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Production Optimization and Reduction of Water Cut of a Horizontal Multilayer Well with Autonomous Inflow Control Devices

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Abstract

The production influx changes from reservoir into the wellbore, this fluctuation is considered to be the main source of problems caused in the production management. The reason is difference between mobility of water and oil. As water is less viscous than oil, it flows faster than oil. The high water production rate requires larger water treatment facilities ultimately increasing the operating cost, meanwhile there is lesser provision for these facilities in offshore setup. In this paper it is described, how advanced well completion equipped with autonomous inflow control devices AICDs increases oil production while reducing water flow rates even after water breakthrough. The compatibility of AICDs is evaluated for better water production management in mature fields. In order to counter these problems a simulation study is required to design the well completion along with the required number of packers, devices and their sizes. The inflow control technology is capable to create higher or lower drawdown on the reservoir in order to assure the maximum flow of oil while restricting water to flow through. Autonomous ICDs proved to be the best inflow control devices and are efficient to be used in well with very high water cuts i.e. up to 90%. This study shows the application of AICDs for production optimization and reduction of water cuts in mature oil fields.

Keywords: Smart Completions; Inflow Control Devices; Mature Oil Fields; Completion Design; Performance Evaluation.

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1. Introduction

The properties of reservoir keeps on changing with respect to time such as petrophysical properties, fluid properties, fluid contacts and layer pressure in the zones where horizontal wells are drilled to get maximum reservoir contact, also these reservoir changes can give birth to various challenges like early gas and water breakthrough and reduced production rates of oil. The smart well completions can be deployed to counter these challenges as the smart completion tools can manage the reservoir influx towards wellbore. As the reservoir influx is managed the production performance of the well will be optimized [2].

The downhole flow control devices such as inflow control devices, autonomous inflow control devices and swell packers are considered to be the main components of the smart completion assembly. The most commonly deployed AICD is rate controlled production device (RCP) [15]. Main purpose of AICD is to generate a variable plunge, these variations depend on the properties of fluids and flow rate, based on the aperture between a levitating disc and the top plate of housing also on the inlet nozzle size. The fluid enter though inlet of RCP which is nozzle, applies hydraulic pressure on the disc and spread radially through the aperture between housing and disc, though the special passage, fluid revolves around the disc and discharges through the outlet ports in the housing. The pressure drop is artificially created for the desired fluid with the help of critical design of device and the ability to balance the forces effectively. The momentum of jetting fluid through nozzle and the net pressure difference above and below the disk created by pressure drop due to friction of fluid, as the fluid flows through the gap to the outlet ports.

2. Method Section

Different cases are studied in this research related to smart completions. Two trajectories with three different completion designs are simulated. After the production reaches pleatue it starts to decline rapidly, that is the point where incorporating smart completions become mandatory. The water is less viscous than oil, it break throughs and starts to produce at surface to avoid water production and yeild maximum amount of oil necessary steps are taken. IPM suit is used to simulate the well completions and trajectories. In first case a horizontal artificial well is simulated with PROSPER the results are generated and compared with the other two cases of smart multilayer wells and results are concluded. The artificial lifted horizontal well is compared with a smart well that is lifted with and without artificial lift system. The production responses are then compared to conclude the results where smart well proved to perform better for high water cut conditions. The completion profiles are simulated and sensitivity analysis is done on PROSPER, and on the basis of results best case was choosen. The prime goal of this research was to eliminate the produced water and to maximize the oil production also to recover maximum reserves. The produced water is harmful Comparison of base case where a horizontal well is simulated with a smart multilayer artificially lift well. Quantifying the production rates and analyzing sensitivities of base case and after installation of smart well completion equipped with AICDs with REVEAL simulation software. Evaluation and estimation of production rates, percentages of produced fluids, and pressure drop (decline curve analysis) after installation of AICDs. Analyzing the after effects of varying PVT properties on AICDs performance. The last step is to conclude results, discussions related to advancement of Smart well technology and comparisons simulating various case by varying parameters like GOR, WOR, GLR, reservoir pressure, and water cut.

3. Results

PROSPER and REVEAL simulation software are used for completion design and evaluating production performance. The results obtained from simulation of different cases are shown in this chapter. The effects of completion design on production rates are estimated also the change in water production after installation of smart completion is simulated and discussed.

3.1. Case 1 Horizontal ESP Well

The IPR pressure and temperature sensitivities for different water cut percentages i.e. (0, 10, 20, 50, 75, and 90%) in horizontal well lifted on ESP show in Figure 1. The data is summarized as flow type is tubing flow lifted with ESP and well is cased with single branch. The reservoir pressure is 4800 psi, reservoir temperature is 225 ºF and 78 percent water cut. Subsequently it can be seen that water cut does not affect IPR pressure curve but its effects can be clearly seen on IPR temperature curve. At higher flow rates the temperature difference increases with different water cut percentages and it combines at a single point on AOF where the temperature becomes constant that's 221.5 ºF.

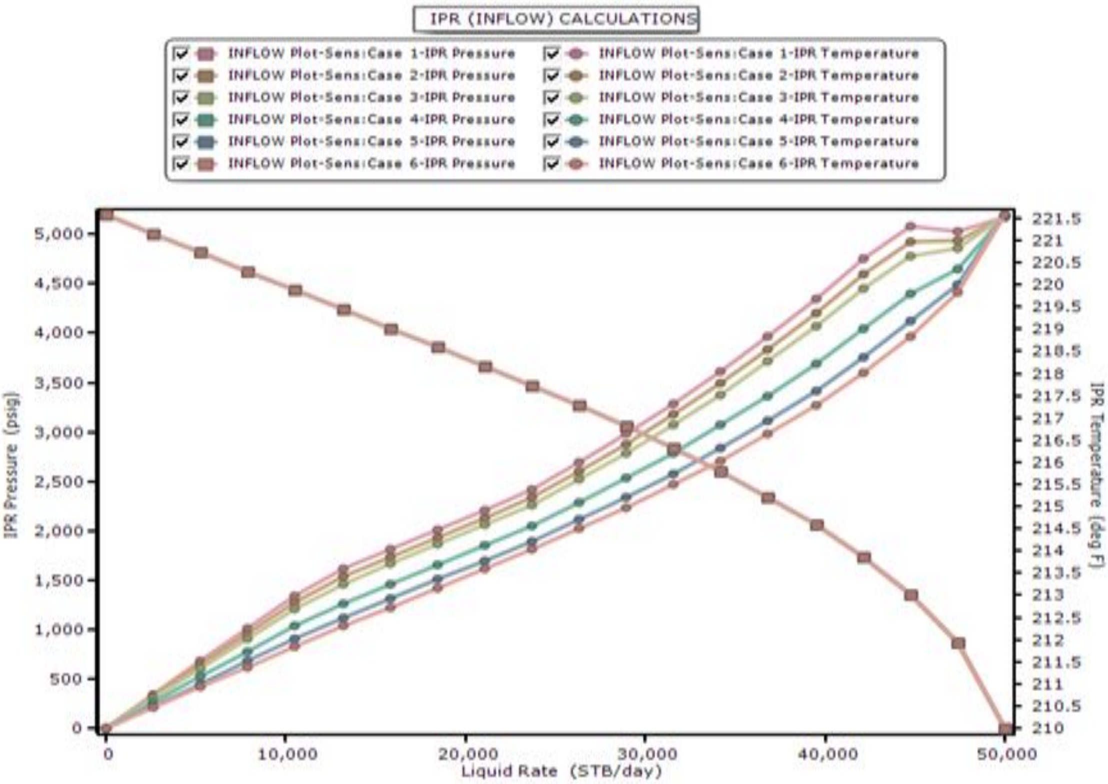

Figure 1: IPR Curves for water cut sensitivities.

This IPR pressure and temperature curve is generated for a horizontal well lifted with ESP shown in Figure 2. The reservoir pressure is 4800 psi and reservoir temperature is 225 ºF, at AOF the well is producing 56000 STB/day. At optimum conditions of pressure and temperature the maximum flow rate should be 22000 STB/day.

