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Analysis and Synthesis of Horizontal Wells in Hassi R'Mel Oil Rim, Algeria

R. Recham
PED/Sonatrach Inc.
Algeria

Z. Nennouche
PED/Sonatrach Inc
Algeria

Abstact

The objective of this study is to analyze the experience of drilling horizontal wells in Hassi R'Mel oil rim, Algeria. The excepted results are: higher well productivity, better oil recovery, lower water and gas coning, minimum cost of production operations and maximum profit.

For the Hassi R'Mel oil rim, recovery of the oil using only vertical wells is difficult because water and gas coning result in low oil production rate and high cost of production operations. Then using only vertical wells exhibit a drilling of a large number of wells which could affect the profitability of the development project especially in the presence of thin oil thickness.

A field development of Hassi R'Mel oil rim is needed, the technique of drilling horizontal wells is chosen as an alternative to some vertical wells, since horizontal wells provide options whereby pressure drawdown can be minimized, coning tendency can be minimized, high oil production rate can be achieved and consequently the cost of production operations can be reduced.

The first horizontal well OWPZ1 in Algeria was drilled in 1991 in Hassi R'Mel oil rim. Since, many horizontal wells have been drilled based on the optimization simulation study of the Hassi R'Mel oil rim development. Eight horizontal wells were chosen for this study with the objective to analyze their performance and assess their profitability.

Introduction

The Hassi R'mel field is located approximately 500 kilometers South of Algiers in the Northern Grand Erg occidental of the Algerian Sahara. Early evaluations of the discovery by the drilling of well HR-1 in November 1956 revealed it to be one of the largest gas fields in the world which has an oil rim existing primarily along the Eastern and Southern margins of the field.

Hassi R'mel oil rim is a thin oil thickness reservoir sandwiched between a large gas cap support and a bottom aquifer throughout the entire oil rim. The gross thickness of the oil column ranges from 3 to 12 meters with an average permeability of 500 md.

All those factors made the necessity to develop the Hassi R'mel oil rim by implementing horizontal wells, in addition to vertical wells (Mixed Development Strategy), to improve the oil recovery in one hand, and to reduce water and gas coning problems.

One of the main reasons for coning is pressure drawdown. A vertical well exhibits a large pressure drawdown near the wellbore, whereas horizontal well exhibits minimum pressure drawdown, thus horizontal wells provide options whereby pressure drawdown can be minimized, coning tendencies can be minimized, and high oil production rates can be achieved.

For a vertical well, the majority of the pressure drawdown is consumed near the wellbore. Therefore, there is a big drawdown around the wellbore in a vertical well. In the case of horizontal wells, the pressure drop is fairly uniform throughout the reservoir near the wellbore, an extra pressure drop is observed. This pressure drop is, however, very small as compared to that around a vertical wellbore. For horizontal wells, due to low pressure drawdown, one expects a high oil production rate without water coning.

In a reservoir with bottom water or top gas, rising water and downward movement of the gas cap can be controlled to obtain the best possible sweep of the reservoir. This is also called water cresting. With proper operating procedure, the bottom water drive for horizontal wells behaves very similar to a water-flood for vertical wells, resulting in very high recovery. A horizontal well provides an option not only to enhance initial oil-production rates, but also to obtain maximum possible ultimate reserves in a shorter time than a vertical well.

The development and application of horizontal wells drilling technology is causing a revolution in the petroleum exploration and exploitation industry.

Simulation studies were conducted to investigate the feasibility and performances of various patterns of conventional vertical wells. The effect of horizontal well length, the optimum perforated drain hole section, the well's position relative to the fluids contacts, the change in production rate and the oil saturation below the oil-water contact were all investigated.

Many horizontal wells have been drilled in Hassi R'mel oil rim based on the simulation study and economic analysis, which was conducted to investigate the optimum number of vertical and horizontal wells (enhance reservoir contact and thereby enhance well productivity) to be drilled in Hassi R'mel oil rim.

There are some cases where horizontal wells have not been effective in reducing water and gas coning. The lack of success is due to operational problems that one encounters while drilling in a very thin pay zone, where precise targeting may be difficult. Additionally, in gas coning, gas break-through in the entry portion of the wellbore is a common problem.

Statement of the Problem

For Hassi R'mel oil rim recovery of the oil is difficult because water and gas coning results in low oil production rate and high cost of production operations.

To overcome reservoir fluid flow problem, horizontal wells are proposed as an alternative to vertical wells to reduce excessive water and gas coning, and capture more oil due to large contact area, low pressure gradients and low drawdown is minimized while still maintaining production. Hence, this will lead to increase in the return on the investment.

Objective of the Study

The predominant objective of this study is to analyze the experience of drilling horizontal wells in Hassi R'Mel oil rim, Algeria. The excepted results are: higher well productivity, better oil recovery, lower water and gas coning, minimum cost of production operations and maximum profit.

Horizontal Well Profils

The development and application of horizontal drilling technology is causing a revolution in the petroleum exploration and exploitation industry. As a result of the advances in drilling and completion technologies in the last two decades, the efficiency and economy of horizontal well have significantly increased. The state of Art applications of the horizontal well technology require better completion designs to optimize production, long term economics and ultimate recoverable reserves.

A multi-disciplinary team effort for an economically successful horizontal technology program in all phases of planning has been established in order to obtain pertinent information before the well is drilled.

A pri-drill geological model was derived for horizontal wells utilizing log data of the surrounding vertical wells. A profile and trajectory was defined and used reconstructed log response as the geo-steering guide to compare with real time log data (LWD) and identify the geological markers during the drilling.

The petrophysical evaluation and the gas indicators were used to choose the zones to be perforated in order to maximize the production of dry oil.

Most of horizontal wells drilled in Hassi R'mel oil rim were designed to be a medium radius with 500 meters long. Prior to drilling, TDT tests were run in the surrounding vertical wells in order to locate the expected fluid contact of horizontal wells.

