CONCEPTUAL DESIGN IN SINGLE RUN WELL TESTING FOR MULTIPLE TEST ZONES

By

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DISSERTATION

Submitted to Petroleum Engineering Programme in Partial Fulfillment of
the Requirements for the Degree Bachelor of Engineering (Hons)

(Petroleum Engineering)

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved,

....

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Project Supervisor

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

This project focuses singularly on the well testing during exploration and appraisal. Well testing is recognized by many operating oil and gas companies to be the most hazardous operation that they regularly operate. Planning a well testing operation is an extremely complex task and requires a lot of experience. Well testing costs are typically accounting for about one third of the cost of an exploration well, and in many cases, much more. The potential for a budget over run can be high, unless there are timely and effective well test planning. Nowadays, there are a lot of well testing systems available. Each system claims to have their own advantages compare to others. Each system can be beneficial in different scenario. However, the trend in recent years shows that the systems are getting more complicated, which require more tools in the test string. This has made the test system not efficient in certain cases, especially in term of cost. The objectives of this project are to: a) Study the single run well testing in multiple test zones technology for as much understanding as possible; b) Propose a design of a more efficient well testing technique; c) Produce a guideline in applying single run well testing in multiple test zones which focuses more on cost factor. The project proposes a design which is more efficient than the latest design proposed at the Offshore Technology Conference held in Houston, Texas, USA, 2-5 May 2011. It is cost efficient as the total cost for well testing equipment is lower than the latest design. The proposed design is planned for permanent use inside the well. If it is a dry well, considering the high rig rate per day and the operating cost, the total cost of leaving the test string inside the well is still lower than the cost of using the latest design. Amount of the time savings depends on individual cases, but surely there is a lot time had been cut. Additional point for this design is it is not complicated to operate it, thus no need extra cost to hire expert to handle the equipments.

ACKNOWLEDGEMENT

First and foremost, I would like to express the most gratitude to Almighty God. I would like to take this opportunity to thank all parties involved in making this project. My deepest gratitude goes to my supervisor, Mr Elias Abllah for the continuous guidance, support and encouragement from the beginning until the final phase of my project. My appreciation is also to a colleague during my internship, Senior Production Technologist Mr Chen Jiun Horng for helping me in completing this project. I would also like to thank the Final Year Project committee for their professionalism and contribution together with their support in providing quality education during the execution of the project. Thank you.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Completions have never been simple. But for today's wells, the industry has had to push the envelope to develop game-changing technologies to operate in increasingly complex environments while reducing rig time, performing downhole functions in a single trip of the work string. Multi-zone completion technologies are increasingly being deployed in nearly every arena worldwide, from long land horizontals to shale and tight gas to the deepest waters.

"The days where an operator drills one well to target one specific zone is becoming more the exception than the norm," said Bryan Stamm, technical manager, Schlumberger Sand Management Division. "As technologies for multi-zone completions become more and more main stream, whether for stacked, single-trip multi-zone, multi-stage fracturing or intelligent completions, we're starting to see the industry become more comfortable with this approach."

Often in a wellbore, more than one zone or formation is intersected for production and/or injection of fluid. Typically, in multiple zone wells a lower zone is completed first. This completion may include gravel pack, standalone screen, expandable screen casing and perforation, or a combination of apparatus and methods. At this stage of the drilling operation it is often desired to test the zone utilizing drill stem testing (DST) to determine certain characteristics of the selected zone and the viability for production and/or injection. Drill stem testing at this stage provides information that can be utilized for decisions regarding further completion of the well.

After completion of the lower zone, the lower zone is then "killed" or isolated utilizing formation isolation valves so that the upper zone can be completed. Once the upper zone is completed it is often desired to test the upper zone for the same reasons as testing of the lower zone. This completion and testing process is performed through several trips in the wellbore in addition to those performed regarding the completion and testing of the first or lower zone.

It is a desire to provide a multiple zone testing system that permits a single trip into the hole to test multiple zones. It is a further desire to provide multiple zones testing system that facilitates separate testing of individual zones and commingled flow testing of multiple zones.

1.2 Problem Statement

Nowadays, there are a lot of well testing systems available. Each system claims to have their own advantages compare to others. Each system can be beneficial in different scenario. However, the trend in recent years shows that the systems are getting more complicated, which require more tools in the test string. This has made the test system not efficient in certain cases, especially in term of cost.

Traditionally, operators consider multi-zone techniques to achieve a more cost-effective installation that is more efficient, and there are operators who are not as concerned with installation efficiency but want to produce selectively, either because of government regulations or their own internal recovery factors. But the trend in recent years, people are looking for both efficiency and recovery, and that is where multi-zone techniques are really starting to thrive.

At the Offshore Technology Conference held in Houston, Texas, USA, 2-5 May 2011, there was a paper presentation by Micah Garrison, SPE, Weatherford International, Ltd., and Morris Cox, SPE, Brad Clarkson, PE, SPE, Nexen, Inc. on the topic of Reinventing Deepwater Exploratory Testing.

Their paper proposed a system which is part of a larger collaboration of operators and service providers innovating DST systems to make them economically viable. Difficulty of DST operations is the huge expense of rig day rates. To counter that problem, this system enables operators to flow a zone while the previous zone is in buildup phase, run the test openhole and eliminate Tubing-Conveyed Perforating (TCP), and run equipment for three zones on a single trip. Amount of the time savings depend on individual cases, but surely there is a lot time have been cut.

The economical wise of the newly proposed system against the older systems is not known.

1.3 Objectives and Scope of Study

The main purpose of this research is to make review and do analysis about single run well testing in multiple test zones technology.

The second objective is to propose a design and guideline in applying single run well testing in multiple test zones.

The whole process of meeting the objective will be show clearly in the report. Intense reading on the reference material has to be done since this project requires a lot of reading in order to gain information about the various well testing techniques and certain simplification has to be applied in deciding the final outcome of this project.

The scope of study is divided into three stages. In order for this research to reach that objective, firstly it identifies all well testing technologies previously and currently being used in the industry. Secondly, review all those technologies to understand the theory behind them, risks, advantages and disadvantages. Finally, this research is to come out with a design and propose a guideline in applying single run well testing in multiple test zones.

1.4 Relevancy of Project

This project will produce a general relationship and comparison between the previous well testing technologies and the latest single run well testing in multiple test zones technologies.

This relationship will give an idea on how these older and new technologies will increase or decrease the cost efficiency of a well testing process depending on the properties of the targeted zones.

1.5 Feasibility of Project within the Scope and Time Frame

Previously, most well testing jobs are done by conventional drill stem testing (DST), which took a long time and could cost USD 10 million or more. Also, the process had encountered severe sanding and incomplete cleanup problems in previous DST attempts. To optimize the testing program, the operator wanted to carry out DSTs only in the very promising zones and investigate other lower-priority zones with an alternative method that would take less time and expense.

In order to decrease the long time which is mostly from the run in hole (RIH) period, single run well testing for multiple test zone is proposed.

There is still no guideline to specify the conditions where the single run well testing for multiple test zones technology is more efficient compare to the conventional single run well testing for single test zone technology.

Currently, more studies are dedicated for another approach for single run well testing for multiple test zones. When there are a lot of technologies available for one purpose, it is now the matter of choosing which one is more efficient than the others.

From the results of this study, the knowledge of well test efficiency from the cost point of view may help operators determine the optimal type of well test to commence for the maximum effectiveness of a test process.

By this determination, the total cost for exploration of a well can be reduced further.

The literature review will be covered in the next section, followed by the description of the experimental methodology in the following part, as well as the current progress. The results will then be discussed. The conclusions of the study are summarized in the last section.

CHAPTER 2

THEORY / LITERATURE REVIEW

2.1 Theory

Performing well tests on single zone wells can be done in cased hole or open-hole. Open-hole well test is usually preferred because it exhibits lower skin damage and improved productivity, especially in low permeability, fractured carbonate reservoirs. For multiple zones testing, cementing and selectively perforating are more common.

