SINGLE WELL PRODUCTIVE MODEL BY USING SYSTEM NODEL ANALYSIS AND PRODUCTION DECLINE

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ABSTRACT

Knowledge on multiphase vertical flow gradient behavior in oil wells is needed for the design of artificial lift systems as well as for the design of well flow productivity. These gradients are directly measured in the well during bottom hole flow pressure surveys. But in most cases these measurements are not available during the installation of artificial lift systems. Also, these measurements cannot be made if the well is not flowing. Therefore, it is necessary to construct these curves using well established vertical multiphase flow gradient correlations. In some reservoirs, these correlations give inaccurate results.

There are a lot of multiphase flow correlations available to the oil industry worldwide, but many times these correlations do not match the real measured pressure data. Consequently, the most accurate correlation must be used, but there may be noticeable error in comparison to actual flow conditions.

In our study, we took well X-1; from Nakhla Field as a case study. Six production tests were used to estimate the well productivity index at different times and flowing pressure surveys were performed and analyzed by using Microsoft Excel and PROSPER software. These were used to calculate and plot the pressure gradient and to compare the results obtained by different methods with actual conditions. Doing so allowed us to find the method that resulted in the smallest error. This was then used to construct the IPR-VLP performance and to make predictions for future performance using sensitivity analysis at different reservoir pressures and gas oil ratios (GOR).

Finally, production decline curve analysis was performed to predict future oil flow rates. Then using nodal analysis, well flow pressure and production dynamics could be estimated under current and future conditions.

INTRODUCTION

The reservoir engineer must have sufficient information about the condition and characteristics of the reservoir/well to adequately analyze performance and forecast future production under various modes of operation. The production engineer must know the conditions of production and injection wells to ensure the best possible performance from the reservoir.

At the start of production, pressure in the wellbore drops sharply and fluid near the well expands and moves toward the area of lower pressure. This movement is retarded by friction against the pore walls and the fluid's own inertia and viscosity. As the fluid moves, however, it in turn creates a pressure imbalance that induces neighboring fluid to move toward the well. The process continues until the pressure drop that was created by the start of production is dissipated throughout the reservoir.

The basis of modern reservoir engineering lies in the quantitative description of unsteady-state, multiphase fluid flow in heterogeneous porous media under the influence of pressure, gravitational, and capillary forces. In the general case, the flow pattern is spatially three-dimensional and three separate phases, oil, water, and gas, may be flowing simultaneously in the reservoir.

Vogel (1968) used a computer program to generate the IPRs for several hypothetical saturated oil reservoirs producing under a wide range of conditions. When applying his method, the only parameters required are the average reservoir pressure Pr, the oil bubble-point pressure Pb, and the stabilized wellbore rate and bottom flowing pressure qo, Pwf and Pr.

Wiggins (1993) used four sets of relative permeability and fluid property data as the basic input for a computer program to generate the IPRs for several hypothetical saturated oil reservoirs producing under a wide range of conditions. As the average reservoir pressure Pr declines, the IPR curve shifts. There are several methods that are designed to address IPR shift. Four simple approximation methods are presented.

The existence of multiphase flow and the problems associated with it have been recognized since 1797. Numerous correlations and equations have been presented on the subject of multiphase horizontal and vertical flow in the technical literature. However, most of the significant contributions have been made since 1945. These contributions are presented separately under multiphase vertical, horizontal, inclined, and directional flow.

GENERAL DATA OF THE WELLS

Nakhla Field Overview

The field is a NW-SE fault bounded horst structure discovered by drilling X01 in 1970. The historical Nakhla development succeeded in two phases. So far 19 wells were drilled. 12 of them were completed as producers whereas 7 were dry and therefore were P&A. 10 wells were stimulated by hydraulic fracture except for X09, it was drilled as a horizontal well, and X10 had high water saturation at the bottom of the reservoir. All wells are producing from the Early Cretaceous Upper Sarir Sandstone formation. The main recovery mechanism is fluid-expansion, with weak edge-water drive in the Eastern part. The well locations can be seen in Figure 1.