As the oil rim is thin the plan was to drill an inclined borehole through the reservoir section and use LWD Resistivity-Gamma Ray to confirm the true depth of the reservoir sands and the position of the gas, oil and water contacts and then to navigate up to the oil zone and land at 1000 meters drain in the section.

The well was geo-steered through the Tag formation until the LWD Resistivity indicate water and then the Density Neutron and MDT pressures, sampling and live fluid analyzer were run to determine the fluid contacts.

The target formation (reservoir) was the Trias gréseux oil bearing sand. The plan was to drill down to the oil-water contact and then to steer back up and land in the desired zone and continue laterally through the reservoir.

Transient Well Test Analysis

Well test analysis of a horizontal well is complex and on many occasions difficult to interpret, because most horizontal well mathematical models assume that horizontal wells are perfectly horizontal and are parallel to the top and bottom boundaries of the reservoir. In general, the drilled horizontal wellbores are rarely horizontal but rather snake-like with many variations in the vertical plane along the well length.

In general, a well test analysis of a horizontal well is conducted to meet the following objectives :

- To obtain reservoir properties
- To determine whether all the drilled length of a horizontal well is also a producing length and
- To estimate mechanical skin factor or drilling and completion related damage to a horizontal well. Based on magnitude of the damage a decision regarding well stimulation can be made.

Horizontal Well Applications

Horizontal Well OWPZ1

The first horizontal well (OWPZ1) in Algeria was drilled in 1991 and put on production in December 1992. A pilote hole has been drilled to locate efficiently fluid contacts.The project was designed to complete a 600 meters horizontal medium radius reservoir drain in the Triassic Argileux gris 'A' formation.

The production begun in December 1992 resulting in 624 cubic meters per day of oil bearing produced through à 40/64 choke with a gas-oil ratio of 208 m3/m3 and a zero percent of water cut.

Because of the high production rate used, a severe water and gas coning occurred and it was decided to produce the well at 200 m3/d through a 32/64 choke.

The plot of historical production of well OWPZ1 (Fig.1) shows that the well is producing at an average oil rate of 200 m3/d from the period of December 1992 to March 1998, with a GOR of 2500 m3/m3 and a water cut of 30%. In April 1998 the oil production rate started decreasing from 200 till 80 m3/d in Septembre 2002, this is due to the increase of th GOR from 2500 to 6000 m3/m3, with an average water cut of 45 %.

The well resulted in a cumulative oil production of 593 000 cubic meters in 10-year production with a net present value of 43.4 MM$.

Horizontal Well OWPZ2

The horizontal well OWPZ2 was drilled in 1998 using a pilote hole to locate efficiently fluid contacts. The CBL logging tool showed a bad cementing job of 30 meters in the horizontal drain hole section from 2615 to 2325 meters. The production started with 106 m3/d of oil bearing through 32/64 choke, resulting with a GOR of 408 m3/m3 with no water production. The horizontal well collapsed in last 300 meters of drain hole length because of the unconsolidated reservoir.

The historical production of well OWPZ2 (Fig.2) from April to December 1999 shows that the oil production keep increasing from 50 to 143 m3/d caused by the increase of the GOR reaching a value of 3334 m3/m3 playing a role of an auto gas-lift, after this period of time a severe gas coning occurred resulting in a high GOR of 6600 m3/m3 causing a decrease of oil production rate from 143 to 42 m3/d from the period of January to July 2000. the last period of the historical production resulted in an average oil rate of 80 m3/d and a GOR of 5500 m3/m3.

The well resulted in a cumulative oil production of 116 000 cubic meters in 5-year production with a net present value of 5.24 MM$.

The drilled horizontal wellbore is rather snake-like with many variations in the vertical plane along the well length (Fig.3), the bad cementing job and the collapsed section of the horizontal well could be the reasons of producing with a high GOR. Production logging can be used to locate the high gas production zones to squeeze the zone off using cement to overcome the gas channeling problems or bridge plug with cement to isolate a part of the horizontal drain hole .

Horizontal Well OWPZ3

The horizontal well OWPZ3 was drilled in 1999 without using a pilote hole to locate efficiently fluid contacts. The well was completed with cemented liner and perforated, resulting in 152 m3/d of oil bearing produced through 30/64 choke. The CBL logging tool showed a bad cementing job of 30 to 40 meters in the horizontal drain hole section from 2205 to 2490 meters.

The plot of historical production of well OWPZ3 (Fig.4) shows a severe water coning occurred very rapidly during the period of March 1999 and 2000 causing a decrease of oil production from 152 to 75 m3/d, and the gas-oil ratio increased from 990 to 1566 m3/m3.

Very soon the water cut dropped to 36 % allowing the well to be produced at an average oil rate of 75 m3/d during the period of April 2000 to May 2003, the water cut and the gas-oil ratio increased from 36 to 48 % and 1500 to 2500 m3/m3 respectively.

The well resulted in a cumulative oil production of 126 000 cubic meters in 4-year production with a net present value of 5.27 MM$.

The bad cementing job in the horizontal well drain hole section could be the reason of producing with a high GOR and water-cut. Production logging can be used to locate the high gas production zones to squeeze the zone off using cement to overcome the gas and water channeling problems.

Horizontal Well OWPZ4

The project was designed to complete a 600 meters horizontal medium radius reservoir drain in the Triassic Argileux Greseux ‘A’ formation, without using a pilote hole. The horizontal well OWPZ4 was completed with cimented liner and perforated in 1999 resulting in 178 m3/d of oil bearing produced through 20/64 choke. The CBL logging tool showed a bad cementing job of 30 to 40 meters in the horizontal drain hole section from the top liner 1828 to 3092 meters

The plot of historical production of well OWPZ4 (Fig.5) shows that the well was producing at an average oil rate and a gas-oil ratio of 155 m3/d and 500 m3/m3 respectively from the period of July 1999 to September 2001 without water production.