An exploratory well in Qatar performed a well test using the basis of this approach. Consequent to this, well tests in China and Oklahoma, (USA), used this approach magnificently. One common well test objective is to establish sufficient flow allowing the chosen reservoir to be evaluated, without the need to stimulate. Although stimulation is not entirely eliminated in this test case, a reduction in test time is achieved. The reduced number of trips into the hole also reduced HSE exposure. This last improvement is particularly important in one well as the well flow stream contained H_2S. Although some operational difficulties were encountered and overcome, the system was proven technically viable, and has the potential for reducing completion and testing time for a multi-zone well, as well as mitigating HSE hazards.

Based on the history of well tests performed above, it is an assurance that this technique has high successful rate. The technique delivers low mechanical skin, may deliver savings of up to 35% over conventional techniques. Less testing procedures mean less HSE exposure.

2.2 Literature review

Well testing is recognized by many operating oil and gas companies to be the most hazardous operation that they routinely commence. The potential for loss of life and assets, or environmental devastation are proportionately higher than at any other time in the drilling or operating of oil and gas wells. Therefore, it is of great importance to the industry that such operations are extremely well planned and executed. Planning a well testing operation is an extremely complex task and requires a lot of experience. The testing of oil and gas reservoirs is one of the few times in an operating oil company when petroleum engineers, drilling engineers, reservoir engineers, geologists and asset managers get together with such a focused objective. Therefore, well test engineering is greatly a discipline that combines knowledge of all of these areas of expertise. The Test Engineer will be the focal point of this group of specialists and will attain the views of the group before then formulating a plan to test the well to meet an agreed set of objectives. Well testing costs are typically accounting for about one third of the cost of an exploration well, and in many cases, much more. The potential for a budget over run can be high, unless there are timely and effective well test planning. There are three types of well testing: 1) During exploration and appraisal – to prove reservoir potential by determining dynamic reservoir properties; 2) During development – to confirm well performance by optimizing completions and ensuring maximum deliverability from each well; 3) During production – to improve field productivity and maximize recovery through the maintenance, monitoring, allocation, and optimization of each well's production. In this project, we focus singularly on the well testing during exploration and appraisal.

2.2.1 What is well testing?

A means of evaluating reservoir performance by measuring flow rates and pressures under a range of flowing conditions and then applying the data to a mathematical model. In most well tests, a limited amount of fluid is permitted to flow from the formation being tested. The formation is isolated behind cemented casing and perforated at the formation depth or, in openhole, the formation is straddled by packers that isolate the formation. During the flow period, the pressure at the formation is observed over time. Then, the formation is closed and the pressure monitored at the formation while the fluid within the formation equilibrates. The analysis of these pressure changes can provide information on the size and shape of the formation as well as its ability to produce fluids.

2.2.2 What is single run well testing for multiple test zones?

A system that facilitates singular testing of multiple zones singularly and performing commingled test without pulling out of the well.

The current process of testing multiple zones in a well includes (well utilizing perforation and gravel packing): 1) trip into hole to perforate first zone; 2) trip into hole to gravel pack/complete lower zone; 3) trip into hole and drill stem test the lower zone, kill the well after the test; 4) trip into hole to perforate upper zone; 5) trip into hole to gravel pack/complete upper zone; 6) trip into hole and drill stem test the upper zone, kill well after the test; 7) trip into the hole with the drill stem tester to configure the hole and test commingled production from the lower and upper zones. Various methods may be utilized to complete the production zones, however, the prior art system typically requires three (3) trips in the wellbore to perform two independent zone tests and a commingled test. This prior art method, while effective, is time consuming and costly.

2.2.3 Development of cased-hole single-trip multiple-zone completion systems

This is another example which is intended to chronicle the development of cased-hole single-trip multiple-zone completion systems with a focus on the systems developed for deepwater applications. The paper also discusses why previous systems have not reproduced globally to become an accepted mainstream sand-face completion technique.

A completion technology that was originally designed for lower-pressure gravel-pack treatments has evolved through four generations of tool systems. Although once perceived as too difficult for deepwater operations, the Generation IV system may prove to be a major factor in reducing completion cost in the economically challenging Lower Tertiary play in the Gulf of Mexico.

The Generation IV Single Trip Multiple Zone Completion System has addressed the major limitations in the three previous versions along with simplifying and reducing system running time. The system improvements will offer the capability to perform multiple hard-rock land fracs in an offshore environment in a single trip and will not sacrifice economic feasibility and safety in doing so.

Single Trip Multiple Zone (STMZ) Development Chronology

Generation I

The multiple zone system developed for this application known as the "Beta" system. It was a low pressure system that allowed:

1. Perforation of all zoned simultaneously
2. Cleaning of the entire interval by pressure washing all perforations

After setting the sump packer, the gravel-pack system only required one trip into the hole using the following sequence of operations:

1) Run the entire screen and liner assembly with a snap latch on bottom, a liner packer on top, isolation packers in between, and the operating string inside the screen liner
2) Snap into the sump packer
3) Set the liner hanger packer and release the setting tool and operating string
4) Set all isolation packers
5) Run a concentric tapered string inside the drill pipe and operating string
6) Sequentially gravel pack all zones through their port collars
7) Return to lower zone and repack if required

Additional features that the system offered were:

1. Downhole rotation during the gravel-packing operation was eliminated
2. A full column of sand laden slurry could be reversed out after sand out without pressuring other intervals
3. Each interval could be repacked during the life of the completion
4. By installing production sealing units with sliding sleeves inside the screen and liner assemblies, any combination of isolated intervals could be produced or selected for water injection

"Beta" system was a success.

Generation II

Generation II included the development of the STMZ and a Single-Trip Dual-Zone System (STDZ). Generation II eliminated:

- the need to run an inner concentric string from surface
- the handling at surface of the inner and outer string when moving the service string to the next interval, accomplished by using a retrievable pack-off that was installed below the upper gravel-pack packer that seals around the outer flush-joint washpipe

As field experience was gained with the system, procedural changes were made, including a two-trip version: gravel-pack assembly was run and packers set on the first trip, and the service tool assembly was run in the second trip.

Generation III

- upgrade the earlier gravel-pack systems (<5,000 psi) to handle higher pressure encountered with frack packing (up to 10,000 psi)
- required the use of higher-rated isolation packers and the top liner packer
- other than upgraded the system, the inner concentric string caused three issues:

1) as the interval lengths increased, required longer make-up time for inner and outer strings
2) pump rate limited by the longer inner string due to ID restriction
3) the concentric reverse path between the 2 strings increased the surface reverse pressure because of induced fluid friction

Generation IV

To the authors' knowledge, there are only 2 generation IV systems (MST and ESTMZ systems) that are satisfactory for the need of deepwater exploration.

The MST System

- reduces frequency and number of trips typically necessary to conventionally stimulate and complete multiple intervals in a wellbore
- although a typical application for the MST system would be for two to six intervals, there is no limit to the number of zones that can be effectively treated

- positive independent zonal isolation for each interval during completion and production
- can be applied to a wide range of zone lengths with limited distance between zones restriction
- allows stimulation of zones in sequence or bypass and return to the individual zones
- pressure integrity tests are performed at the surface as well as down hole
- retrievable and testable dual-element isolation packers provide reservoir separation during stimulation and production
- workstring service tool opening and closing tools allow selective sliding-sleeve circulating device functionality in all zones

ESTMZ System

The objective of ESTMZ System is to optimize the time spent performing the sand-face completion.

- 1 perforating trip, 1 clean-up plug-retrieval trip, one sand-face trip for a well
- The completion system focus on today's gravel-pack needs: higher pressure, higher pump rate, higher proppant placement, and capability to gravel-pack longer intervals.
- The service tool is enhanced with components of current technology.
- The first half of the research will focus in collecting the related information regarding current well test techniques utilized all over the world and single run well testing for multiple test zones. The summary of the activities are as follow:

a) Evaluate the information from journals, books, articles, internet and published thesis.
b) Survey the required materials for well testing.
c) Make comparison between current and previous single run well testing for multiple test zones techniques utilized all over the world.
d) Prepare the literature review report.

