SUCCESS NOVEL OF INTEGRATING PULSED NEUTRON AND COMPREHENSIVE PRODUCTION DATA ANALYSIS TO OPTIMIZE WELL PRODUCTION

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ABSTRACT

Unwanted water production from formation-related issues is always challenging during field development. In carbonate reservoirs, coning and channeling cause excessive water production from heterogeneity or fractures in the formation. In clastic reservoirs, depleted formation and water coning are the reasons for this circumstance. Excessive water production implies not only having less hydrocarbon production but also higher production costs in terms of lifting and water disposal. Identifying the cause and source of water production is important for optimizing field performance.

The initial study suggested that the water zone was far below the produced zone; however, high-water production was occurring. This contradictory result should be confirmed by using tools that can capture the recent conditions of the well while also identifying the source of the water.

For this industry, many downhole tools are used to characterize well and reservoir performance. One is a pulsed neutron tool, which captures the remaining hydrocarbon saturation behind casing in wells and is effectively used for strategic planning in workover wells. Additionally, water diagnostic analysis is used to understand well behavior.

This paper discusses planning and execution using necessary best practices to determine the appropriate tools for identifying current hydrocarbon saturation, reservoir conditions, water conformance problems, and interpretation workflows, as well as the principle of pulsed neutron logging and interpretation results.

Appraisal of formation characteristics is critical to long-term field development planning. Inaccurate appraisal will lead to increased costs for the field.

INTRODUCTION

In a mature reservoir, the oil and gas production often exhibit high water production. On average, for every barrel of oil, there will be three barrels of water produced. It costs more than $40 billion for 75% of the excess water production (Zeinijahromi et.al, 2015).

A mature carbonate reservoir with a complex pore system is capable of producing more than a 90% water cut. This not only shortens sustained oil production but also increases well expenditure costs.

In this study, current geological models suggest a long oil water contact in the reservoir located far away from a perforated interval. Production was more than 90% water cut with less than 10% oil. This result significantly lowers the total oil production of the field.

This phenomenon could be caused by several factors, but generally the problem can be grouped into two big categories. Mechanical problem such as packer integrity and cement bonding, and formation-related problem such as water intrusion through high permeability zones, water coning, etc.

EXCESS WATER PRODUCTION

Naturally, water will be produced alongside hydrocarbon, especially in the later stage of a well. A normal reservoir will typically have both hydrocarbon and connate water. As the oil saturation decreases (oil production), the relative permeability of water will be increased, which then contributes to more water being produced.

It is not necessary to completely shut-off the water production of the well where the water is being injected to maintain the pressure of the reservoir. In this case, the production of oil will be linearly related to the production of the water. The decreasing of the water production will also decrease the oil production. Problems arise when the economic level of produced water-to-oil ratio (WOR) is surpassed due to mechanical issues or reservoir issues. This type of water intrusion is classified as "bad water" (Bailey et al. 2000; Reynolds 2003; Veil et al. 2004).

Excessive bad water production affects the economical aspects of the well such as decreased oil production, unnecessary expense of lifting water, cost of water treatment facilities, and water disposal system (Rabiei, M. 2011). Jackson and Myers (2003) in Rabiei, M 2011 estimated the average cost of disposal methods for the produced water is presented in Table 1.

Based on its cause, excessive water production can be grouped into two categories:

Mechanical/ Completion-Related Problems
In a producing well, the integrity of the well is supported by the completion jewelries such as casing-tubing integrity, cement-bond, packer sealing, etc. A corroded casing/tubing, poor cement-bonding, or leak packer can lead to excessive water production.

A poor completion design also affects the water production. In an oil zone close to a water zone (aquifer), one must consider making the completion interval above, away from the water zone, as effective as possible. This is because the water-oil-contact is dynamic, thus the movement of the WOC can cause the water production (see Figure 1 for illustration).

Reservoir-Related Problems
A reservoir is defined as a rock that can contain and let fluid flow through it. The capability of the rock to let the flow passing through it is permeability. In a well with several rocks on top of each other, the vertical permeability between the layers is possible. This is usually due to fractures and faults that act as a conduit, which connects two different reservoirs.

In a strong water drive reservoir where the water aquifer is just below the oil zone that was perforated and produced, these high vertical permeability conduits will become the channels that connect between water and oil-production zones. This is called “channeling”.

