SPE 112243

Application of Intelligent Well Completion for Controlled Dumpflood in West Kuwait

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This paper was prepared for presentation at the 2008 SPE Intelligent Energy Conference and Exhibition held in Amsterdam, The Netherlands, 25–27 February 2008.

Abstract

This paper describes the philosophy and design of an intelligent well installation in a water dumpflood well in Kuwait and analysis of data gathered. The paper examines the reservoir management capabilities of intelligent wells can lead to significant value in terms of reservoir management in this application.

Dumpflooding, the method by which fluids from one formation are allowed to flow into another formation, has been used for several years in Kuwait as a means of providing reservoir pressure support. Typically, a well is drilled to penetrate both a prolific aquifer and a producing oil reservoir. Under the right conditions, with a higher pressure aquifer, significant quantities of water flow from the aquifer to the oil reservoir.

As production from the oil reservoirs matures, this uncontrolled method of pressure support has led to several reservoir management challenges, including difficulties with flood front control, water breakthrough, conformance management, and inability to quantify the crossflow rate in each well. With declining oil reservoir pressure, the pressure differential between the aquifer and the oil reservoir has increased, leading to destabilization of the aquifer reservoir clastic matrix from excessive drawdown and high flow rates during perforating operations.

In early 2007, a West Kuwait well was completed as a controlled dumpflood well utilizing intelligent well technology. Water from the Zubair aquifer formation flows to the Minagish Oolite oil formation in a controlled and monitored dumpflood process. Utilizing a variable interval control valve, the amount of injection fluid is regulated, while permanent downhole monitoring devices transmit pressure data to surface, enabling evaluation of the flow rate. The intelligent well also permits "soft starts" of the dumplood to avoid borehole destabilization.

The methods described in the paper may be considered for improved reservoir management on a field wide basis wherever dumpflooding is used for pressure maintenance.

Introduction

The oilfields of western Kuwait - Minagish and Umm Gudair - were discovered in 1958 and 1962 respectively. The primary oil producing formation in both of these fields is the early Cretaceous age Minagish Oolite, an undersaturated carbonate formation composed of porous grainstones and packstones deposited in shallow marine shoals. The oil from the Minagish Oolite was produced by primary depletion, gas injection and weak aquifer drive through the initial 40 years with little or no water cut. By the early eighties, reservoir pressure had declined, and the flowing bottom hole pressure of the wells was not high enough to sustain significant natural flow from each well. Electrical submersible pumps were installed to bolster the production to desired rates. This, however, increased the rate of reservoir pressure decline.

In an effort to reduce the declining pressure and increase oil production, a method of replacing the volume of oil extracted from the reservoir was required in order to diminish and reverse the trend of reservoir pressure decline. Conveniently, a major aquifer reservoir, the Zubair formation is regionally extensive, is structurally higher than the Minagish Oolite, and is at a higher pressure. The Zubair is a sandstone formation of moderate competence and 1 Darcy to 3 Darcy permeability. Dumpflooding water from the Zubair to the Minagish Oolite was first tried in the Minagish field, and later in a peripheral well dumpflood pilot project in the Umm Gudair field (Quttainah and Al-Hunaif , 2005).

Dumpflooding is the method by which fluids from one formation are allowed to flow into another formation, and thereby provide reservoir pressure support. Typically, a well is drilled to penetrate both a prolific aquifer (or gas zone) and a producing oil reservoir. Under the right conditions, with a higher pressure aquifer (or gas zone), significant quantities of water (or gas) flow from the aquifer (or gas zone) to the oil reservoir.

The intent of the dumpflood projects is to direct underground water from the Zubair aquifer into the Minagish Oolite zone without the need to produce the water to surface. Prior to the inclusion of intelligent well equipment in the dumpflood well completions as described in this paper, dumpflood projects have simply allowed uncontrolled flow from one reservoir to the other. Monitoring of the rate of crossflow and volumes of fluid produced from the Zubair and injected in the Minagish Oolite has depended on infrequent and episodic wireline production logging. The requirements and basic philosophies of the Kuwait dumpflood projects are described in detail by Quttainah, Al-Hunaif and Al-Maraghi (2005).

Despite the benefits of the dumpflood projects, challenges with monitoring and managing the dumpflood wells and managing the reservoir pressure maintenance project continue, including difficulties with flood front control, water breakthrough, conformance management, and the inability to quantify the crossflow rate in each well. For example, with the decline of the Minagish Oolite formation pressure, the pressure differential between the Zubair and Minagish Oolite has increased, resulting in excessive drawdown on the Zubair and large production flux rates in new dumpflood wells, risking formation destabilization of the clastic matrix and sand production from the Zubair.

Intelligent Well Technology for Dumpflood Control

An intelligent well completion is a system capable of collecting, transmitting and analyzing completion, production, and reservoir data, and taking action to better control well and production processes without physical intervention. The value of the intelligent well technologies comes from their capability to actively modify the well zonal completions and performance through downhole flow control, and to monitor the response and performance of the zones through real time downhole data acquisition, thereby maximizing the value of the asset. An Intelligent Completion combines a series of components that collect, transmit and analyse completion, production and reservoir data, and enable selective zone control to optimize the production process.

Flow Control Devices. Most current downhole flow control devices are based on or derived from sliding sleeve or ball-valve technologies. Flow control may be binary (on/off), discrete positioning (a number of preset fixed positions), or infinitely variable. The actuating motive force for these systems may be provided by hydraulic or electric systems. Current-generation hydraulically operated flow control devices have evolved to be more reliable, more resistant to erosion, provide greater flow control, and generate greater opening and closing forces.

Feedthrough Isolation Packers. To realize individual zone control, each zone must be isolated from each other by packers incorporating feedthrough systems for control, communication, and power cables.

Control, Communication and Power Cables. Current intelligent well technology requires one or more conduits to transmit power and data to downhole monitoring and control devices. These may be hydraulic control lines, electric power and data conductors, or fiber optic lines. For additional protection and ease of deployment, multiple lines are usually encapsulated and may be armored.

Downhole Sensors. A variety of downhole sensors are available to monitor flow performance parameters from each zone of interest. Several single-point electronic quartz crystal pressure and temperature sensors may be multiplexed on a single electric conductor, thus allowing very accurate measurements at several zones.

The use of intelligent well technology to monitor and control dumpflood wells is described by Glandt (2003), and a specific application of intelligent well technology in a gas dumpflood well is decribed by Lau et al. (2001). In the gas dumpflood case, gas from a deep gas reservoir was produced into a wellbore and allowed to crossflow to the gas cap of an overlaying oil reservoir, in order to support pressure in the oil reservoir. The success of the case cited has led to similar completions in the same oilfield.

