APPLYING HYDRAULIC FRACTURING IN EXTENDING PERFORATION LENGTH

By

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DISSERTATION REPORT

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Universiti Teknologi PETRONAS

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STATUS OF DISSERTATION

APPLYING HYDRAULIC FRACTURING IN EXTENDING PERFORATION LENGTH

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CERTIFICATION OF APPROVAL

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ABSTRACT

"Applying Hydraulic Fracturing In Extending Perforation Length" is a final year project which consist of two parts, gather relevant literature data and simulate pressure transient. The main outcome is to evaluate the hydraulic fracturing treatment effectiveness in extending perforation penetration. The core of this project is simulation using pressure and production rate history in order to obtain reservoir data before and after hydraulic fracturing. The author has divided Final Year Project 1 (FYP 1) into two phases namely, (1) Write literature review on the project, (2) Gather raw data on real case study continuously for the whole FYP 1. In Final Year Project 2 (FYP 2), it is the continuous from FYP 1 and focusing on full analysis of pressure and production rate data from real well. Kappa Saphir Well Test Software is the main tool for this project. Analysis can be performing after run the pressure and production data in the software. Firstly is analysis on the well test job sequence. During this part, the author will separate the fluctuation of plotted pressure data history accordingly to operation or job done following the time period. Thus, the author can know the response of the pressure towards the job done by engineer. Second, the author does the analysis on pressure transient. In this period, selected reservoir model and type curve will try to be match with the plotted pressure. As the model match, the well properties can be estimated. The analysis will be performing on pressure and production data before and after hydraulic fracturing treatment. For the last part, the author will evaluate the effectiveness of hydraulic fracturing. After gone through with this project, the author conclude that hydraulic fracturing can increase the production from a reservoir and perforation length as well as reservoir properties are changing after performed hydraulic fracturing.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Hydraulic fracturing is an effective technique for increasing the productivity of damaged wells or wells producing from low permeability formations. Much research has been conducted to determine the effect of hydraulic fractures on well performance and transient pressure behavior. The results have been used to improve the design of hydraulic fractures. Result to date of hydraulic fracturing treatments, however, vary from extremely successful to extremely disappointing failures. The disappointing failures and the need to critically energy crisis have raised the need to critically understand the stimulation process and devise means of optimizing the effectiveness of these treatments. A presentation from one of SPE Paper titled "A Study of The Application of MHF to The Tight Muddy "J" Formation Wattenberg Field, Adams and Weld Counties, Colorado" stated some of the basic important parameters controlling the success of hydraulic fracturing. The paper emphasized pre –job planning and pre-stimulation well testing and noted a requirement for further research and development. Since then, the data and tests needed for stimulation design have become more clearly defined.

1.2 Problem Statement

The no or low production from a reservoir is a function of mechanical problems in the well completion, low reservoir pressure, wellbore damage, low formation permeability and insufficient perforation length. If later is the case, stimulation is the most efficient method of solving the problem for limited producing wells. Besides that to identify the specific cause of the problem the pressure response of flow tests in single wells is analyzed by pressure transient analysis methods. The application of these methods will define reservoir parameters which are used in two ways directly related to the actual development in the execution of a stimulation treatment. Firstly, the prediction of the future well performance to evaluate whether the treatment design is economically justifiable and operationally viable. The second is the evaluation of the effects of the stimulation treatment in the porous medium to determine treatment parameters such post-treatment skin, fracture length.

1.3 Objective

1) To do a review of pressure transient analysis interpretation related to hydraulic fracturing.
2) To determine reservoir properties before and after hydraulic fracturing.

1.4 Scope of Study

The purpose of this research is to do research of pressure transient analysis interpretation related to hydraulic fracturing. .Firstly, analyzes pressure transient encountered in pre-stimulation tests which means before perform the hydraulic fracturing treatment and identifies formula necessary to calculate the reservoir parameters required for fracturing treatment design. Secondly, analyzes the pressure transient in post-stimulation flow tests which means after perform the hydraulic fracturing treatment and reviews the formula for calculating the parameters of the hydraulically created fractures. After that, determine reservoir parameters before and after hydraulic fracturing to evaluate the effects of hydraulic fracturing treatment.

1.5 The Relevancy of the Project

A brief review of pressure transient analysis of before and after the well have been fractured will be perform to inform the practicing engineer the needed of pre and post stimulation period in evaluating the efficiency of hydraulic fracturing. Besides that, this research can be a reference for the engineer if facing low or no production problem in tight oil bearing reservoir due to insufficient perforation length.

1.6 Feasibility of the Project

This research is feasible to be conducted within the given time frame due to following factors:

a) Software

This research is feasible to be conducted through simulation using well test analysis softwares namely Kappa Saphir or Pansystem. Pansystem software is available in UTP Academic Block 15 while Saphir software is available in PCSB KLCC.

b) Raw Data

Most of the data need to require from PCSB KLCC. Thus, need to contact staff there during the research period.

CHAPTER 2
LITERATURE REVIEW

2.1 Extending the perforation penetration

In cased hole completions, perforations are needed to create a hole through the steel casing so that the reservoir can be produced. The holes are typically formed by shaped explosives that perforate the casing and make a fractured hole into the reservoir rock for a short distance. In many cases, the holes created by the perforation guns do not provide enough surface area and it becomes desirable to create more area in contact with the wellbore.

In some cases, more area is needed if the reservoir is of low permeability. In other cases, damage caused by drilling and completion operations can be severe enough that the perforation tunnel does not effectively penetrate through the damaged volume near the bore. This means that the ability of fluids to flow into the existing perforation tunnels is too limited. One way to achieve more stimulation is by carrying out a hydraulic fracture treatment through the perforations.

If permeability is naturally low, then as fluid is drained from the immediate area, replacement fluid may not flow into the void sufficiently quickly to make up for the void age and so the pressure drops. The well cannot then flow at a rate sufficient to make production economic. In this case, extending a hydraulic fracture deeper into the reservoir will allow higher production rates to be achieved.

Hydraulic fracturing is performed by injecting high pressure fluids into the wellbore and into the perforation tunnels to cause the rock formation to fracture. This can either be done by injecting hydraulic fluid from surface, a process called hydraulic fracturing or using an explosive to generate a high speed gas flow, a process called propellant stimulation.

2.2 Reservoir types

The identification of reservoir types is made by interpretation of the pressure response in flow tests, which is basically a pattern recognition exercise.

The three types of reservoir generally accepted in the literature are:

a) Homogeneous reservoir, where one permeable medium has a constant permeability throughout and flows radially to the wellbore.
b) Naturally *fractured reservoir, in which two permeable medium exist in the* reservoir, the lower permeability flows into the higher permeability and only the highest permeability flows to the wall.
c) Layered reservoir, when two permeable mediums exist in the reservoir, there is flow or no flow between them and both of them flow to the wellbore.

The pressure response of the three basic reservoir models have been simulated solving the basic diffusivity equation linearized for particular initial and boundary condition.

2.3 Flow regimes

Independent of the type of reservoir, when a formation is tested the pressure response will reflect different patterns governed by parameters affecting the region of particular flow regimes as follows:

a) The wellbore effects; the pressure response in this regime is governed mainly by the volume of the wellbore from the perforations to the shut in valve, it also reflects the effects of the zones in direct communication with the wellbore : damaged zone, partial penetration zone and hydraulically fractured zone.

b) The infinite acting portion of the pressure response is the flow regime when the reservoir is acting as if it was infinite in extent and is not affected by outer boundaries.

c) The external boundary flow regimes, which reflects the type of boundary flow regime, which reflects the type of boundary surrounding the drainage region of the well.

2.4 Interpretation of pressure transient plot

Since pressure interpretation is pattern recognition exercise the way to analyze the pressure response is by plotting pressure data versus a function of time in different coordinates. Plot that must be made in any test interpretation is a diagnostic plot of pressure change and elapsed time during the period such as main flow and build up in log-log coordinate. All the data should be used.

The log-log plot is used to identify the type of reservoir and model to be used for interpretation, to identify the different flow regimes and if necessary to calculate parameters comparing it to theoretical models of similar response. Once the different flow regimes have been identified, each one can be separated and specialized plots generated for the specific flow regimes, from which the parameters affecting the pressure response can be calculated . Specialized plots likes Cartesian or Semilog plots of pressure and a function of time used to analyze specific flow regimes from which the parameters affecting the pressure response can be calculated.

The interpretation will be completed by checking for consistency of results from both plots. If there is no consistency, this means that the wrong model has been selected for interpretation, if there is consistency, and then the analysis is correct. However, since the pressure response could match different models, it can be concluded only that if the reservoir is the same as the selected model, the calculated parameters define the assumed reservoir

For an oil well: $$C = \frac{\mathrm{qBo}}{24\mathrm{m}'}$$

For a gas well: $$C = \frac{0.420\mathrm{qZt}}{\mathrm{m}'}$$

Where

qo Oil Flow Rate, bbl/day

qg Gas Flow Rate, bbl/lday

Bo Oil Formation Volume Factor, RB/STB

m Slope of a line

t Time, hours

The infinite acting radial flow semilog plot of pressure versus Horner Time, has a straight line with a slope (m), which can be used to calculate permeability, skin and reservoir pressure.

For an oil well:

$$K = \frac{162.6\ \mathrm{q\ Bo\ u}}{\mathrm{mh}}$$

$$S = 1.151\left[\frac{\mathrm{P_{1hr} - P_{wf}}}{m} + \log\left(\frac{K}{u\emptyset c r_w{}^2}\right) + 3.23\right]$$

For a gas well:

$$K = \frac{1637\ \mathrm{q\ u\ Z\ T}}{\mathrm{mh}}$$

$$S = 1.151\left[\frac{\mathrm{P^2{}_{1hr} - P^2{}_{wf}}}{m} + \log\left(\frac{K}{u\emptyset c r_w{}^2}\right) + 3.23\right]$$

Where

Bo Oil Formation Volume Factor, RB/STB

u Fluid Viscosity, cp

h Reservoir Height, ft

m Slope of a line

K Reservoir Permeability, mD

Ø Porosity

C Wellbore Storage Constant, bbl/psi

r_w Wellbore Radius, ft

The extrapolation of the semilog straight line infinite shut in time will be used to calculate the average reservoir pressure at the time of the test. Next the log-log plot can be matched to one of the type curves and using the given equations for the axes a selected match point will be used to calculate the parameters characteristic of the model represented by the type curve, usually these are: effective permeability, skin factor and wellbore storage factor.