The heterogeneous nature of the fluvio-lacustrine reservoir creates challenges, and the reservoir is partly substituted by a volcanic sequence. Identification of these volcanoclasticfacies, located especially in the western part of the reservoir, has been impossible so far due to an acoustic impedance identical to that of reservoir sandstone. The overall reservoir properties are poor with permeabilities of 0.1 to 10 md and exceptional properties (> 20 md) in the south-east part, around the X10 area. An overview of the field parameters are presented in Table 1.

In our study, we took well X-1;(G1) from the Nakhla Field as a case study. Six production tests were used to estimate the well productivity index at different times. Flow pressure surveys were collected and analyzed using PROSPER software. It was used to compare the results obtained by different methods with actual wellbore conditions to find the most accurate method. In addition, the actual data was used to construct IPR-VLP performance curves and make predictions for future performance using sensitivity analysis at different reservoir pressures and gas oil ratios (GOR). Finally, production decline curve analysis was performed to predict future oil flow rates. Using nodal analysis, current and future well flow pressure and production capability were estimated

CALCULATION AND FINAL RESULTS

The procedure followed in this work is listed in the following steps:

1. Data for selected well from Nakhla oil field were collected. Tables 6 through 11 showed the pressure survey for this well.
2. The PROSPER software was used to calculate pressure at different depths (pressure gradient) by using different correlations available to the PROSPER software. This data was then used to investigate their application within acceptable accuracy in the interpretation of multiphase flow characteristics.
3. For each pressure survey test, find the method with the least error at each time.

4. For each pressure survey test, matching techniques were used to reduce error between the correlation and actual conditions at each period of time.
5. By using nodal analysis (IPR-VLP), the correlation giving the most accurate results was given.
6. Finally, this information was used to find the best method for a general correlation in the Nakhla oil field.
7. Production decline analysis was performed to estimate future production. This was compared to nodal analysis results to predict future bottom hole flowing pressure and well production potential.

Applications:

- Design and optimize well completions including multi-lateral, multilayer, and horizontal wells.
- Design and optimize tubing and pipeline sizes.
- Design, diagnose, and optimize the use of gas lift, hydraulic pumps and ESP systems in wells.
- Generate lift curves for use in simulators.
- Calculate pressure losses in wells, flow lines, and across chokes.
- Predict flow temperatures in wells and pipelines.
- Monitor well performance to rapidly identify wells requiring remedial action.
- Calculate total skin and determine breakdown (damage, deviation or partial penetration).
- Unique black oil model for retrograde condensate fluids, accounting for liquid dropout in the wellbore.
- Allocate production between wells.

Fancher Brown correlation gave unacceptable results when compared to the pressure survey data, but after applying a matching technique using PROSPER software, we can get relatively accurate results. The accuracy can be increased by matching nodal analysis to the reservoir pressure. Consequently, the Fancher Brown correlation can be considered the best correlation for Well X01 at different flow rates and with different choke sizes. This also allows for the application of sensitivity analysis for different reservoir pressures and GORs for future reservoir performance. Using Table 3, the error square for the production decline period was exponential with initial oil rate 0f 1,518 bbl/day and decline factor of 0.133419 year-1.

CONCLUSION

From the study conducted on Well X-1 in Nakhla Oil Field; the following conclusions can be summarized:

- It is concluded that the existing multiphase flow pressure gradient correlations cannot be used for some oil reservoirs without an error.
- The actual measured of flowing pressure gradients when compared with all the existing correlations in some cases given a good matching and other times do not give any match with the actual measured pressure data.
- Fancher and Brown multiphase flow correlation can predict for any well in the reservoir when the future flow rate is known for any future multiphase flowing pressure gradients.
- Production decline analysis is a useful tool for future prediction for reservoir and/or well fluid production, consequently combined with the nodal analysis can be forecast the well potential and future bottom hole flowing pressure.
- The reservoir pressure and the gas oil ratio are the main factors effecting on the calculations of multiphase flowing pressure correlations especially in case of solution gas drive.
- Some of the multiphase correlations given acceptable results if compared with actual or real data measured ones, but didn’t have any solution in nodal analysis as in case of

Mukerjee Brill correlation, and some of them given low value of error but there results and behavior in the nodal analysis not acceptable as in case of Beggs and Brill correlation.