The benefits of intelligent completions in dumpflood wells are as follows:

- Ability to monitor wellbore producing and injection pressure in real time
- Ability to monitor crossflow rate and quantify flow rate in real time
- Ability to determine productivity index and injectivity index for the producing zone and injection zone respectively
- Ability to perform pressure transient analysis independently on both the production zone and the injection zone to determine each reservoir pressure, kH, skin, and potential for productivity/injectivity improvement through stimulation
- Ability to independently stimulate and clean-up both the production zone and the injection zone
- Ability to pre-produce the injection zone to reduce regional wellbore pressure and benefit from pre-production of hydrocarbon
- Ability to “soft-start” the dumpflood process, initially and after shut-in, to reduce the drawdown pressure transient and geomechanical shock to the wellbore of the producing zone
- Ability to monitor and control drawdown pressure and flow flux rate to maintain flow conditions within wellbore stability and sand control guidelines

Intelligent Well Dumpflood in Western Kuwait

In the western Kuwait application, an intelligent completion was utilized in a dumpflood well, allowing full control of the rate of water flow into the Minagish Oolite from the Zubair formation. The intelligent completion design enabled remote monitoring of the flow rate in the well without the need for intervention.

For the first Kuwait dumpflood intelligent well application, an interval control valve (ICV) was deployed on the production tubing to control the rate of flow of water from the Zubair formation to the Minagish Oolite formation, along with a permanent dual pressure monitoring system (PDHMS) to transmit pressure and temperature data to a surface acquisition unit for display and recording. (Figure 1). The well completion, from top to bottom, is comprised of the 5-1/2" production tubing from surface, a 9-5/8" x 5-1/2" feedthrough packer, the 5-1/2" dual gauge mandrel, a 5-1/2" ICV situated just above the Zubair formation, a 5-1/2" production tubing extension from the ICV to a permanent packer installed above the Minagish Oolite formation. The production tubing extension incorporates a seal bore assembly which stabs into the lower permanent packer.

Execution and installation of this type of completion can be done in two ways to address well control issues and the pressure differential between the two zones. One method is to perforate the Zubair formation with casing guns, install the lower permanent packer on wireline, then install the rest of the intelligent completion, stabbing the production tubing extension into the permanent packer and setting the upper feedthrough packer hydraulically. The Minagish Oolite formation is then perforated with through-tubing guns. The second method is to perforate the Minagish Oolite formation first, set the lower permanent packer on wireline with a pump-out plug, perforate the Zubair formation, circulate out debris above the permanent packer, then run the rest of the intelligent completion, stabbing the production tubing extension into the permanent packer and setting the upper feedthrough packer hydraulically, followed by expelling the pump-out plug by applying pressure on the production tubing.

Water flows from the Zubair formation into the annular space between the casing and the production tubing extension, and up to the ICV. It flows through the ICV, then down the production tubing extension, through the permenant packer, into the production liner and into the perforations at the Minagish Zubair formation. The PDHMS monitors pressure in the annulus and tubing simultaneously, upstream and downstream of the ICV. Knowing the differential pressure across valve, the valve coefficient (Cv) and the density of the fluid allows an estimation of the flow of fluid through the valve to be calculated. (Konopczynski et al., 2004) In the actual completion string the permanent downhole monitoring system (PDHMS) gauges are positioned immediately above the ICV, so the pressure drop across the ICV can be measured by simply subtracting the gauge reading in the annulus from the gauge reading in the tubing.

Anticipated Performance

Given the information provided on the expected reservoir properties, analysis ensured the suitability of the reservoirs for an intelligent dumpflood completion. The analysis was based on the anticipated static reservoir pressures of 4500 psi and 3800 psi in the Zubair and Minagish Oolite, respectively. In order to estimate the injection rate of the well, a nodal analysis was peformed, represented graphically in figure 2, which represents the differential pressure (Pressure Drop) across the ICV as a function of flow rate through the valve, for the 10 open positions of the valve.

The "delta P Zubair Minagish" line represents the calculated equilibrium flow rate of the dump flood against the pressure drop introduced by the valve, with the anticipated static reservoir pressures and productivity/injectivity indices. We can see from the graph, when the valve is fully open, the maximum theoretical flow rate expected was approximately 52,000 bbls/day, and when the valve is closed, the differential pressure across the valve was estimated at 1300 psi. The graph also shows the anticipated pressure drop across the ICV as a function of flow rate for each position of the valve. The intersection of each of this family of curves with the "delta P Zubair Minagish" curve represents the anticipated flow rate and pressure drop at each setting of the ICV.

The intention of the well completion is to provide a flow rate of approximately 35,000 bbls/day to the Minagish Oolite formation from the Zubair. Flow rate and drawdown on the Zubair is controlled by the ICV and monitored with the PDHMS.

Concern was initially raised over the potential for erosion of the completion components due to the tendency of the Zubair formation to produce small amounts of sand and the potential high velocities at the anticipated maximum flow rate. Wellbore flow analysis was undertaken to determine the magnitude of flow velocities in relation to recommended erosional velocity limits for the water dumpflood well equipped with the intelligent well completion. The size of the production casing (liner) across the dumpflood completion was reviewed to determine the optimal size considering flow velocity and erosional concerns. Due to the corrosive nature of the water produced from the Zubair, corrosive resistant alloys were used for the completion components.

Initial Performance Post-Completion

Following the successful completion of the well, the Minagish Oolite formation was perforated and stimulated with acid through coiled tubing. Post stimulation and prior to opening the ICV, the static pressures recorded at the pressure gauges were 3979 psi on the annulus, and 3232 psi on the tubing. Translating these pressures to the respective depths of the top perforations of the Zubair and Minagish zones gives a reservoir static pressure of 4000 psi for the Zubair and 3902 psi for the Minagish.