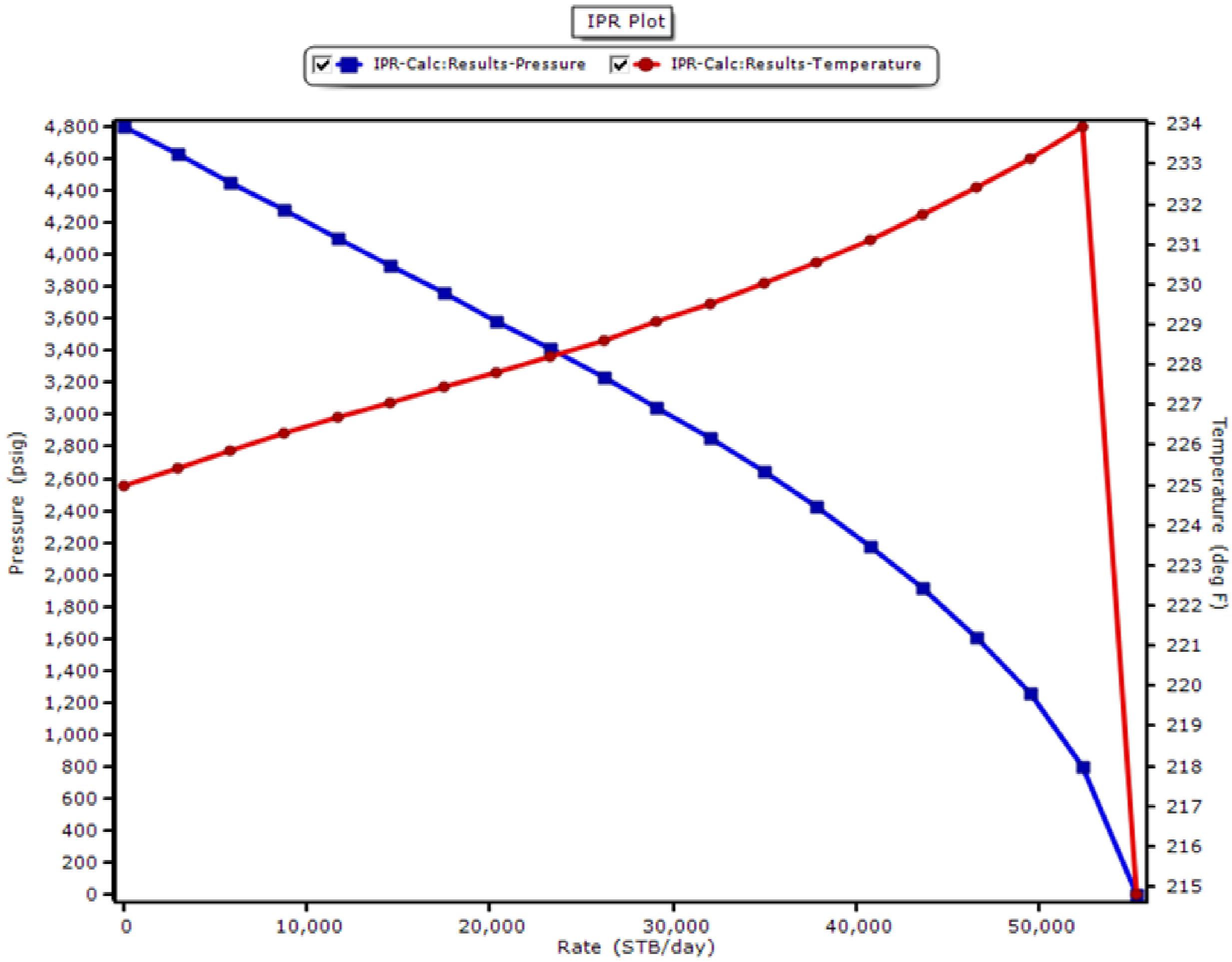

Figure 2: IPR pressure and temperature curves.

3.1.1. ESP Performance Efficiency

The Reda ESP efficiency graph is shown in Figure 3, it portrays four factors motor efficiency, amperes, power factor and motor speed at (40, 50, 60, 70 Hz). The power factor curve and motor efficiency curve are parabolic while amperes and motor speed show a slight linear trend on graph. ESP used is Reda maximus with a Reda motor 540 operated on 3897 volts and 69.5 amperes and produces 420 horse power. The pump is Reda DN3500 here 'D' shows diameter of pump which is 4 inch and 'N' shows the material type or metallurgy of pump then 3500 is model number of pump, this pump can lift approximately 4500 RB/day. The pump consist of 215 stages, a stage is combination of impeller and diffuser, and it is installed at a depth of 5000 ft. submersed in 500 ft. liquid column. The VSD is adjusted at a frequency of 60 Hz and surface voltage is 3400 volts. The optimum operating point is at 3300 RPM where efficiency is 70% and operating frequency is 57 Hz.

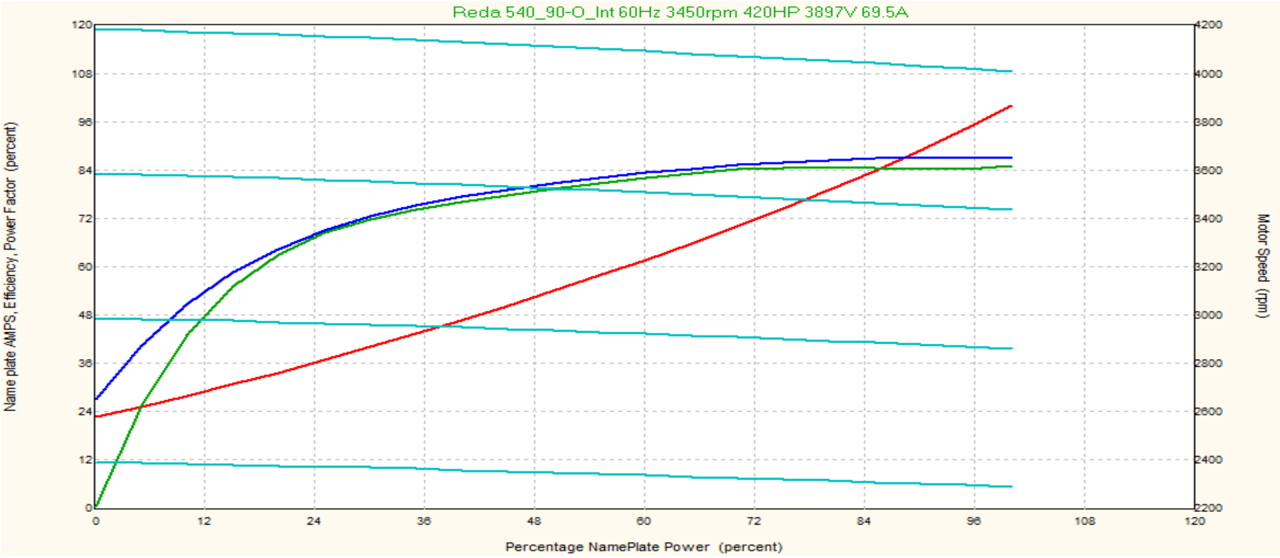

Figure 3: Reda ESP efficiency curve.

The Table 1 shows the production testing data where values of IPR and VLP pressures are shown along with oil, water and gas production rates. Before attaining maximum reservoir contact (MRC) by drilling a horizontal well the oil production is 600 STB/day with 0% water cut while the gas production is 0.46 MMSCF/day. The case is iterated after well is converted to a horizontal MRC well to check for the improvements in production.

Table 1: Production sensitivity data.

