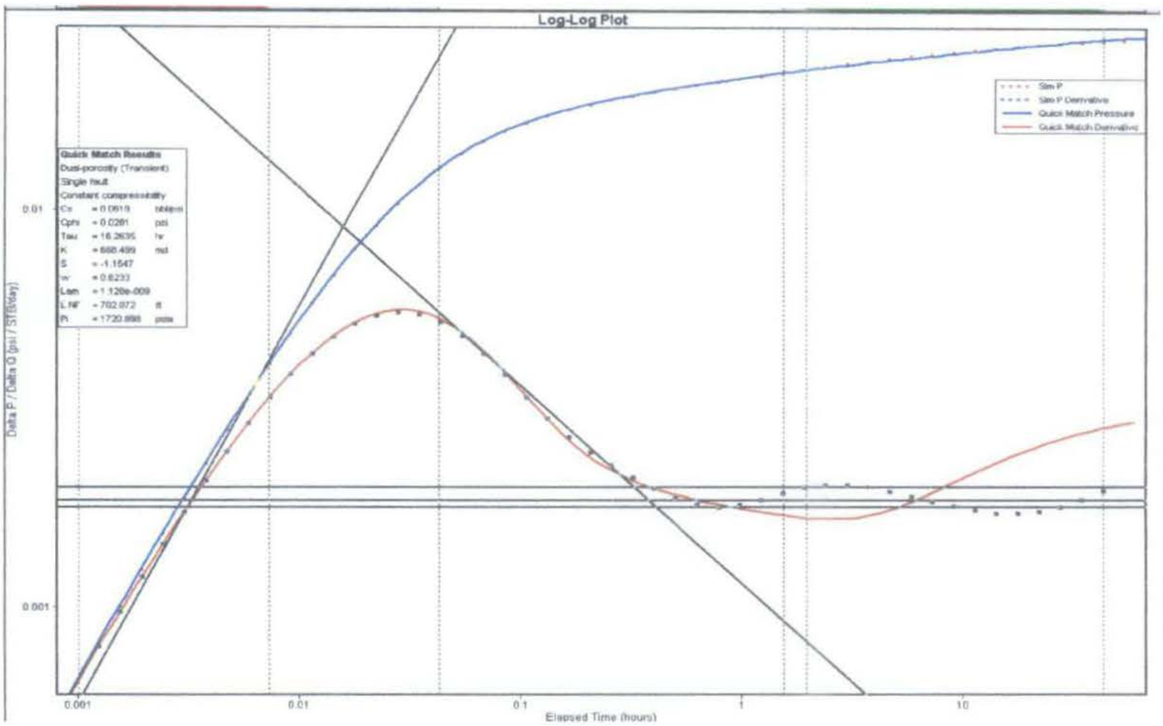

Figure 34: CASE 3- Simulated well test analysis response at Well 3 when observed from Well 7