During commissioning of the well, the ICV was opened from the close position to choke position 5. As a precautionary measure the choke position was adjusted at 6 hourly intervals to allow for gradual stabilisation of the flow. This practice was also adopted to guard against a significant transient drawn down on the Zubair, and to avoid potential wellbore destabilization and sand production problems associate with the increased draw down. Choke position 5 was chosen as the maximum allowable postion in the operating procedure based on the anticipated productivity data to avoid destabilizing the wellbore and matrix in the Zubair.
Figure 3 illustrates the data gathered during this initial flowing phase. A characteristic which can been seen on all graphs is the step effect of opening the valve from the closed position, through steps 1 to 5. Figure 3 shows the change in measured tubing and annulus temperature and estimated flow rate as the valve was opened from the closed position to open position number 5. As the observed flow rates were lower than predicted, additional testing was planned with the following steps:

1. Valve initially in position number 5
2. Close ICV, observe build up
3. Step through ICV opening from position 1 through to 10

Figure 4 represents the data recorded from the PDHMS during the test, showing the wellbore flowing pressure of the Minagish Oolite and the Zubair at the ICV datum depth and the derived flow rate. We can clearly see the initial shut-in phase, where the valve has been closed, followed by stepping from position 1 to 10. The estimated flow rate is calculated from the differential pressure across the valve. We can see at position 10, there is little or no pressure drop across the valve, thus indicating that the valve is allowing maximum flow, from the Zubair to the Minagish Oolite. The noise on the production rate at position number 10 is caused by there being virtually zero differential pressure across the valve to differentiate flow rate. Most critically, in the full open position, the maximum flow rate is observed to be approximately 10,000 bbl/d, far short of the target 35,000 bbl/d.

The data from this test was used to generate productivity index (PI) and injectivity index (II) measures for the Zubair and Minagish Oolite formations, respectively, as shown in figures 5 and 6. The measured PI for the Zubair of 260 bbl/d/psi is consistent with the anticipated performance of this zone, while the measured II for the Minagish Oolite of 9.8 bbl/d/psi is far short of the original anticipated performance. Added to this, the difference in pressure between the two formations (at the ICV datum depth) is far less at 747 psi compared to the original anticipated difference in pressure of 1300 psi. Based on this performance, it was decided to reperforate and restimulate the Minagish Oolite formation.

Well Performance Post Re-Perforation and Stimulation of the Minagish Oolite

After the re-perforation and re-stimulation of the Minagish Oolite, a mult-rate test was again conducted through all 10 positions of the ICV. Figure 7 shows the wellbore flowing pressure of the Minagish and the Zubair at the ICV datum depth, and the derived flow rate. In the full open position, the maximum flow rate is 26,000 bbl/d, indicating significant improvement with the re-perforation and re-stimulation. Figures 8 and 9 show the productivity index (PI) and injectivity index (II) measures for the Zubair and Minagish Oolite formations, respectively, before and after the stimulation. The productivity index of the Zubair formation is relatively constant at approximately 260 to 290 bbl/d/psi, as would be expected, and within the anticipated measurement uncertainty band. The injectivity index of the Minagish Oolite improved significantly to 18.1 bbl/d/psi from 9.8 bbl/d/psi, and is comparable to the original anticipated injectivity index. If the pressure differential between the two zones was similar to that originally anticipated, the dumpflood could be capable of delivering close to 40,000 bwpd in the full open ICV position.

Intelligent Dumpflood Well Number 2 – Performance

A second dumpflood well in a different West Kuwait field was completed with a similar intelligent well completion. Post completion, the well was tested by slowly opening the ICV through to position 7. Figure 10 shows the wellbore flowing pressure of the Minagish and the Zubair at the ICV datum depth, and the derived flow rate. In position 7, the maximum flow rate is 24,000 bwpd. Figures 11 and 12 show the productivity index (PI) and injectivity index (II) measures for the Zubair and Minagish Oolite formations, respectively, after completion. The productivity index of the Zubair formation is similar to that seen in the first intelligent completion dumpflood well at approximately 226 bbl/d/psi. The injectivity index of the Minagish Oolite is significantly higher in this well at 30.5 bbl/d/psi. In the full open position, this well should be capable of dumpflooding close to 30,000 bwpd.

Conclusion

The use of intelligent completion technology and remotely controlled hydraulic Interval Control Valve is a reliable and cost effective solution for a controlled dump flood. With the ability to constantly monitor and control the flow from the aquifer to support the production reservoir, we can reduce the requirement for production logging and surface facilities, such as water handling and treatment, while reducing the uncertainties and exposure of an uncontrolled dump flood. More significantly, the initial applications of this technology have demonstrated its usefulness in understanding well and reservoir performance, and in identifying requirements for remediation and stimulation. Further gains will be realized by incorporating the real time data available from these and future intelligence wells in the reservoir surveillance program and simulation models to better manage the overall field dumpflood, thus improving ultimate recovery.

Acknowledgement

Our gratitude goes to the management of Kuwait Oil Company and the Ministry of Energy of the State of Kuwait for their support and permission to publish this paper. We would also like to thank the management of WellDynamics for the support and permission to publish this paper.

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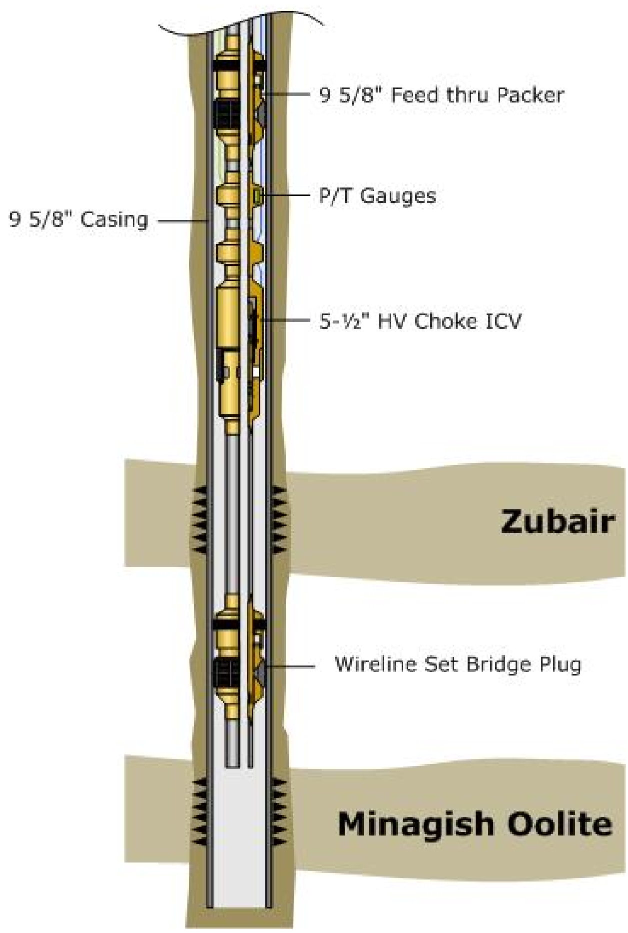

