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FIELD APPLICATION OF POD SYSTEM FOR PRODUCING MULTIPLE RESERVOIRS IN MASILA BLOCK-YEMEN

Abdulrahman Al-Gunaid, Staff Production Engineer, Canadian Nexen Petroleum Yemen
Kevin Snively, Production Engineering Supervisor, Canadian Nexen Petroleum Yemen

Abstract

Canadian Nexen Petroleum Yemen (CNPY) operates the Masila Block in Yemen on behalf of the partners; CNPY, Occidental Petroleum and Consolidated Contractors Company. The Masila Block encompasses 18 fields with over 380 oil producers and 95 water injector/disposal wells. A total of 2 Million barrels of fluid are produced daily utilizing Electric Submersible Pumps (ESP's) as the only means of artificial lift. Within Masila Block there are 9 separate and distinct Oil Producing Formations with different pressure regimes, including natural aquifer support and pressure maintenance by both low and high pressure water injection. In almost every well, multiple oil reservoirs are present, often with several hydraulically distinct and discrete layers within each reservoir. Consequently, a single well may have several oil reservoirs that for Field Operation or Economic reasons it is desired to have simultaneous production. The challenge is to efficiently produce multiple reservoirs, at different pressures from a single production well bore. There is a potential for sand production from some reservoirs, especially the shallower formations. Thus, a conventional style dual completion of 2 ESP's with 1 ESP below an isolation packer and 2 tubing strings was considered unsuitable. The preferred design would be fully retrievable under all production conditions, using only a single tubing string and have both ESP's above the isolation packer. CNPY has extensive operating experience with 2 ESP's installed on 1 tubing string. One system being field tested is to put an ESP inside a sealed container (POD) to produce the lower reservoir from below the isolation packer, while concurrently producing the upper reservoir by a second ESP. The "POD" is situated above, and connected to the packer by a Seal Bore Assembly. Production would thus be segregated maintaining hydraulic isolation at the reservoir but commingled within the tubing. This paper will discuss the application of a "POD" system in the Masila Block and the results achieved to date.

Background

Canadian Nexen Petroleum Yemen (CNPY) operates the Masila Block oil fields in Yemen with production commencing in 1993. Maslia Block is still under development with three drilling rigs and three service rigs. Early in the development of Masila Block, it was determined that high volume ESP's were the optimum artificial lift method and these are exclusively used for production. Because ESP's are the only method used in Masila, efficient use of this equipment is essential for success of our capital investment in Yemen. Favorable reservoir characteristics have allowed for numerous wells to be equipped with specifically designed ESP's and different configurations of downhole equipment to efficiently produce the oil reserves.

The main producing reservoir (Qishn) is a sandstone formation with an extensive regional aquifer that supports and maintains the reservoir pressure while most of the Secondary Horizons lack aquifer support and require Pressure Maintenance (PM) by water injection. Depending on the reservoir, surface injection pressure may be as low as 400 psi (line pressure) or as high as 3500 psi. The reservoir parameters and the well characteristics of Masila block are described in Table (1).

Production Strategy

The production strategy of CNPY is to optimize the oil production from the Block in a cost, and operationally, effective manner. This is done by use of the following techniques:

1. Use the natural pressure support from the Aquifer to produce oil from the Qishn reservoirs until they are completely swept before re-completing wells to another formation.

2. Maximize oil production from the Secondary Horizons by using appropriate PM and Water Flood techniques to capture the behind pipe reserves. While most PM wells operate at line pressure, development of deeper and tighter reservoirs required significantly higher injection pressures. In 2001, CNPY applied the technology of boosting the surface injection pressure from 400 psi to 3500 psi. This made it possible to inject water into the tight formations and start a PM recovery scheme in these pressure depleted reservoirs.

3. Use Y-tools in all wells with more than one perforated interval. This is to directly measure the zonal contribution of oil and water from each interval by regular logging with Production Logging Tools (PLT). Unswept oil could be identified as behind casing reserves in uncompleted formation intervals through logging with Carbon/Oxygen tools.