- Matching techniques is a useful tool in the PROSPER software to matching multiphase correlations to the actual or real data points in order to reduce the value of the error in both optimizing the best correlation and nodal analysis for example as in case of Fancher Brown correlation; and vice versa in some of them increases the values of error like Hydro-3P correlation.

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Table 1- Nakhla Field Data Summary

General Data	
Reservoir highest drilled top (X18)	11,900 ft TVD ss
Lithology / Depositional Environment	Fluvial Sandstone
Reservoir unit	Upper Sarir
Area of field sector development	13 km^2
Reservoir pressure (initial)	6,000 psia @ 12,150 ft TVD ss
Reservoir temperature	288 °F
Oil Water Contact	12,368 ft TVD ss
Aquifer drive	weak
Rock Properties	
Thickness of Flow Units	5 – 20 ft
Porosity Cut – Off	4 %
Porosity	4 -18 %
Permeability	0.1 – 100 mD
Water saturation (porosity > 4 %)	20 % - 70 %
Fluid Properties @ initial conditions	
Oil	
Formation Volume factor	1.56
Saturation pressure	4,580 psia
Flash initial solution Gas / Oil Ratio	1,130 scf/STB
Viscosity @ reservoir condition	0.38 mPas
Density @ reservoir condition	38.3 lb/ft^3
Water	
Water Formation Volume factor	1.07
Water viscosity @ reservoir condition	0.6 mPas
Water density @ reservoir condition	67.3 lb/ft^3
TVD ss: True Vertical Depth sub sea	

Table 2- Well X01 Test by Test Analysis Results by PROSPER Software.

Well	Test Type	Date	VLP-Best Correlation
X-01	FPS	1995	Beggs and Brill
X-01	FPS	1996	Beggs and Brill
X-01	FPS	1999	Beggs and Brill
X-01	FPS	2002	Duns and Ros Original
X-01	FPS	2004	Petroleum Expert-4
X-01	FPS	2006	Hydro-3P

Table 3- Well (X-1) Production Decline Period Analysis:

Range Analyzed			
	Start Date	End Date	n
Range Analysis	3/31/2003	9/30/2008	67
qe	50		BPD

B	Slope	Intercept	a_i	q_i	Sum E^2
0.00	0.000013	0.999268	0.133419	1,517.48	4.840E+05
0.05	0.004712	0.693259	0.135949	1,520.85	4.845E+05
0.10	0.006659	0.480498	0.138578	1,524.36	4.850E+05
0.15	0.007057	0.332952	0.141305	1,527.99	4.858E+05
0.20	0.006649	0.230654	0.144136	1,531.76	4.867E+05
0.25	0.005874	0.159744	0.147078	1,535.67	4.878E+05
0.30	0.004982	0.110603	0.150136	1,539.74	4.891E+05
0.35	0.004108	0.076556	0.153319	1,543.96	4.906E+05
0.40	0.003319	0.052973	0.156633	1,548.35	4.924E+05
0.45	0.002640	0.036642	0.160087	1,552.91	4.943E+05
0.50	0.002074	0.025338	0.163691	1,557.65	4.965E+05
0.55	0.001613	0.017514	0.167453	1,562.59	4.990E+05
0.60	0.001244	0.012101	0.171385	1,567.73	5.018E+05
0.65	0.000953	0.008358	0.175498	1,573.09	5.049E+05
0.70	0.000726	0.005770	0.179805	1,578.68	5.084E+05
0.75	0.000550	0.003982	0.184321	1,584.50	5.122E+05
0.80	0.000415	0.002746	0.189060	1,590.59	5.165E+05
0.85	0.000312	0.001893	0.194040	1,596.95	5.212E+05
0.90	0.000234	0.001304	0.199279	1,603.59	5.263E+05
0.95	0.000175	0.000898	0.204799	1,610.55	5.320E+05
1.00	0.000130	0.000618	0.210623	1,617.84	5.383E+05
				Minimum =	**4.840E+05**