Point	**Liquid Rate STB/day**	**Oil Rate STB/day**	**Water Rate STB/day**	**Gas Rate MMscf/day**	**VLP Pressure (Psi)**	**IPR Pressure (Psi)**	**dP Perforation (Psi)**
1	40	40	0	0.03200	0	4451.36	0
2	46.0551	46.0551	0	0.03684	3216.64	5196.64	0
3	53.0267	53.0267	0	0.04242	3207.62	5196.14	0
4	61.0537	61.0537	0	0.04884	3197.19	5195.55	0
5	70.2958	70.2958	0	0.05624	3185.13	5194.88	0
6	80.937	80.937	0	0.06475	3171.17	5194.1	0
7	93.1889	93.1889	0	0.07455	3155.02	5193.21	0
8	107.296	107.296	0	0.08584	3136.35	5192.18	0
9	123.538	123.538	0	0.09883	3114.76	5191	0
10	142.238	142.238	0	0.11379	3089.85	5189.63	0
11	163.77	163.77	0	0.13102	3061.17	5188.06	0
12	188.561	188.561	0	0.15085	3028.28	5186.26	0
13	217.105	217.105	0	0.17368	2990.78	5184.18	0
14	249.969	249.969	0	0.19998	2948.38	5181.78	0
15	287.809	287.809	0	0.23025	2852.86	5179.02	0
16	331.376	331.376	0	0.26511	2727.51	5175.85	0
17	381.539	381.539	0	0.30523	2635.07	5172.19	0
18	439.295	439.295	0	0.35144	2510.54	5167.98	0
19	505.794	505.794	0	0.40463	2403.53	5163.14	0
20	582.359	582.359	0	0.46589	2308.42	5157.55	0

The Figure 4 shows the IPR VLP curve, the intersecting point is known as operating point. It is concluded that if the MRC horizontal wells are drilled they can boost up the oil rates, here in this case oil production increased from 600 STB/day to 2545 STB/day but due to a narrow oil window water production also increases. The water cut reaches to 78.8 percent (9455 RB/day), due to high water production rates there is a need for the water treatment facility which requires routine maintenance hence, increases the operating cost.

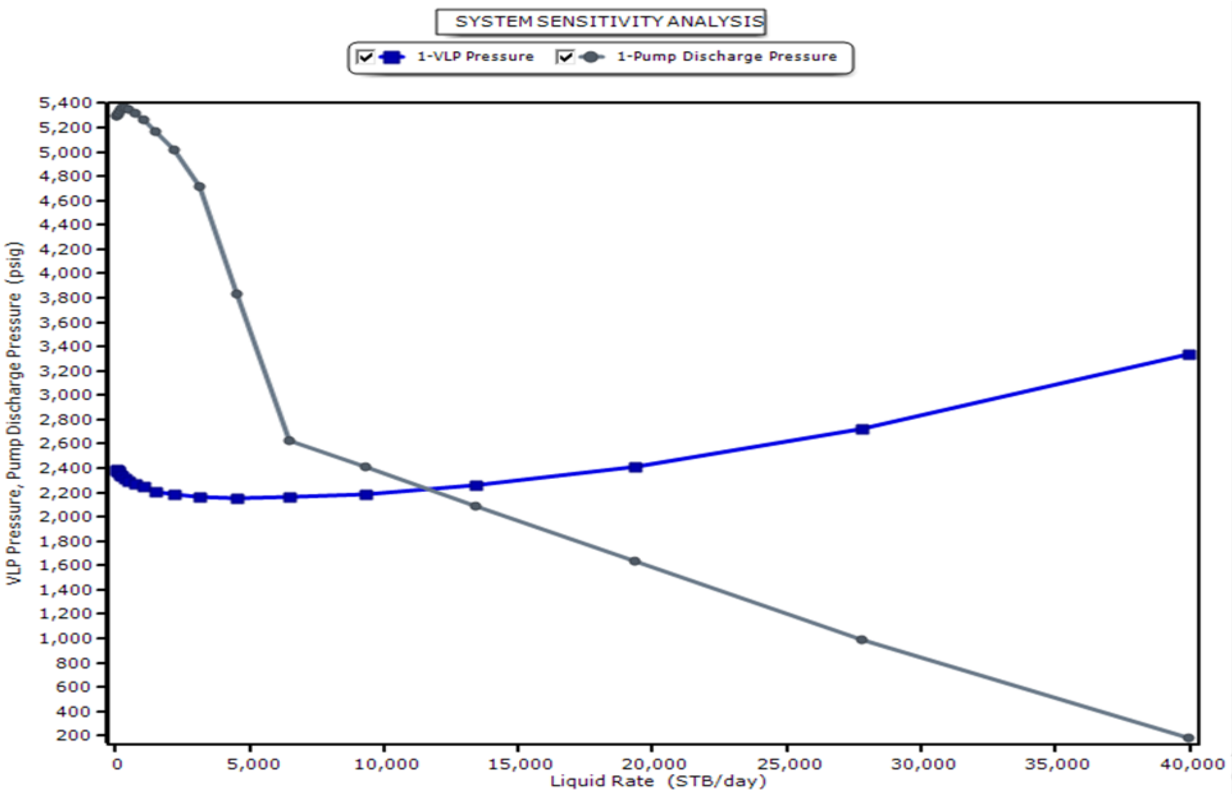

Figure 4: Pump discharge vs VLP graph.

The Reda ESP efficiency graph is shown in Figure 5, it portrays four factors motor efficiency, amperes, power factor and motor speed at (40, 50, 60, 70 Hz). The power factor curve and motor efficiency curve are parabolic while amperes and motor speed show a slight linear trend on graph. this pump can lift approximately 4500 RB/day. The pump consist of 215 stages, a stage is combination of impeller and diffuser, and it is installed at a depth of 5000 ft. submersed in 500 ft. liquid column. The VSD is adjusted at a frequency of 60 Hz and surface voltage is 3400 volts. The optimum operating point is at 3450 RPM where efficiency is 83%.

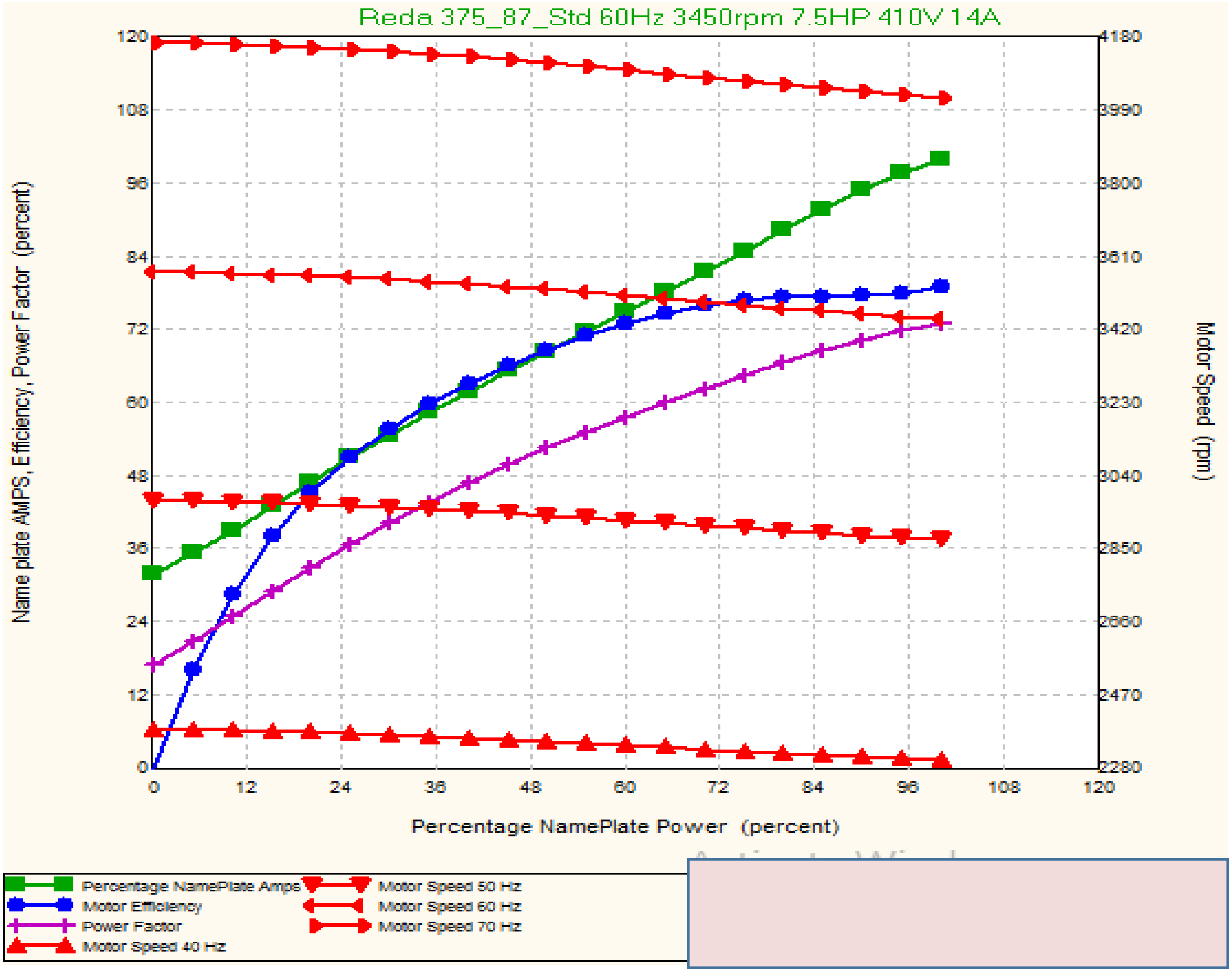

Figure 5: ESP motor performance for different frequencies.