2.5 Post Treatment Period

After the treatment execution and well clean up, the well should be shut in for stabilization and a single rate test performed to evaluate the effects of the stimulation on the porous medium. After the hydraulic fracture treatment was carried out, the test analysis will give the fracture half length and fracture conductivity. For the analysis the log-log plot of all the data of the period selected should be drawn and compare with type curves modeling the behavior of a treated well. The most commonly used type curves for hydraulic fractures are the uniform flux conductivity fracture for unpropped fractures, and the finite conductivity fracture for propped fractures.

The flow regimes existing in hydraulic fractures wells that can be analyzed are:

a) Fracture linear flow analysis : - The fracture linear flow analysis governed by the laws of the expansion of the fluid in the fracture system. Constitutive equations for this type of flow analysis are similar to that of the formation linear flow analysis. However estimates of fracture properties are dependent on fracture porosity and permeability which are seldom available. The practicality of this type of flow analysis is low.

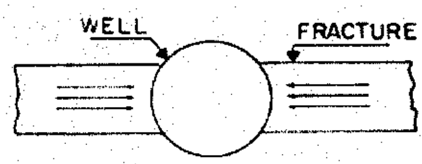


Figure 2.1: Fracture linear

b) Bilinear flow regime analysis:- this is a type of analysis of flow behavior that has not been considered in the literature until very recently. It is called bilinear flow because two linear flows occur simultaneously. One flow is linear incompressible flow within the fracture and the other is a linear compressible flow in the formation. A biliniear flow is exhibited by finite conductivity fractures with a small dimensionless storage capacity.

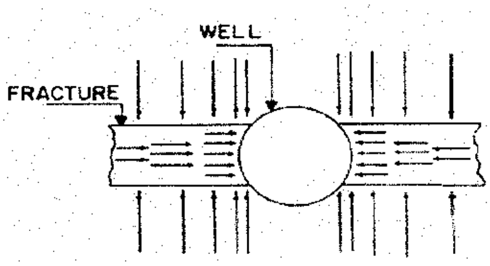


Figure 2.2: Bilinear flow

c) Formation linear flow analysis:- When linear flow into the formation dominates (at early times), pressure/time behavior can adequately model reservoir behavior. A plot of bottom hole pressure versus a square rootof time function will result in a straight line with a slope related to fracture half-length(L_f) and formation permeability. An independent estimate of formation permeability,K, must be available if we wish to estimate half length. The fracture conductivity also can be determined. The intercept of the above mentioned straight line is related to formation properties and fracture conductivity.

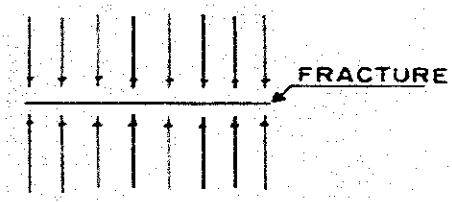


Figure 2.3: Formation linear flow

d) Pseudo-radial flow regime:- with the cessation of bilinear flow, the formation linear flow and pseudo-radial flow regimes follow. There are many cases where production periods are not long enough to allow the development of this flow regime during the pressure buildup phase. Modified pseudo-radial flow analysis techniques can be applied to these short-term tests to estimate fracture characteristics.

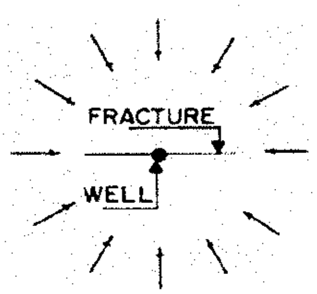


Figure 2.4: Pseudo-radial flow

The bilinear flow regime specialized plot is Cartesian plot of pressure function change vs. the fourth root of time. This plot will have a straight line with a slope (m'') that can be used to calculate fracture conductivity s follows:-

Oil case: $$Kf\,Wp = \frac{1944.8\,(q\,Bo\,u)}{(h\,m'')^2\sqrt{\emptyset\,u\,ct\,K}}$$

Gas case: $$Kf\,Wp = \frac{1.978 \times 10^5\,(q\,u\,Z\,T)}{(h\,m'')^2\sqrt{\emptyset\,u\,ct\,K}}$$

Where

Kf Horizontal Propped Fracture Permeability, mD

Wp Propped Fracture Width

Bo Oil Formation Volume Factor, RB/STB

u Fluid Viscosity, cp

Ct *Total System Compressibility, l/psi*

h Reservoir Height, ft

K Reservoir Permeability, mD

T Reservoir Temperature, ^{o}R

The specialized plot for the formation linear flow regime is a Cartesian plot of pressure function change versus the square root of the function of time. The slope of the straight line portion of the plot (m"') can be used to calculate the fracture half length:

Oil well: $$Xf = \frac{406\,(q\,Bo)}{h\,m'''}\sqrt{\frac{u}{K\,Ct\,\emptyset}}$$

Gas well: $$Xf = \frac{41.0\,(q\,Z\,T)}{h\,m'''}\sqrt{\frac{u}{K\,Ct\,\emptyset}}$$

Where

Xf Fracture Half Length, ft

Ct Total System Compressibility, l/psi

$\emptyset$ Porosity

h Reservoir Height, ft

The buildup infinite acting radial flow regime specialized plot is a semilog plot of pressure function versus Horner time. To reach this flow regime very long flowing and subsequent shut-in times are necessary. If the flow regime s reached the plot will have a straight line with slope (m) from which the permeability and new skin can be calculated using the same equations developed in the pre-fracture test paragraph.

For the uniform flux conductivity type curve the time match point will give the fracture half length, xf :

$$Xf = \sqrt{\frac{2.637\,E-4\,K}{\emptyset u\ ct}}$$

For the finite conductivity fracture, the time match can be used to calculate fracture half length using the same equation. Using dimensionless fracture conductivity Fc_D type curve matched, the dimensionless fracture conductivity can be calculated from:

$$Kf\,Wp = Fc_D \times Xf \times K$$

Where

Kf Horizontal Propped Fracture Permeability, mD

Wp Propped Fracture Width

Fc_D Dimensionless Fracture Conductivity,

Xf Fracture Half Length, ft

K Reservoir Permeability, mD

The results of post treatment test should be checked for consistency within engineering accuracy. If agreement exists, the right model has been selected and the parameters represent the reservoir and fracture geometry.

CHAPTER 3
METHODOLOGY

3.1 Project Activities

Listed below are the project activities for the research:

- Research Paper Work
- Project Work (Literature)
- Reservoir Model Simulation
- Analysis on Well Test Job Sequence
- Pressure Transient Analysis
- Progress Report
- Technical Paper
- Poster Presentation
- Pre-EDX
- Dissertation Submission
- Presentation

3.2 Key Milestone

In completing the project, the author plays an important role as an investigator/researcher; doing all the literature study and look for his/her own approach to work on the topic. Thus, assistance and supervision from the assigned supervisor is essential to ensure the student is on the right path and follow the schedule. This could be done through a good communication medium such as weekly meeting, progress report and consultations. Progress report shall be submitted according to the schedule so that any corrective measure can be taken and indirectly both student and supervisor will have good and up-to-date information.

Final Year Project I

Final Year Project II

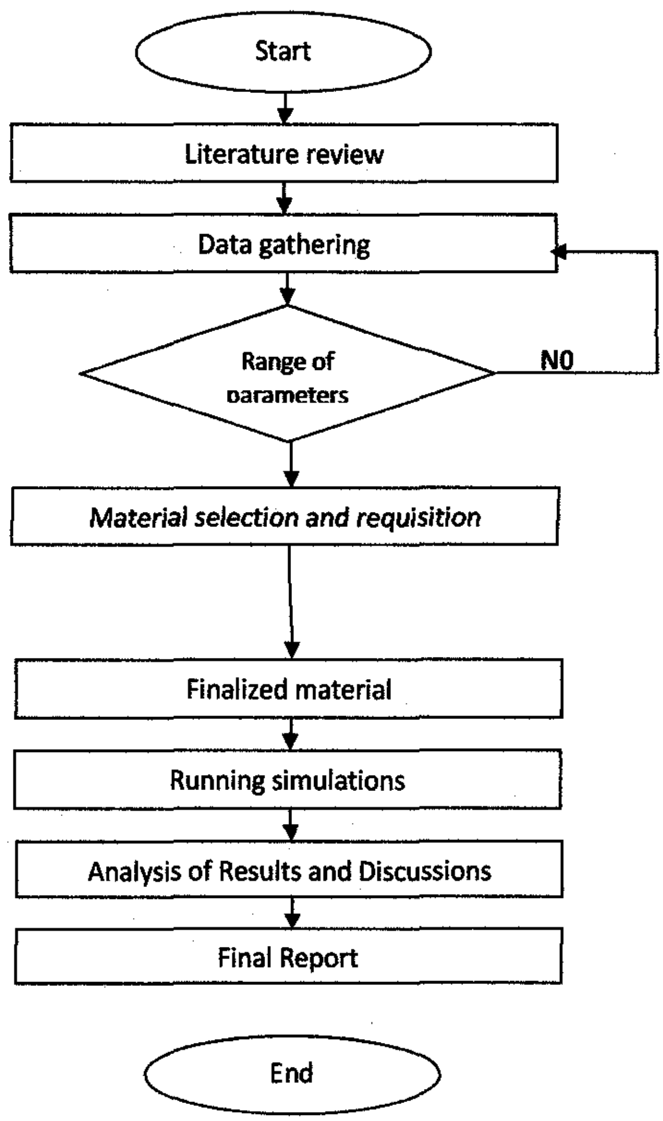


Figure 3.1: Procedure Identification

3.3 Gantt Chart

Table 3.1 Gantt Chart Final Year Project 1

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Studies about FYP Topic																						
Selection of FYP Topic																						
PRELIM Research Work																						
Submit PRELIM Report																						
Project Work (literature)																						
Seminar 1																						
Submit Progress Report																						
Submit INTERIM Report																						
Oral Presentation																						
Real Data Gathering																						
Experiment Runs																						

Table 3.2 Gantt Chart Final Year Project 2

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Real Data Gathering	■														
Select Needed Data	■	■	■	■	■										
Analysis Well Test Job Sequence		■	■	■	■	■	■	■							
Reservoir Model Simulation		■	■	■	■	■	■	■							
Progress Report Submission					■										
Pressure Transient Analysis						■	■	■							
Pre-EDX, Poster presentation,								■							
Final Report submission								■							
EDX										■	■	■	■		
Project Runs	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Final Oral presentation															■

■	Progress

- **Data Gathering**

1) Get real case study raw material
2) Analyze and compile all the raw material in data base
3) Interpret all the data and review the geological history of the field. This will help the person to understand about the field.
4) All the data will be simulated in software to perform pressure transient analysis before performing hydraulic fracturing in the well.
5) From that, the parameters given from the software can be used to estimate well properties for hydraulic fracture treatment.
6) The reservoir model and the parameters will be compared between the result after performing hydraulic fracturing and result gained before hydraulic fracturing treatment in order to make sure the consistency of parameters estimated and right model has been selected as well as evaluating the efficiency of hydraulic fracturing treatment..