Table 4- Well X-1, Decline Period Error Analysis

Decline Type	Exponential	#
b =	0.00	#
a_i =	0.133419	/Year
q_i =	1,517.48	BPD
$q_{cal.}$ @ end =	728.21	BPD

Table 5- Well X-1 Production Decline Analysis Results

Period	From	To	
	3/31/2003	9/30/2008	
# of Points	67		#
b =	0.00		#
q_i =	1,517		BPD
a_i =	0.133419		1/year
q cal. at end of Period	728		BPD
N_P at end of Period	7.518		MMbbl
Assumed q_e	50		BPD
Remaining Reserves	1.857		MMbbl
Total Reserves	9.375		MMbbl

Table 6- Well X01: 1995 Flowing Pressure Survey Test Data.

Well Name:	X-01
Test Type:	Flowing Gradient Survey
Date:	29-10-1995
KB:	211
Reference Depth (RD):	12,150

Depth (ft KB)	Pressure (psia)	Temperature (°F)
0	1,151	192.9
-4,000	1,916	226.2
-8,000	2,807	250.8
-12,000	3,766	271.1
-12,300	3,840	281.3

Table 7- Well X01: 1996 Flowing Pressure Survey Test Data.

Well Name:	X-01
Test Type:	Flowing Gradient Survey
Date:	20-07-1996
GL:	195
Reference Depth (RD):	12,150

Depth (ft GL)	Pressure (psia)	Temperature (°F)
0	891	192.9
-3,000	1,437	226.2
-6,000	2,043	250.8
-9,000	2,717	271.1
-11,000	3,203	281.3
-11,900	3,413	284.5
-12,300	3,515	285.1

Table 8- Well X01: 1999 Flowing Pressure Survey Test Data.

Well Name:	X-01
Test Type:	Flowing Gradient Survey
Date:	06-10-1999
GL:	195
Reference Depth (RD):	12,150

Depth (ft GL)	Pressure (psia)	Temperature (°F)
0	407	192.9
-3,000	866	226.2
-6,000	1,363	250.8
-9,000	1,930	271.1
-11,000	2,342	281.3
-12,000	2,561	284.5
-12,250	2,616	285.1
-12,320	2,631	285.2
-12,370	2,641	285.8

Table 9- Well X01: 2002 Flowing Pressure Survey Test Data.

Well Name:	X-01
Test Type:	Flowing Gradient Survey
Date:	27-01-2002
GL:	195
Reference Depth (RD):	12,150

Depth (ft GL)	Pressure (psia)	Temperature (°F)
0	445	85.6
-3,000	831	210.2
-6,000	1,288	240.4
-9,000	1,815	262.1
-11,000	2,209	275.1
-11,500	2,314	278.5
-11,750	2,367	280.0
-12,206	2,460	282.0

Table 10- Well X01: 2004 Flowing Pressure Survey Test Data.

Well Name:	X-01
Test Type:	Flowing Gradient Survey
Date:	28-04-2004
GL:	195
Reference Depth (RD):	12,150

Depth (ft GL)	Pressure (psia)	Temperature (°F)
0	673	79.8
-3,000	1,023	214.9
-5,000	1,280	232.7
-7,000	1,565	249.9
-9,000	1,880	265.6
-11,000	2,216	277.7
-12,000	2,395	281.6
-12,233	2,436	282.3

Table 11- Well X01: 2006 Flowing Pressure Survey Test Data.