Figure 6 depicts pump performance for minimum and maximum pump rate, it also portrays the head, power and efficiency of pump. This information is necessary to evaluate optimum operating point for the ESP in-order to maximize the run time of ESP and to avoid the workovers. The optimum point can be concluded as the pump minimum rate point where the value of head, power and efficiency are at their maximum points, while ESP can produce up to 3500 RB/day.

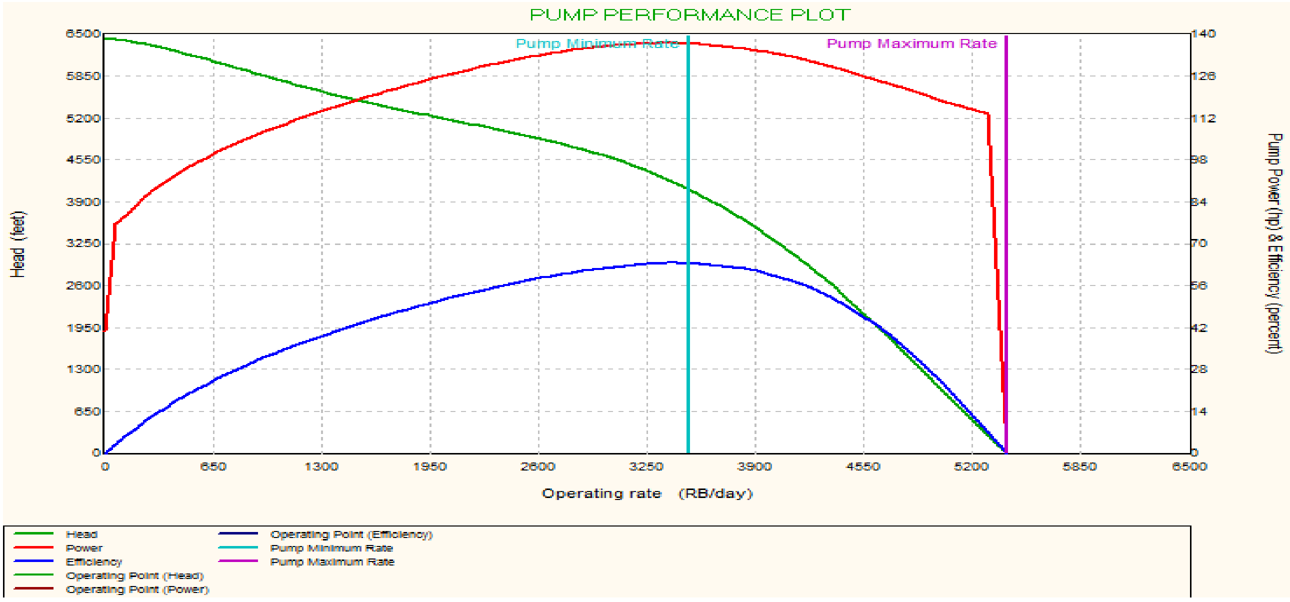

Figure 6: Pump performance plot.

The Table 2 & 3 shows the production testing data where values of IPR and VLP pressures are shown along with oil, water and gas production rates. Before attaining maximum reservoir contact (MRC) by drilling a horizontal well the oil production is 8475 STB/day with 78.8% water cut while the gas production is 3.81 MMSCF/day. The case is iterated after well is converted to a horizontal MRC well to check for the improvements in production.

Table 2: Production rate calculated vs measured.

Sr. No.	Label	Value	Units
1	Calculated Liquid Rate	13193.8	STB/day
2	Calculated Oil Rate	2797.07	STB/day
3	Calculated Water Rate	10396.7	STB/day
4	Calculated Gas Rate	1.25868	MMscf/day
5	Calculated Bottom Hole Pressure	3777.68	Psig
6	Measured Liquid Rate	21000	STB/day
7	Measured Oil Rate	4452	STB/day
8	Measured Water Rate	16948	STB/day
9	Measured Gas Rate	2.0034	MMscf/day
10	Measured Bottom Hole Pressure	3980.84	Psig
11	% Difference Liquid Rate	-37.1726	Percent
12	% Difference Oil Rate	-37.1726	Percent
13	% Difference Water Rate	-37.1726	Percent
14	% Difference Gas Rate	-37.1726	Percent
15	% Difference Bottom Hole Pressure	-5.10345	Percent

Table 3: Production rates VLP and IPR.

Point	Liquid Rate STB/day	Oil Rate STB/day	Water Rate STB/day	Gas Rate MMscf/day	VLP Pressure (Psi)	IPR Pressure (Psi)
1	40	8.48	31.62	0.003816	4726.9	1197.23
2	57.5396	12.2975	45.328	0.0054889	4795.54	1175.89
3	82.7586	17.5440	65.2137	0.0078952	4793.59	1146.27
4	119.039	25.2363	93.8027	0.011356	4790.78	1113.59
5	171.224	36.2996	134.925	0.016335	4786.74	1077.63
6	246.287	52.2129	194.074	0.023486	4780.92	1041.21
7	354.257	75.5025	279.155	0.033796	4772.56	1003.02
8	509.56	108.027	401.533	0.048612	4760.52	961.198
9	732.945	155.384	577.561	0.059923	4743.22	921.75
10	1034.26	223.503	830.757	0.10038	4718.33	923.499
11	1516.44	321.485	1194.95	0.14067	4682.52	1029.97
12	2180.23	462.42	1718.81	0.20809	4631.02	1241.98
13	3137.45	665.14	2472.31	0.29931	4556.93	1920.77
14	4512.85	956.73	3556.15	0.43010	4450.37	3687.06
15	6491.28	1376.15	5115.13	0.61927	4297.07	3693.49
16	9336.98	1979.44	7357.54	0.89075	4076.56	3721.5
17	13430.2	2847.21	10582	1.28124	3759.35	3791.12
18	21000	4452	16548	2.0034	3172.62	3930.84
19	27786.6	5890.77	21895.9	2.65084	2646.49	4256.02
20	39968	8373.21	31494.8	3.01299	1662.11	5004.86

3.2 Case 2 Multilayer Smart Well

The following Table 4 shows reservoir model data which includes three different reservoir layers with variable pressures i.e. 5200, 5320, 5325psig respectively. The layer flowing radius and layer roughness are same for all three reservoir layers. The well is defined as multilayered horizontal well as it can be seen in the table that measured depth and true vertical depth are not same. The column that shows the layer type, actually indicates the smart tools section and the packer sections. The perforated section is where AICDs are installed while the blank section shows the spacer tube and swell packers.

Table 4: Model data input screen for multilayer smart well.