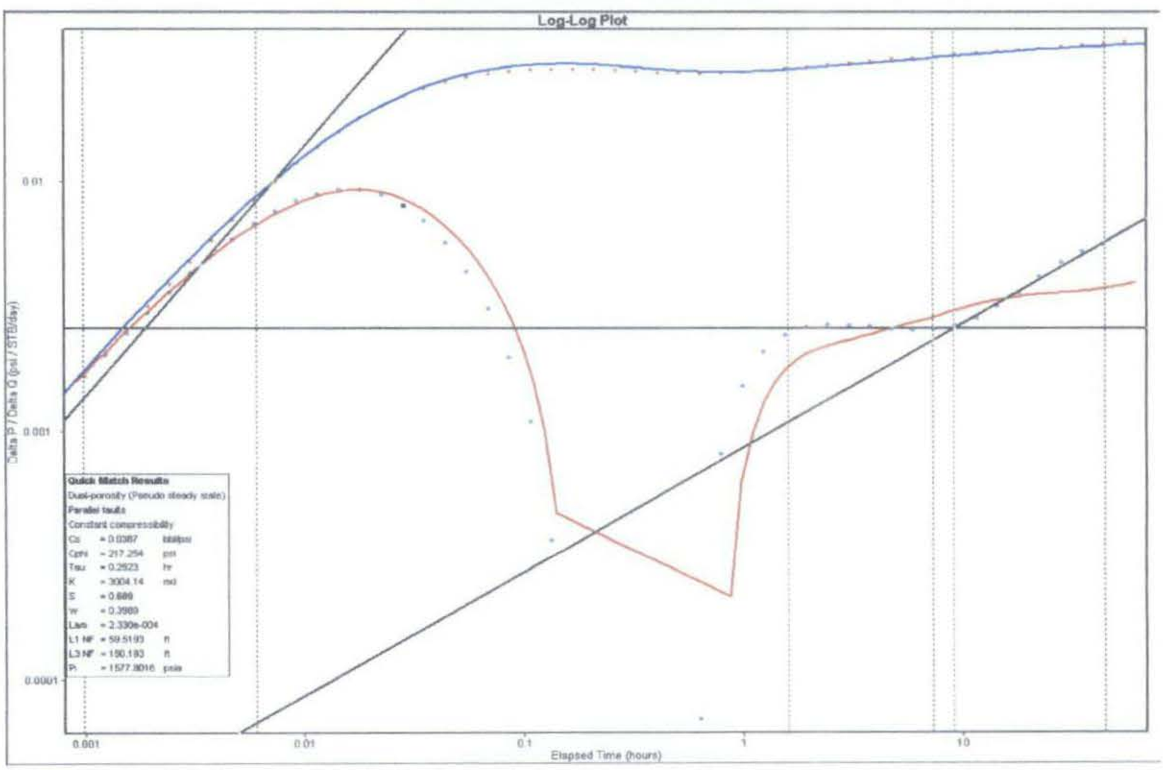

Figure 35: CASE 4- Well Test Analysis response at Well 4 when observed from Well 7