4. Control water production to maintain maximum oil production. Based on PLT interpretation when an interval is identified as completely swept of oil, that zone is isolated from production. Zonal isolation can be done either by setting a permanent bridge plug, cement squeeze of selected perforations or by use of a Straddle Packer Assembly. When a zone is identified as having a high water production rate but still contributes oil, then this zone has the flow restricted by a Down Hole Choke (DHC) with an appropriately sized recoverable insert.

5. Continuously monitor well production with a SCADA system (Surface Control and Data Acquisition). This data is available to each engineer in real time. Instant monitoring of the well production parameters ensures wells are produced at the best possible rate and ESP condition. Down hole parameters are monitored with multisensors and are also available through SCADA. In some specific well applications, the multisensors are used to control the ESP production rate.

6. Develop and implement the latest Artificial Lift Technology to meet our production needs and requirements. Requirements were that production casing would not be larger than 9⅝" and that PLT logging had to be possible in all wells with multiple perforation intervals.

Oil well deliverability can exceed available equipment capability; to develop opportunities for increased fluid production rates and to accelerate production of the recoverable reserves has required CNPY to pursue innovative ESP alternatives. Below are some of the ESP developments used within Masila block:

- Dual ESP – single zone. Two parallel ESP's are configured to produce a single reservoir. Both ESP's produce into a single tubing string and are independently powered from two sets of power generation equipment through two power cables. While the ESP's could be run individually, the application is intended for simultaneous operation of both ESP's. This system proved to be very reliable and allowed for higher production rates than was available with a single ESP.

- 1000-hp Tandem Upper Tandem (TUT)

ESP. This system was first developed by CNPY to increase the withdrawal rate from high PI wells. By coupling two motors together to power one pump, greater horsepower could be installed and delivered downhole, resulting in greater production rates. Similar to the Dual ESP, there are two sets of surface power generation equipment and two power cables. This system has proven to be highly successful in maximizing production rates over the last few years.

- 1600-hp ESP system. This system is a larger version of the Dual ESP. There is a 1000-hp ESP assembly, with one power cable, and a second 600-hp ESP assembly with one power cable. This system was developed after the success of the dual ESP's and the 1000-hp TUT assembly. This system allowed for greater well drawdown and higher production rates.

- Dual ESP - Dual zone (POD), this system consists of two ESP's run in parallel and configured to produce from two separate reservoirs. The experience and the knowledge gained from running Dual ESP's and their success led to the introduction of the POD system in the field. This paper will discuss the design of this system, application, advantages & disadvantages of the system and the field results achieved to date. So far three systems of this type have been installed in the field and three more are planned for installation in 2007.

Introduction to POD system

The POD system is designed for the simultaneous production of two separate reservoirs with two ESP's from inside a single wellbore. By using the POD system, reservoir crossflow is eliminated by keeping all production segregated within the casing. Full wellbore integrity and zonal isolation is maintained at all times (see Figure 1). Most of the downhole equipment, including both ESP's, is placed above the top perforations, thereby reducing any risk associated with potential sand fill problems. Isolation of the lower ESP within a pressured capsule allows for the production of the reservoirs to be regulated via control of each ESP. CNPY's 9⅝" casing diameter and high produced fluid rates made it preferable for fluid production to be commingled within one 5 ½" tubing string. In the first installation, in Well # A, a down hole flow meter was installed to measure the production from the lower pump. Unfortunately the tool failed after two weeks of operation. Due to the unreliability of the tool for the long term, CNPY decided to not install it in the next installations. Fluid commingling has the disadvantage that one zone, usually the lower, must be periodically shut in for a short test period to determine the individual zone production. However, an advantage is that higher fluid rates can be produced.

Successful application of this technology made a substantial benefit to the Masila Block operations by making it possible to use existing wellbores for accelerated secondary zone exploitation while continuing to produce the main Qishn reservoirs.