Well Name:	X-01
Test Type:	Flowing Gradient Survey
Date:	02-05-2006
GL:	195
Reference Depth (RD):	12,150

Depth (ft GL)	Pressure (psia)	Temperature (°F)
0	916	174.0
-1,000	1,011	188.0
-3,000	1,225	210.0
-5,000	1,457	229.0
-7,000	1,709	247.0
-9,000	1,981	263.0
-11,000	2,272	276.0
-12,000	2,425	280.0

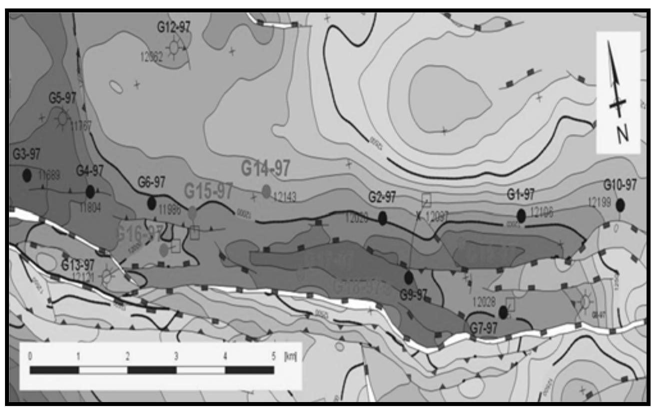

Figure 1- Nakhla field well location map

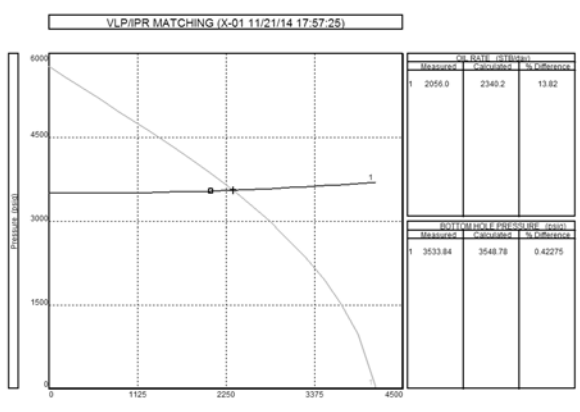

Figure 2- Well X01-1995; Nodal analysis by using Fancher Brown VLP correlation before matching VLP curve.

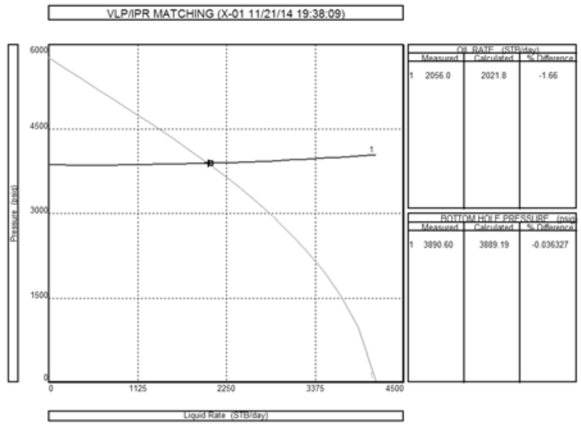

Figure 3- Well X01-1995; Nodal analysis by using Fancher Brown VLP correlation after matching VLP curve.

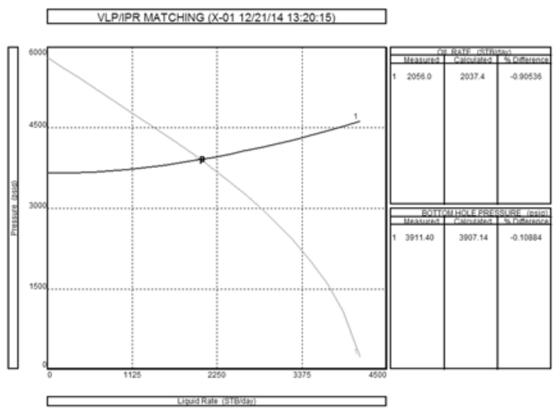

Figure 4- Well X01-1995; Nodal analysis by using Fancher VLP correlation after matching reservoir pressure.