2.2.4 Cost-Effective Deepwater Testing

Case study:

Operator uses integrated productivity solution for India deepwater gas well

Challenge

Test a deepwater well with multiple heterogeneous high-permeability gas-bearing zones.

Solution

Used MDT (Modular Formation Dynamics Tester) interval pressure transient testing (IPTT) and InterACT, real time monitoring. Integrated IPTT results in SWPM (single-well predictive model) for predicting absolute openhole flow potential (AOFP) and well deliverability.

Results

Saved rig time and cost by providing measurements of productivity and AOFP.

Difficult testing environment

An operator working in deep water offshore India found that applying conventional drill stem testing (DST) took a long time and could cost USD 10 million or more. Also, the operator had encountered severe sanding and incomplete cleanup problems in previous DST trials. To optimize the testing program, the operator wanted to carry out DSTs only in the very promising zones and investigate other lower-priority zones with an alternative method that would take less time and expense.

Optimizing testing

The group chose the MDT dual packer IPTT, integrated with an SWPM analysis to determine formation parameters and estimate well deliverability.

IPTTs were conducted using the inflatable straddle packer system of the MDT tester. The transient sequence consists of single or multiple flow periods induced using the downhole pump, followed by a pressure buildup.

Analysis of IPTT transients yielded initial reservoir pressure, nearby gas mobility, and an estimate of the openhole skin factor of various zones. The results were used in a numerical single well model to predict the commingled deliverability of several layers.

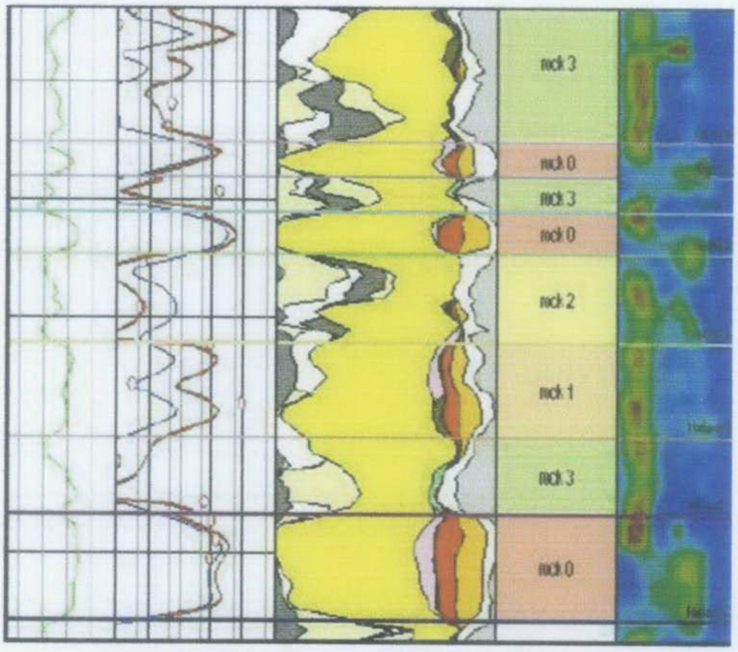
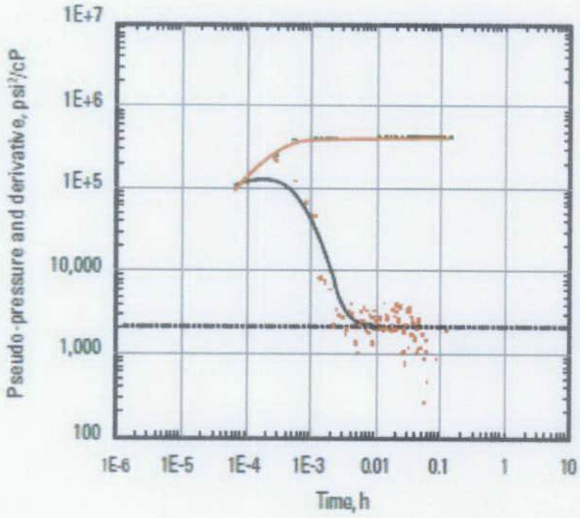


Figure 1: Well log section and rock types in the gas-bearing zone in SWPM analysis



(Left) Flow regime identification plot for MDT IPTT buildup.

(Below) Well deliverability from nodal analysis.

Figure 2: Graph of Pseudo-pressure and derivative versus time

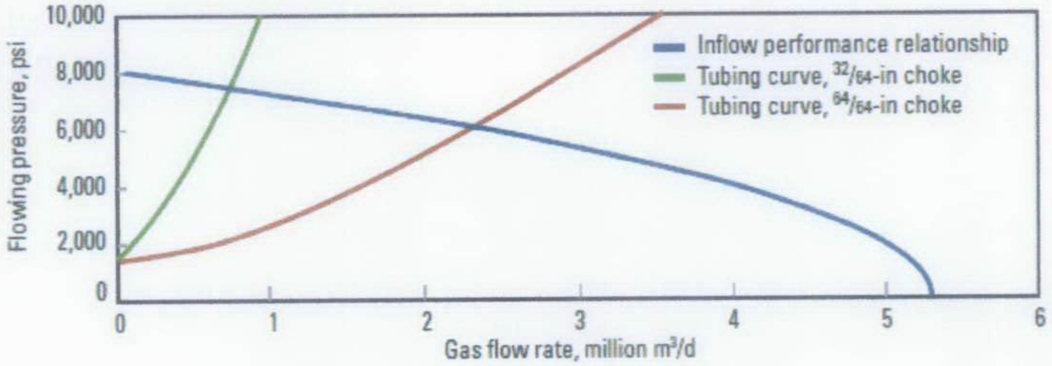


Figure 3: Graph of flowing pressure versus gas flow rate

Two-step approach

Two-step approach is used to determine the commingled AOFP of gas wells.

First, it conducted a multiple-station MDT IPTT survey and interpreted the data to estimate reservoir parameters (permeability, skin, and reservoir pressure). The non-Darcy flow coefficient was computed using the Swift & Kiel expression, and an analytical pseudo-steady state equation was used to establish single-point AOFP for each of the tested zones.

Second, the team extended routine modelling and incorporated features such as scaled permeability data, rock types, and hydraulic flow units – through interpretation of a CMR-Plus (Combinable Magnetic Resonance) log and wireline petrophysics – into a model. The model was built using both a numerical simulator and a cumulative permeability-thickness product for the gas-bearing zones, using average reservoir pressure and temperature for the whole zone of interest.

AOFP and well deliverability prediction

The success of single well simulation allowed the operator to estimate total AOFP for multiple zones using the commingled technique. Well deliverability estimation was included using production tubular and choke information in the simulation model. This technique saves a lot in rig time and cost. It is done by providing estimates of productivity and AOFP without resorting to a conventional four-point deliverability test.

CHAPTER 3

METHODOLOGY

3.1 Key Milestones and Elaboration

Figure 4 below describes the overall milestones and general flow of this project.