Components and configuration of the POD

Figure 1 is an example of a typical down-hole assembly for the installation of the POD system in a Masila well. The major components of the POD are a common 5½" production tubing string, two independent ESP's with separate power cables, one isolation packer with seal bore, and the POD Assembly. The top ESP is hung between a Y-tool and the Pump Support Sub (PSS) while the bottom ESP is placed in a sealed POD with a 7" flush joint casing body. Specialized cable clamps are used to avoid potential problems during installation and future retrieval. An isolation packer with seal bore and tail pipe is set between the two zones. The bottom of the can is equipped with a seal assembly which is latched into the packer.

Two check valves were installed in the system. A 3.5" flapper check valve is installed above the top pump between the ESP and Y-tool. A 2.25" WJ check valve is installed in the

3.5” tubing between the two ESP’s. The check valves prevent fluid recycling and allow each ESP to operate independently.

Both ESP’s were equipped with an ESP multisensor to provide instantaneous monitoring of downhole parameters.

The fluids from the upper reservoir, are outside the POD, and are produced through the top ESP. Production from the lower reservoir passes through the packer, into the POD, through the bottom ESP and into the bypass tubing leading to the top ESP. Production from both ESP’s is commingled at the Y-tool and produced to surface by the common production tubing.

Surface equipment

Because of limited Central Power Plant and Hi-line transmission resources in Masila, the surface equipment for the POD equipped wells consists of two diesel-powered generators and two VSD’s. Based on our ESP selection we maintain the maximum applied voltage to the motors at 4500 volt. The effective horsepower delivered from the motor assembly to the pump may be less than the name plate horsepower. This is due to voltage losses through the surface equipment, and the harmonic imbalance due to well site power generators.

Well selection and preparation for the POD installation.

Vertical wells with multiple zones, and different reservoir pressure regimes, are usually good candidates for the installation of the POD system in order to avoid fluid crossflow between reservoirs. Also, wells with multiple reservoirs separated by a long true vertical distance (TVD) may also be good candidates for this type of ESP application in order to overcome limited drawdown of the lower zone that could result from commingling production.

Prior to the installation of the POD system, candidate wells are subjected to extended production testing for each zone. Each reservoir is tested by itself for a period of several months in order to have a detailed understanding of the reservoir characteristics. This allows for a thorough and rigorous design of each ESP before the POD equipment is installed.

To assist in the well selection, produced water samples are collected and analysed to ensure water compatibility. Incompatible waters lead to scale formation that would be difficult to treat or remove without rig intervention.

Each detailed system design is based on the availability of equipment in stock at the Masila warehouse, the productivity of the two zones, well bore geometry and the total dynamic head (TDH) requirements to lift fluid to surface. As a result we developed a method to design the POD system using the ESP design software.

Modeling and design of the POD system

The current ESP design software available in the market is not set up to model and size a dual ESP production system. Therefore CNPY developed a modeling method to simulate the ESP actions and to select the ESP components using the ESP design software. This method is known as the Tubing Split Method. The modeling steps are as follows:

1. Each ESP is modeled as a separate case in the design software. The tubing string for each ESP is defined as close as possible to the installed tubing. The Upper ESP will produce exclusively through the 5½” tubing to surface, while the Lower ESP will produce through the tubing connecting the 2 ESP’s. This tubing consists of 2 different sizes; a length of 3½” tubing between the pump discharge head and the PSS, and a length of 2⅞” by-pass tubing between the PSS and the Y-block.
   Note: The 5½” tubing string above the upper ESP handles the combined production from both ESP’s. Flow inside this tubing, should be partitioned based on the expected contribution from each ESP. For example; assume the Upper

ESP produces 6000 bfpd and the Lower ESP produces 3000 bfpd; therefore the 5½" production tubing (with a volume capacity of 0.0238 bbl/ft) will handle 9000 bfpd. Therefore, 66% of the produced volume is contributed from the Upper ESP and 34% is from the Lower ESP. From published Engineering data, 66% of the 5½" tubing capacity is 0.01571 bbl/ft which is equivalent to the capacity of 4 ½" 11 lb/ft EUE tubing. To model the Upper ESP performance, within the design software, the ID (4.026") of this tubing string is used for the well design. By applying the same concept for the Lower ESP; the Software will use 2.797" ID tubing (3 ½" 10.2 lb/ft OD tubing) for the design.