Figure 1 – Dumpflood Completion

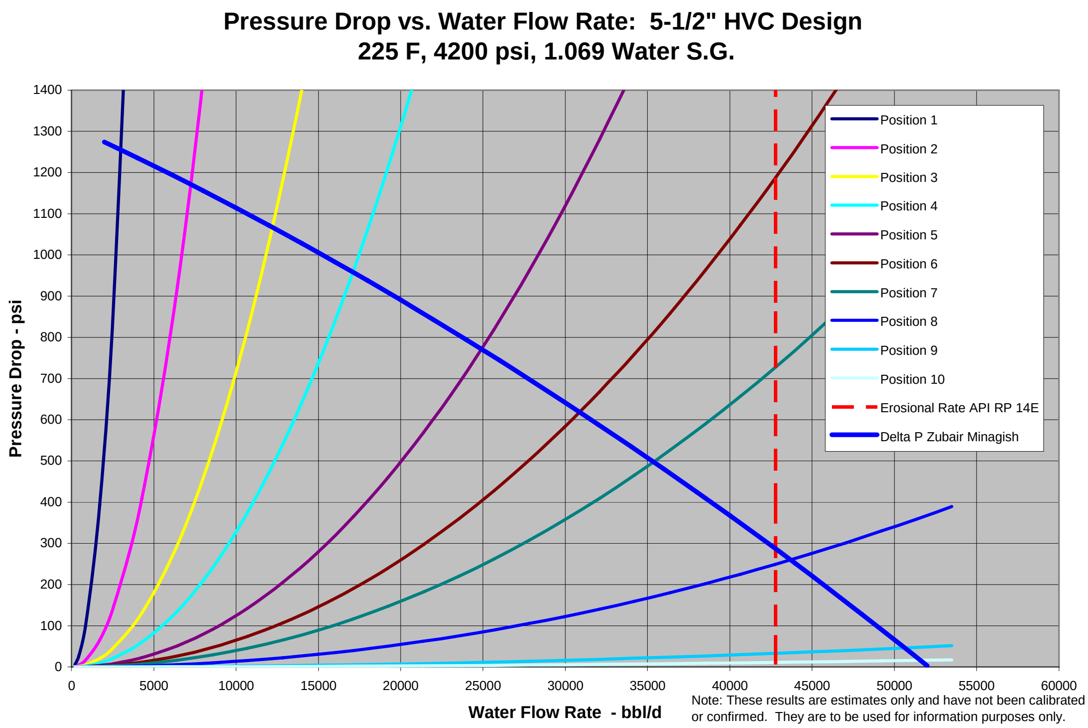

Figure 2 – Delta P between Zubair and Minagish Oolite at ICV depth as a function of flowrate, and pressure drop across the ICV as a function of flowrate for each valve position