- **Simulation design**

1) Run the Kappa Saphir Well Test Software with the data input from well properties. Pressure and rate data will be plot and appear on the simulation.
2) Matching the data plotted with selected reservoir modeld'
3) Get estimated parameters from the result given in the software.
4) Do comparison of the result before and after performing hydraulic fracturing.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Data Gathering

4.1.1 Well Background

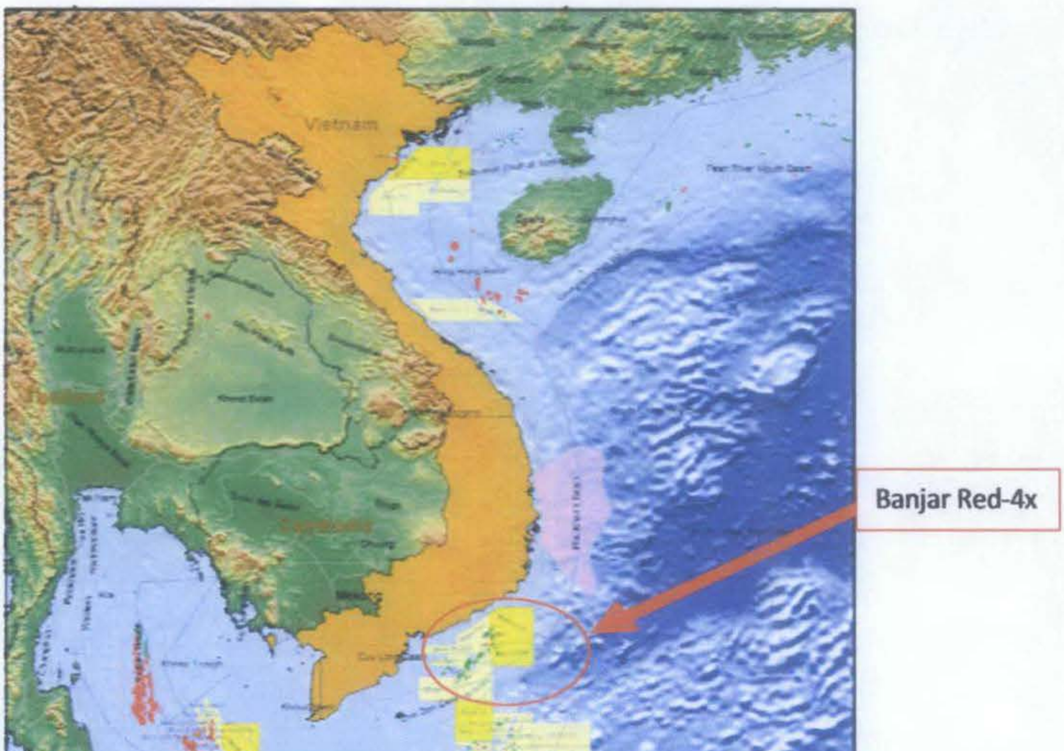


Figure 4.1: Banjar Red-4x well location

Banjar Red-4x is a vertical appraisal well drilled in the southern part of Mekong Basin, Offshore Vietnam. The well is located in water depth of 60 m. The nearest offset wells are Banjar Red 2x/ST-1 situated 2.3 km north east of Banjar Red. Banjar Red-4x well is approximately 160 km east of Vung Tau Supply Base. The well was spudded on the April

2009 using the jack up rig Trident-16, and reached Final Total Depth at 3937 m-MDDF,30 m into the weathered basement on May 2009.

Two production test with one hydraulic fracturing were conducted in Oligocene sandstones inside 7" liner. Drill Stem Test (DST) was used as a test string instead of completion string to evaluate the Pre and Post Fracturing period since this is an appraisal well and the well will be plugged and abandon after completing the test.

DST#1 was carried out to confirm the fluid type and evaluate the well performance. It was done without hydraulic fracturing and was perforated with 2500 psi underbalanced. However, the well was unable to flow naturally due to tight oil bearing reservoir. The well was only able to flow to surface with nitrogen lifting via coiled tubing and nitrogen kicked off.

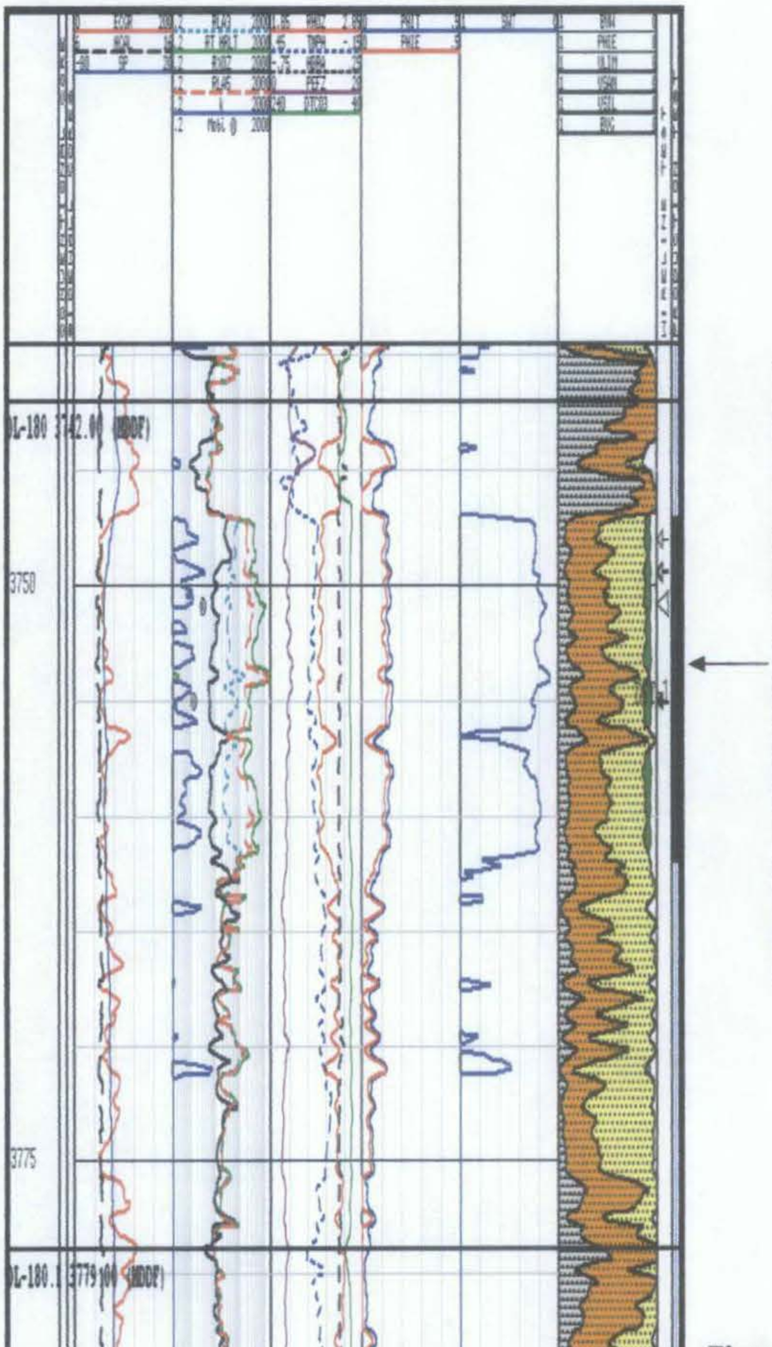
As there was no natural flow and the recovery rates during Nitrogen lift were very low, which was intermittent and could not establish relative constant flow for longer duration. Therefore, the recovery rate was estimated using *Horner Equivalent Rate* by dividing cumulative recovery with total producing time.

$$\frac{Q\,[cumulative\ recovery]}{t_p\,[total\ producing\ time]} = q\,[recovery\ rate]$$

DST#2 was conducted with hydraulic fracturing treatment in order to confirm fluid type, evaluate well performance and evaluate the hydraulic fracturing effectiveness. The well was not able to flow naturally during Pre Fracturing period due to tight oil reservoir. The Post Fracturing period was conducted to evaluate the increment of production, fracture half length and productivity index after hydraulic fracturing treatment have been applied.