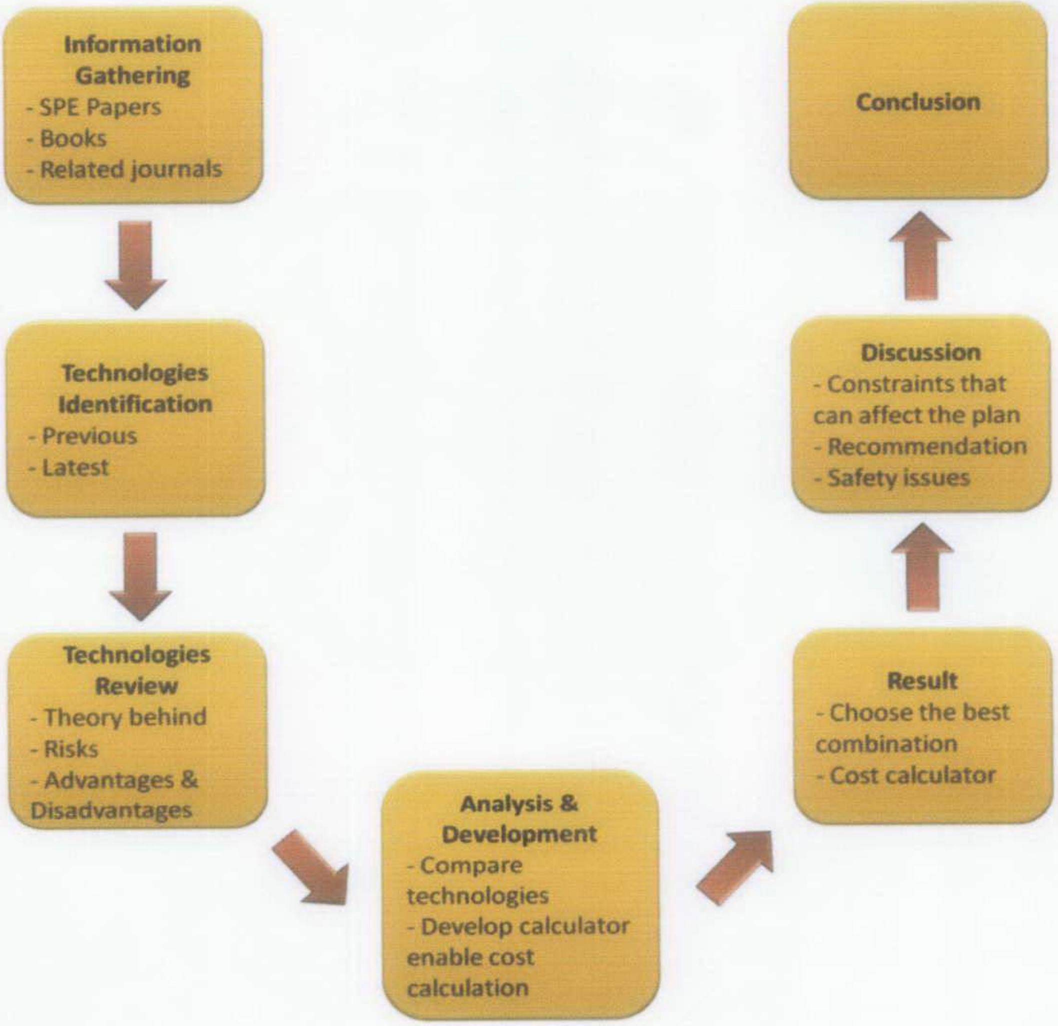


Figure 4: Flowchart Representation of Project Key Milestones

a) Gathering information sources

This was the first step to be taken, where the author will go through a lot of websites and library searching for any SPE papers, journals, and books published that are related to the topic given. Since well testing is a very complicated process that requires knowledge from many disciplines, it is a must to gather as much information from various aspects.

b) Technologies identification

It is then a must to identify the many types of technologies available in the industry all around the world. This research includes all the technologies previously or currently applied.

Since there were not many direct references related to the case study, all the available resources will be studied carefully and will try to extract as many information as possible that will help in developing the further movement of this project.

c) Technologies review

Subsequent to indentify technologies, review about those technologies is needed. The aim is to find out the theory behind those technologies, the possible occurrence or experienced risks, and the advantages and disadvantages of each technology.

d) Analysis and development

In this part, we are to compare the findings of previous step. Select a few methods, and carry out improvements anywhere possible. It is to find the most suitable combination, or arrange for a totally new technology if possible.

e) Result

After we have done with the review and analysis, several important decisions on design can be made therefore the author will try to produce a draft plan as the first design layout to the single run well testing for multiple test zone.

At this stage, we can already expect which type of method that compatible with the needs and condition of the current situation so that the function of the well testing can be expanding not only to a certain criteria.

f) Discussion

Discussion will be conducted to find the way to improve the design for the future successor and also to find the constraint that has to be overcome in order to run things smoothly all along the making process. The safety issue related to the design and mechanism will be discussed as well.

3.2 Research Methodology/ Project Activities

3.2.1 Formation Testing

Formation testing may be made before or after running casing, cementing, and perforating. (Of course the few wells that are completed open-hole are tested only open-hole). Cased-hole completions are tested through perforations. Open-hole testing followed up by cased-hole testing is also standard in several areas.

The formation test is the final proof of a well's initial capability to produce oil and gas in paying quantities. Cores and logs tell which formations are likely to produce and where to perforate them, but predictions are not the best data on which to install an expensive completion. In general, formation tests are most useful in reservoirs with medium to high permeability (greater than 15 or 20 millidarcy).

Wireline formation testers and drill stem test tools (DSTs) may be used during or after the end of drilling. When considering a well for completion, both types of formation tests may be used.

3.2.2 Wireline Formation Test

A wireline formation test is a low-cost, quick way to measure pressures at specific depths. This technique is originally intended to sample formation fluids. Additional benefits of wireline testing are lower costs and less risk than drill stem testing.

The test tool is consist of a rubber pad with a valve in it, a pressure gauge, and testing chambers and sampling chambers interconnected by valves. The tool may be run with a bottomhole pressure gauge or with a logging sonde.

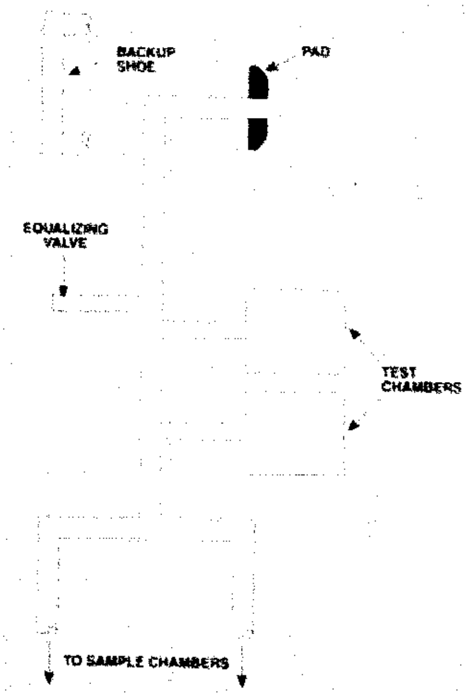


Figure 5: Wireline formation tester design

The zone to be tested is positioned by wireline depth measurement or by SP log. A backup shoe kicks out to press the pad against the formation sidewall, forming a hydraulic seal from mud in the wellbore. In cased holes, perforations are made into the rock matrix to permit flow into the tool.

The pad valve is opened, and formation fluids enter the tool and initial shut-in pressure is recorded. For a period of flow, a test chamber valve is opened and a small piston draws fluids at a steady rate while pressure in the chamber is logged at the surface. Usually a second test chamber is opened for a second flow period. After the second flow period, the final shut-in pressure is recorded.

Since the test chambers each hold less than an ounce, fluids drawn into them are nearly 100 percent mud filtrate. A sample chamber may be opened to draw a few gallons of formation fluid. In porous, permeable, well-consolidated formations, reservoir sample may be obtained in the sample chamber.

After a valve is opened to equalize pressure, a getaway shot is fired to release the tool. The tool is then retrieved, unless it is designed to make more than one test per trip downhole.

Wireline formation tests are helpful for investigating oil and gas shows, taking quick readings of hydrostatic pressure and flowing pressure, and estimating permeability. Wireline tests help in making predictions for zone productivity and may be used in planning more sophisticated formation tests, such as drill stem tests. However, fluid samples are little and tested intervals are thin. Therefore, the most useful information usually obtained is formation pressure.

3.2.3 Drill Stem Test

The drill stem test (DST), like the wireline formation test, was developed as a formation fluid sampling method.