When the production rate is too high, the pressure difference will push the water near the wellbore and draw water to prematurely break through the oil water contact. This is called “coning”. This coning and channeling are the two major causes for excessive water production in oil wells (Chan 1995; Seright 1998).

WATER SURVEILLANCE TOOLS AND METHODS

Many methods are available in the market for well surveillance specifically as water diagnostics. Various options offer to mitigate excessive water production inside or outside tubular pipe through direct tool deployment or available data analysis such as water control diagnostics based on production data, pulsed neutron log, production logging, and acoustic based tools.

WATER DIAGNOSTIC ANALYSIS

The typical problems related to water production in producing wells are channeling, coning, and breakthrough (fingering). In channeling, a high-pressure water formation near a low-pressure hydrocarbon reservoir may find a path via a channel in a poor cement job or naturally fractured formation. Coning happens when high production rates are introduced in thick formations with high vertical permeability. Term of breakthrough usually happens in sandstone formations with various porosity and permeability.

Production data is crucial to understanding well behavior in time. In order to correctly address the problems of the well, the cause of unwanted water production must be determined first. The log-log plot of production data and the water oil ratio (WOR) or gas oil ratio (GOR) provide an insight for well performance evaluation (Chan, 1995). In Figures 2 and 3, coning and channeling can be estimated using the WOR’ (time derivative of WOR).

A study shows (Al Hasani et al., 2008) that the WOR and WOR’ data plotted against elapsed time can be used to indicate the type of water breakthrough. Water coning, multilayer channeling, and near wellbore problems are the common problems noticeable in water diagnostics.

PULSED NEUTRON

The Pulsed Neutron Logging (PNL) tool was designed to emit a high energy neutron (14MeV) pulse into the behind casing/formation, by using a pulsed neutron generator, and detecting the returned response in the form of gamma particles. This “pulsed” algorithm will be different depending on the mode of the tool. There are Capture, Carbon-Oxygen (C/O)/CO, KUTh, and Oxygen Activation modes. While acquiring C/O data in CO mode, the tool will automatically measure other data such as capture and oxygen-activation data, and vice versa (Figure 4). However, the additional measurement is used only for qualitative analysis, not for quantitative analysis.

Carbon-Oxygen Mode
Pulsed neutron technology using the C/O method was first introduced in the 1970s. This technology was widely used as a method to identify oil in a formation where the water formation salinity is unknown. Unlike capture mode pulsed neutron technology, the C/O mode measurement is not affected by the salinity of water in the formation.

The C/O tool identifies the amount of carbon, oxygen, calcium, and silicon by using a spectrum analysis of the inelastic gamma rays produced by the neutron interaction between surrounding nuclei (F.E. Fox, et al, 1999). The measured elements are then used to calculate reservoir fluid saturation by incorporating the ratio of Carbon-Oxygen (C/O) and Calcium-Silica (Ca/Si) with porosity.

In order to obtain the best measurement of C/O data, the accuracy must be increased by logging multiple passes with a low logging speed. This allows better accuracy and more improved reliability of the results. Modern C/O tools also utilized a higher density crystal, which allows a better dynamic range in the spectrum analysis of C/O data.

PRODUCTION LOGGING

Production logging tools, as shown in Figure 5, are available in a wide range for all types of downhole environments: vertical, deviated, and horizontal wells. The full range sensor is equipped for flow rate measurements, fluid identification, well diagnostic solution, and correlation tools.

The output of sensors provides simultaneous and continuous measurement in static or dynamic downhole conditions. Production logging data is acquired usually with the tool moving either in an upward or downward direction, depending on deployment method. Data acquisition can also be made stationary where the sensor records over a particular period of time.

All production logging sensors measure flow behavior inside the tubular pipe, except for the temperature sensor. The mainstays of logging for fluid movement detection inside and outside the tubular pipe were taken by temperature survey. Typically, temperature surveys are run continuously in a well with depth. A change in temperature compared to the geothermal profile indicates fluid movement.

NOISE LOGGING

Microphones are utilized in noise surveys to detect fluid movement downhole even if it happens outside the tubular pipe, as long as both flow and pressure drop were established. Most industry recommendations have the noise tool combined with the temperature sensor to provide qualitative and sometimes quantitative assessment of the downhole flow profile.

The temperature survey in a continuous pass is used prior to performing the noise log survey. Meanwhile, a stationary survey is usually taken as a main pass in the noise survey, measuring both the amplitude and frequency spectrum of the sound at various station points. The idea of having a stationary survey is to minimize the noise effect of the cable/tool moving inside the pipe.