Layer	Layer Type	Layer IPR Model	Layer Skin Model	Measured Depth (feet)	True Vertical Depth (feet)	Layer Pressure (Psig)	Layer Flowing Radius (ft.)	Layer Roughness (inches)
Top				9275	9000			
1	Perforated	Darcy	By Hand	9305	9025	5200	0.3175	0.0006
2	Blank			9318	9035		0.3175	0.0006
3	Perforated	Darcy	By Hand	9350	9060	5320	0.3175	0.0006
4	Blank			9370	9075		0.3175	0.0006
5	Perforated	Darcy	By Hand	9405	9100	5325	0.3175	0.0006

This IPR pressure and temperature curve shown in Figure 7 is generated for a multilayer smart well lifted with ESP. The reservoir pressure is 5200 psi and reservoir temperature is 236 ºF, at AOF the well is producing 33000 STB/day. At optimum conditions of pressure and temperature the maximum flow rate should be 18000 STB/day.

This IPR pressure and temperature curve shown in Figure 7 is generated for a multilayer smart well lifted with ESP. The reservoir pressure is 5200 psi and reservoir temperature is 236 ºF, at AOF the well is producing 31045 STB/day. Moreover, IPR pressure curve is generated for three layers i.e. layer 1, 3, and 5 respectively. The AOF for layer 1 is 8462 STB/day, for layer 3 is 9152 STB/day and for layer 5 is 13429 STB/day.

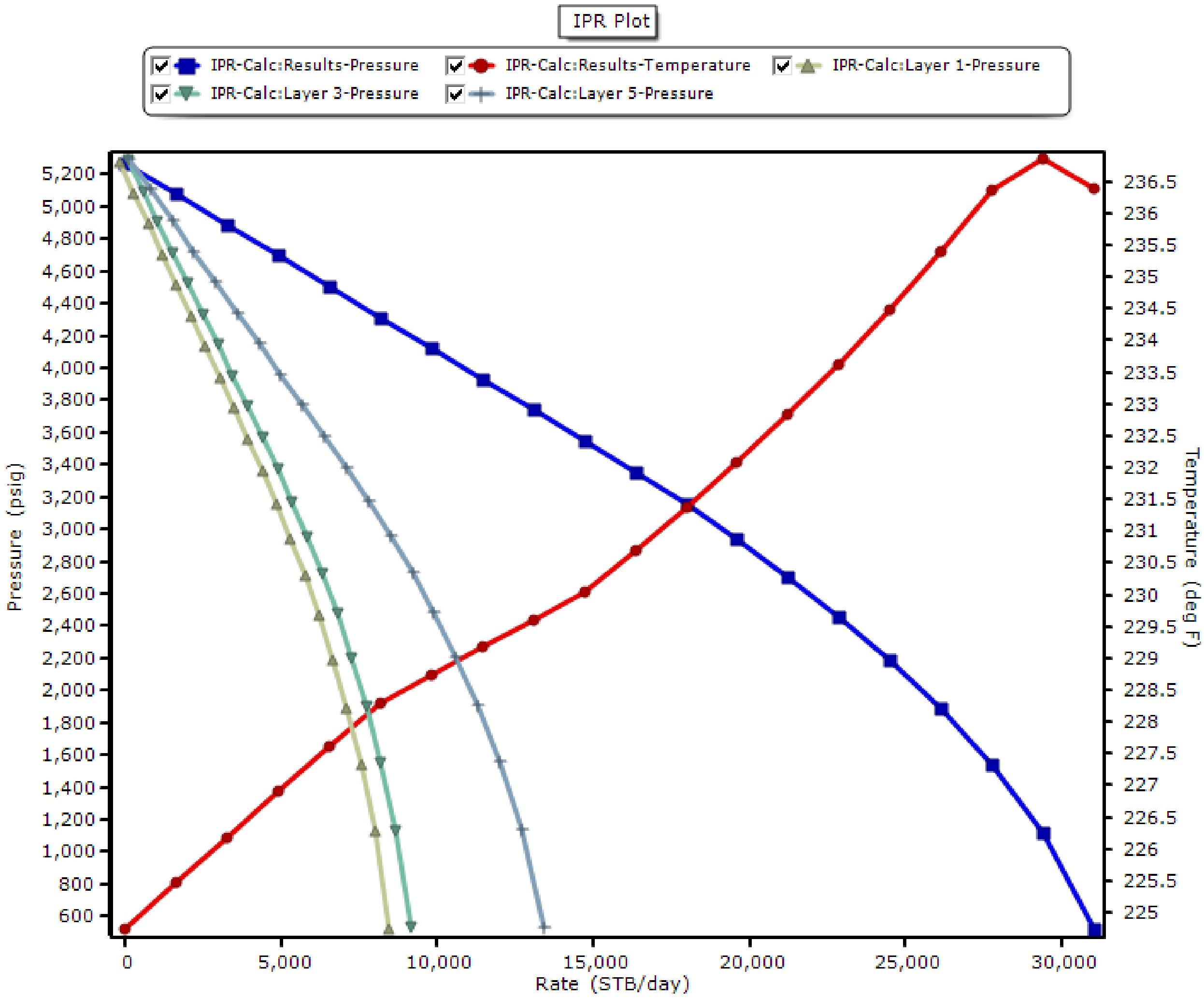

Figure 7: IPR temperature and pressure plot for individual reservoir layers.

The Figure 8 shows the ESP motor performance in multilateral wells, where motor efficiency, power factor, and motor speed at different operating frequencies. ESP motor is operating at 60 Hz producing 3450 RPM at 69.5 Amps. According to the interpretation of graph the pump can perform better at 63-66 Hz of frequency, which would be an optimum point to produce maximum oil in a smart multilateral well without damaging the ESP motor.

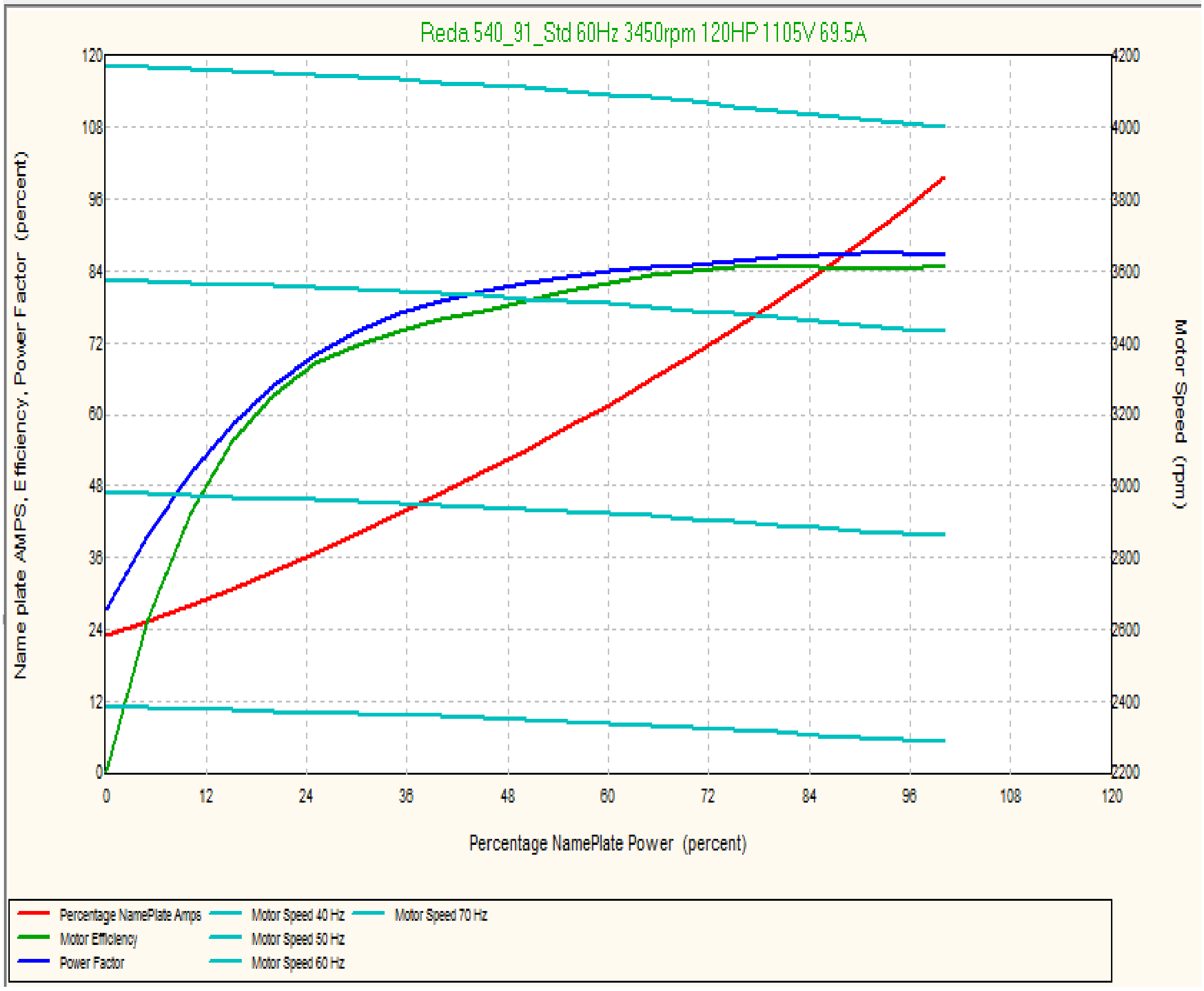

Figure 8: ESP motor efficiency in multilayer smart well.