4.1.2 Petrophysical Evaluation

- **DST #1**



- Petrophysical parameter:
  8.4m of net sand
  Net to Gross: 0.23

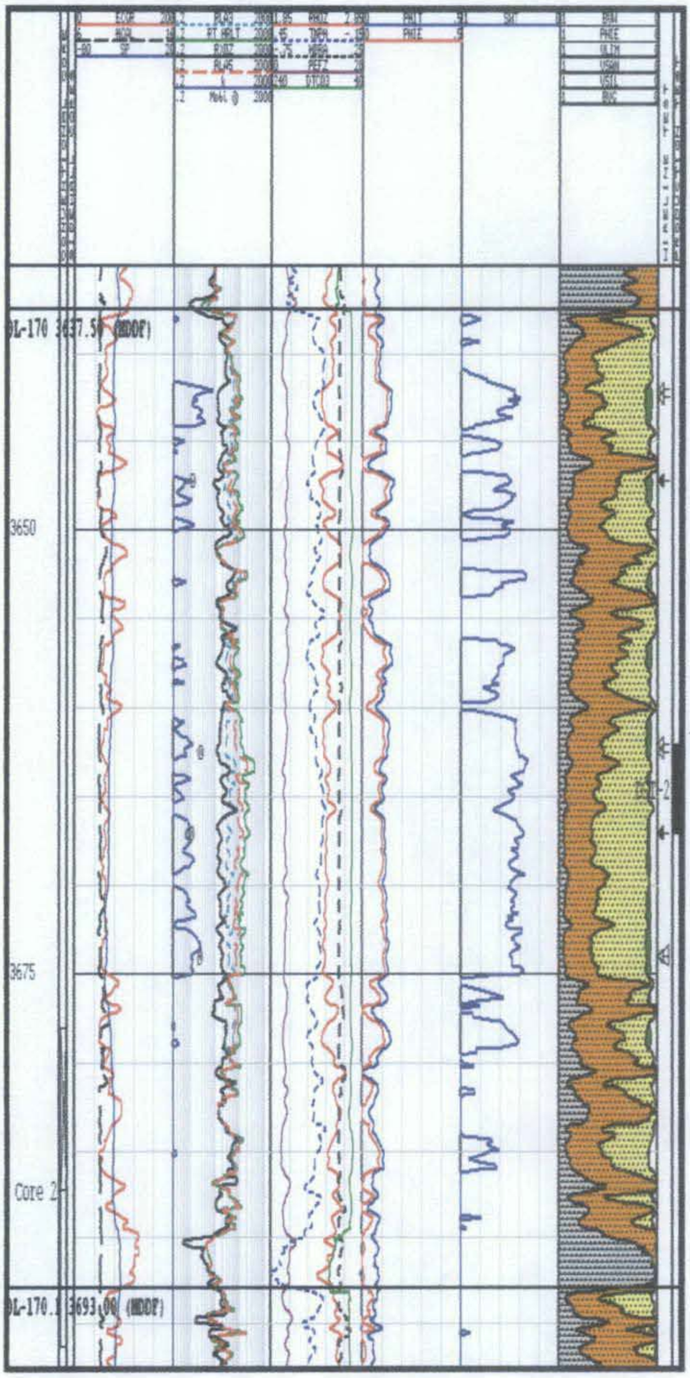
- Perforation interval:
  3747.0-3762.0

- Mudlogs: Poor gas reading but good oil shows at some intervals

- DST confirmed presences of oil, however no natural flow

Figure 4.2: Logging well data for DST#1

- **DST 2**



- Petrophysical parameter: 17.7of net sand N/G: 0.32
- Perforation interval: 3662.0-3665.0m
- Based on MDT and logs the interval is evaluated as possible oil. The MDT results indicates that the mobility is very low with 1.3-13mD/cp.
- DST with hydraulic fracturing confirmed oil

Figure 4.3: Logging well data for DST#2

4.2 Analysis on Well Test Job Sequence

4.2.1 DST #1 (Perforated without Hydraulic Fracturing)

The well was perforated using Mechanical Drop Bar Firing System by releasing drop bar manually from the Flowhead to activate the gun. Good indication of gun fired was observed at surface by bubbling / air flow from the choke manifold ¼" needle line. The Coiled Tubing Unit (CTU) was rigged up since the Shut In Well Head Pressure (SIWHP) was only increased from 18 to 20 psia after about 1 hour monitoring. Coiled Tubing (CT) with Nitrogen (N2) Kicked Off was carried out for lifting purpose to back produce 50 bbls of seawater cushion and 7 bbls of 10 ppg brine completion fluid below downhole tester valve since it is expected that the well would not able to flow due to tight formation based on SIWHP trend.

After about 12 hours run in hole coiled tubing with N2 to 3690 m-MDDF (between downhole tester valve and packer), total of 70 bbls of liquid (20 bbls of oil + 50 bbls of cushion seawater / brine completion fluid) were recovered at surface. When the N2 was stopped pumping via coiled tubing, no liquid recovered at surface. Based on this result, it can be concluded that the reservoir is an oil reservoir bearing with tight formation. The oil density was measured onsite using Hydrometer at 32.5oAPI @ 60oF. Decision was then made to terminate the test since the main objective of DST#1 well test is to confirm fluid type. It had been confirmed that the formation is an oil reservoir with tight formation.

The well was shut in at downhole tester valve for Main Build Up and at the same time to pull out of hole the coiled tubing. The well was then killed with 10 ppg brine prior to pull out of hole the test string.

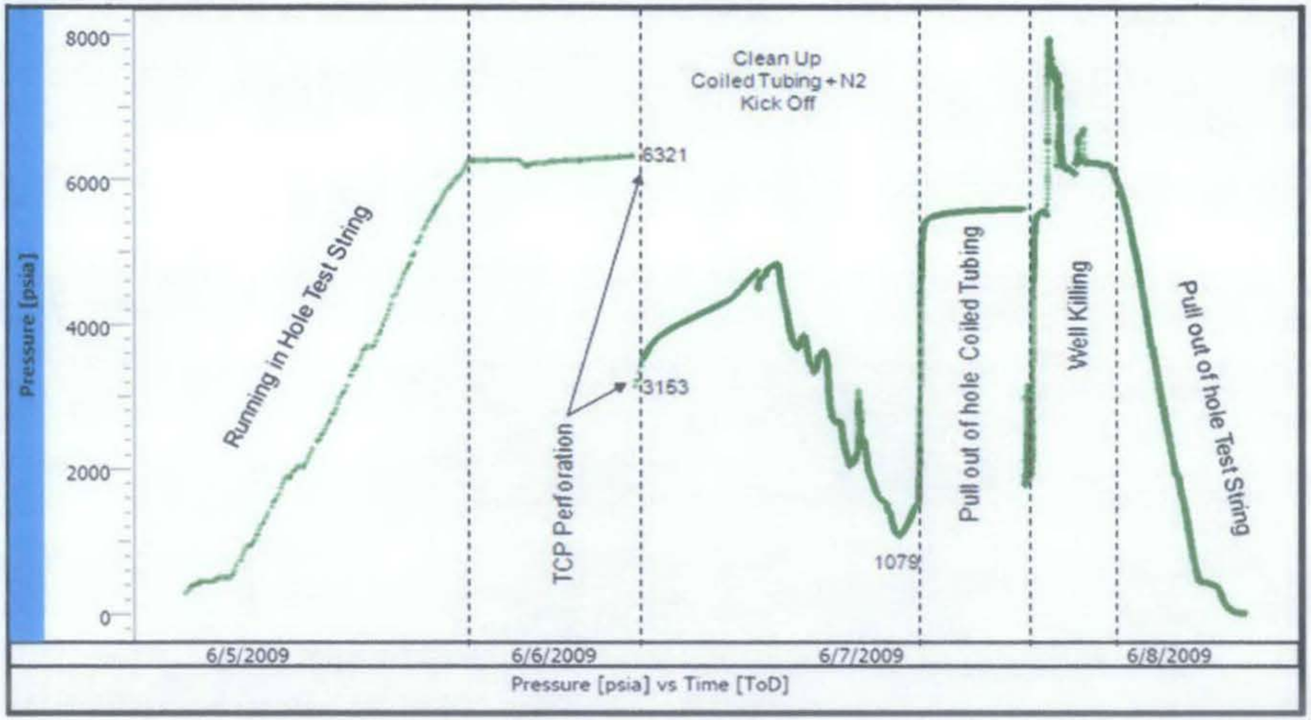


Figure 4.4: Bottomhole Pressure Response for DST #1

4.2.2 DST #2 (Perforated with Hydraulic Fracturing)

The well was perforated with Wire line Casing Gun, 4-½" Power Jet Omega 4505 HMX. The test string was run in hole after the well was perforated with 5 meters of 4-½" PJO 4505 with 570 psi overbalance against formation pressure. Full seawater cushion was used (that created 350 psi underbalance for initial flow) to pressure test the test string prior to hydraulic fracturing operations. After the packer was set, the well was opened at downhole tester valve and kept closed at choke manifold. The Coiled Tubing Unit (CTU) was rigged up since the Shut In Well Head Pressure (SIWHP) recorded was only increased with less than 5 psi within 30 minutes surface shut in.

1) Pre Fracturing Clean Up

Pre Frac Clean Up was carried out by running in hole Coiled Tubing (CT) starting with 350 scf/min of Nitrogen (N2) pumping rate to unload and continued run in hole to 3640 m with N2 pumping rate of 600 scf/min. Total of 129 bbls of liquid had been recovered at surface with an estimated of +/- 25 bbls of oil.Unable to measure GOR during this period as the well was flowed by N2 lifting.

Attempted was made to position the Fracturing vessel while lifting the well with N2. However, the Fracturing vessel was unable to hold its position at starboard site as per plan. Thus, the fracturing line that been installed, welded and inspected at starboard site had to be rigged down and moved to port site.Continue rigged up fracturing line at port site. At the same time attempted was made to flow well either naturally or using coiled tubing. Shut in well at surface to allow formation fluid entering the DST string prior to flow to surface

2) Pre Fracturing Main Flow and Pre Fracturing Main Build Up

Pre Frac Main Flow and Pre Frac Main Build Up were not carried out due to well not able to flow naturally.

3) Fracturing Operations

After the fracturing line had been completely rigged up, welded and inspected at port site, fracturing hose was connected from fracturing vessel to rig. The fracturing lineswas pressure tested to 10 K psi from BJ Fracturing unit at frac vessel to SLB Flowhead on rig floor prior to fracturing operation. Step Rate Test and Mini Frac were carried out prior to main treatment of fracturing operation.

Step Rate Test was conducted by pumping slick water at various pumping rate while the surface pumping pressure being monitored.

Step	1	2	3	4	5	6	7	8	9	10	11	12
Pumping Rates (bpm)	0.5	0.75	1.0	1.25	1.5	2.0	3.0	5.0	7.0	9.0	12.0	15.0

Table 4.1: Pumping rates for step rate test

Step op rate test was carried out starting from 0.5 to 15 bpm followed by step down ratetest then shut in for about ½ hour. **Mini Frac (Figure** was then carried out at constant pumpingrate of 18 bpm as below followed by shut in for about 1 hour for monitoring.