2. After entering the values for the casing, tubing strings and PI in the software, the design model for each ESP is run separately. Based on the design output, select appropriate ESP components.
3. Run the Software simulator as two separate cases for the ESP's
4. Adjust the tubing volume and the PI for both ESP models as required to get a good match between the model design and the real life performance.

Assembling and Running Procedure.

Prepare the work floor and the proper handling equipment to assemble and run the POD assembly.

1. Run in the hole with the 9⅝" isolation packer c/w 6" seal bore and tail pipe on wire line, set packer between the two zones.
2. Assemble the 7" POD with the seal bore assembly. Pressure test the POD to 500 psi using a retrievable plug. Do not run the POD into the well, keep it hanging from the slips.
3. Assemble the Lower ESP complete with multisensor and position it inside the 7" POD. Connect the electrical cable through the RMS penetrator.
4. Install the POD hanger seal and complete the RMS cable splice.
5. Install the middle tubing.
6. Assemble and install the Upper ESP complete with Multisensor and Y-tool assembly.
7. Continue running the whole assembly on 5 ½" tubing.
8. Space out the tubing string and sting into the isolation packer.
9. Make the power cable connections at surface and prepare to start the POD

Note: All ESP equipment should be handled with care and should be run in hole slowly. The two power cables should be protected with specialized dual cable clamps made for this purpose. These dual cable clamps are attached at each tubing collar and enclose the two cables on opposite sides of the collar. Test the power cable and multisensors while running in the hole. Extra precautions must also be observed by the service rig crew and the ESP service technician on the floor while assembling and running the equipment

Start up Procedure:

Once the unit is on bottom and all surface mechanical and electrical connections have been made:

1. Start the upper ESP at a reduced frequency, refer to the Software model for the appropriate start up frequency. Allow adequate time for the fluid to reach surface as this will confirm the proper rotation of the upper ESP. Wait until the ESP has stabilized surface and down hole parameters.
2. Start the lower ESP, at a reduced frequency, refer to the Software model for the appropriate start up frequency. Monitor the surface and down hole parameters for both ESP's and ensure both pumps are operating properly and running within the pump curves.
3. Two days after well stabilization, ESP speed up can be achieved as appropriate.

Field Results:

CNPY installed the first POD assembly in the year 2001 in Well A. Unfortunately this installation lasted only for three months. The lower ESP failed due to the rapid decline of the reservoir pressure of the secondary zone reservoir. The ESP was operating in a severe down thrust condition resulting in the failure. However, the POD system showed a good initial production increase by ~2000 bopd. The incremental oil gain from the installation date until pump failure was 292 MBO see figure (2). A detailed engineering evaluation and failure analysis of the equipment was done in order to understand how the ESP failed and to improve the run life for subsequent installations.

In the second and third installations, the reservoirs were subjected to extended production testing in order to have a better understanding of their deliverability and to properly size the ESP's for production. This change resulted in more rigorous ESP designs and improved run lives.

The second "POD" system was installed in September 2005 in Well B. As a result of this installation, the oil production increased by 200 bopd and the incremental oil gain to the end of December 2006 was 96 MBO see figure (3).

The third "POD" installation was in Well C in July 2006. The initial increase in oil production was ~220 bopd and the incremental oil gain to the end of December 2006 was 97 MBO. A significant improvement in the decline curve was noticed in this well see figure (4).

The three figures (2,3 and 4) demonstrates the operational success of the POD system in Masila block. To the end of December, 2006, the introduction of the POD system has added 485,000 bbl of additional produced oil to Masila block from three wells. This is an average of ~162,000 bbl per well and the future looks promising.