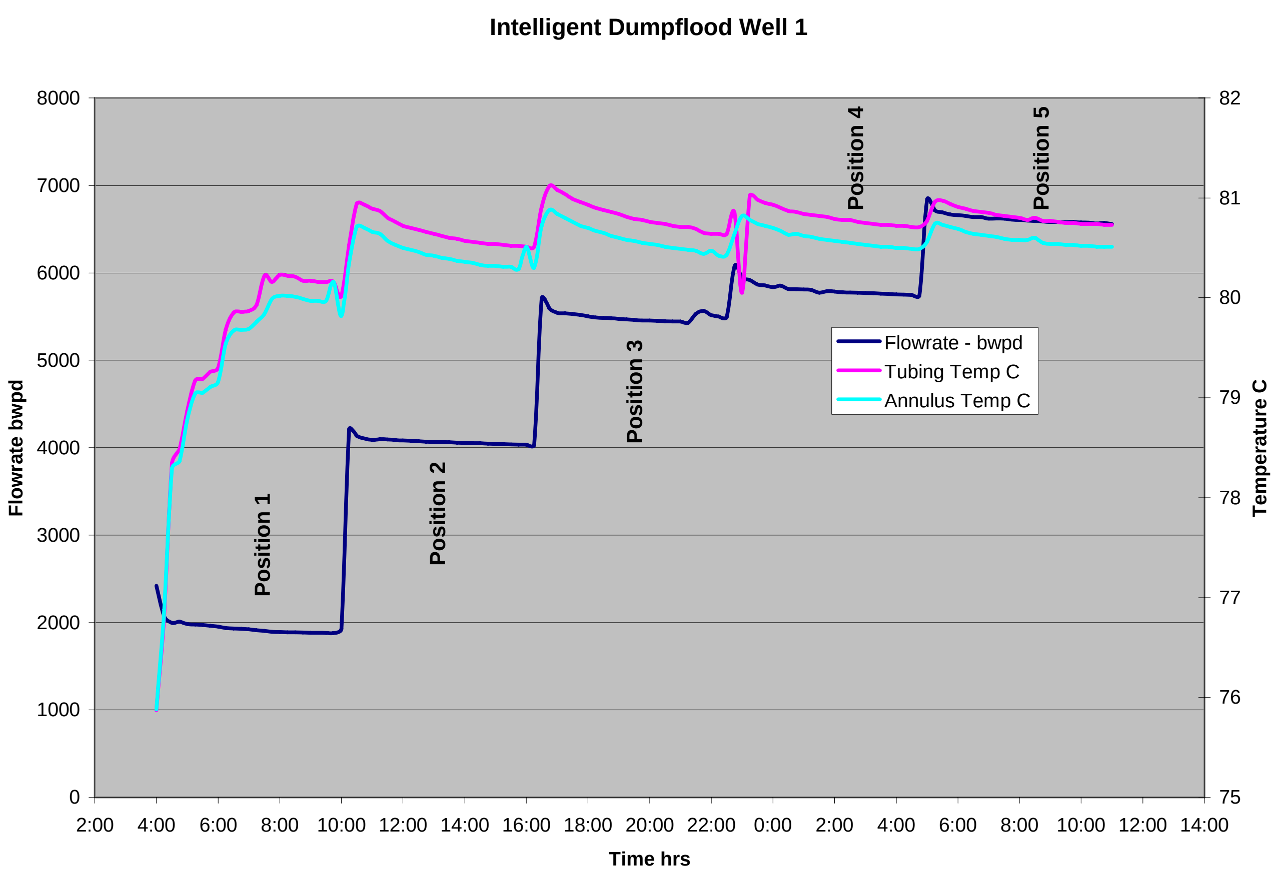

Figure 3 – Post Completion Flow Rate and Temperature

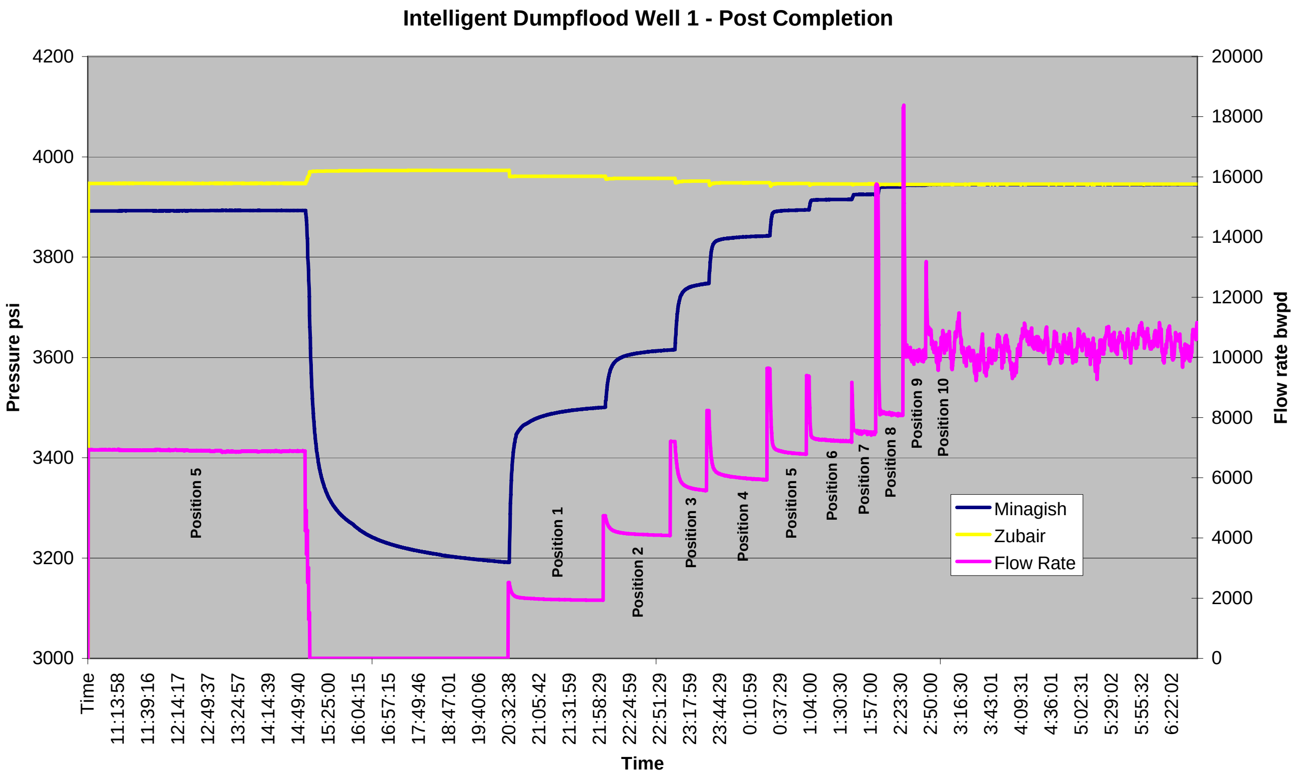

Figure 4 – Intelligent Dumpflood Well 1 - Pressure and Flow Rate During Multi-Rate Test Post Installation