The following Figure 9 depicts the ESP performance deployed in a multilayer smart well. The graph shown in figure portrays the ESP motor operating frequencies with maximum operating rate that ESP can produce at a specific RPM. The minimum and maximum operating ranges are shown in red color while the blue line shows the best efficiency of ESP at 66.5 Hz. At optimum conditions maximum operating rate is 5700 RB/day and minimum operating rate is 3650 RB/day.

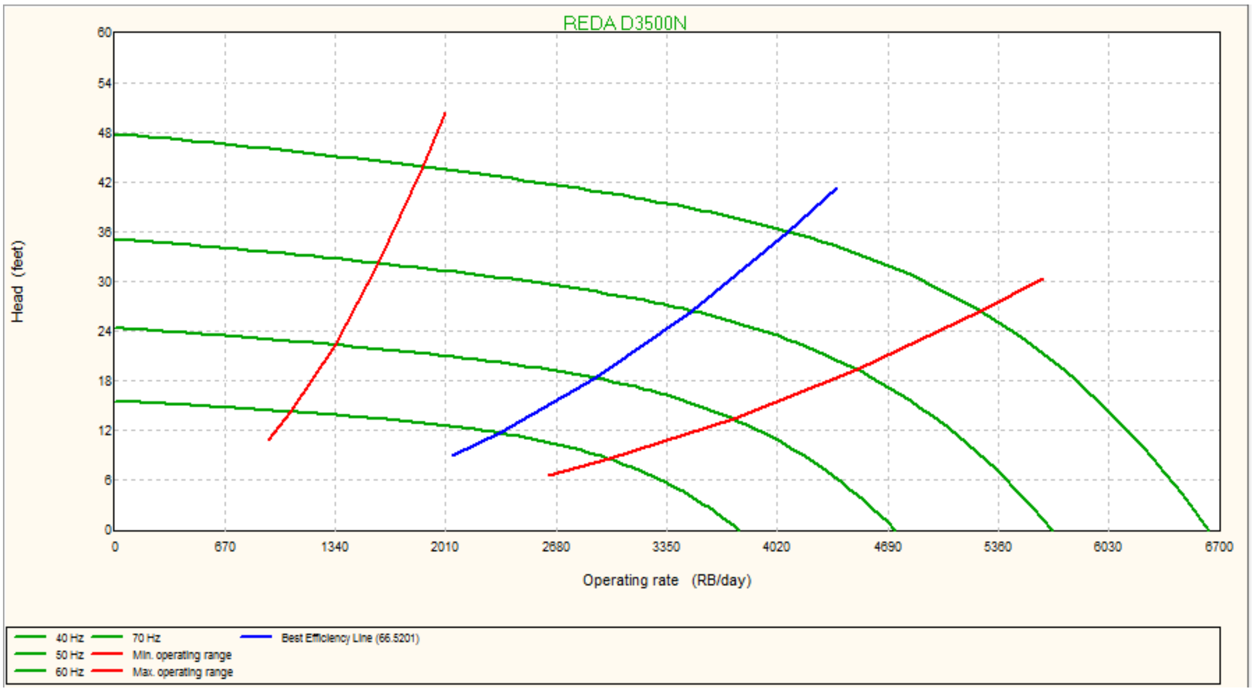

Figure 9: ESP performance efficiency plot deployed in multilayer smart well.

In Figure 10 the electrical submersible pump performance plot is shown where it indicates liquid head, ESP power, efficiency, and ESP operating ranges. The operating rate ranges between 1600 RB/day to 4500 RB/day, while the optimum operating rate is 3600 RB/day. At optimum point pump generates a 5400ft head, 162 HP pump power, and efficiency is 70%.

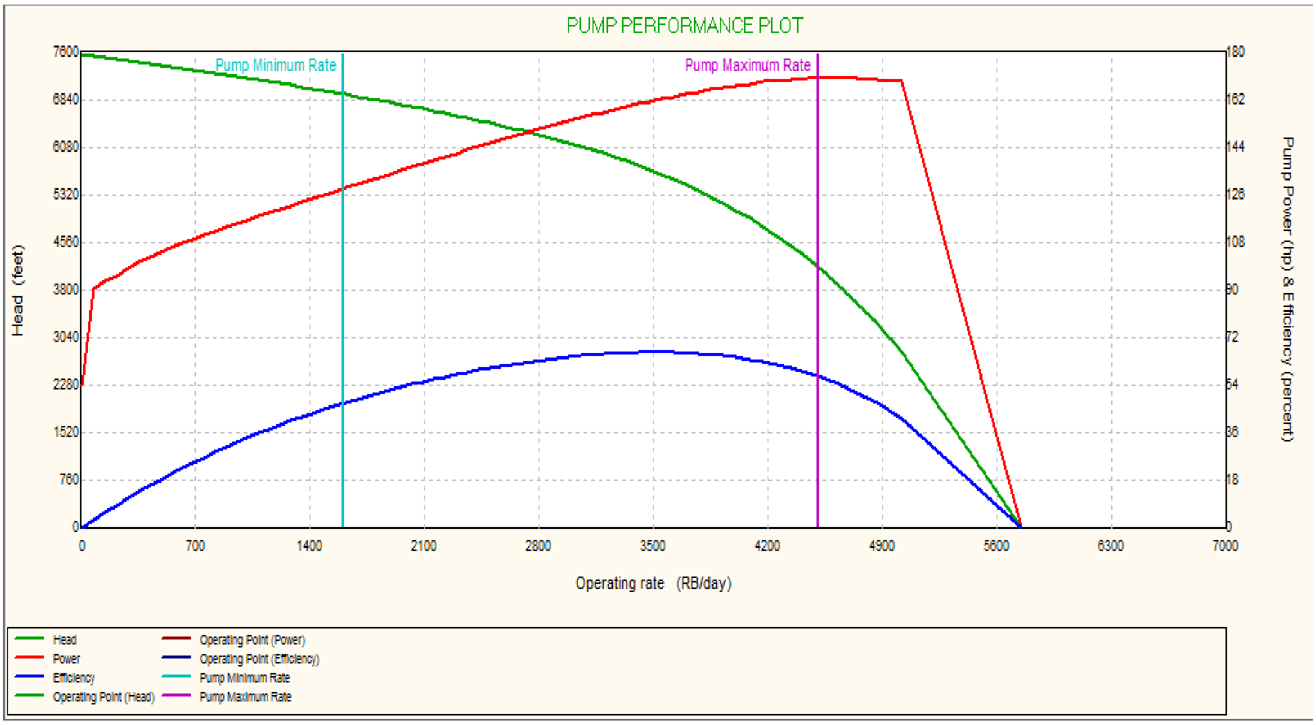

Figure 10: Pump performance plot.