Performance and Production Monitoring

On a continuous basis all ESP production related data is gathered, analysed and appropriate actions taken. The pump intake pressures are recorded from the down hole sensors and the operating frequency is adjusted as required. Using a Mass flow meter at the well head allows the total produced fluid and water cuts to be continually monitored.

Advantages and Disadvantages of the system

Advantages of such system are:

1. Accelerate and optimize production from the secondary reservoirs.
2. No crossflow or limited drawdown issues as both zones are separated. The production from each zone is kept segregated until it reaches the production tubing.
3. Ability to measure production from each zone by shutting down one ESP and keeping the other ESP running. The production from each pump is measured by difference.
4. The two ESP's can be operated independently or simultaneously.
5. No power cables below perforations.
6. Utilize existing well bores for secondary zones exploitation and reduce the number of producing wells.
7. Eliminates the cost of drilling a new well

Disadvantages of this system are

1. No logging or pressure surveys can be achieved.
2. Risk that equipment can become stuck if the upper reservoir produces sand.
3. One ESP has to be turned off in order to test and measure the production from each reservoir.

Conclusion

CNPY has benefited from the POD concept and has applied it to produce wells that have both the prolific Qishn reservoir and lesser productive Secondary Horizons. Greater oil production and accelerated reserve recovery has been realized. We plan to expand the multiple ESP application and POD system to other wells with multiple reservoirs and with different reservoir characteristics.

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Reservoir and Well data in Masila block

Table (1)

Depth ft	5700 - 11600
Hole type	Vertical, Horizontal, Deviated and multilateral
Casing size	9 5/8”
Formation	Sandstone Limestone
Pressure psi	700 - 3500
PI bfpd/psi	0.2 - 80
Temperature F	165 – 250 F
Oil Gravity API	17 – 34 API
Water	<3500 ppm TDS
GOR scf/bbl	5 - 1500
Bupple point psi	50 - 2000