3.2.3.1 DST Tools

DST tools come in two basic types that may be used for open or cased holes:

A. Single-packer DST tool
- Isolates formations from below the tool to the bottom of the hole
- Perforated pipe is made up below the packer
- Formation fluids enter the wellbore and flow through the perforations, through the tool, and up the drill stem to the surface

B. Straddle-packer DST tool

- Isolates the formation bed or beds between two packers
- The tool is similar to the single-packer tool, in that the lower packer is basically the same as the upper packer except that it is turned upside down
- Distance from packer to packer depends on the thickness of the test zone
- Formation fluids enter perforated pipe between the packers and flow upwards

❖ Inflatable straddle tool

- Consists of two packers spaced exactly as the straddle-packer DST
- The only difference is that the inflatable straddle tool is usually set by pump pressure instead of mechanically set

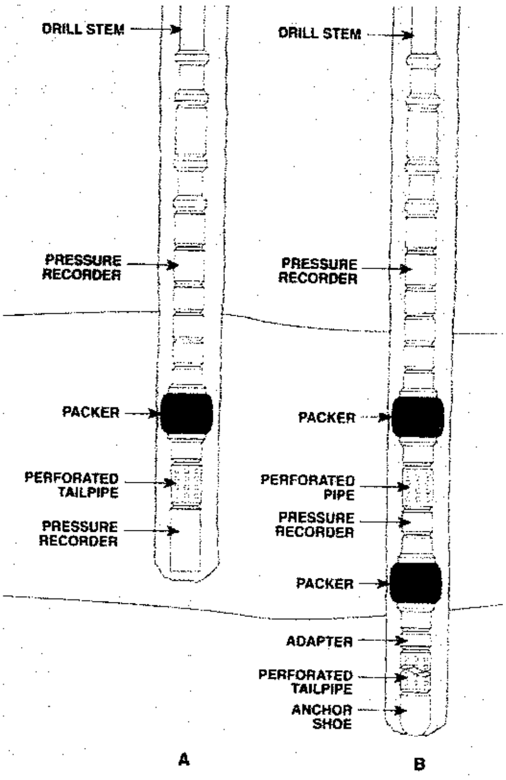


Figure 6: Drill stem test tool assemblies: a) single-packer; b) straddle-packer

3.2.4 Surface Facilities for Well Testing

Surface facilities are designed to accommodate the formation fluids brought to the surface through the production tubing during a well test. These facilities allow the operator to control the test flow rate, to separate the total flow stream into its components of oil, gas, and water, to measure the flow rate of each component, to collect a representative sample of each component, and to store or dispose of the produced fluids. In a development field, these facilities are part of a permanent installation. For an exploration well test, the surface facilities are temporarily assembled on the test location.

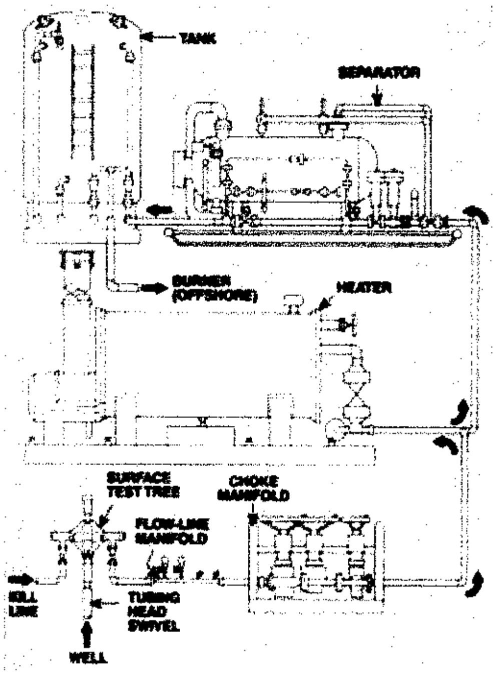


Figure 7: Surface well-test components

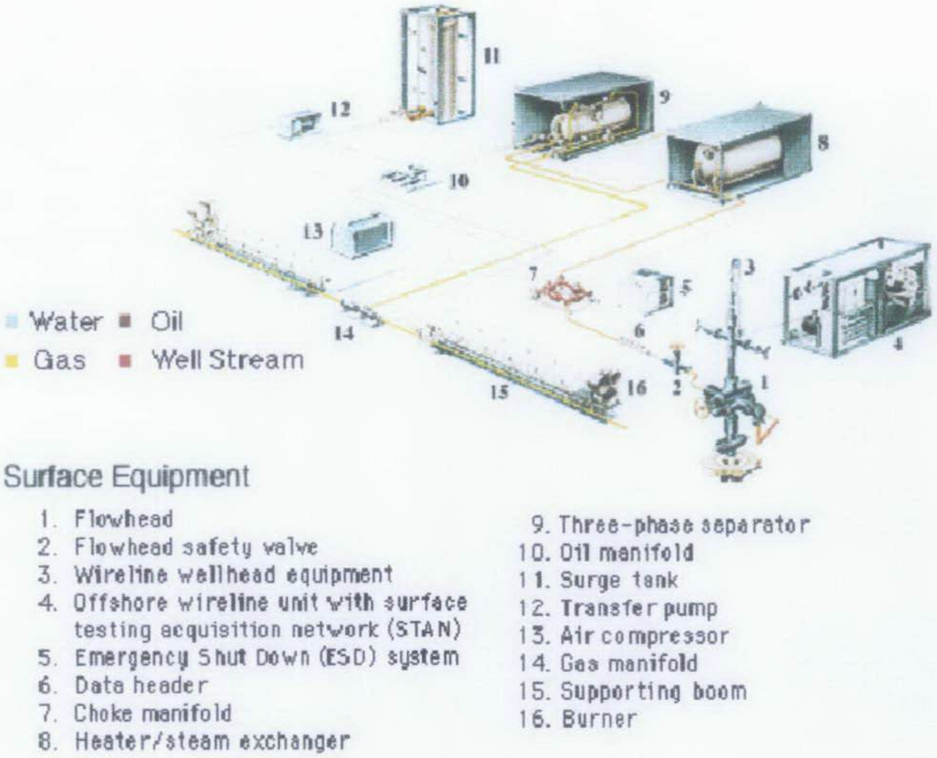


Figure 8: Surface facilities for exploration well testing

The flowing stream from the wellhead is normally regulated by the choke manifold. This choke manifold generally consists of two types of valves:

1. Variable-size opening regulated manually
   - Used while production is being initiated and the rate of flow stabilized.

2. Fixed-size opening ("positive" choke)
   - Used during the stable flow period.
   - Either choke provides an estimate of the flow rate, which is related to:
     1. The diameter of the choke
     2. The pressure drop across the manifold

The sample valve downstream of the choke manifold allows one to determine what fluids are being produced during the initial cleanup flow. Samples are taken to ensure that the flow stream is free of load fluid, drilling mud, formation sand, or perforation debris before the stream is diverted from the cleanup storage tanks to the flow-separation facilities.

The separation facilities consist of:

1. Heater

The last stage of pressure reduction prior to separation can be provided by a heater choke, if necessary. Since this pressure drop may be quite large, it can cause considerable cooling of the flow stream. The heater choke is therefore located at the inlet to a heater. The purpose of the heater is to raise the temperature of the flow stream. The resulting reduction in viscosity of any oil or condensate facilitates the subsequent separation of gas entrained, or water emulsified, in the oil.

2. Separator

The separator is a cylindrical tank that provides the residence time required for the phases to separate by gravity segregation. The separator is operated nominally at a sufficiently low pressure to give a gas-oil ratio approximating that at standard conditions. If the outlet pressure from the heater is high, then the separation process may require 2 stages:

a) The first stage, the high-pressure stage, separates the flow stream into a gas phase and a commingled liquid phase. The gas phase flows from the top of the separator through an orifice rate meter and on to a flare, where it is burned.

b) The liquid phase is discharged to the second-stage (low-pressure) separator, which is a three-phase unit. Here a final separation into gas, oil, and water occurs. The gas production rate is again measured by an orifice meter prior to being flared. Each liquid phase is measured individually by a meter prior to being collected in storage tanks. The oil phase may then be disposed of by an oil burner, if environmental conditions permit.