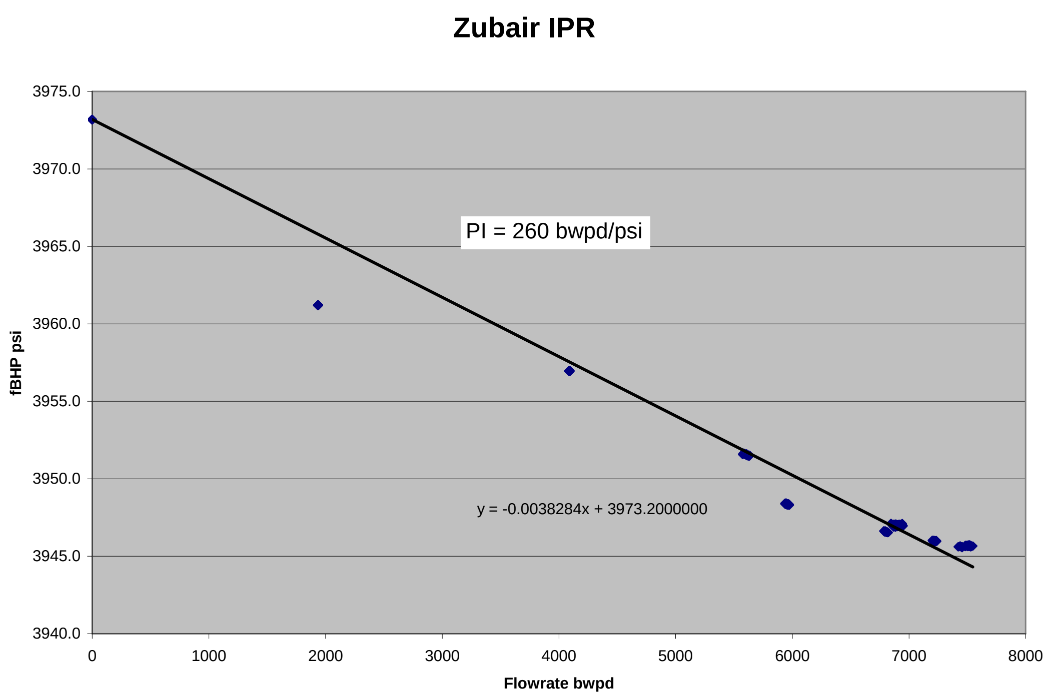

Figure 5 – Intelligent Dumpflood Well 1 - Zubair IPR Post Completion

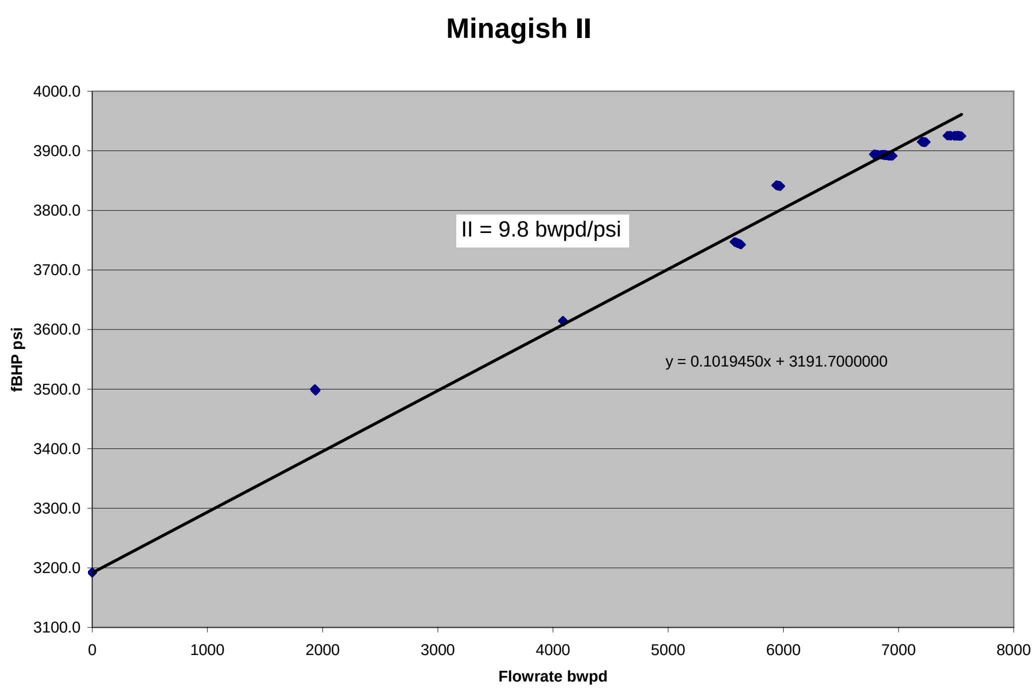

Figure 6 – Intelligent Dumpflood Well 1 - Minagish Oolite Injectivity Post Completion

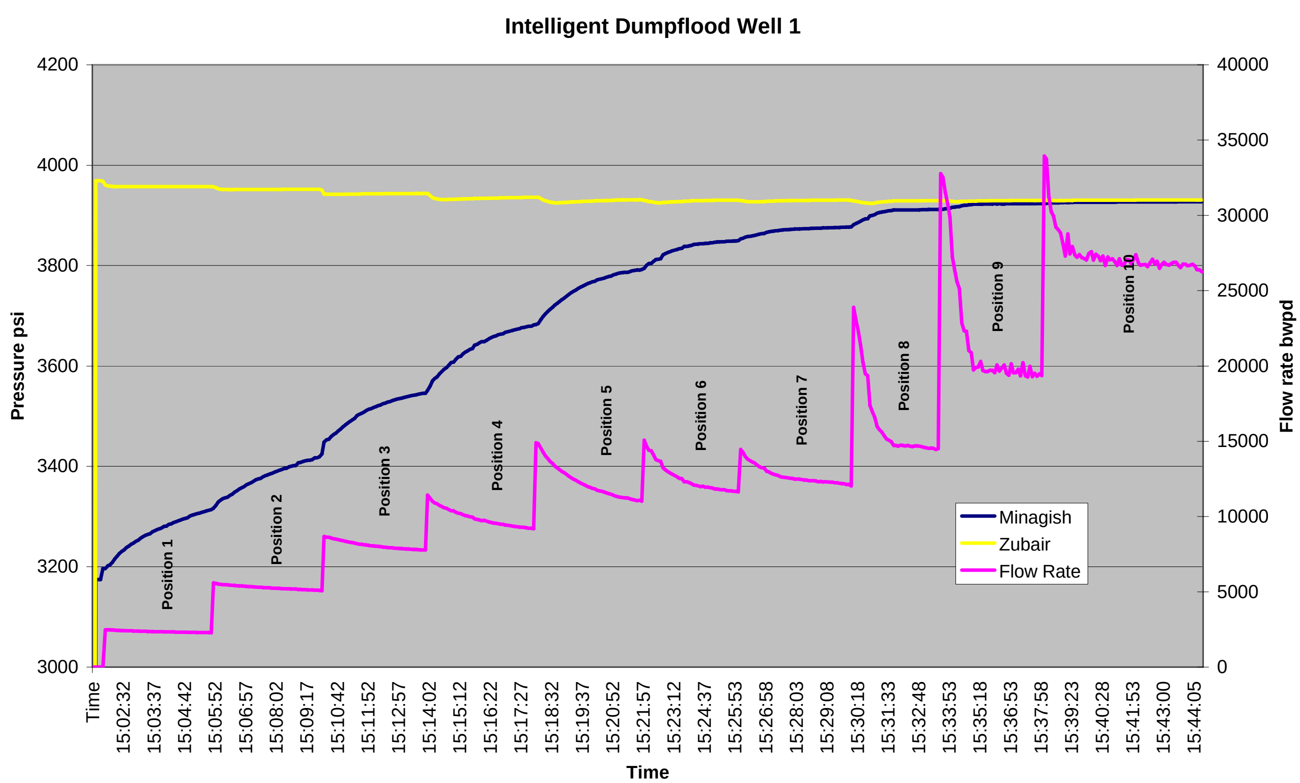

Figure 7 – Intelligent Dumpflood Well 1 - Pressure and Flow Rate During Multi-Rate Test Post Minagish Stimulation