OTHER TECHNIQUES

Other techniques are also well known in industry for evaluating fluid movement such as radioactive tracer logging and oxygen activation.

JOB PLANNING AND EXECUTION

Any cased hole logging job has a unique form. The well problem obviously requires understanding before plans to resolve the issues can be made. Using all available information such as open hole databases, reservoir properties, historical production data, surrounding wells, and any previous well interventions is necessary before running cased hole logs. General information as standard requirements for each type of logging job can be listed (Smolen, 1996): an accurate well sketch including deviation and restrictions, downhole conditions, surface/well head conditions, length of tool string, safety considerations, and continuous operation or limited to daylight operation.

The objective of this job was to obtain the remaining oil saturation level in this well, especially at the perforated zone where excessive water production was observed. The key factor was to acquire a reliable C/O measurement to get oil saturation in this well, and also to investigate the water source.

C/O measurement was chosen as the most effective way to obtain the remaining oil saturation while also possibly detecting the location of the water source. The execution of the job was done by incorporating capacitance and temperature data as a valuable measurement, in addition to C/O measurement.

RESULT AND INTERPRETATION

The WOR and WOR derivative plot from well B-1 indicates a channeling/fracture type of water breakthrough. It started with decreasing water production and then rapidly increasing water production, which is a channeling profile. The channeling profile shows at least two trends, where the first layer of breakthrough happened at around 200 days, the steepest trend observed. The second layer breakthrough was then observed at around 500 days.

The pulsed neutron data was acquired in well B-1 with the objective to determine the remaining oil saturation and water breakthrough source. The remaining oil saturation was determined by using CO data while the source of water was determined using oxygen-activation data.

The results of PNL (Figure 6) suggest that there was remaining oil saturation in this well, and a water-flow inside the borehole was observed below the existing perforated interval (orange box above xx30ft).

The highest remaining oil saturation was located at around xx10ft and xx28ft. The initial plan was to perforate zone 1 and zone 2, based on openhole and production data.

After the PNL results were obtained, the initial plan was revised (Figure 7) to exclude the low remaining oil saturation at zone 2 and keep the zone 1 with 20-40% oil saturation. Additionally, after seeing the water-flow coming from the bottom section of the existing perforated interval, the plug was then installed above the existing perforated interval to block the water-flow. The oil production was significantly improved by more than 1,000 bopd (Figure 8), and brought the water cut down to 0%.

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TABLES

Produced water management costs (After Jackson and Myers 2003)

Management Option	Estimated Cost ($/bbl)
Surface discharge	0.01–0.8
Secondary recovery	0.05–1.25
Shallow reinjection	0.1–1.33
Evaporation pits	0.01–0.8
Commercial water hauling	1–5.5
Disposal wells	0.05–2.65
Freeze-thaw evaporation	2.65–5
Evaporation pits and flow lines	1–1.75
Constructed wetlands	0.001–2
Electrodialysis	0.02–0.64
Induced air flotation for de-oiling	0.05
Anoxic/aerobic granular activated carbon	0.083

Table 1: Example of estimated cost for water management

FIGURES

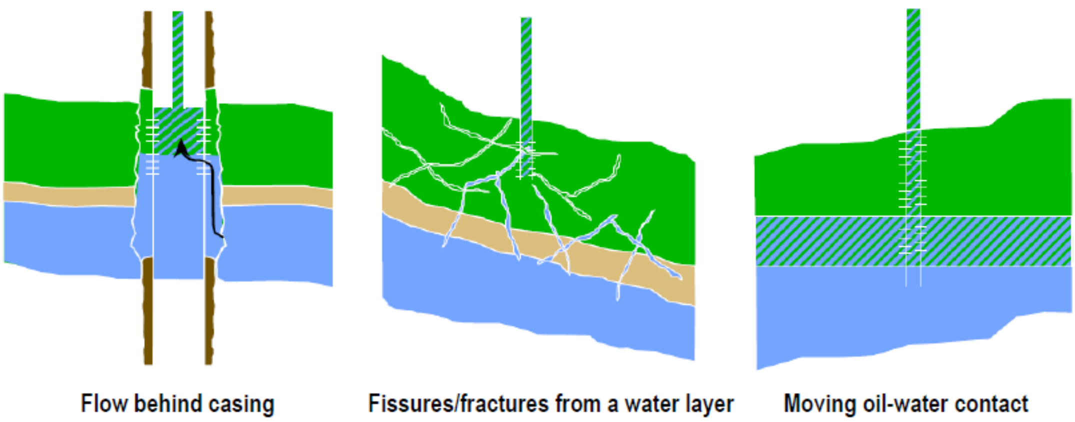

Figure 1: Cause of excessive water production from mechanical/completion-related problems (Elphick & Seright, 1997)