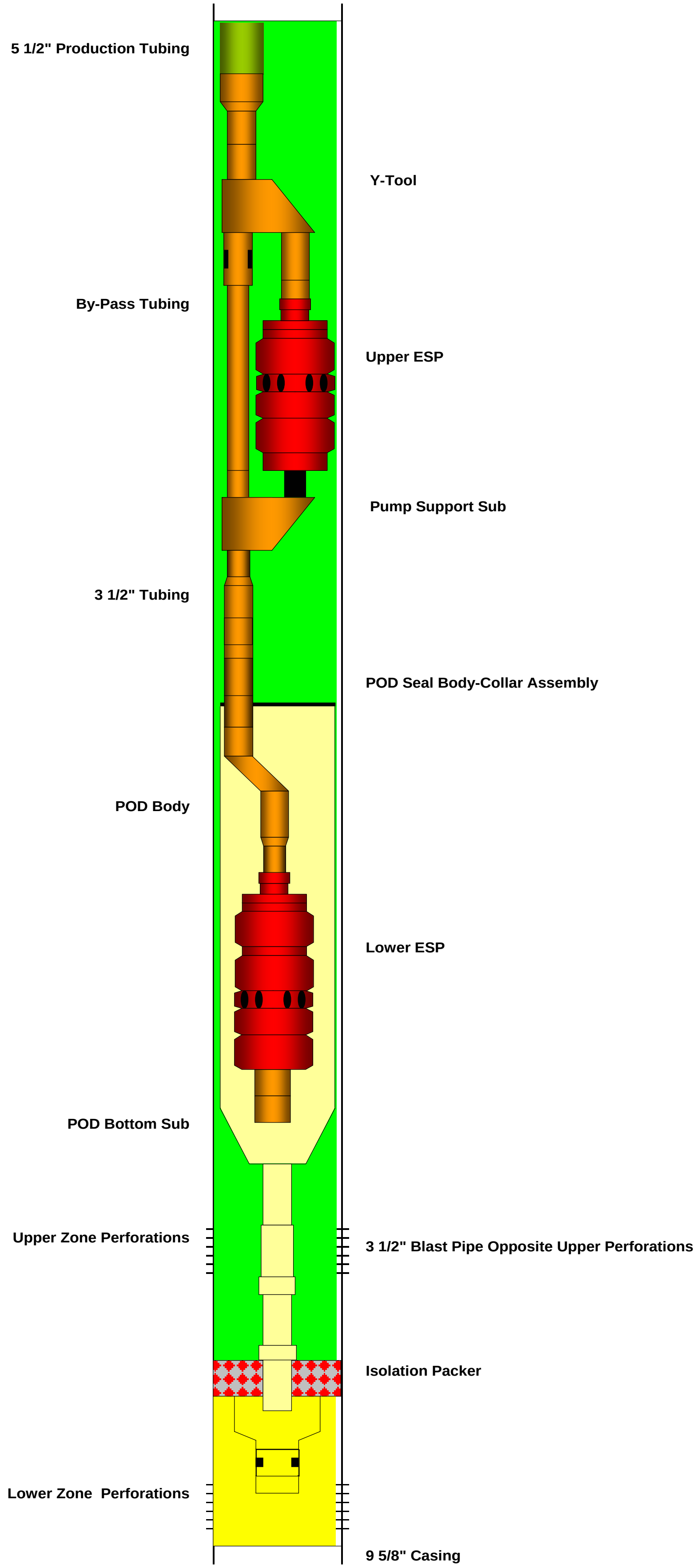

Figure (1)
Typical configuration for POD equipped well

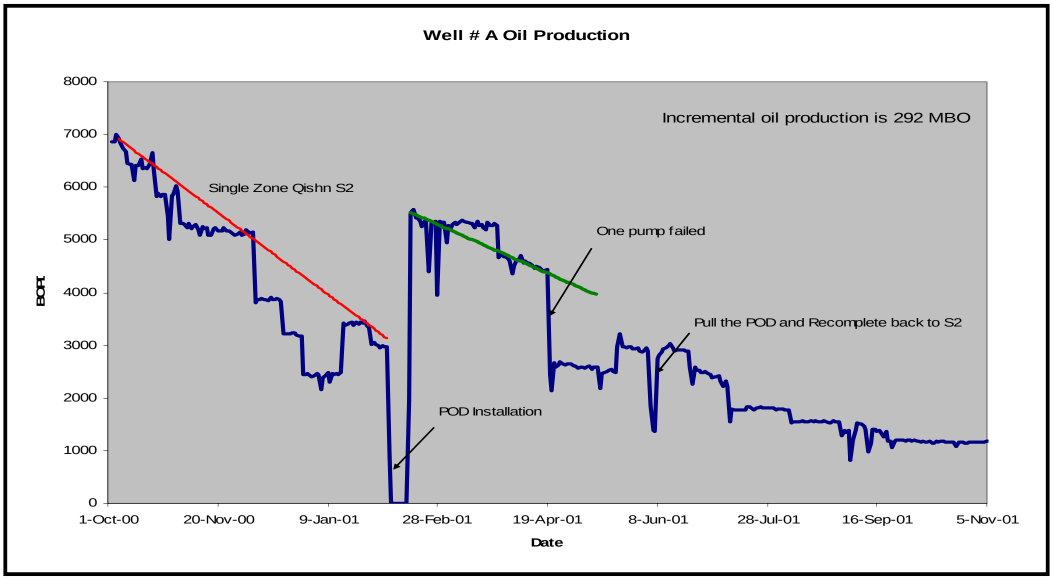

Figure (2)