3.3 Equipments and Tools

In this analysis project, there is no specific engineering software and hardware required towards the completion of this project. The information required is gathered from the reports of past well testing jobs, the examples from the books, and from articles on the internet.

If this project is to be continued afterwards, there might be the need to run simulation of the proposed outcome. When that time comes, specific engineering software will be needed to run the simulation.

3.4 Key Milestones Completed and Future Planning

There are two semesters in the completion of this project. The research semester and the analysis work semester. There are two Gantt Charts below for each of the semesters:

FINAL YEAR 1st SEMESTER (JAN 2011)		Week														
No.	**Task Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Selection of FYP topic		■						MID SEM BREAK							
2	First meeting with supervisor		■													
3	Preliminary research work			■	■	■	■									
4	Submission of Preliminary Report						■									
5	Seminar **(Proposal Defense and Progress Evaluation)**										■					
6	Progress report preparation									■	■					
7	Submission of Progress Report										■					
8	Data Gathering on previous projects and conventional techniques							■		■	■	■				
9	Comparison between conventional and multi zone testing techniques							■		■	■	■				
10	Discussion and Project Alteration											■	■	■	■	
11	Final Report preparation												■	■		
12	Interim Final Report Submission														■	
13	Oral Presentation															■

Figure 9: The Gantt Chart for the Research Semester

FINAL YEAR 2nd SEMESTER (MAY 2011)		Week															
No.	**Task Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Project Work Continues	▨	▨	▨	▨	▨	▨	▨	MID SEM BREAK								
2	Submission of Progress Report									○							
3	Project Work Continues									▨	▨	▨	▨	▨			
4	Pre-EDX												○				
5	Submission of Draft Report													○			
6	Submission of Dissertation (soft bound)														○		
7	Submission of Technical Paper														○		
8	Oral Presentation															○	
9	Submission of Project Dissertation (Hard Bound)																○

Figure 10: The Gantt Chart for Analysis Work Semester

CHAPTER 4

RESULTS AND DISCUSSION

The Comparison between the conventional techniques and the current techniques

The study compares the conventional techniques of well testing job with the current technique of single run well testing for multiple test zones.

The result is divided into three, surface section, subsurface section and cost calculation.

4.1 Surface Section

Surface section mainly focuses on the rig type used for the testing operation. Water depth is the main factor considered in deciding the type of rig to be used. In one rig type, there is also variance in the design according to water depth thus varying the daily rate of the rig. The example of water depth, rig type, and average day rate used in the calculation is shown in Table 1 and Table 2.

Water Depth (ft)	Rig Type	Average Day Rate (USD)
< 250	Jackup IC	73000
250	Jackup IC	80000
300	Jackup IC	93000
300 +	Jackup IC	141000
< 4000	Semisub	291000
4000 +	Semisub	419000

Table 1: Values used for calculation of 1st Choice

Water Depth (ft)	Rig Type	Average Day Rate (USD)
< 250	Jackup IS	142000
250	Jackup IS	137000
300	Jackup IS	60000
300 +	Jackup IS	70000
< 4000	Drillship	241000
4000 +	Drillship	461000

Table 2: Values used for calculation of 2nd Choice

*The day rates provided above are the current day rates for each rig type drawn from the RigLogix database. These numbers, which include both competitive and non-competitive rigs, are updated on a daily basis.

4.2 Subsurface Section

4.2.1 Latest Design Available

From the studies of previous and existing well testing technologies, there is a finding about the latest well testing string design proposed at the Offshore Technology Conference held in Houston, Texas, USA, 2-5 May 2011.