6/12/09	WHP [psia]	Remarks
01:15	1712	Start Pumping for Step Rate Test with Slick water at 0.5 bpm.
01:39	1321	Shut-down for 20 min and monitor WHP.
01:45	1160	
01:58	985	Pumping 2500 gals of LF-3500 for Mini-Frac. 5 bbl/min Pumping rate & Ppump = 4800 psi.
02:03	7676	Increase pumping rate gradually to 18 bbl/min. Ppump = 8500 psi.
02:06	6493	Pump 400 gallons of LF-3500 with rate 18 bbl/min. Ppump = 6500 psi.
02:10	5847	Pump 2500 gallons of LF-3500 with rate 18 bbl/min. Ppump = 6500 psi.
02:11	5648	Pump 4375 gallons of Slick water for flushing.
02:15	2012	Stop pumping and monitor WHP.

Note:

WHP is the Well Head Pressure recorded at Flowhead on rig floor.

Ppump is the surface pumping pressure at BJ Frac pump on Frac vessel.

Figure

Step Up Rate Test will gives fracturing extension pressure and rate while Step Down Rate Test is to determine friction if it is perforation dominant or tortuosity (fracture entry) dominant and to determine the value of the friction.

- If perforation friction > 500 psi □ re-perforate need to be considered
- If tortuosity > 500 psi □ pump proppant slugs in the pad stage to clean up the frac.
- If total entry friction is < 500 psi □ proceed with main treatment as per plan.

Surface Read Out was carried out to download the downhole data and sent to town for analysis prior to **Main Treatment of Fracturing operation**. The objective is to analyze closure pressure, fracturing fluid efficiency (leakoff) and redesign the main fracturing pump schedule if necessary.

After the analysis was carried out and agreed between town and rig, the main treatment was then conducted as per plan at 18 bpm pumping rate as per below since the entry friction is less than 500 psi. After completing main treatment, the well was shut in at surface and the pressure decline was monitored.

12/06/09	Qpump [bpm]	Ppump [psia]	WHP [psia]	Remarks
10:40				Start to pump 238 bbls Pad (Cross-Linker)
10:50	18	6200	6963	
10:55	18	6400	6269	
11:00				Pump 74 bbls Slug (Proppant)
11:04	18	6600	6400	
11:05				Pump 166.6 bbls Pad
11:10	18	6000	6200	
11:15				Pump 77.7 bbls Proppant conc 2 ppa
11:17	18	6000	6230	
11:18				Pump 126 bbls Proppant conc 4 ppa
11:23	18	7000	6300	
11:25	18	7000	6327	Pump 225.8 bbls Proppant conc 6 ppa
11:37	18	8000	7300	
11:38				Pump 145 bbls Proppant conc 8 ppa
11:41	18	7000	7100	
11:47				Pump 76 bbls Proppant conc 10 ppa
11:50	18	8000	7800	
11:51	18	8000	8100	Pump 84.8 bbls Flush (Base Gel)
11:52	18	9000	8300	
11:53	18	9000	8893	
11:54	18	9000	8800	
11:57				Stop Pumping and monitor pressure

Note:

- *Qpump is the actual pumping rate applied on Frac vessel.*
- *Ppump is the actual surface pumping pressure applied at pump on Frac vessel.*
- *WHP is the Well Head Pressure recorded at Flowhead on rig floor.*
- *While pumping the last concentration of proppant:*
  - *Continue pumping until reach the P limit.*
  - *Pumped 76 bbls instead of 142 bbls as per planned due to pumping pressure increased (limited some of the equipment working pressure)*

4) Post Fracturing Clean Up

The well was opened after 4 hours of main treatment to allow breaker to break since fluid breaker inside the cross-linker gel was designed to break after about 3 to 4 hours. The Coiled Tubing Unit (CTU) was rigged up while waiting on breaker. **Post Fracturing Clean Up (with CT and N2)** was carried out by running in hole Coiled Tubing (CT) starting with 350 scf/min of Nitrogen (N2) pumping rate to unload well and continued run in hole in stages to 1500 m with N2 pumping rate was increased to 450 scf/min. The well was opened at 16/64" adjustable choke and beaned up gradually to 40/64" and flowed to burner boom thru Sacrificial Lines. 40/64" choke size was selected to reduce the erosion effect due to proppant flow back. Traces of gel and proppant were started to produce at surface after 3 hours from the start of running CT with N2 kick off and stationed at 1500 m. ½ hour later, traces of oil started to produce at surface.

The well was kicked-off with coiled tubing and N2for about 11.5 hours prior to unload frac fluid until the well able to flow naturally. Once the well are able to flow naturally, coiled tubing was pulled out of hole and flowed the well naturally up to 44/64" choke thru separator for had to be beaned down to 24/64" for about 15 minutes to allow chopper landing to wind direction towards to Helideck area. No water was produced towards the end of Post Fracturing Clean Up at 44/64" choke. Once the well considered clean from water and/or proppant, the well was then flow for Main Flow. about 4.5 hours for Post Fracturing Clean Up (Natural Flow). During this period, of the choke had to be beaned down to 24/64" for about 15 minutes to allow chopper landing to wind direction towards to Helideck area. No water was produced towards the end of Post Fracturing Clean Up at 44/64" choke. Once the well-considered clean from water and/or proppant, the well was then flow for Main Flow.

5) Post Fracturing Main Flow

Post Fracturing Main Flow was carried out at 32/64" fixed choke and flowed thru main line and Separator for about 10 hours. However, when flowing well at 32/64" during Main Flow, the water start produced to surface with chloride content ranges between 1200 to 2000 mg/l.

The Base Sediment &Water (BS&W) was fluctuated between 0.3 and 17 % during Main Flow. The water produced is the frac fluid (Cl = 500 mg/l) that had been pumped to the formation during hydraulic fracturing which indicate it is not formation water. Beside that, the BS&W was recorded zero towards the end of Main Flow (no water production).

During Post Fracturing Main Flow period (last 3 hours reading / towards the end of Main Flow), the production was trend are as below:

- WHP declined from 905 to 882 psi
- Oil production rate fluctuated between 1730 – 1900 stb/d
- Gas production rate slightly declined between 1.21 – 1.18 MMscf/d
- GOR fluctuated between 618 – 695 scf/stb
- BS&W declined from 5% to zero

The average and stable values were taken and reported for Qoil, Qgas, GOR, and BS&W of the Post Fracturing Main Flow period based on the last 3 hours reading towards the end. During Post Frac Main Flow period at 32/64" fixed choke, the well was produced with an average and stable values of **oil** at **1830 stb/d**, 1.2 MMscf/d of gas and 654 scf/stb of GOR.

During Post Fracturing Clean Up at 44/64" choke, no water was produced at surface. However, when flowing well at 32/64" during Post Fracturing Main Flow, the water start produced to surface with chloride content ranges between 1200 to 2000 mg/l. The BS&W was fluctuated between 0.3 and 17 % during Main Flow. The water produced is the fracturing fluid (Cl = 500 mg/l) that been pumped to the formation during hydraulic fracturing which indicate it is not formation water. But then, the BS&W was recorded zero towards the end of Main Flow (no water production).

Decision was made to flow the well during Post Frac Main Flow for 10 hours based on BS&W became zero towards the end even though the WHP kept declining for about 5 to 9 psi/hr. No proppant was produced at surface. Based on production trend, estimate about at least 2 days to get the WHP trend to be stabilized. Since the rig operating cost is expensive, the well was then shut in for main build up period.

6) Post Fracturing Main Build Up

Attempted was made to shut in well for Post Fractruing Main Build Up at downhole tester valve but no indication of downhole tester valve closed. Suspected the downhole tester valve ball valve had been washed out due to flow back of proppant during Post Fracturing Clean Up. Decision was made to shut in well at surface Choke Manifold and the downhole tester valve was cycled to hold open position. After 6 hours shut in at surface, Surface Read Out (SRO) was run in hole with wireline. Attempted to established communication with downhole gauges but failed. SRO was then pulled out of hole and Pressure Transient Analysis (PTA) was carried out using surface data that is SIWHP.

7) Post Fracturing Extended Flow

Post Fracturing Extended Flow was carried out at 28/64" fixed choke for 8 hours. Smaller choke size was selected for this period to get more stabilized production compared to 32/64" choke.

During Post Frac Extended Flow period (last 2 hours reading / towards the end of Main Flow), the production was trend are as below:

- WHP kept declined from 1040 to 1015 psi
- Oil production rate quite fluctuated between 1650 – 1750 stb/d
- Gas production rate quite stable between 1.06 – 1.09 MMscf/d
- GOR quite fluctuated between 611 – 647 scf/stb
- BS&W is zero

The average and stable values were taken and reported for Qoil, Qgas and GOR, of the Post Fracturing Extended Flow period based on the last 2 hours reading towards the end. During Post Fracturing Extended Flow period at 28/64" fixed choke, the well was produced with an average and stable values of oil at **1673 stb/d**, 1.07 MMscf/d of gas and 643scf/stb of GOR.

8) Post Fracturing Final Build Up

Post Frac Final Build Up was carried out to ensure good quality data for PTA. The well was shut in at surface due to downhole tester valve was suspected washed out by proppant flow back during Post Frac Clean Up. The SIWHP was sent to town every 6 hours to optimize the shut in period. Based on quick look PTA interpretation using SIWHP, the Post Fracturing Final Build Up was carried out for 16 hours. To get true permeability (radial flow), would require extremely long shut-in (1000 hrs) which is impractical. Since the pressure derivative still continues to have linear trend, it was decided to shorten the build-up to 16 hours only.

9) Well Killing

The well was killed by pumping 90 bbls of brine from surface due to downhole tester valve failed to close. After pumped 90 bbls of brine, suspected downhole tester valve was closed based on tubing pressure increased rapidly to 3500 psi. The downhole tester valve was cycled to hold open position and continued pumped another 25 bbls of brine at 4 bpm with 200 psi pumping pressure. The well was monitored and flow checked with good indication of no pressure build up. The packer was then unseated with 30 klbs over pull. Observed static losses of 140 bbls/hr on trip tank. The packer was then reset again while mixing Hi-Vis pill. Attempted was made to bullhead with Hi-Vis but the tubing pressure increased to 1900 psi. Suspected the PCT is lost cycle. The annulus pressure was then increased to 2400 psi to ensure downhole tester valve open. Pumped 20 bbls of Hi-Vis and displace with 90 bbls of 10 ppg brine.