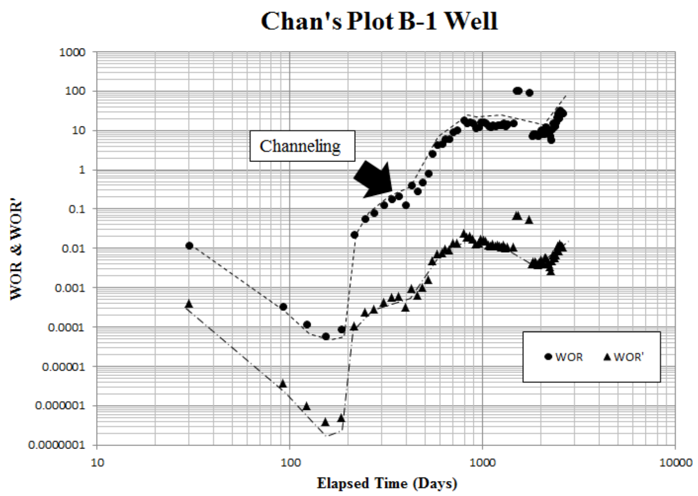

Figure 2: Example of WOR and WOR' derivative for water diagnostic

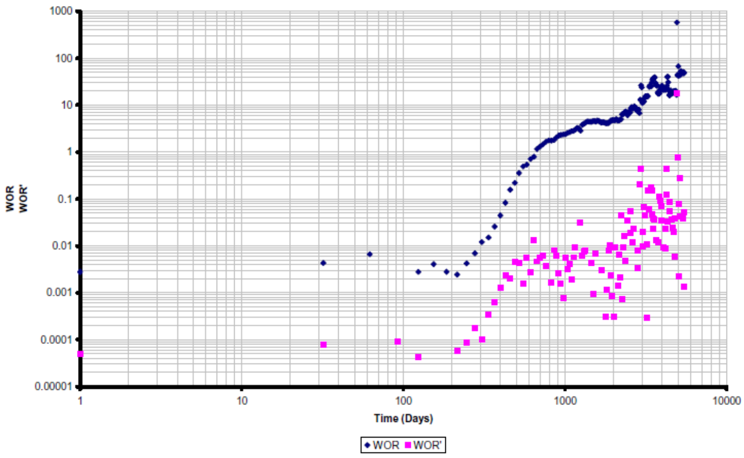

Figure 3: Water coning followed by channeling, WOR and WOR' derivatives

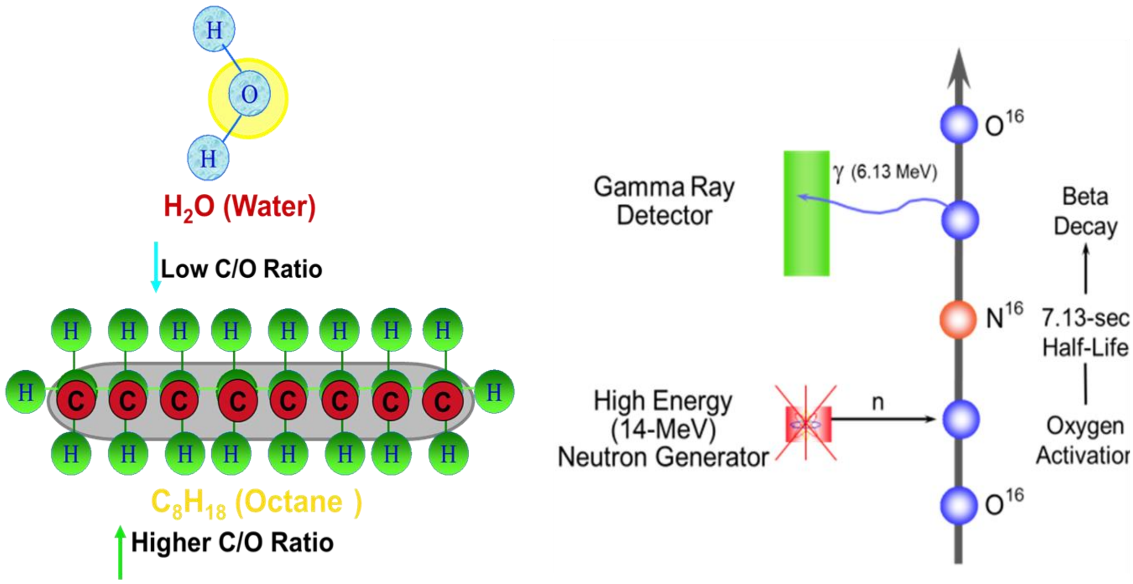