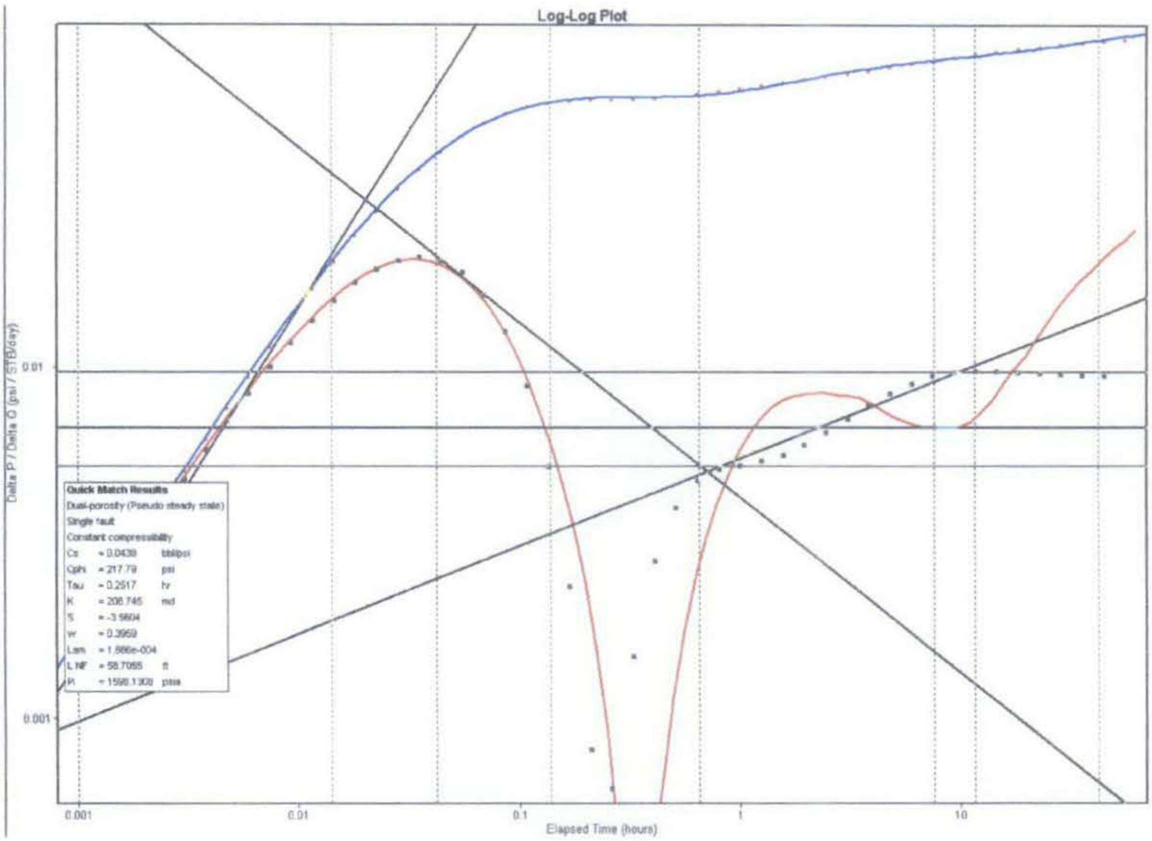

Figure 36: CASE 5-Simulated Well Test Analysis response at Well 4 when observed from Well 2

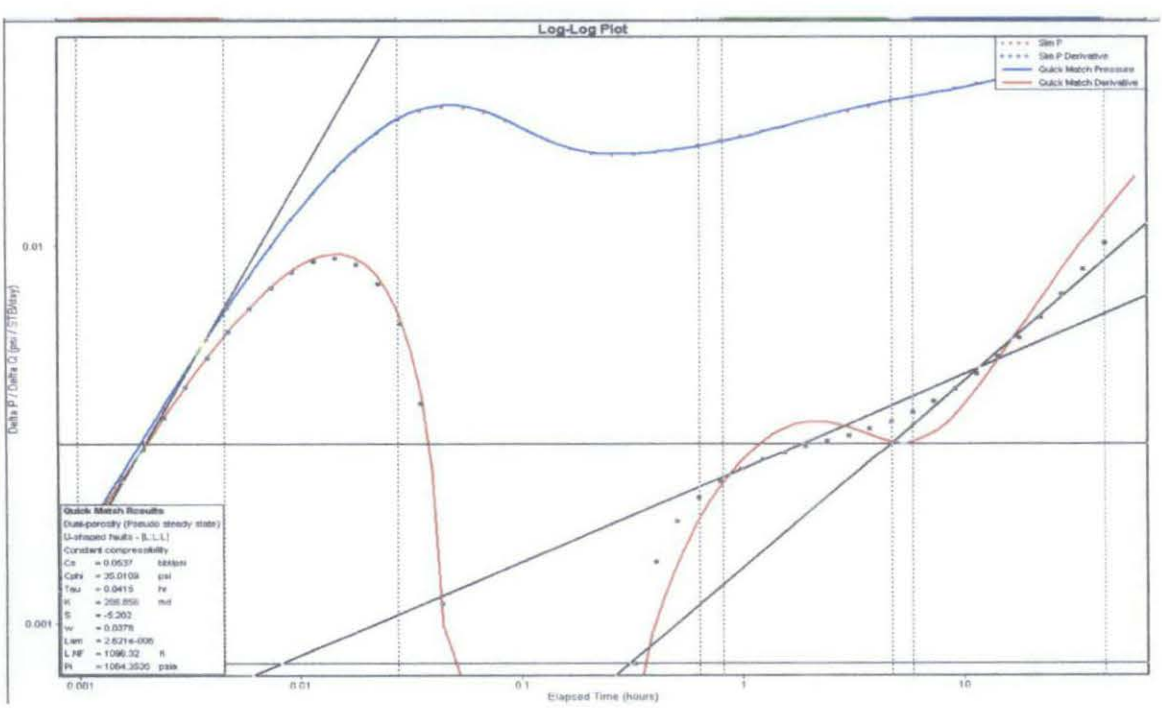

Figure 37: CASE 6- Simulated Well Test Analysis response at Well 7 When observed from Well 3.