In the second period from Octobre 2001 to May 2003, the plot shows that the gas-oil ratio decreases very rapidly to 100 m3/m3 causing a decrease of oil rate till 70 m3/d. this could be explained by the shut-in of the injection well adjacent to the horizontal well OWPZ4.

The well resulted in a cumulative oil production of 154 000 cubic meters in 4-year production with a net present value of 8.14 MM$.

Although the CBL showed a bad cementing job in a part of the horizontal drain hole section, the horizontal well still produce with low GOR and water-cut which could explained by a horizontal barriers since the type of the reservoir is shaly laminated reservoir intercepted by clean sands.

Gas-lift Optimization of Well OWPZ4

The end of the historical production of well OWPZ4 shows that the well is producing at low oil rate (77 m3/d) and a GOR of 143 m3/m3 with 4% of water cut. Since the horizontal has a significant potential of oil production, gas-lift application is suitable for production optimization for this well.

Because of lack of energy the well cannot produce oil with water-cut higher than 20%.

To overcome this problem the well is subjected to gas-lift application, the simulation results (Fig.6) shows that by injecting 8000 m3/d of gas with 20% of water-cut, the well can produce at a rate of 160 m3/d. Many sensitivity runs have been done with different water cut to optimize gas injection rater and oil production rate.

Table 1 Simulation Results of Gas Lift Application

Gas Lift Application Results of Well OWPZ4		
Water cut (%)	**Gas Injection Rate (m3/d)**	**Oil Production Rate (m3/d)**
20	0	0
20	8000	160
40	10000	80
60	15000	50
80	20000	22

From the results we can say that gas-lift application is suitable for production optimization of well OWPZ4.

Horizontal Well OWPZ5

The drilling of the horizontal well OWPZ5 was not effective. The lack of success is due to operational problems encountered while drilling in a very thin pay zone. The precise targeting was difficult resulting in a wrong pay zone level toward the water zone. Then it was decided to plug the horizontal drain hole and to perforate the inclined section of the well in the oil pay zone.

After the perforation the well resulted in 88 m3/d of oil bearing produced through 32/64 choke.

The plot of historical production of well OWPZ5 (Fig.7) shows that the oil production rate increases from 30 to 127 m3/d and suddenly the well is shut-in. The average gas-oil ratio and water cut are 180 m3/m3 and 10 % respectively.

Gas-lift Optimization of Well OWPZ5

The well is shut-in and can not produce oil because of lack of energy. To overcome this problem the well is subjected to gas-lift application for production optimization, the simulation results (Fig.8) shows that by injecting 6000 m3/d of gas with 15% of water-cut, the well can produce at a rate of 180 m3/d. many sensitivity runs have been performed with different water cut to optimize gas injection rater and oil production rate.

Table 2 Simulation Results of Gas Lift Application

Gas Lift Application Results of Well OWPZ5		
Water cut (%)	**Gas Injection Rate (m3/d)**	**Oil Production Rate (m3/d)**
25	0	0
25	6000	180
40	15000	140
60	20000	75
80	30000	35

From the results we can say that gas-lift application is suitable for production optimization of well OWPZ5.

Horizontal Well OWPZ7

The horizontal well OWPZ7 is the first well to be drilled perpendicular to the flank of an anticlinal to the southwest of the rig location, with an azimuth on 110° North and the length of 500 meters. The well was completed with cemented liner and perforated and the CBL tool showed a very good cementing job. The well resulted in 678 m3/d of oil bearing produced through a 32/64 choke with a gas-oil ratio of 102 m3/m3.

The plot of historical production of well OWPZ7 (Fig.9) shows that the well is producing during the period of January to September 2001 with an average oil rate and gas-oil ratio of 180 m3/d and 130 m3/m3 respectively. The oil production rate decreases dramatically from 180 till 50 m3/d because of the shut in of the injection wells adjacent to OWPZ7 and OWPZ4 from the period of Octobre 2001 to May 2003.

The well resulted in a cumulative oil production of 98 000 cubic meters in 2-year production with a net present value of 3.18 MM$.

Transient Well Test Analysis of Well OWPZ7

The horizontal well OWPZ7 is the first horizontal well to be subjected to a measurement and analysis of drillstem test (DST) pressure, which a practical and economical means for estimating important formation parameters prior to well completion.

The interpretation using the software SAPHIR for the pressure and pressure derivative analysis, matched very well a model (Fig.10) with boundary of parallel faults (channel) with a homogeneous reservoir, where the results of reservoir and well characteristics are as follows:

- Reservoir pressure : 3064.41 psia
- Productivity index : 59.37 STB/d/psia
- Reservoir conductivity (kh) : 57200 md-ft
- Reservoir permeability (k) : 2180 md
- Vertical anisotropy ratio (kz/kv) : 0.238
- Wellbore damage (skin) : +7.5
- Delta p skin : 49.43 psi

The wellbore damage with a positive skin of 7.5 tell us that a part of the horizontal well is unproductive, where stimulation of the well is needed.

Gas-lift Optimization of Well OWPZ7

The end of the historical production of well OWPZ7 shows that the well is producing at very low oil rate (51 m3/d) and a GOR of 135 m3/m3 with no water production. Since the horizontal has a significant potential of oil production, gas-lift application is suitable for production optimization for this well.

Many sensitivity runs have been done to match pressure and production data using the Sotware PERFORM. The results show that the well can not produce oil with water-cut higher than 25%.

To overcome this problem the well is subjected to gas-lift application, the simulation results (Fig.11) shows that by injecting 15000 m3/d of gas for 25% of water-cut the well can produce with an optimum oil rate of 175 m3/d. many sensitivity runs have been done with different water cut to optimize gas injection rater and oil production rate.

Table 3 Simulation Results of Gas Lift Application

Gas Lift Application Results of Well OWPZ7		
Water cut (%)	**Gas Injection Rate 5m3/d°**	**Oil Production Rate (m3/d)**
25	**0**	**0**
25	**15000**	**175**
40	**15000**	**122**
60	**20000**	**85**
80	**20000**	**33**

From the results we can say that gas-lift application is suitable for production optimization of well OWPZ7.