Since the downhole tester valve is lost cycle, the SHRV rupture disc was ruptured to displace 150 bbls of 10 ppg brine by reverse circulated thru SRHV. The Packer was then unseated to monitor trip tank and it was observed that static losses at 66 bbls/hr. Rigged down the Coflexip hoses, Flowhead and EZ-Valve and rigged up circulating head and lines while mixing mixing 40 ppb LCM pill. Spot 50 bbls LCM above SHRV and observed static losses was reduced to 18 bbls/hr. Test string was pulled out of hole with tubing and at the same time monitored closely static losses. Once all the tubing pulled out of hole, static losses was 4 bbls/hr during pulling out DST assembly at slip joints. After completed pull out of hole the test string, the DST#2 test interval section was plugged and isolated with cement plug.

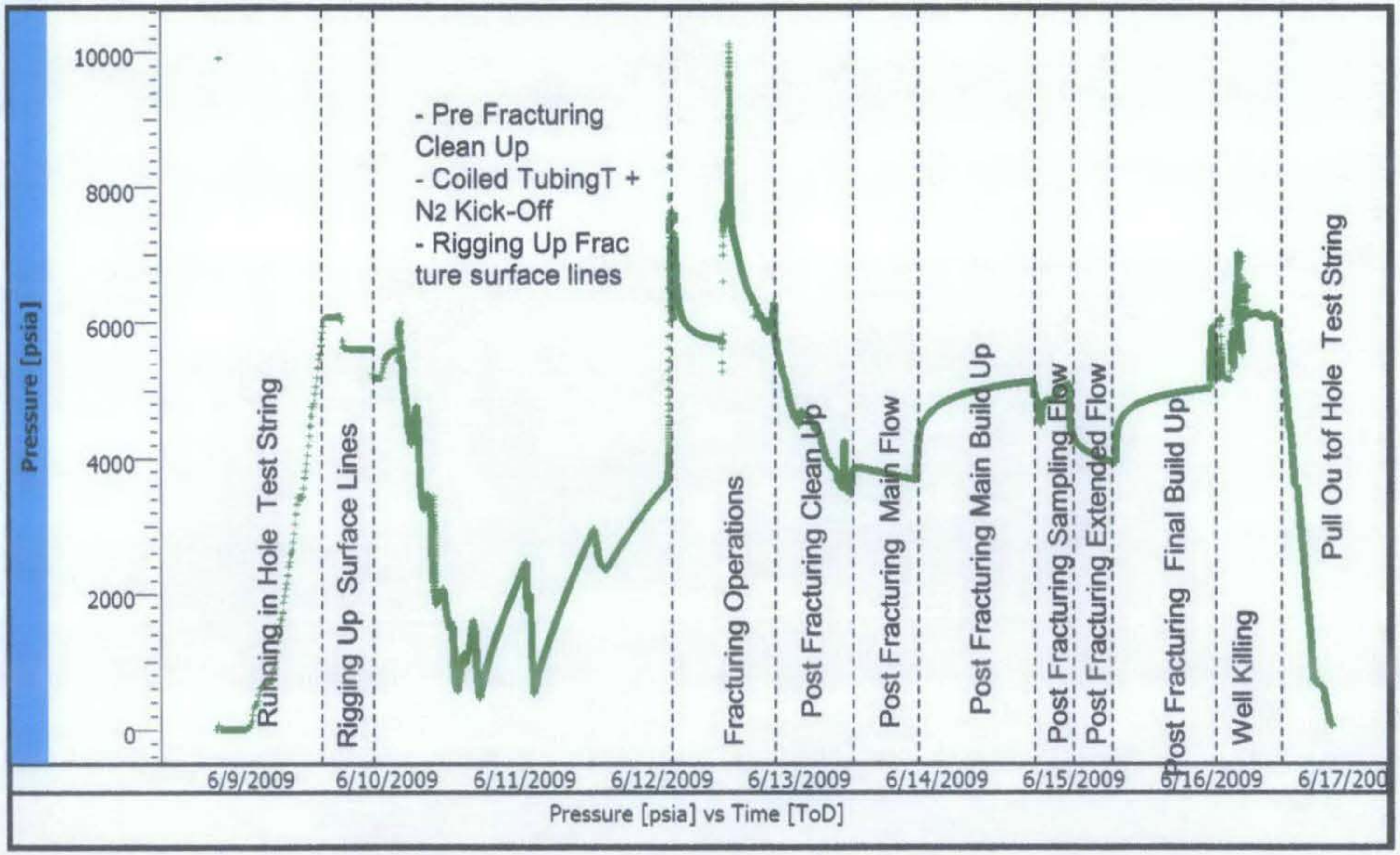


Figure 4.5:Bottomhole Pressure Response for DST #2

4.3 Pressure Transient Analysis

The purpose of the analysis is to determine the reservoir properties such as permeability, skin factor and fractures length during before and after fracturing, also to assess the efficiency of fracturing job.

4.3.1 DST #1 (*Perforated without Hydraulic Fracturing*)

4.3.1.1 Diagnosis

As there was no natural flow and the recovery rates during N2 lift were very low, which was intermittent and could not establish relative constant flow for longer duration. Therefore, the recovery rate was estimated using *Horner Equivalent Rate* by dividing cumulative recovery with total producing time.

$$\frac{Q\,[cumulative\ recovery]}{t_p\,[total\ producing\ time]} = q\,[recovery\ rate]$$

The interpretation was performed on the Main Build-Up since it exhibits a more stable behavior. The field gradient was estimated to be 0.22 psi/ft based on static gradient from gauges during shut-in. All PVT parameters were estimated using black oil correlation.

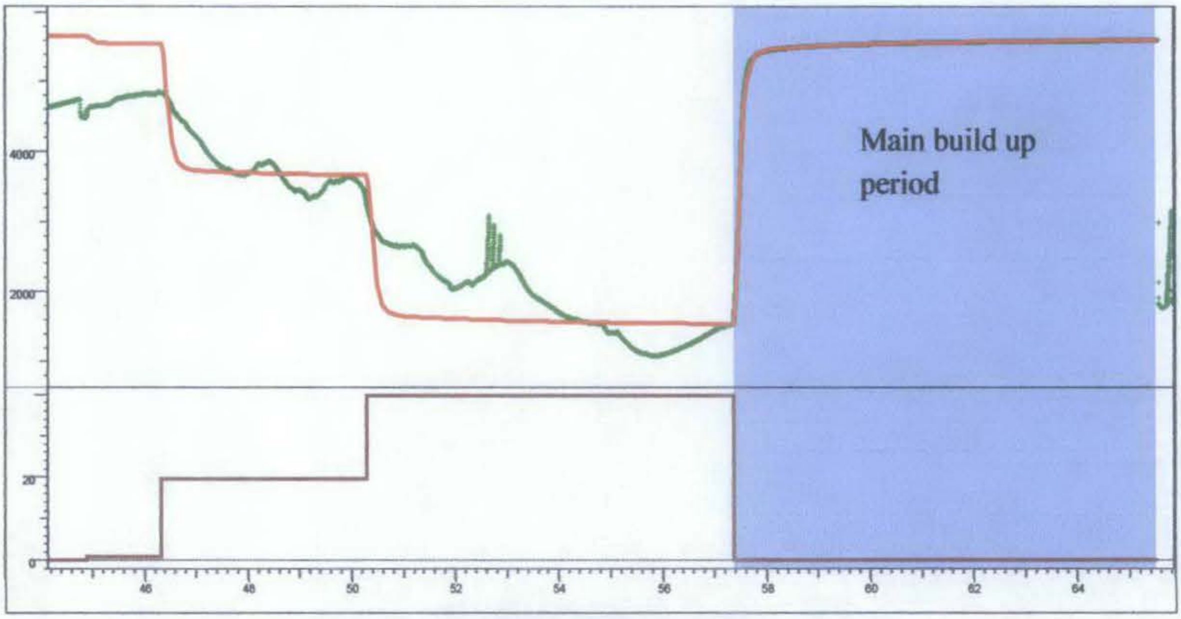
At early time, the pressure and derivative curves exhibited unit slope and follow by a very sharp hump, indicated large wellbore storage or skin effect. Based on temperature behaviour, the middle time regime begins after 0.9 hours of shut-in. The diagnosis suggested permeability is about 1 md ± 15%.

Properties	Value
Reservoir pressure	5702.57 psia
Reservoir temperature	271 °F
Porosity	13.2 %
Reservoir net thickness	8.4 m
Wellbore radius	0.35167 ft
Pwf	1540 psia
Oil rate	39.8 stb/d
Water rate	0 stb/d
Gas gravity (Air = 1)	0.8
Oil gravity	33 °API
Rock compressibility	3×10^{-6} psi^{-1}
Gauge depth	3708.93 m-TVDDF

Table 4.2: Well Parameters for Data Input DST#1

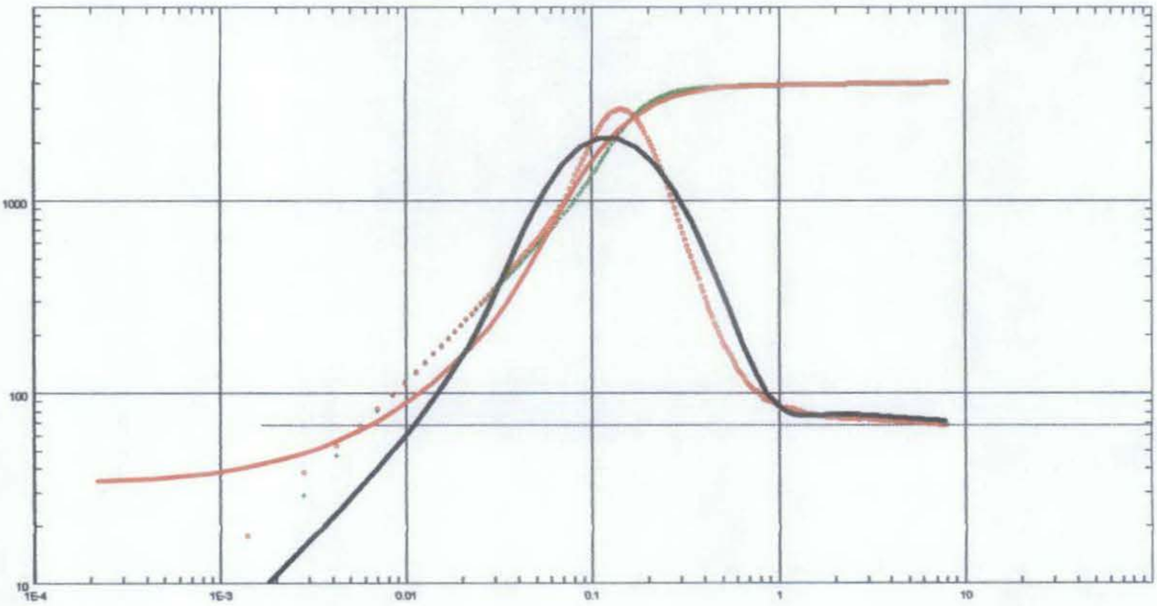
4.3.1.2 Interpretation

The model of infinite acting reservoir was chosen. The average permeability is estimated to be 1 md with pro3ductivity index of 0.01 stb/d/psi and total skin of 24.The model has *poor match on flowing pressure since there was no natural flow. From the simulation, the* initial reservoir pressure is extrapolated to be 5676 psia at datum (3750 m-TVDDF) using 0.22 psi/ft shut-in static gradient. It is considered acceptable even though it is 26 psi lower than initial reservoir pressure measured by RFT, as the rate data was estimation only.