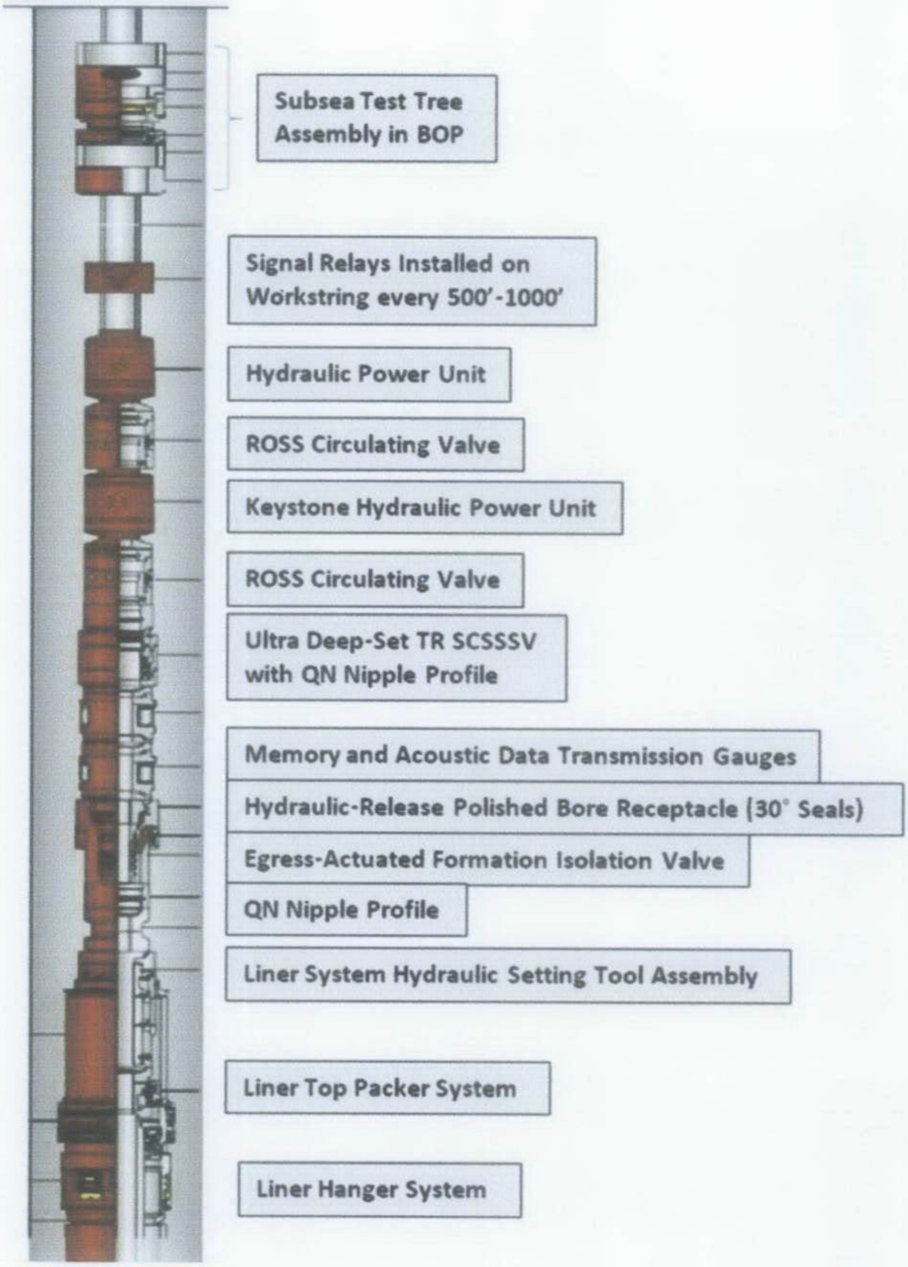


Figure 11: Latest well testing string design

Items	Descriptions
Swellable Annular Isolation Packer	Chemically activated by contact with Oil Based Mud at Reservoir Temperature, provides the robust second line of annular isolation
Annulus Casing Packer	Actuated by differential pressure on ID, effectively isolates openhole target zones on annulus
ROSS Remotely Operated Sliding Sleeve	Actuated by RFID, Pressure Pulse or Timer, the ROSS controls the flow of the well at the sandface, isolating the system ID for subsequent zone flow while executing buildup test
Hydraulic Power Unit	Scans for RFID Signals, Pressure Pulses and contains Timer; provides up to 10,000psi hydraulic muscle to operate ROSS Sleeves and Fall-Through Flappers
ROSS Screen Shrouded Sliding Sleeve	Allow flow testing to continue in the event of excess sand production
Memory and Acoustic Data Transmission Gauges	Receives, stores, and acoustically transmits critical formation pressure and temperature to surface in real time using a series of sonic relays throughout the workstring
Fall-Through Flapper Zonal Isolation Valve	Actuated by RFID, Pressure Pulse or Timer, provides enhanced well control capability and an alternative point point to execute buildup tests while flowing subsequent intervals
Liner Hanger System	A device used to attach or hang liners from the internal wall of a previous casing string
Liner Top Packer System	Packer set by high pressure
Liner System Hydraulic Setting Tool Assembly	The end type of tubing
QN Nipple Profile	Nipple is barrier in the tubing
Hydraulic-Release Polished Bore Receptacle (30° Seals)	As an expansion joint when extreme movement is expected in the production tubing. Also as separation tool for removal of production tubing
Ultra Deep-Set TR SCSSSV with QN Nipple Profile	Tubing retrievable surface controlled subsurface safety valve. provides a seal area and a locking profile
ROSS Circulating Valve	Open as displacing hole for kill-weight mud system to alleviate hydrostatic extremes
Acoustic Telemetry Relays	Transmit gauge data via acoustic telemetry, along with TR-SCSSV control lines
Subsea Test Tree Assembly in BOP	For contingency operations, provides flow restriction

Table 3: List of instruments and descriptions for the latest design

This design aimed for usage in single run multiple zones well testing. This string is to be retrieved after the well test is completed. The design is a little bit different for each level of formation in a single well. For three layers of formation to be tested, it will require three of this set in one long string. Looking at this design which is so complicated and full of equipments, it is predictable that the cost of this string is very expensive.

From the information obtained from communication through e-mail with one of the presenter of this design, Mr. Micah Garrison, SPE, Weatherford International, Ltd., "The particular application for which I designed the system in for an environment in which a $1MM USD spread-cost rig operation is used in the deepwater- therefore, a lot of the system components are designed with that in mind- and it justifies the additional expense of the equipment. As well, when a miss-run can cost a minimum of $2-3 MM USD, we plan heavily to implement and provide backup contingency equipment - again because the cost of failure is so great."

He stated that the minimum cost (if successful without any miss-run) is $1MM USD, which is already very costly for a well test. This is why the proposed design comes with very simple design and low cost.

4.2.2 Proposed Design

Looking at the complicated and very costly latest design proposal, this project comes out with a much simpler design which is obviously much cheaper. This design is intended for permanent usage inside the wellbore, and if it is a drywell, the cost of leaving the instruments inside the well is still much cheaper than the cost of failure of the latest design proposal.

Table 4 below is the list of instruments and their prices. The prices are for instruments that are applicable for high temperature and high pressure, up to 300 degree Fahrenheit and 10,000 psig.

Proposed Testing Equipments	**Price (USD)**
Fall-Through Flapper Zonal Isolation Valve	75000
Hydraulic Power Unit	30000
Swellable Annular Isolation Packer	25000
ROSS Remotely Operated Sliding Sleeve	98000
Hydraulic Power Unit	30000
Pressure and Temperature Sandface Gauge Carrier with Acoustic Data Transmission	25000
Swellable Annular Isolation Packer	25000
Tubing hanger	80000
Subsea Test Tree Assembly in BOP	150000
TOTAL Price	**538000**

Table 4: List of instruments and prices of proposed design

Figure 12 below is the illustration of the arrangement of the instruments in the proposed test string. This illustration shows well test string just for a single layer payzone. For multiple layer payzone in a single well, all needed to do is just repeat the equipments starting from the first swellable annular isolation packer downwards.