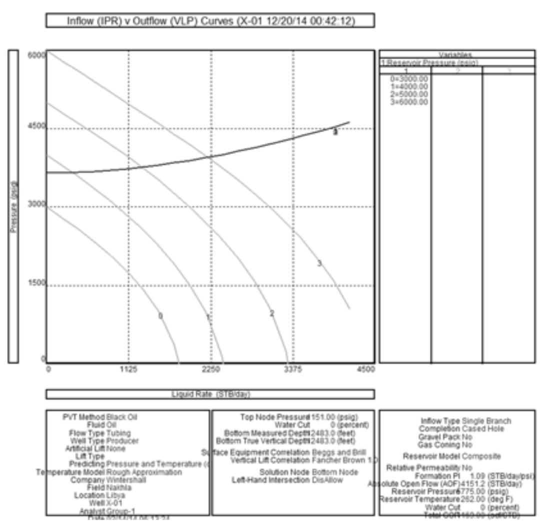

Figure 5- Well X01-1995; Sensitivity analysis to reservoir pressure by using Fancher Brown VLP correlation after matching.

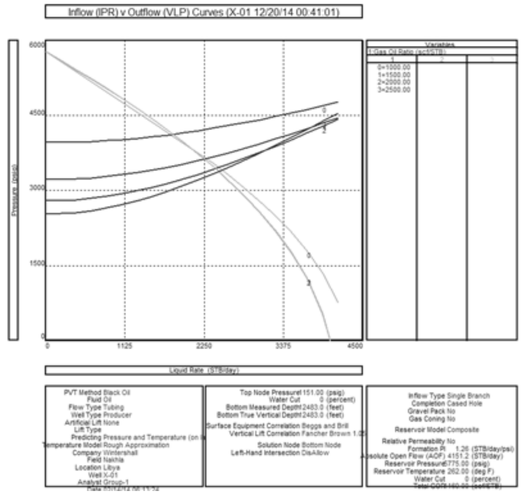

Figure 6- Well X01-1995; Sensitivity analysis to GOR by using Fancher Brown VLP correlation after matching.

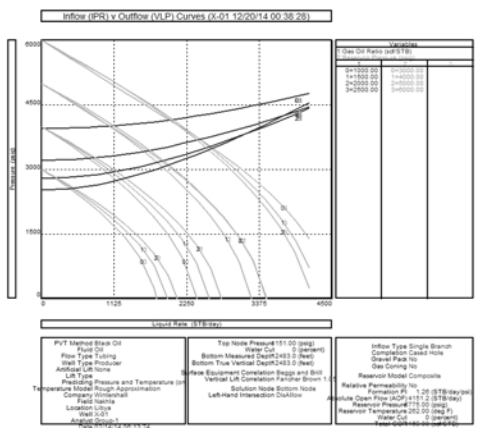

Figure 7- Well X01-1995; Sensitivity analysis to reservoir pressure & GOR by using Fancher Brown VLP correlation after matching.