History plot (Pressure [psia], Liquid Rate [STB/D] vs Time [hr])

Figure 4.6: History Match (Infinite Acting Model)



Log-Log plot: p-p@dt=0 and derivative [psi] vs dt [hr]

Figure 4.7: Log-log Type Curve Match (Infinite Acting Model)

4.3.1.3 Pressure Transient Analysis Results

Properties	Results
Reservoir model	Infinite Acting
Wellbore storage	5.54×10^{-5} bbl/psi
Skin	24.4
Total flow capacity	31.5 md.ft
Permeability	1.14 md
Radius of investigation	90.1 ft
Initial pressure, Pi at datum	5676.10 psia
Productivity index, PI	0.0097 stb/d/psia]

- RFT pressure at datum (3750.2 m-TVDDF) = 5702.57 psia
- Distance from datum to downhole gauge measuring point = 41.27 m
- *Fluid static gradient = 0.2193 psi/ft*
- Drill Floor = 30 m-AMSL, Water depth = 60 m-BMSL

Table 4.3: Results Analysis for DST#1

4.3.2 DST #2 (Perforated with Hydraulic Fracturing)

4.3.2.1 Diagnosis

The test consisted of two main periods: pre- and post-fracturing. None of the pre-fracturing period could be analysed due to large wellbore storage effect (surface shut-in) *and partial penetration skin (Sp estimation ≈ 31). The interpretation was performed on the* build-ups in post fracturing period since they exhibit more stable behavior. The field gradient was estimated to be 0.29 psi/ft based on RFT pressure plot. All PVT parameters were estimated using black oil correlation.

The pressure and derivative curves exhibited unit slope at early time showed large wellbore storage (0.021 bbl/psi) since the well was shut-in at surface. The small "hump" and flat derivative signature in middle time give average permeability of 8.8 md and very negative skin (-3.2), demonstrated immediately the efficiency of the fracturing job. This is equivalent to fractures length of 17.6 ft. However, the derivative deviated upwards and exhibited a ¼ slope at late time, suggesting the fractures could be longer and the flat derivative was probably not matrix permeability. The diagnosis suggested the radius investigation had reached 410 ft in 20 hours of shut-in.

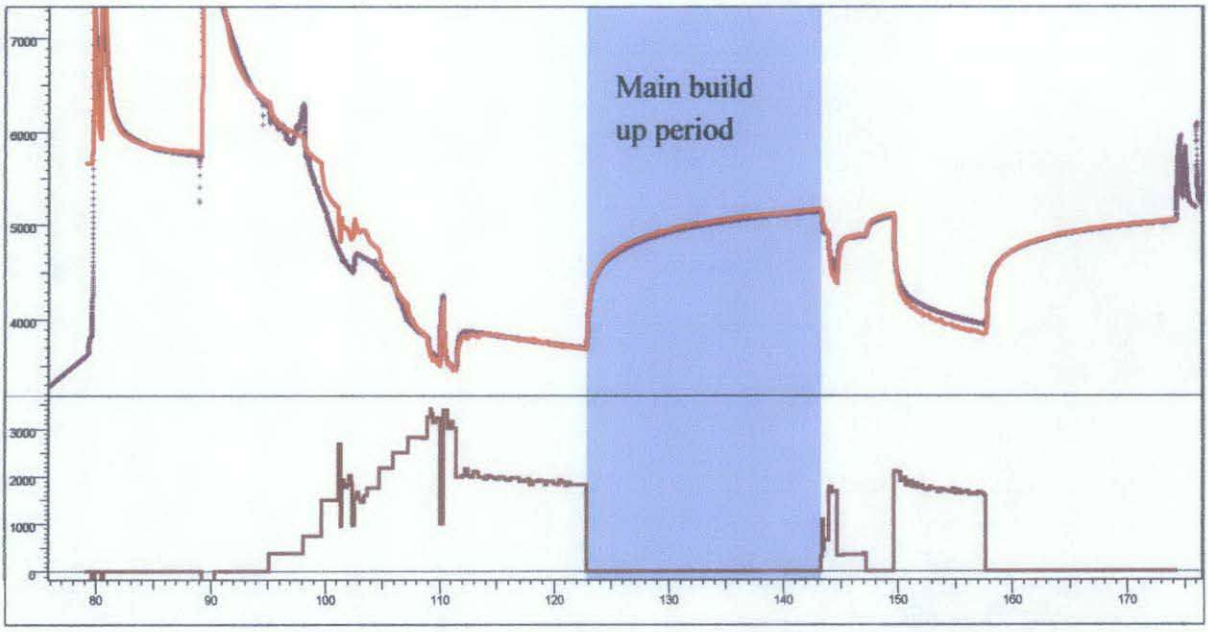
Properties	Value
Reservoir pressure	5662.66 psia
Reservoir temperature	260 °F
Porosity	12.5 %
Net thickness	17.7 m
Wellbore radius	0.354167 ft
Pwf	3690 psia
Oil rate	1830 stb/d
Gas gravity (Air = 1)	0.764
Oil gravity	33 °API
Rock compressibility	3×10^{-6} psi^{-1}
Gauge depth	3631.74 m-TVDDF

Table 4.4 : Well Parameters for Data Input DST#2

4.3.2.2 Interpretation

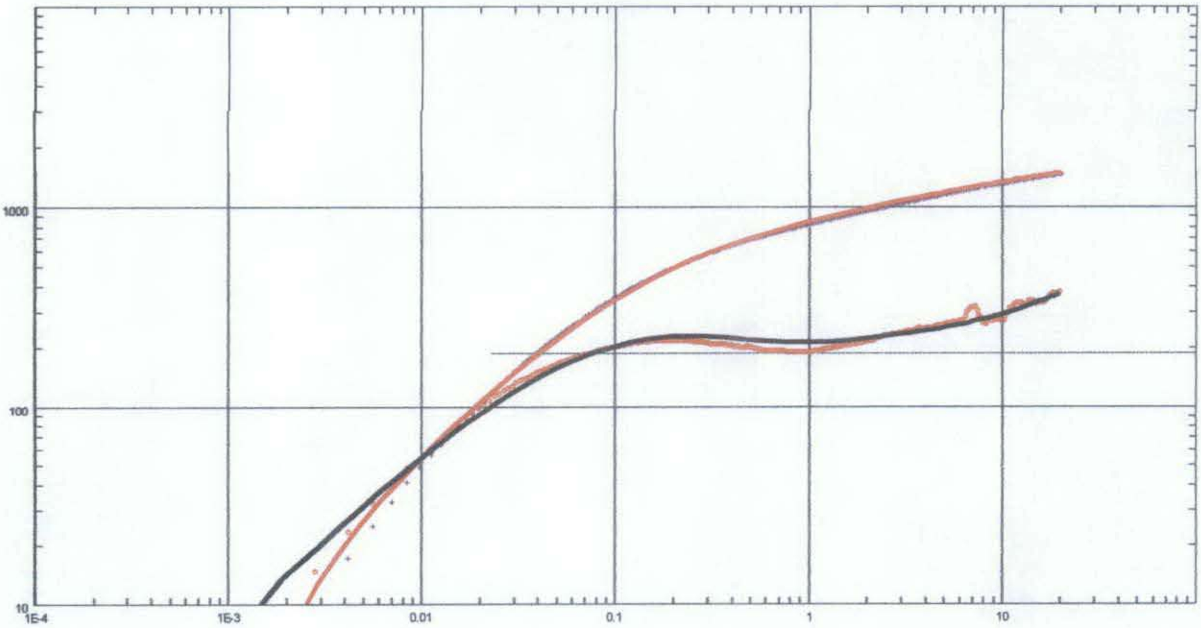
The model of parallel boundaries were first used, but the distance of the boundaries and fractures length obtained were much smaller than the expected value. The finite conductivity fractures model was then chosen, in agreement with information given by geology, petrophysic and production technology. The fractures length was calculated to be 298 ft, justified with the length estimated and volume of proppants pumped-in. The productivity index significantly increased to 1.0 stb/d/psi, compared to the PI value (0.15 stb/d/psi) estimated for case without fracturing.

The permeability is estimated to be 1.6 md, which is consistent with the permeability range estimated from CMR. Hence, the first stabilization seen was probably due to large wellbore storage and skin across perforation tunnel. With this low permeability value, we will required 40 days of shut-in to reach second radial flow signature, which is impractical in this test. The radius of drainage is estimated to be 177 ft. In overall, the model has good pressure history match.