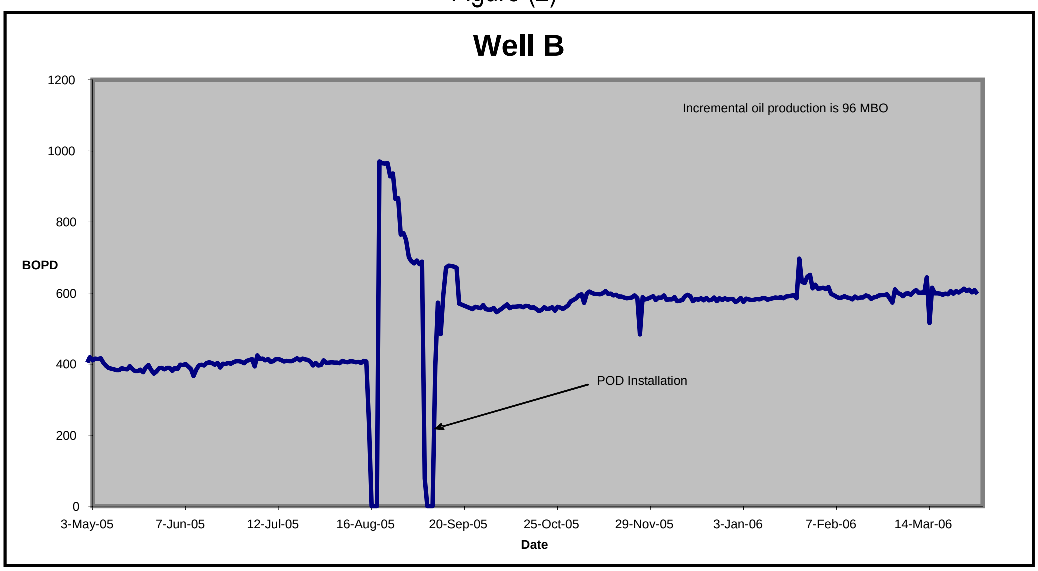

Figure (3)

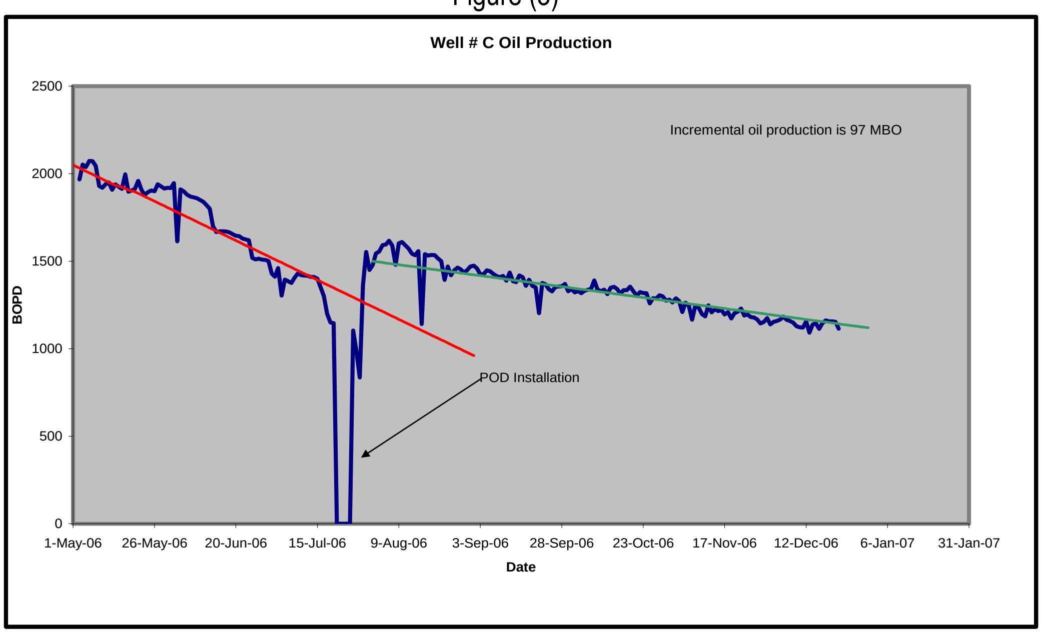

Figure (4)