Horizontal Well OWPZ8

The horizontal well OWPZ8 was placed on the East Hassi R'mel anticline flank in the level 'A' sandstone, going 110° direction fairly perpendicular to this flank, almost parallel to bed Azimuth. The well was drilled in 2001, completed with cimented liner and perforated resulting in 379 m3/d and a gas-oil ratio of 105 m3/m3. The CBL logging tool showed a bad cementing job of 20 to 50 meters in the horizontal drain hole section from the 2685 to 3015 meters.

The plot of historical production of well OWPZ8 (Fig.12) shows that the oil production rate drop continuously from 107 to 45 m3/d because of a high increase of the GOR from 575 till 4240 m3/d, with an average water cut of 10 %.

The bad cementing job of the horizontal well drain hole section could be the reason of producing with a high GOR. Production logging can be used to locate the high gas production zones to squeeze the zone off using cement to overcome the gas channeling problems.

Transient Well Test Analysis of Well OWPZ8

The interpretation for the pressure and pressure derivative analysis, matched very well a linear composite model with infinite boundary for a homogeneous reservoir (Fig.13). The results of reservoir and well characteristics data are as follows:

- Reservoir pressure : 2943.21 psia
- Productivity index : 41.53 STB/d/psia
- Reservoir conductivity (kh) : 22100 md-ft
- Reservoir permeability (k) : 709 md
- Wellbore damage (skin) : -3.14
- Delta p skin : 35.52 psi

Horizontal Well OWPZ9

The horizontal well OWPZ9 was drilled in 2002, completed with cemented liner and perforated resulting in 332.5 m3/d and a gas-oil ratio of 108 m3/m3. The CBL tool showed a good cementing job.

The plot of historical production of well OWPZ9 (Fig.14) shows that the oil production rate drop continuously from 127 to 45 m3/d, the gas-oil ratio and water cut increase from 130 to 370 m3/m3 and from 5 to 20 % respectively.

Transient Well Test Analysis of Well OWPZ9

The interpretation for the pressure and pressure derivative analysis, matched very well a model with boundary of one fault with a homogeneous reservoir (Fig.15). The results of reservoir and well characteristics data are as follows :

- Reservoir pressure : 3051.16 psia
- Productivity index : 36.34 STB/d/psia
- Reservoir conductivity (kh) : 19200 md-ft
- Reservoir permeability (k) : 586 md
- Vertical anisotropy ratio (kz/kv) : 0.175
- Wellbore damage (skin) : 3.7
- Delta p skin : 32.82 psi

We can say that a part of the horizontal well is unproductive since the wellbore is damaged with a positive skin of 3.7 and a stimulation of the well is recommended.

Gas-lift Optimization of Well OWPZ9

The end of the historical production of well OWPZ9 shows that the well is producing at very low oil rate (45 m3/d) and a GOR of 260 m3/m3 with 19% of water cut. Since the horizontal has a significant potential of oil production, gas-lift application is suitable for production optimization for this well.

Because of lack of energy the well cannot produce oil with water-cut higher than 15%.

To overcome this problem the well is subjected to gas-lift application, the simulation results (Fig.16) shows that by injecting 4000 m3/d of gas with 15% of water-cut, the well can produce at a rate of 180 m3/d. many sensitivity runs have been done with different water cut to optimize gas injection rater and oil production rate.

Table 4 Simulation Results of Gas Lift Application

Gas Lift Application Results of Well OWPZ9		
Water cut (%)	**Gas Injection Rate (m3/d)**	**Oil Production Rate (m3/d)**
15	**0**	**0**
15	**4000**	**180**
25	**6000**	**160**
40	**8000**	**125**
60	**10000**	**100**
80	**12000**	**90**

From the results we can say that gas-lift application is suitable for production optimization of well OWPZ9.

Summary

As more wells are drilled, more experience (learning curve) will become available which will further enhance the outlined concepts leading to more efficient, economical, and safer horizontal drilling operations.

Horizontal wells were drilled in Hassi R'Mel oil rim to improve oil recovery by repressing the coning problem experienced in conventional wells. Steps taken to facilitate an optimum completion in the geologically heterogeneous reservoir included petrophysical logging, cementing the liner to avoid collapse and to provide isolation, and selective perforating. Disappointing early gas and water breakthrough in some horizontal wells resulted in lower than expected oil recoveries.

Conclusions and Recommendations

Proper planning and economic evaluation of a proposed horizontal well requires an accurate geological model and reservoir data sufficiently accurate to conduct a reliable simulation study. Without such an approach the economic success of a horizontal well should be considered of high risk.

The measurement and analysis of drillstem test (DST) pressure behavior affords a practical and economical means for estimating important formation parameters prior to well completion.

- The horizontal wells drilled parallel to bedding plan North 110° present 80% of perforable cleaned sand of the total horizontal drain hole section whereas, the horizontal wells drilled perpendicular to bedding plan North 200° present 60%.
- The advantage also of drilling horizontal wells parallel to bedding plan allows to plug the end of the horizontal drain hole section if water breaks through since the horizontal drain hole is perpendicular to the flank.
- The high inverted angle technique has been successfully applied in Hassi R'Mel oil Rim instead of expensive pilote hole.
- A very good cementing job has to be done using a completion with cemented liner and perforated to avoid collapse and minimize water and gas channeling.
- The drilled horizontal wellbore are rarely horizontal but rather snake like many variations in the vertical plane along the well length and this could result in a severe water and gas coning.
- The simulation study using gas-lift optimization is suitable for the horizontal wells OWPZ4, OWPZ5, OWPZ7 and OWPZ9 to improve oil recovery.