Figure 4: Carbon-Oxygen Measurement and Oxygen-Activation

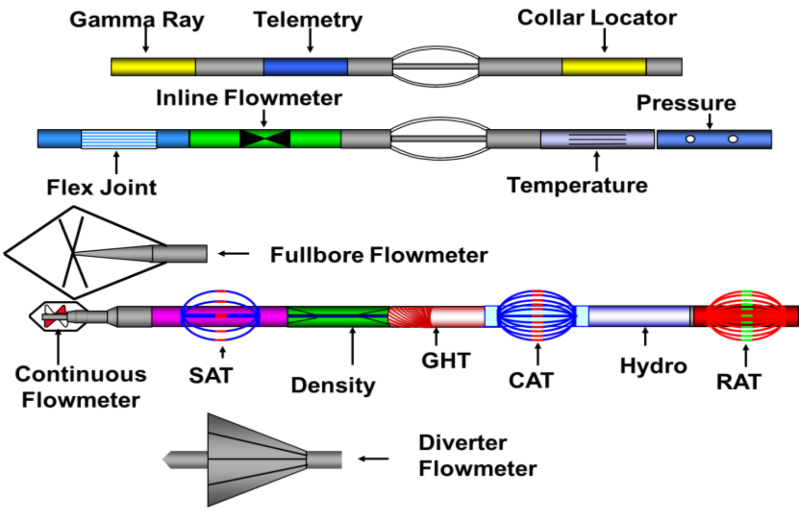

Figure 5: Sensor options for production logging

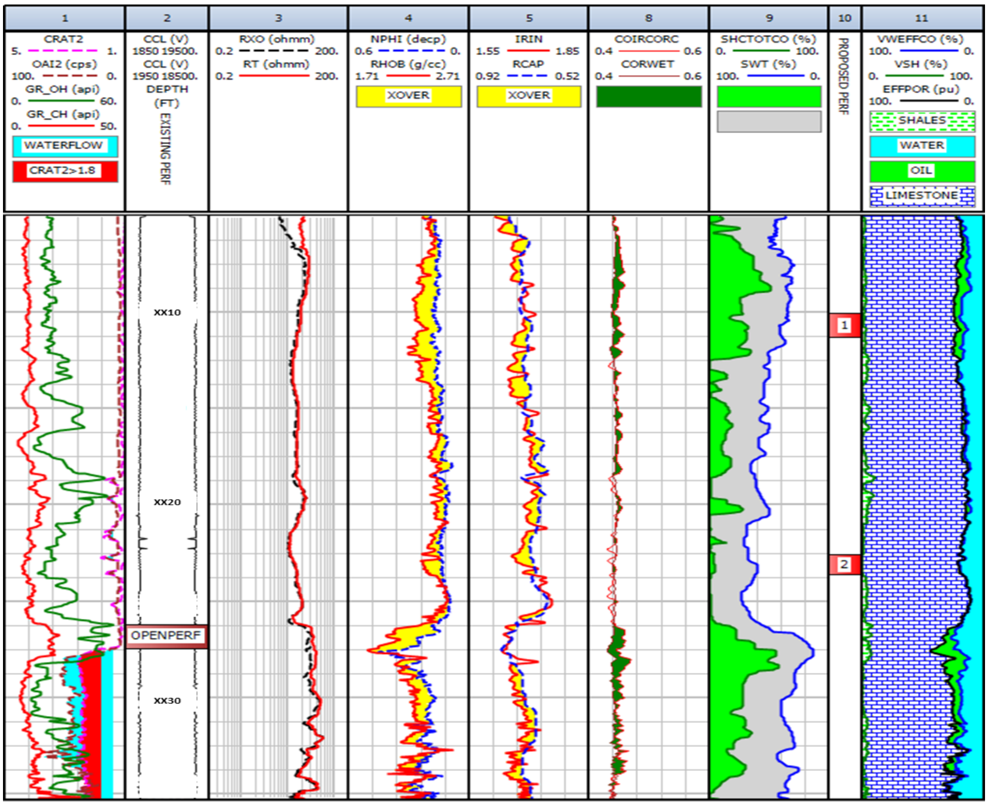

Figure 6: PNL Result of B-1 Well, shows remaining oil saturation and water-flow inside borehole