Figure 11 illustrates gradient transverse plot for multilayer smart well, gradient shows the properties changes associated to the depth. The pressure line shows a steady trend and pressure drops as the fluid flows through wellbore, at 9000 ft. pressure is 4800 psi but it declines to 3850 psi at a depth of 5800 ft. where ESP is installed. The fluid flowing pressure starts to rise up as it enters the ESP and reaches 5100 psi, the plunge can be seen in pressure line due to outflow, multiple factors are involved in this pressure drop like friction, flow type, wall roughness of pipe, gravitational force and the restrictions of flow path. At 9000 ft. of depth the temperature is around 210 ⁰F, a sharp drop can be seen at 5800 ft. where ESP is installed, this sharp decline is due to rotation of impellers and diffusers. The temperature declines below 100 ⁰F near to the surface, this continuous drop is due to gradient, and values of pressure and temperature are very much dependent on depth.

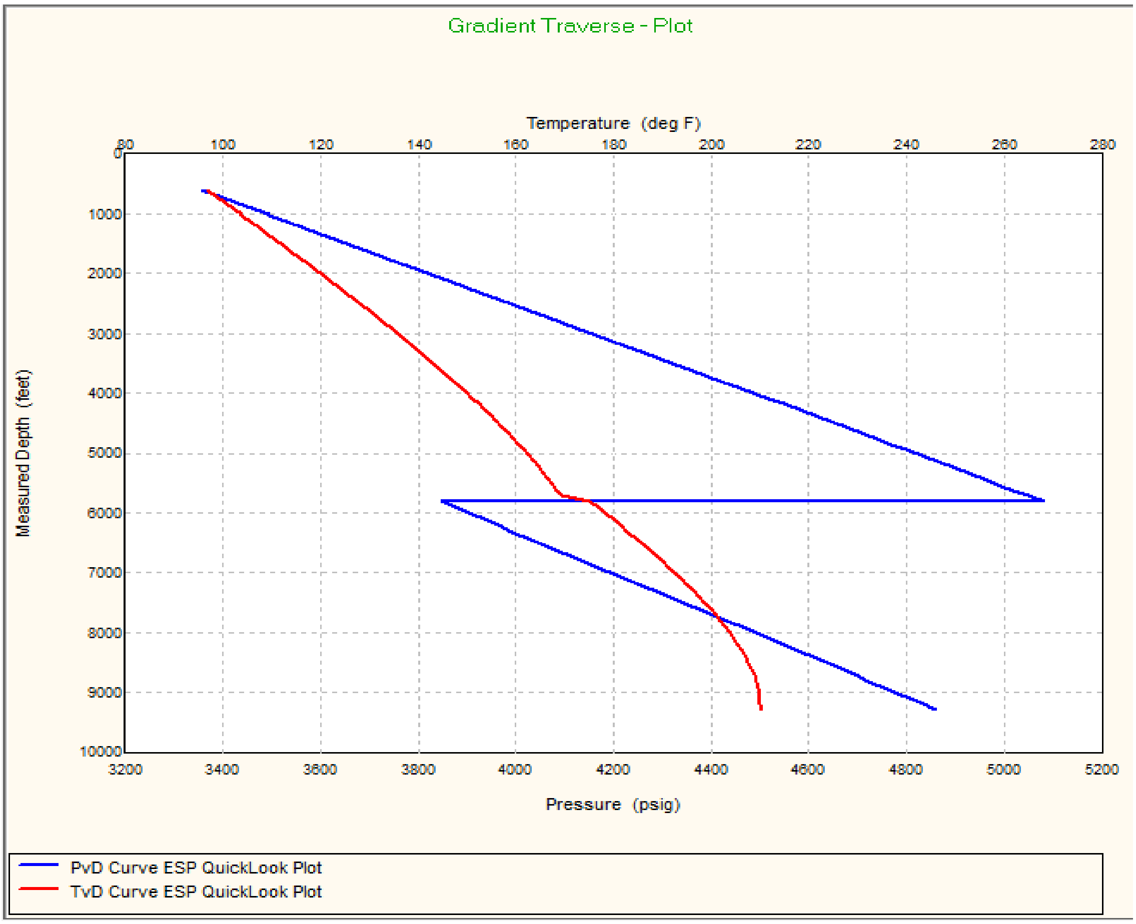

Figure 11: Gradient transverse plot for multilayer smart well.

3.3. Case 3Multilayer well without ESP

In Figure 12 IPR pressure and temperature curve is shown and it is generated for a naturally flowing multilayer smart well. The reservoir pressure is 5200 psi and reservoir temperature is 236 ⁰F, at AOF the well is producing 28433 STB/day. Moreover, IPR pressure curve is generated for three layers i.e. layer 1, 3, and 5 respectively. The AOF for layer 1 is 7751 STB/day, for layer 3 is 8383 STB/day and for layer 5 is 12299 STB/day.

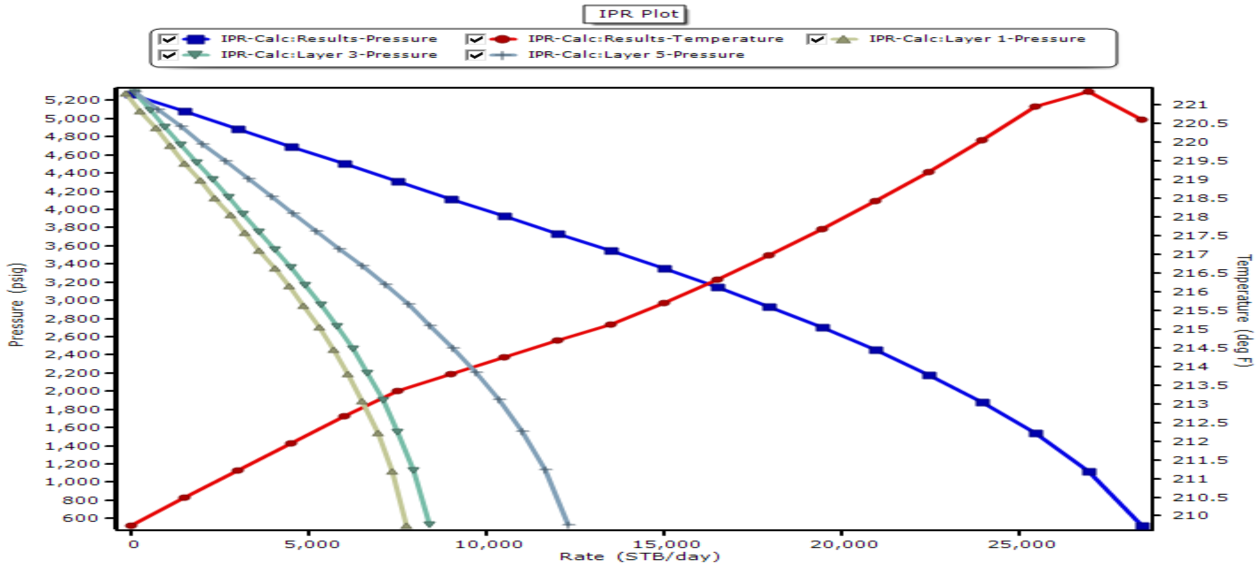

Figure 12: IPR temperature and pressure plot for individual reservoir layers.

The Figure 13 shows the cumulative production history of AICD project for 5 years period. The cumulative water production reaches to 21000000 STB while the cumulative oil production 9500000 STB. The cumulative water production line shows steady rocketed behavior but, as the line is linear it means water production is rising in a controlled manner. Furthermore unlike conventional production history results, no sharp curves are observed. The reservoir has underlying strong aquifer, where horizontal well is shown equipped with smart completion tools like ICD and AICD.