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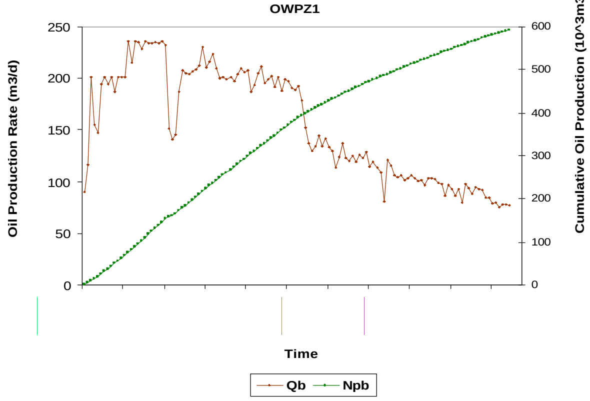
Figure 1
Historical Production Rate ad its Cumulat ive of Wel
OWPZ1



Historical Gas Oil Ratio and Water Cut
OWPZ1

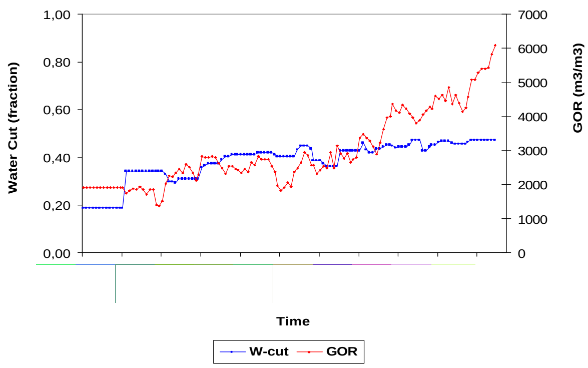


Figure 3 Horizontal profile of well OWPZ2

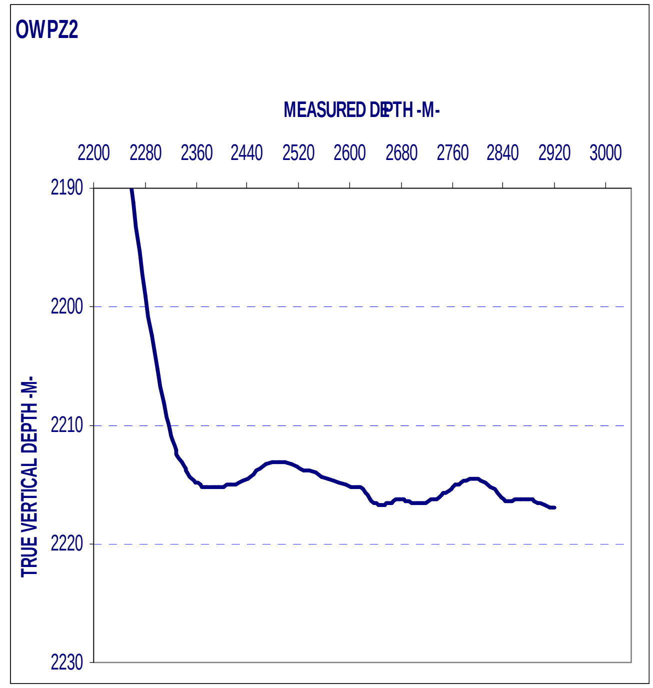
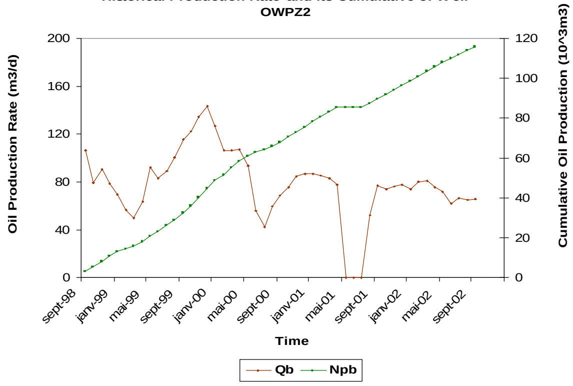


Figure 2
Historical Production Rate and its Cumulative of Well
OWPZ2



Historical Gas Oil Ratio and Water Cut
Puits OWPZ2

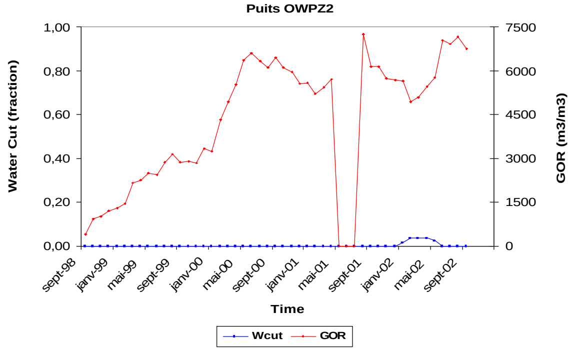
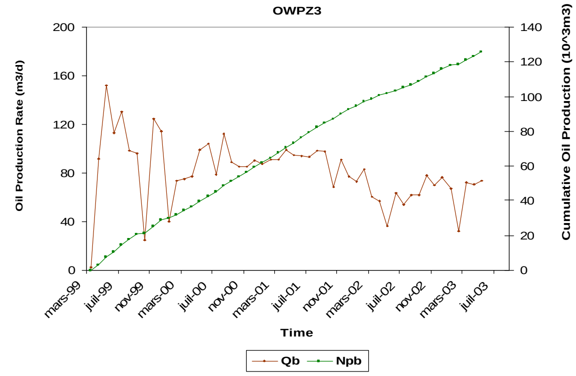
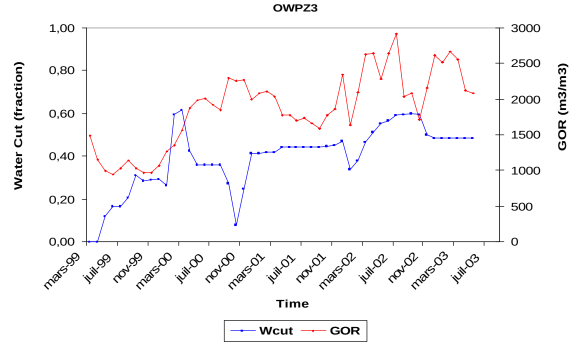
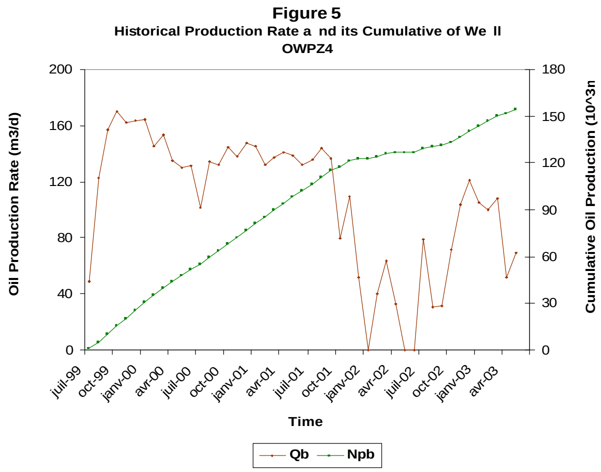