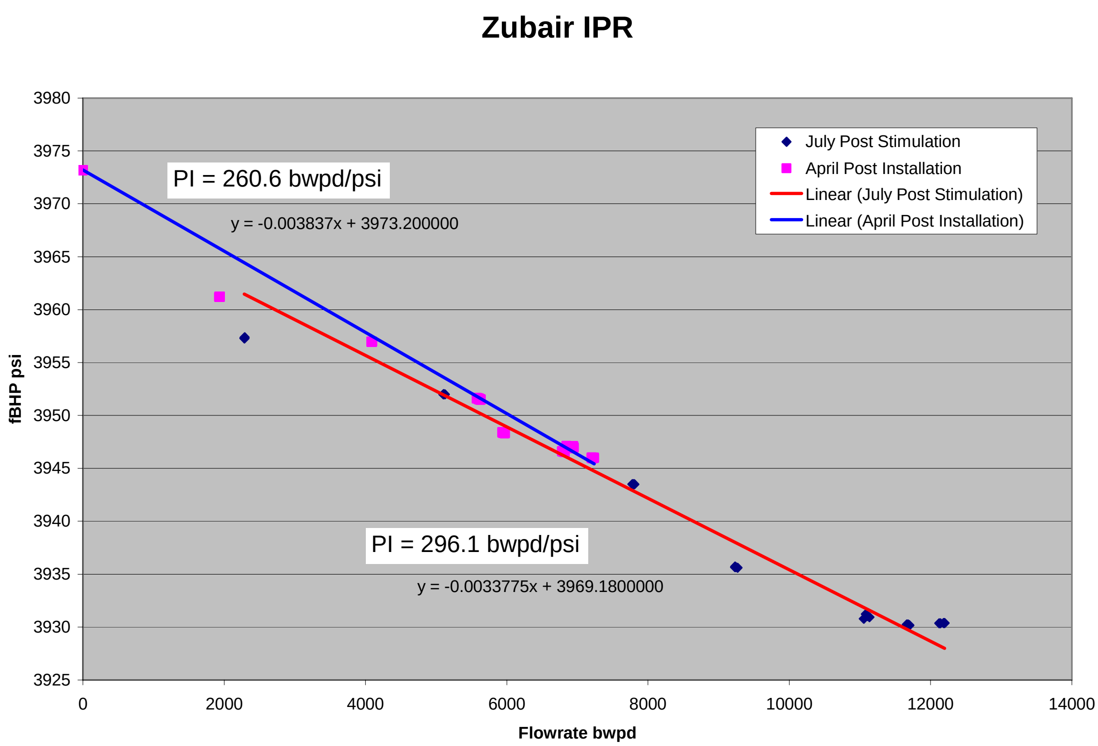

Figure 8 – Intelligent Dumpflood Well 1 - Zubair IPR Post Completion and Post Minagish Stimulation

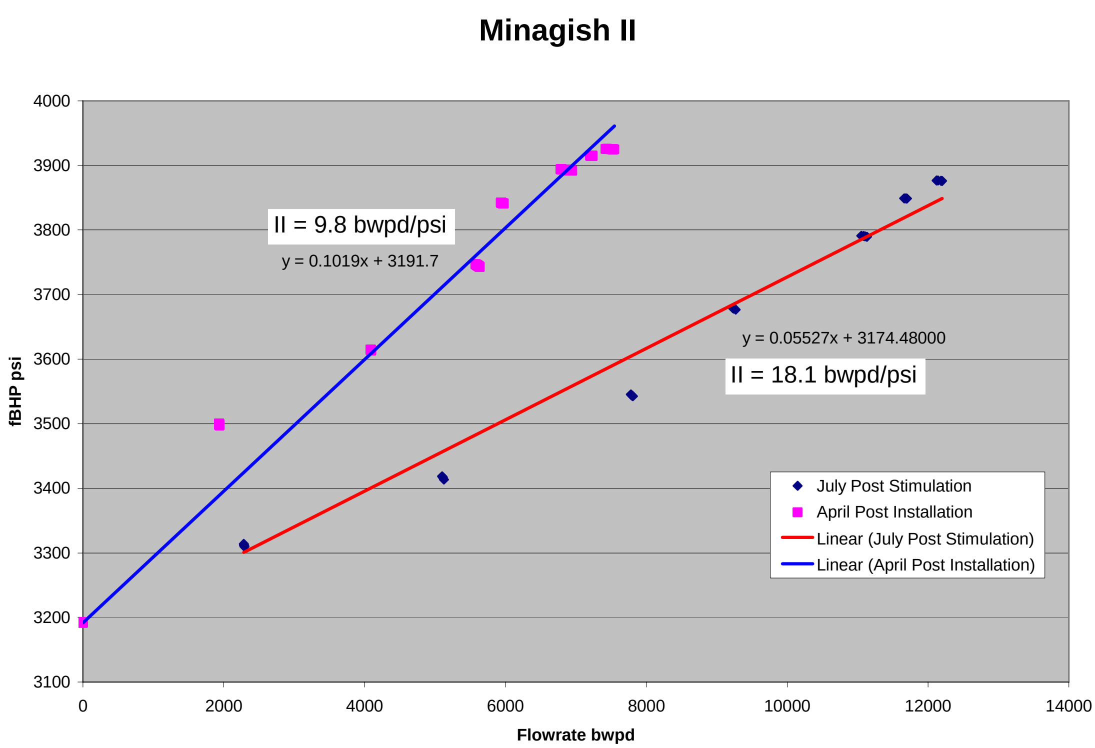

Figure 9 – Intelligent Dumpflood Well 1 - Minagish Oolite Injectivity Post Completion and Post RePerf and Stimulation

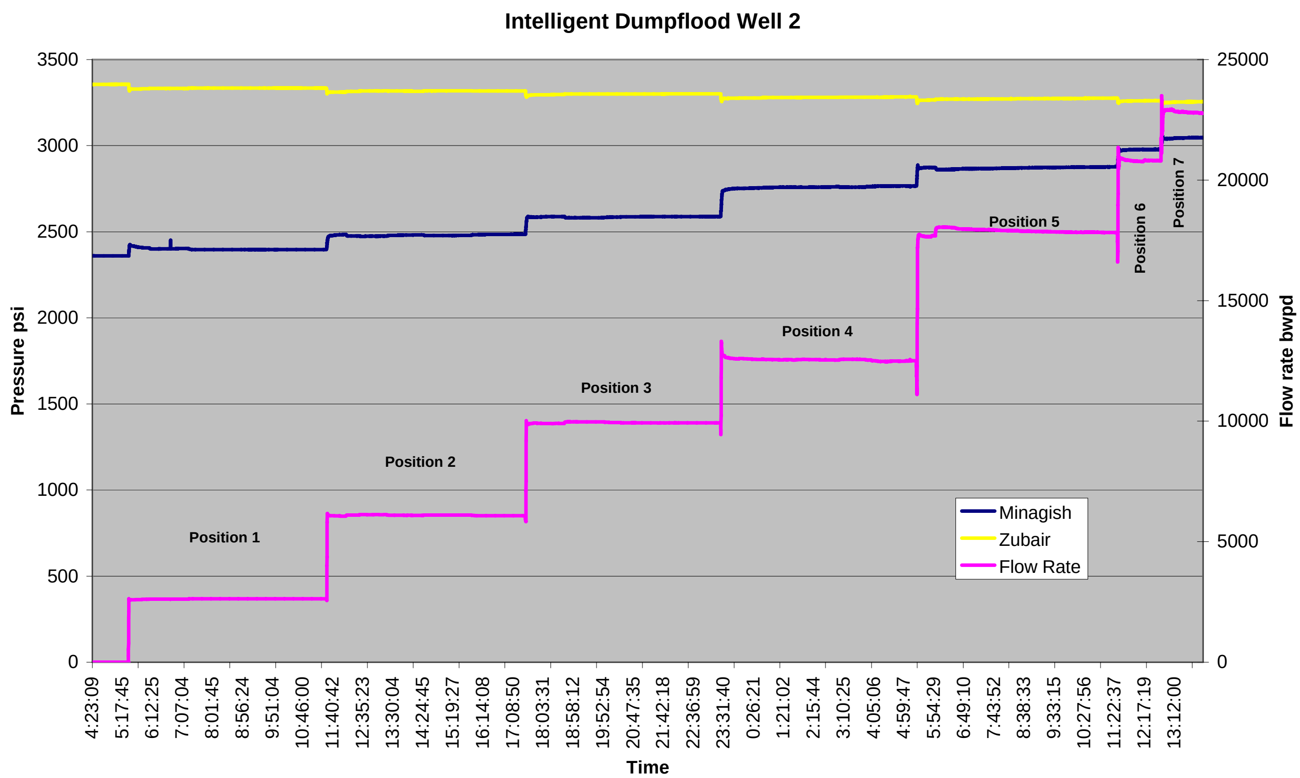

Figure 10 – Intelligent Dumpflood Well 2 - Pressure and Flow Rate During Multi-Rate Test