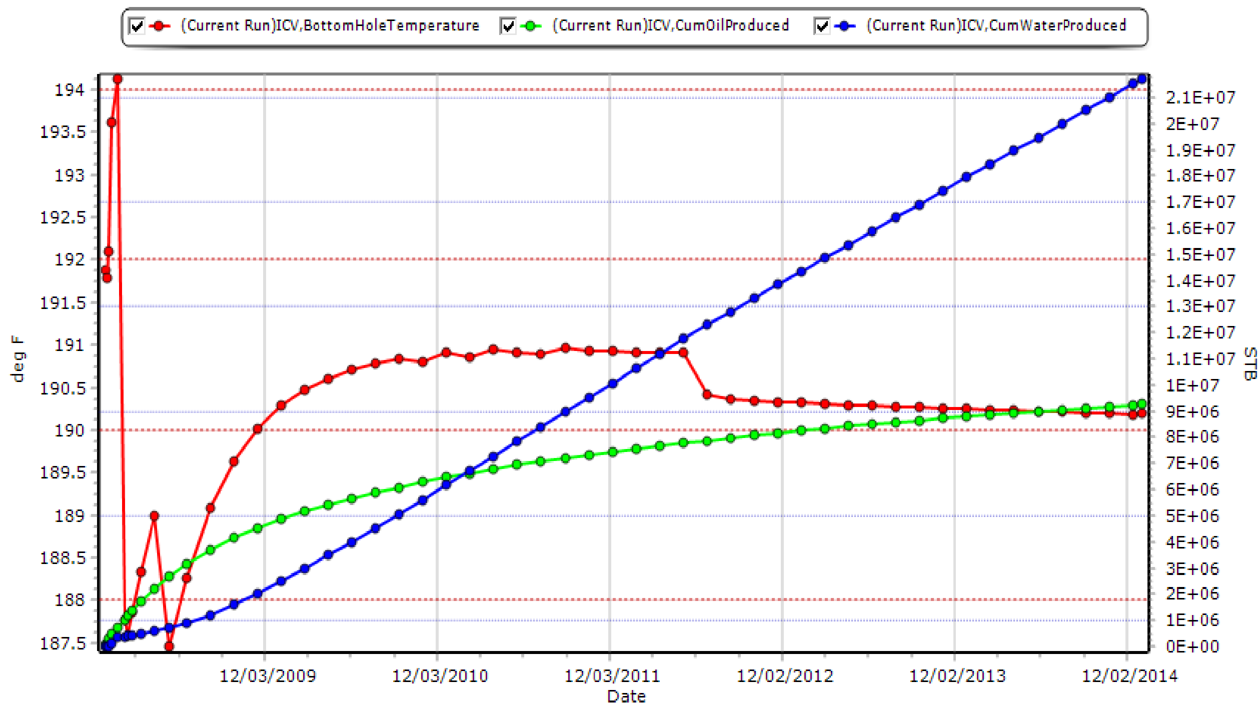

Figure 13: Cumulative water produced by AICD Project.

The Figure 14 shows the cumulative production history of AICD project for 5 years period. The cumulative water production reaches to 8.5E+07 STB while the cumulative oil production 15000000 STB. The cumulative water production line shows steady rocketed behavior but, as the line is linear it means water production is rising in a controlled manner. Figure 16 portrays cumulative oil production and gas oil ratio plot where a small plunge is seen in gas oil ratio line while oil production curve rises to 16000000 STB cumulative production for 5 years and if extrapolated it will further increase.

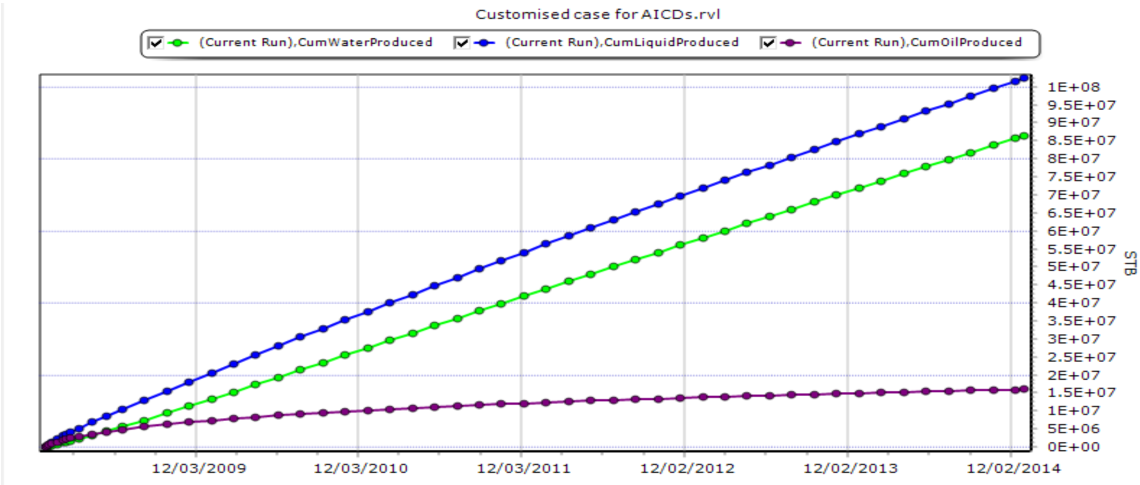

Figure 14: Cumulative Production rates.

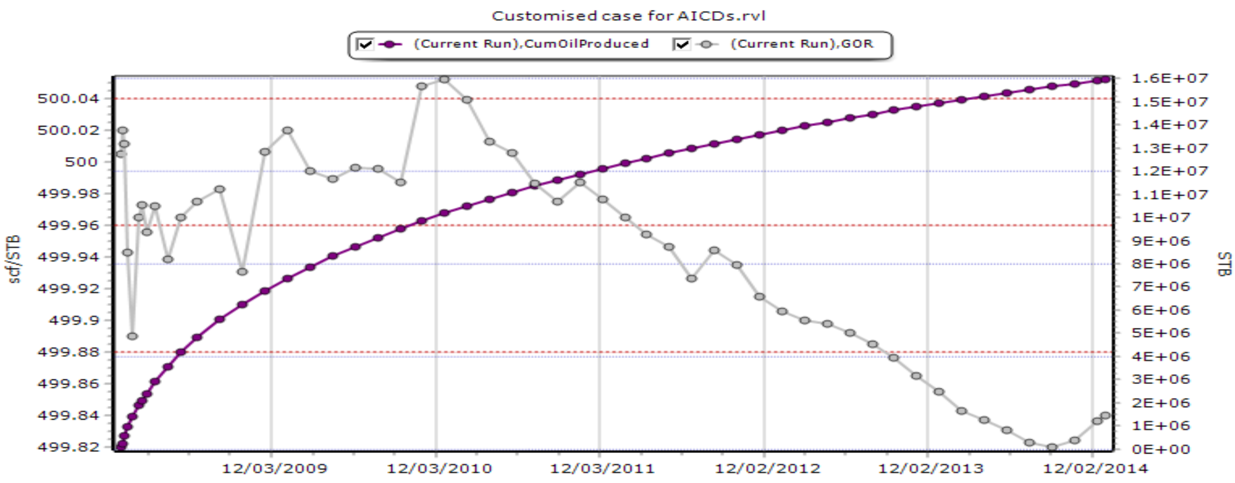

Figure 15: Cumulative Oil Production and Gas Oil Ratio.

4. Discussion

The researh is carried out to simulate and design a smart mutilayer well completion for high water producing wells. The AICDs restricted water production and optimized oil production which proved to be feasible. The Initial pressure was 5000 psi it drops to 3750 psi then a plummet observed in pressure curve and pressure drops to 3650 psi in the first year of production. The average water injection rate rises to 17550 STB/day in first three years and then starts to decline, it declines to 6000 STB/day at the end of 10 years of production.

The difference observed in water production does not make a significant change when the production rates are also increasing, it means still it requires to install a water treatment facility.

In this study the crude API is taken as 38.8º which is light, the difference in oil-water viscosities should be higher in order to separate them and produce higher percentages of oil.

5. Conclusions

After installing AICDs cumulative water production reaches to 21000000 STB while the cumulative oil production 9500000 STB results are generated using simulation software PROSPER and REVEAL. The bottom hole pressure drops form 5000 psi to 3650 psi with respect to time and dp is 1350 psi for the 1 year production after plateau.

1. The well was producing on ESP artificial lift system and water production was monitored to be 78.8% of total production.
2. After installation of AICD the water production declined from 78.8% to 68%.
3. The average water production rates were calculated as 9590 STB/day and oil production rate was 4338 STB/day.
4. The initial reservoir pressure was 5000 psi that drops to 3650, the total pressure drop (dp) was 1350 psi in 5 years of time.
5. Fluid viscosity has a great impact on AICDs performance. In this research cases are simulated for low viscosity crudes, for heavy oil reservoirs water cut can be reduced by higher percentages.

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