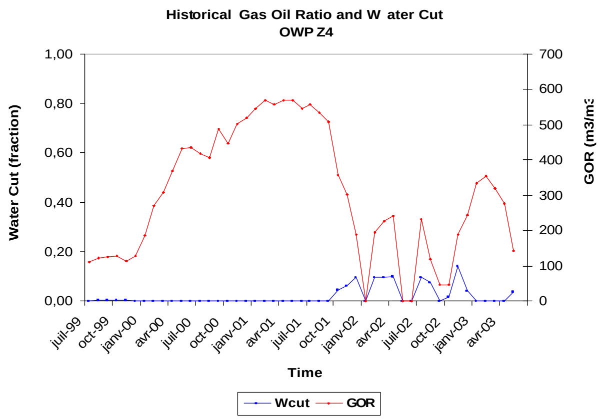
Figure 4
Historical Production Rate and its Cumulative of We ll
OWPZ3

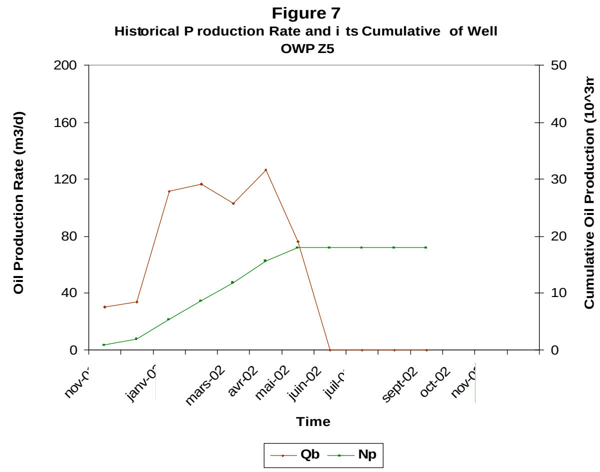


Historical Gas Oil Ratio and Water Cut
OWPZ3









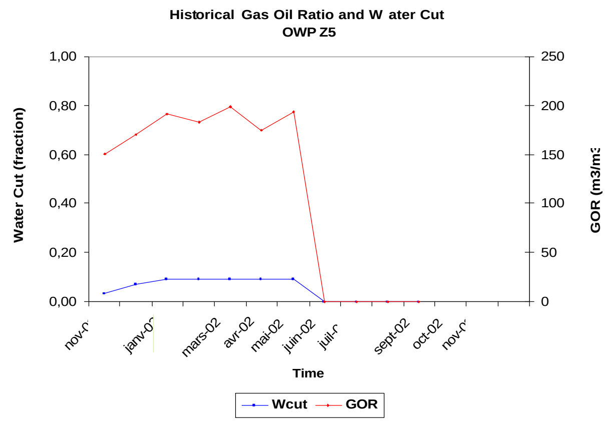


Figure 6 Simulation Results of gas-lift well OWPZ4

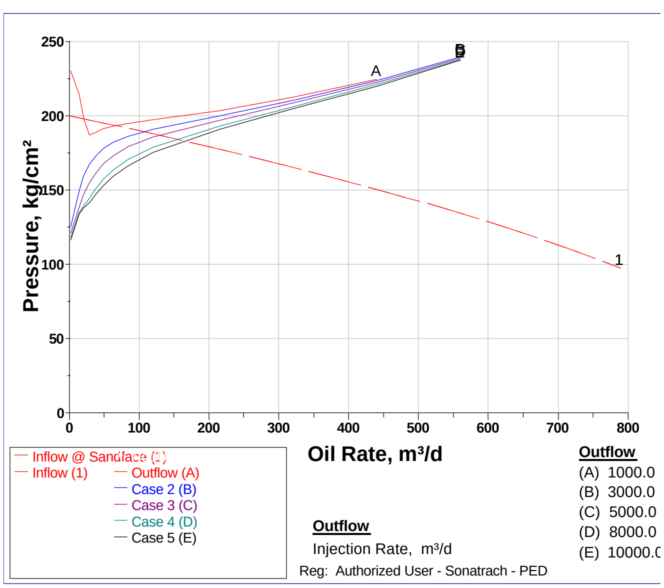