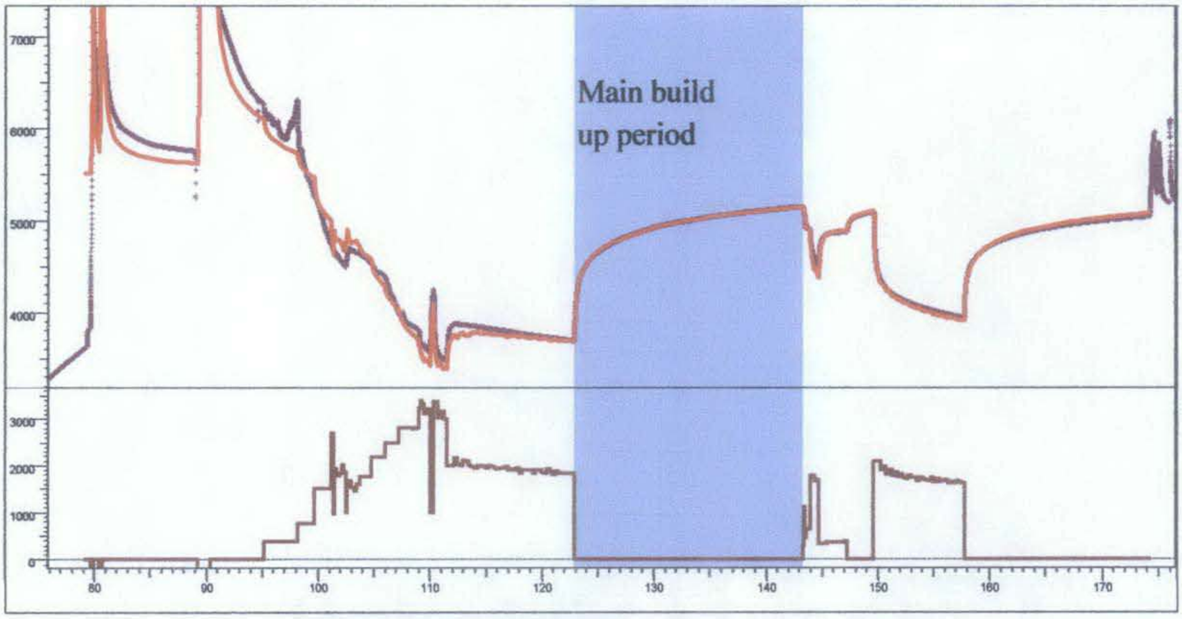
History plot (Pressure [psia], Liquid Rate [STB/D] vs Time [hr])

Figure 4.8: History Match (Parallel Boundaries Model)



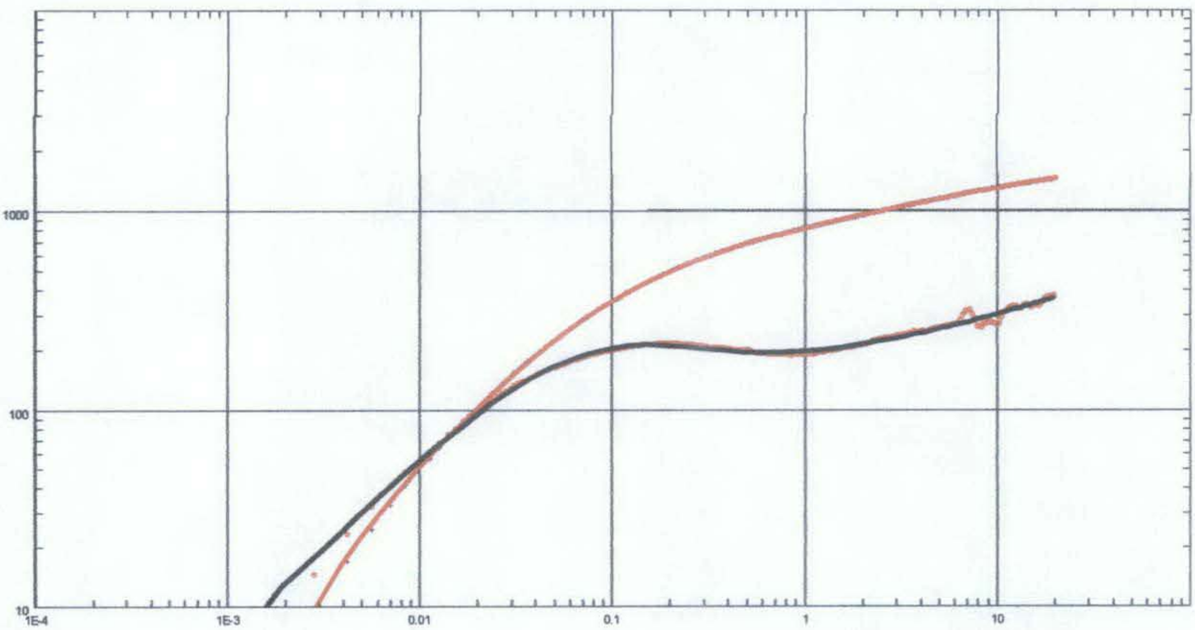
Log-Log plot: p-p@dt=0 and derivative [psi] vs dt [hr]

Figure 4.9: Log-log Type Curve Match (Parallel Boundaries Model)



History plot (Pressure [psia], Liquid Rate [STB/D] vs Time [hr])

Figure 4.10: History Match (Finite Conductivity Fractures Model)



Log-Log plot: p-p@dt=0 and derivative [psi] vs dt [hr]

Figure 4.11: Log-log Type Curve Match (Finite Conductivity Fractures Model)

4.3.2.3 Pressure Transient Analysis Result

Properties	**Results**	
Reservoir model	Parallel boundaries	Finite conductivity fractures
Wellbore storage	0.0131 bbl/psi]	0.0136 bbl/psi]
Skin	-2.96	0.05
Fracture length	13.7 ft	297.5 ft
Fracture conductivity	-	1555 md.ft
Total flow capacity	517 md.ft	94.7 md.ft
Permeability	8.91 md	1.63 md
S – No flow	76.5	-
E – No flow	-	-
N – No flow	163	-
W – Constant P	-	-
Radius of investigation	413 ft	177 ft
Initial pressure	5697.39 psia	5543.49 psia
Productivity index,PI	0.9271 stb/d/psi	1.0054 stb/d/ps
Remarks		**Most likely**

Table 4.5 : Results Analysis for DST#1

4.4 Discussion

Properties	**DST#1 (Perforated only)**	**DST#2 (Perforated with Hydraulic Fracturing)**
Reservoir model	Infinite Acting	Finite conductivity fractures
Wellbore storage	5.54×10 bbl/psi	0.0136 bbl/psi
Skin	24.4	0.05
Total flow capacity	31.5 md.ft	94.7 md.ft
Permeability	1.14	1.63
Radius of investigation	90.1 ft	177 ft
Initial pressure	5676.10 psia	5543.49 psia
Oil rate	39 stb/d	1830 stb/d
Productivity index, PI	**0.0097 stb/d/psia**	**1.0054 stb/d/psia**
Fracture length [ft]	-	297.5 ft
Fracture conductivity	-	1555 md.ft
Remarks		**Stimulation successful**

Table 4.6: Results Comparison Between DST#1 and DST#2

1) Fracturing job was successful conducted from low oil rate (39stb/d) increased to high oil rate (1830 stb/d). This proven that stimulation likes hydraulic fracturing can extend the penetration length of perforation especially in tight oil formation..

2) Insufficient penetration can affect the reservoir production. This maybe was caused by mechanical problem such as equipment failure. Wrong type of gun used can contribute to the problem.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the current result and discussion, we can see the analysis for well test job sequence had been detailed out. First analysis is production test for DST #1 which had been carried out without hydraulic fracturing after perforation in order to confirm fluid type and well performance. Second analysis is production test for DST #2 which had been carried out with hydraulic fracturing after perforation in order to confirm fluid type, well performance and evaluate the hydraulic fracturing treatment effectiveness. Both tests had been worked out after the petrophysic confirmed the presence of oil in the reservoir.

Then, pressure transient analysis had been performed. For DST#1, after done the history and type curve matching, the model of infinite acting reservoir was chosen because has the best fit. For DST#2, the model of finite conductivity fractures was chosen after gave the best match with history plot and type curve. Properties of the well also changed after executed the hydraulic fracturing treatment. Result from DST#1 showed the oil rate and productivity index are low which are 39stb/d and 0.0097 stb/d/psia. After performed hydraulic fracturing, result from DST#2 showed the oil rate and productivity index increased which are 1830stb/d and 1.0054stb/d/psia. Hence, this proved that hydraulic fracturing can increase the production from a reservoir and perforation length as well as reservoir properties are changing after performed hydraulic fracturing.

5.2 Recommendations

Based on the results and conclusion obtained from this project, a few recommendations for future works to improve this project are listed as follow: -

1) Consideration of having horizontal wells for all procedures.

2) Good perforation techniques must be made in order to prevent cost spending in stimulation job just for extending perforation length because stimulation job need to consider additional cost.

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Nomenclature

Bo Oil Formation Volume Factor, RB/STB

C Wellbore Storage Constant, bbl/psi

Cd Dimensionless Concentration, (equation 10)

Cpl Mass of Proppant per Volume or Llqula, Ibmlgd

Cps Mass of Proppant per Slurry Volume, *Ibm/gal*

Ct Total System Compressibility, lJpsi

D Lit Turbulence Factor,

Fc_D Dimensionless Fracture Conductivity,

h Reservoir Height, ft

K Reservoir Permeability, mD

Kf Horizontal Propped Fracture Permeability, @

P Reservoir Pressure, psi

Pwf Flowing Reservoir Pressure, psi

P_D Dimensionless Pressure Change

qo Oil Flow Rate, bbl/day

qg Gas Flow Rate, bblIday

r_w Wellbore Radius, ft

t Time, hours

t_D Dimensionless Time

Dt Period Elapsed Time, hours

Dte Argawal Equivalent Time,

tp Production Time, hours

T Reservoir Temperature, 'R

u Fluid Viscosity, cp

W Fracture Width, ft

Wp Propped Fracture Width

WH Hydraulic Fracture Width,inches

Xf Fracture Half Length, ft

Ø Porosity

APPENDIX

DST#2

Density of 20/40 Carbolite =	100	[lb/ft3]
Dry proppant volume =	128000	[lbs]
=	1280	[ft3]
=	308.8730624	[bbl]
Fractures width, W =	1.2	[cm]
=	0.039370079	[ft]
Fractures height, H =	17.7	[m]
=	58.07086614	[ft]
Fractures length, xf =	297.4684	[ft]
=	86.8492	[m]

Figure A: Fractures Length Estimation