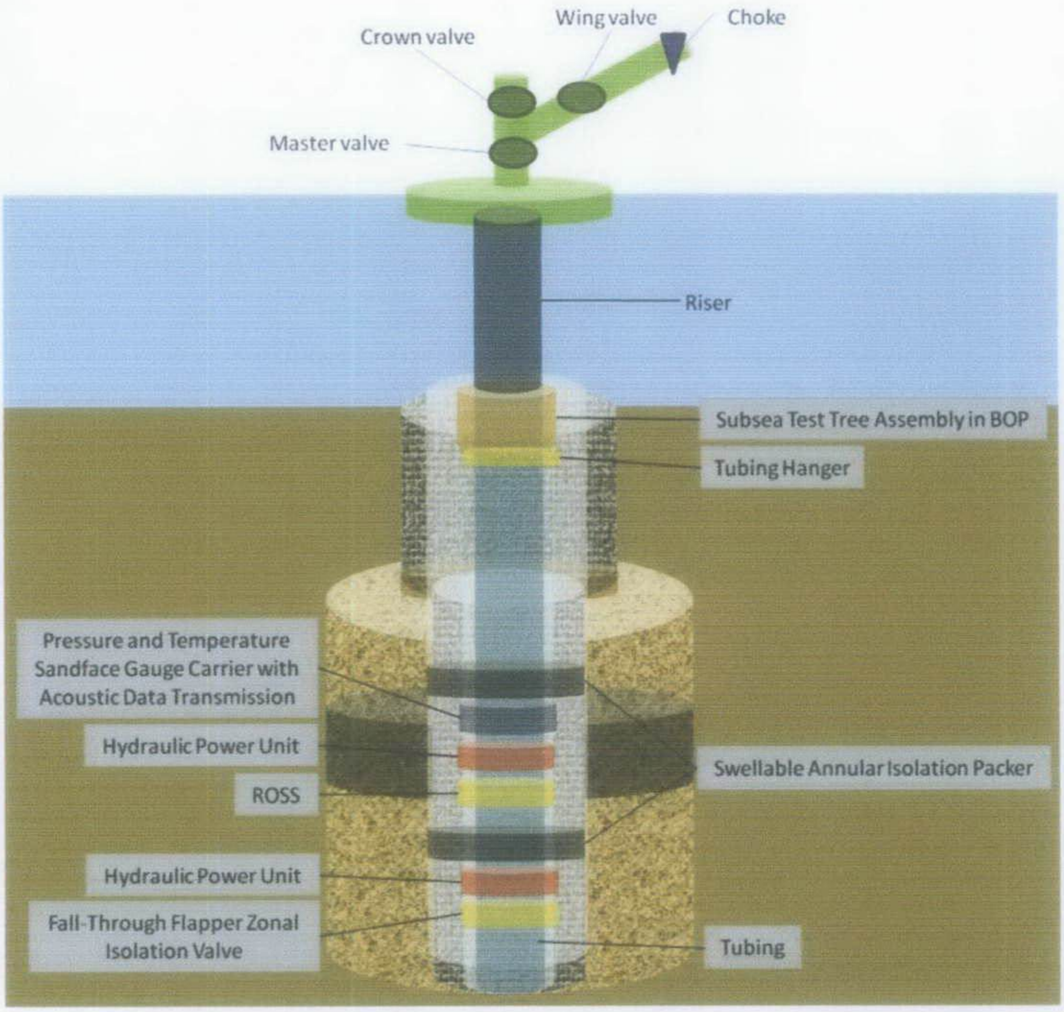


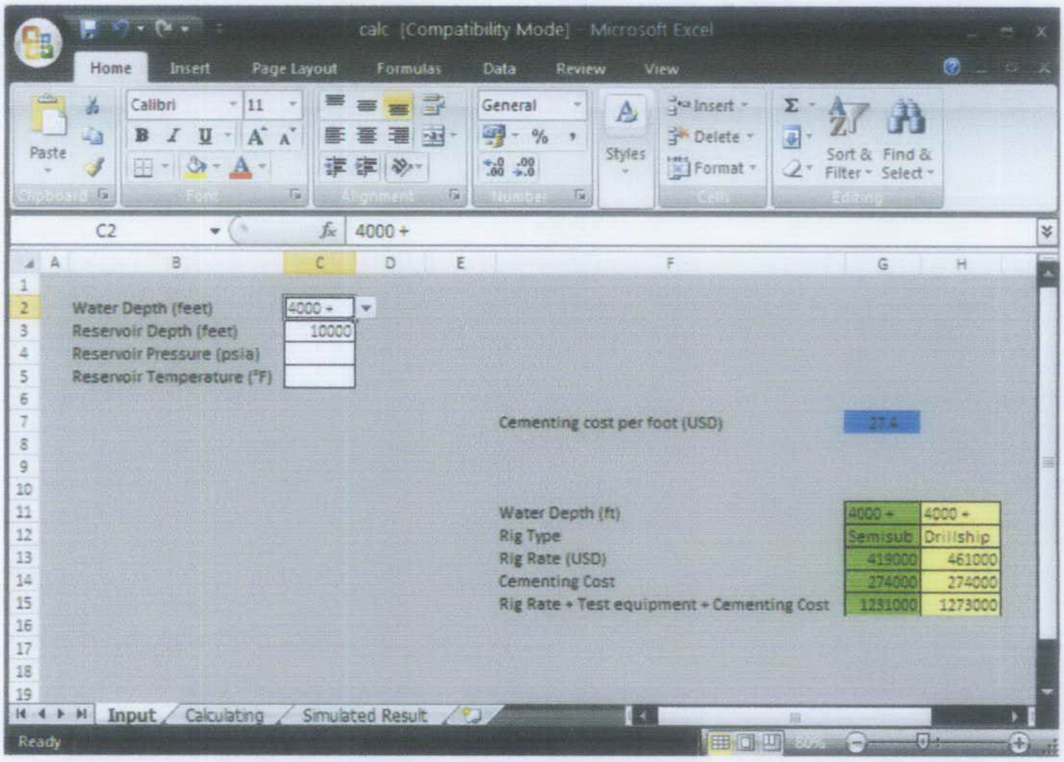
Figure 12: Illustration of the proposed well testing string

4.3 Calculation of Well Testing Cost

Because the lack of information regarding the actual detail cost of the latest available well testing design proposed by Micah Garrison, SPE, Weatherford International, Ltd., and Morris Cox, SPE, Brad Clarkson, PE, SPE, Nexen, Inc., at the Offshore Technology Conference held in Houston, Texas, USA, 2-5 May 2011, as the companies have to keep their cost details confidential, it is still unable to determine the exact results for the case of well testing cost. It is to be expected, however, there will be a general increase in efficiency of well testing techniques as cost reduced.

What can be done for now is to calculate the cost of design proposed in this project, and compare it with the estimated cost informed by Mr. Micah Garrison which is around $1MM USD. The cost calculation is done by taking into account the cost starting from the rig and downward to the targeted zone.

To ease the calculation process, this project comes out with a calculator. This calculator is built using Microsoft Office Excel 2007. The first sheet of the calculator, which is the input sheet, is shown in Figure 14 below.



C2 4000 +

Water Depth (feet) 4000 +
Reservoir Depth (feet) 10000
Reservoir Pressure (psia)
Reservoir Temperature (°F)

Cementing cost per foot (USD) 27.4

Water Depth (ft)	4000 +	4000 +
Rig Type	Semisub	Drillship
Rig Rate (USD)	419000	461000
Cementing Cost	274000	274000
Rig Rate + Test equipment + Cementing Cost	1231000	1273000

Figure 13: Input page of the calculator

At the top left side of this input sheet is where the user will enter the value of water depth in feet, the reservoir depth in feet, the reservoir pressure in psia, and the reservoir temperature in degree Fahrenheit. After that, the calculation is done automatically and the result is shown at the bottom right side of this first sheet. Estimation cost of cementing is done by calculating the example cost from Kumang field as shown in Table 5 below.

Example from Kumang Cost estimation	
Total Depth (ft)	8300
Total Cementing cost (USD)	227400
Cost of cementing per foot (USD)	27.4

Table 5: Estimation cost of cementing per foot

The result in green column is the first choice suggested while the yellow column is the alternative suggested. The result shows suggestion of rig type can be used, the rig rate, the cementing cost, and the total cost which include the rig rate, cost of test equipments, and the cementing cost.

To give a much clearer view of the results, graph is produced at the third sheet of the calculator. Example of the graph produced is shown in Figure 14 below.

This graph is based on the value obtained as shown in Table 6 below.

Water Depth (ft)	1st Choice (USD)	2nd Choice (USD)
< 250	885000	954000
250	892000	949000
300	905000	872000
300 +	953000	882000
< 4000	1053000	1103000
4000 +	1231000	1273000

Table 6: List of cost calculated according to well depth

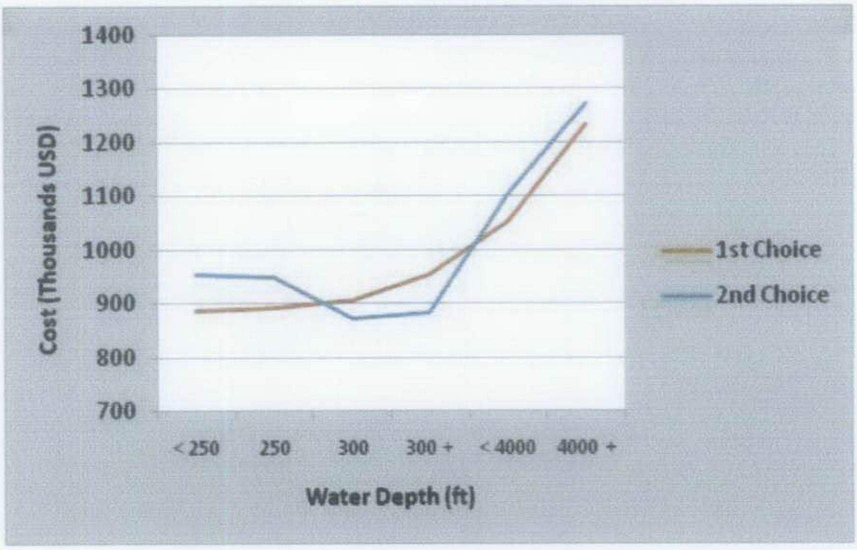


Figure 14: Example graph of cost versus water depth

Figure 14 shows an example graph of the cost versus the water depth. In this graph, there are two lines available, which are the line of the first choice and the second choice suggested by this calculator. In choosing between the two choices available, it is obvious the choice with lower cost will be chosen. But as we can see in the graph, the first choice suggested by the calculator is not applicable at all water depth. In the middle of the graph there is a bit change in trend of the second choice, which the cost is much lower than the first choice. So for that depth range, it is wiser to choose the second choice.

Comparing this newly proposed design, there is only single trip into the targeted zone, without tripping back to the surface as we are installing the equipments permanently at the targeted zone. There is additional time saved here. The amount of the time savings depends on individual cases, but surely a lot of time had been cut. This time factor is very important, because when we are dealing with oil and gas works, time is money. Additional point for this design is it is not complicated to operate, thus it does not require extra cost hiring expert to handle the equipments.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

i. The study of the single run well testing in multiple test zones technology has the fruitful outcome. But from my point of view, it is too costly for such a simple procedure.

ii. A much simpler and cheaper design with absolute capable equipments is proposed. It is cost efficient as the total cost for well testing equipment is lower than the latest design.

iii. Guidance in applying the testing system is provided by the developed calculator. It focuses more on cost effectiveness.

Although currently many jobs are done by focusing more on the quality of well test job, the cost as the second factor, but if there are more than one choices of almost equal quality, it is clear that the cheaper one will be the priority.

5.2 Recommendations

There are some steps needed to be done in order to prove that this proposed design can actually works. First simulation of this design must be run. Other than that, the cost of equipments can still be reduced if the pressure and temperature of the reservoir is lower. Due to lack of information source, this project could only obtain prices of certain instruments. In the future, it would be easier if the project is done with permission and under supervised of any company that could provide the prices of instruments used in this proposed design.

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