Figure 8 Simulation Results of gas-lift well OWPZ5

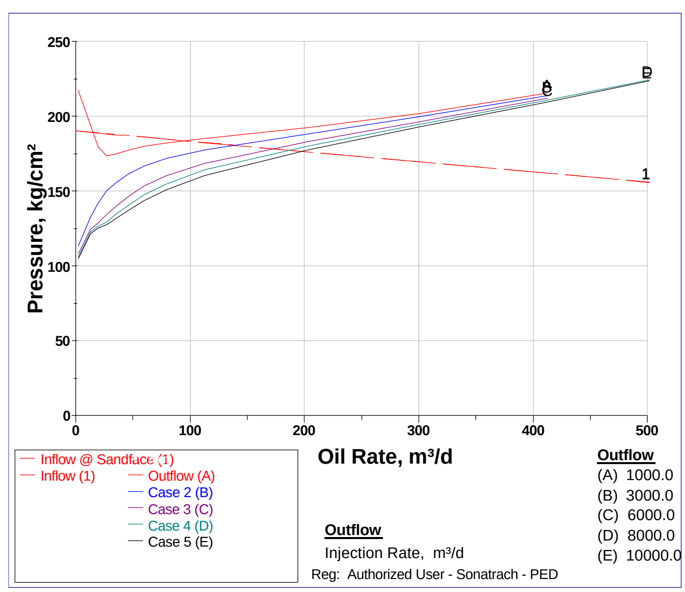
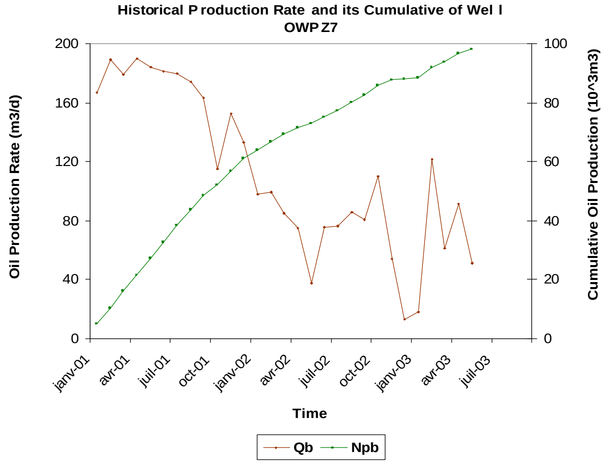


Figure 9



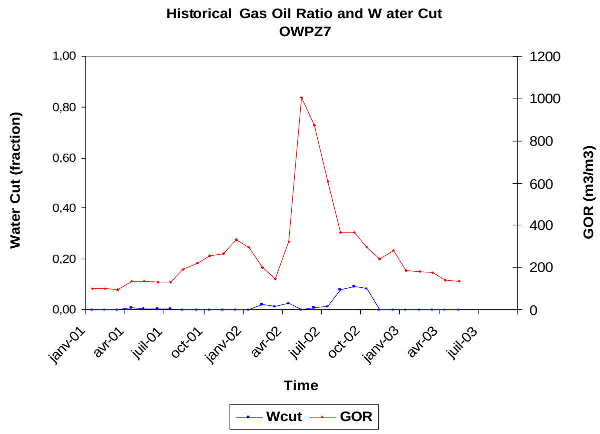


Figure 11 Simulation Results of gas-lift well OWPZ7

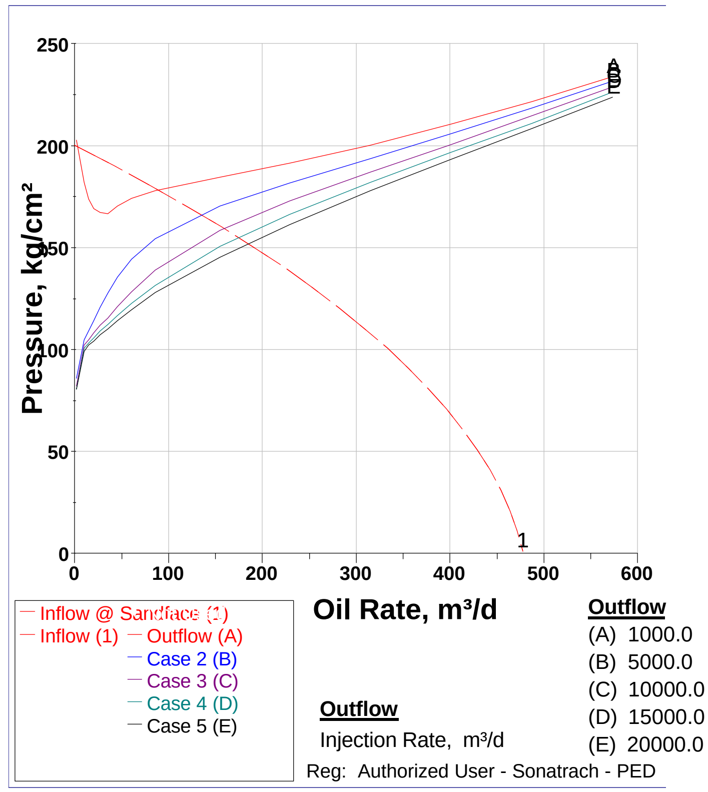
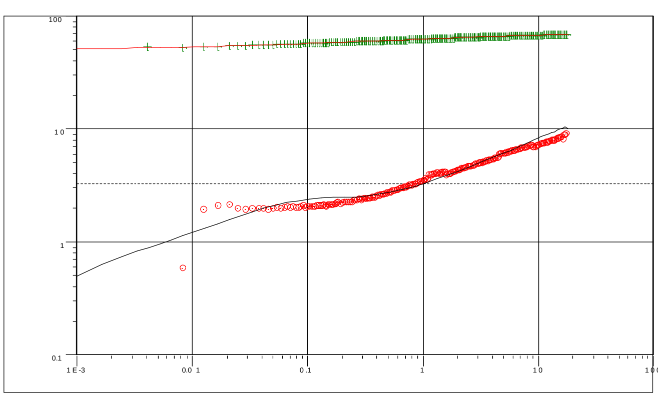
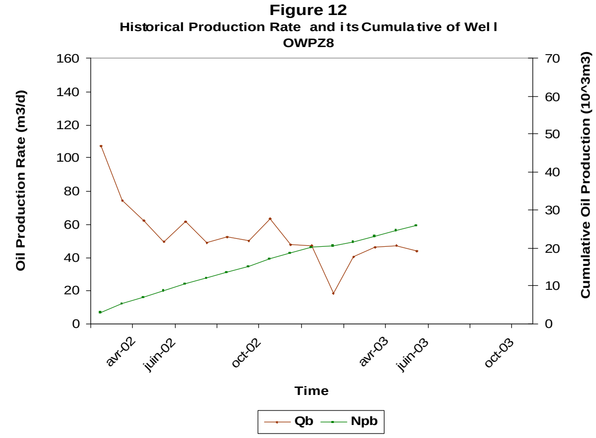