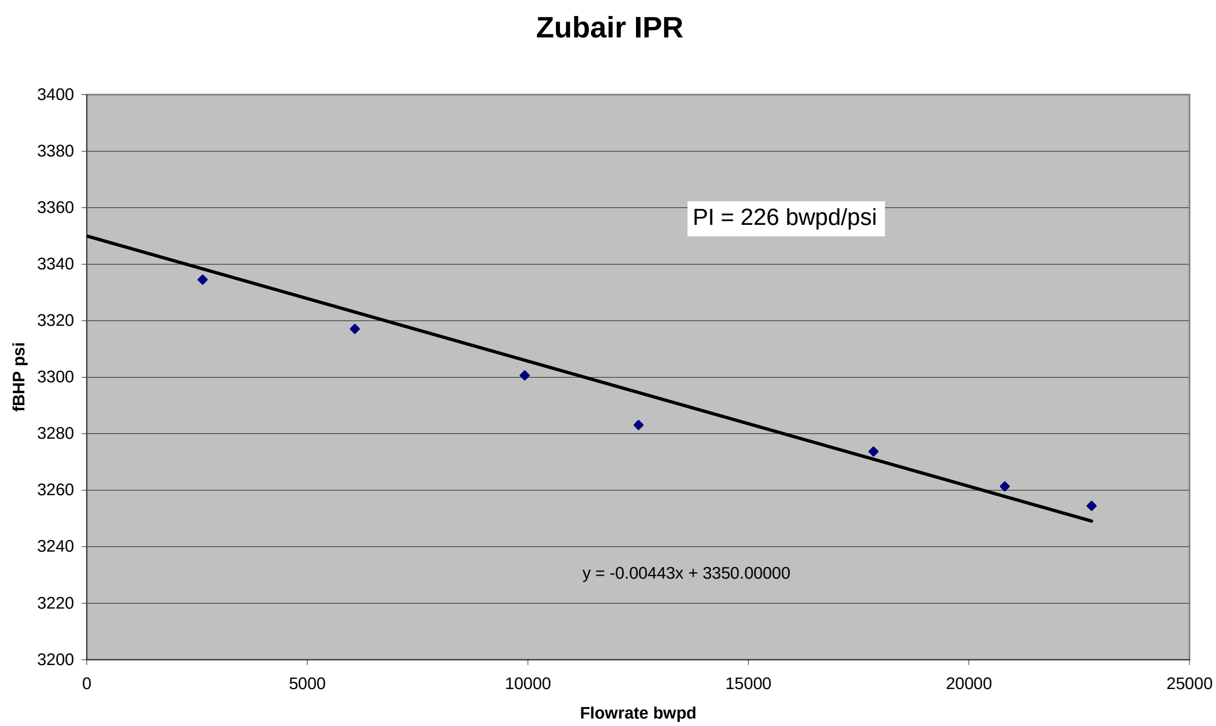

Figure 11 – Intelligent Dumpflood Well 2 - Zubair IPR Post Completion

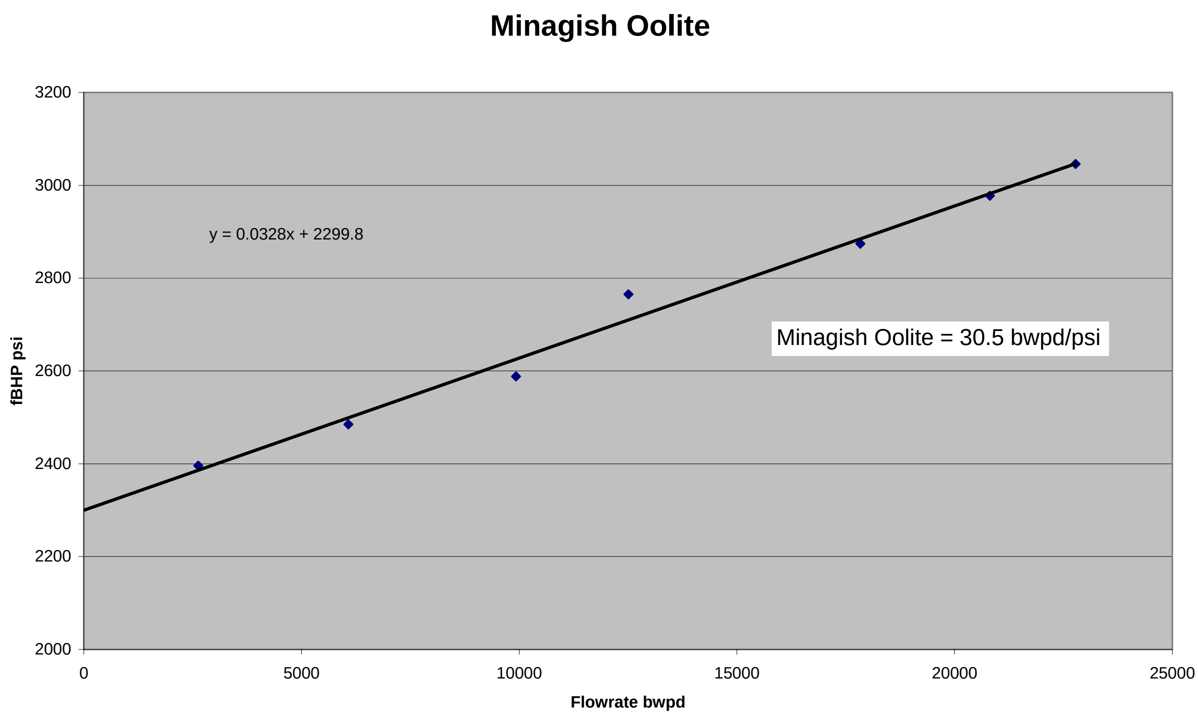

Figure 12 – Intelligent Dumpflood Well 2 - Minagish Oolite Injectivity Post Completion