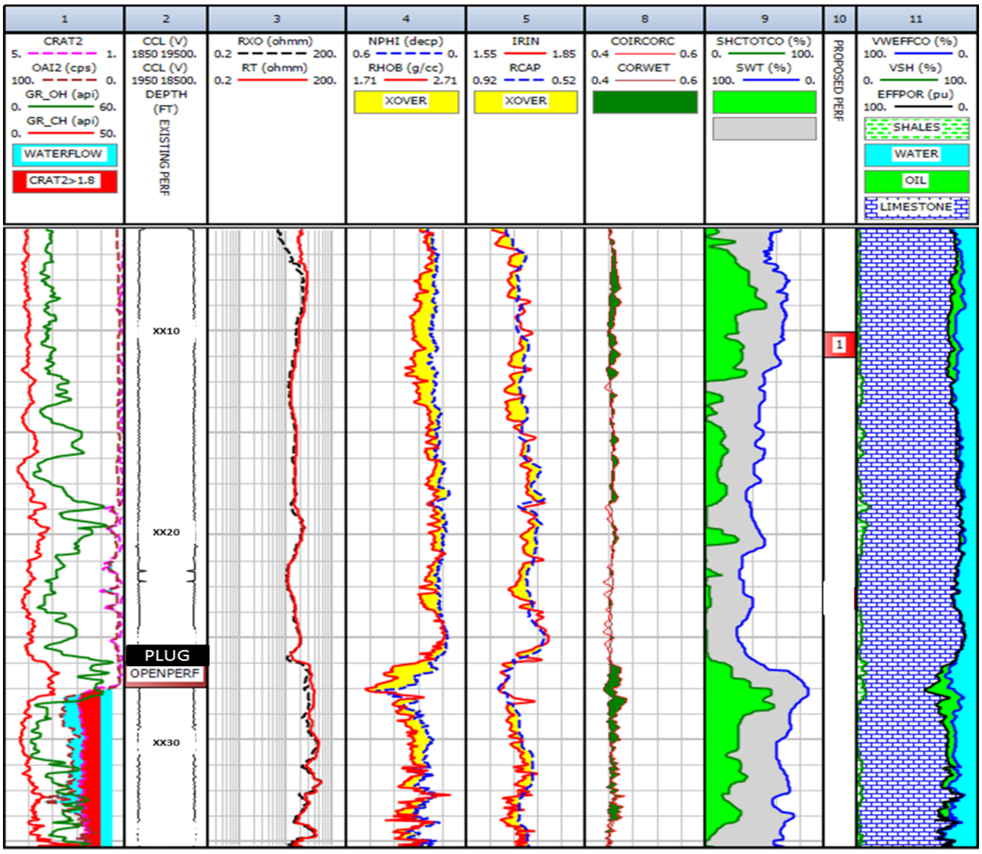

Figure 7: The revised plan after PNL result at B-1 Well

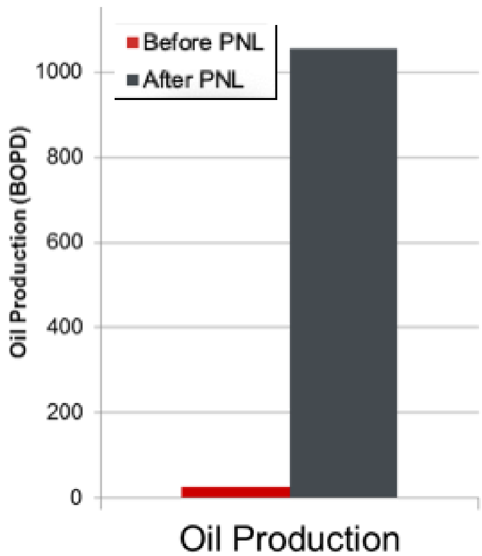

Figure 8: Oil production in B-1 Well after changing the plan