Figure 10 Transient well test analysis well OWPZ7



Log-Log plot: dp and dp' [psi] vs dt [hr]

Figure 12



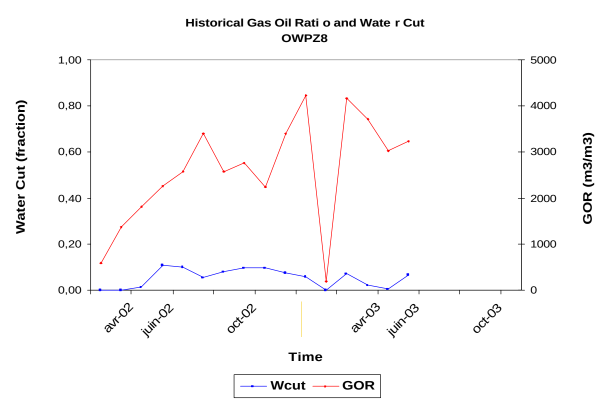
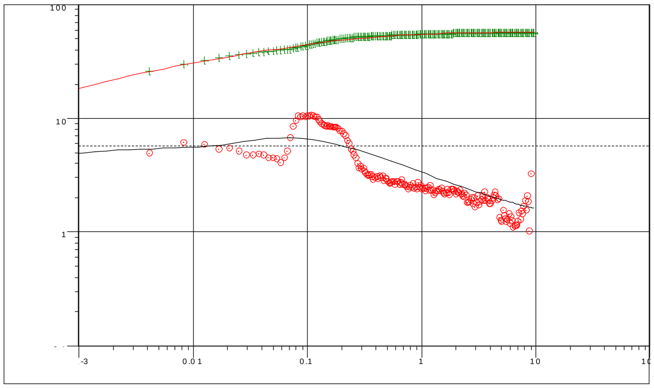
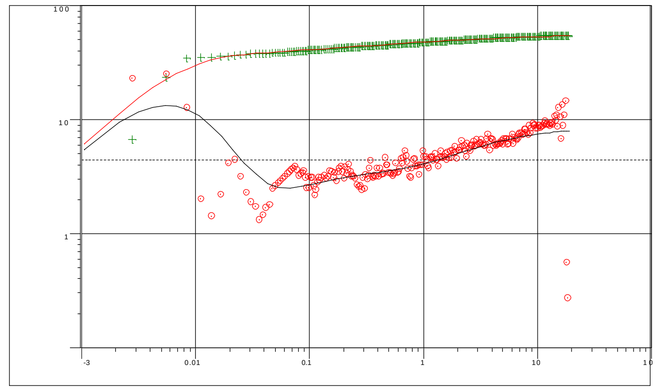


Figure 13 Transient well test analysis well OWPZ8



Log-Log p lot: dp and dp' [psi] vs dt [hr]

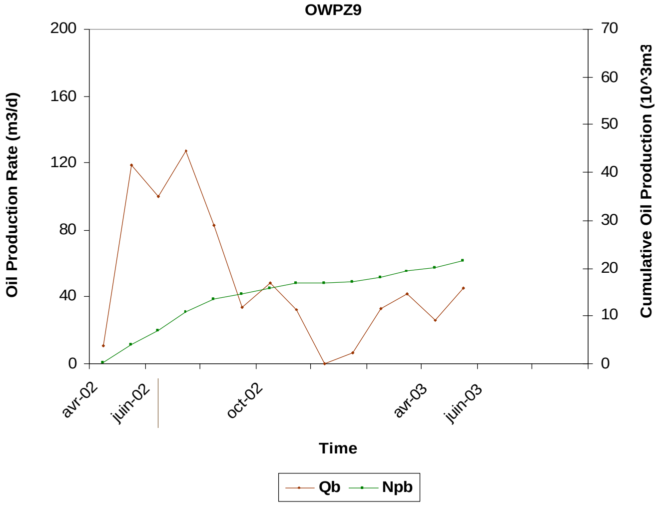
Figure 15 Transient well test analysis well OWPZ9



Log-Log plot: dp and dp' [psi] vs dt [hr]

Figure14

Historical P roduction Rate and its Cumulative of We ll OWPZ9



Historical Ga s Oil Ratio and Wa ter Cut OWPZ9

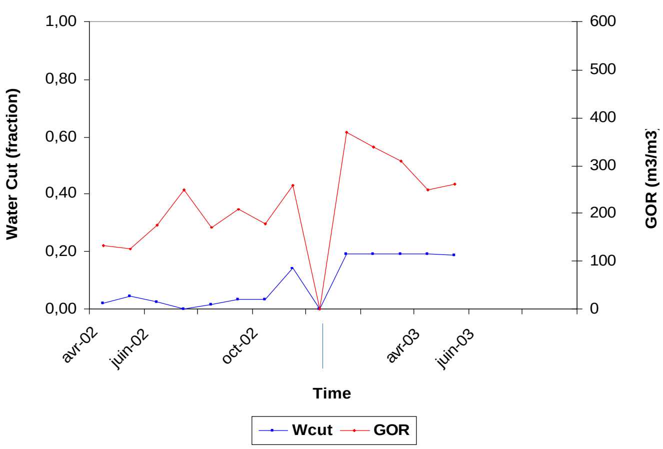


Figure 16 Simulation Results of gas-lift well OWPZ9