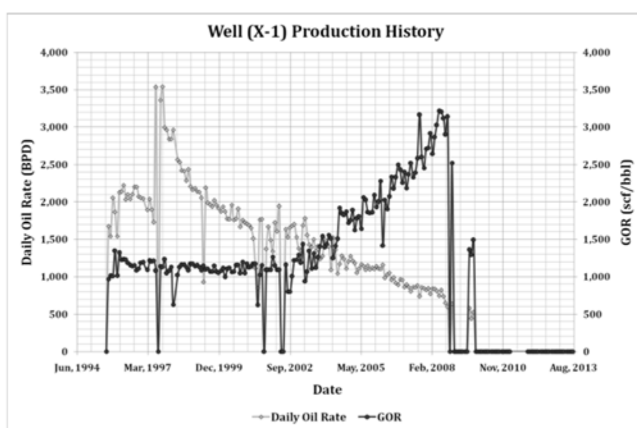

Figure 8- Well X-1 Oil Production and GOR History

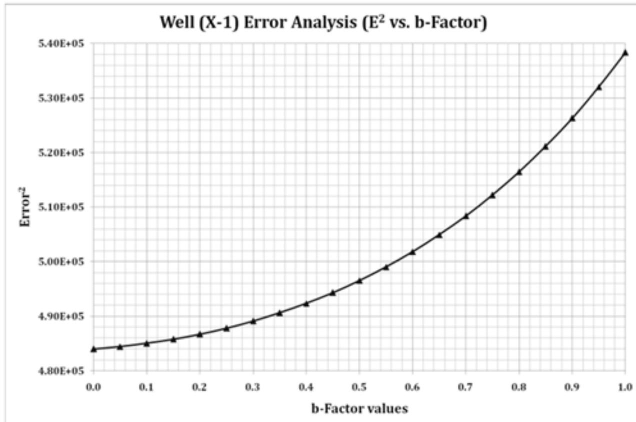

Figure 9- Well X-1, Decline Period Error Analysis

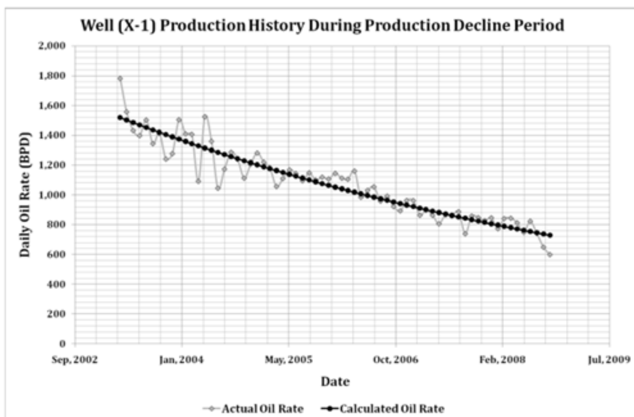

Figure 10- Well X-1, Decline Period Analysis Linear Plot. (Actual and Calculated Oil Rate)

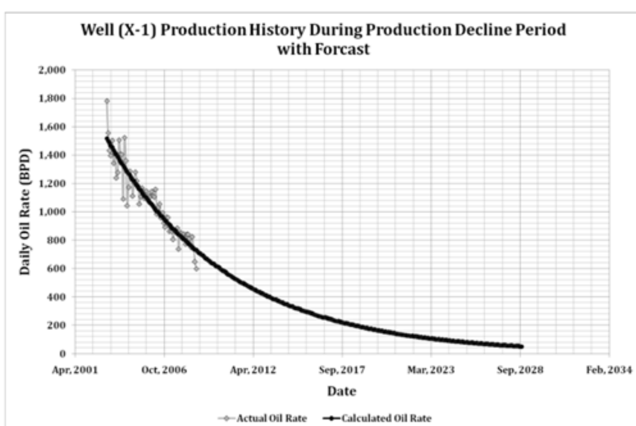

Figure 11- Well X-1, Decline Period Analysis with Forecast Linear Plot. (Actual and Calculated Oil Rate)

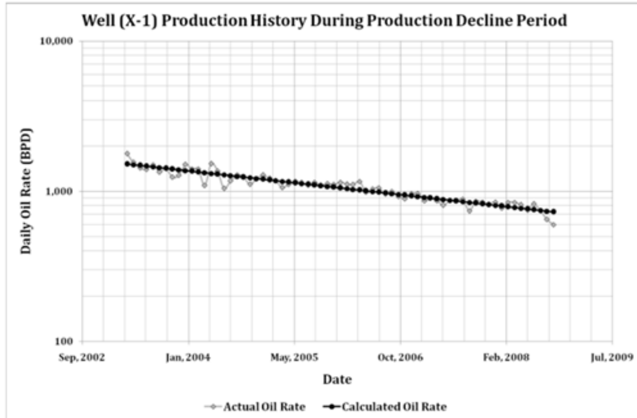

Figure 12- Well X-1, Decline Period Analysis Semi-log Plot.(Actual and Calculated Oil Rate)

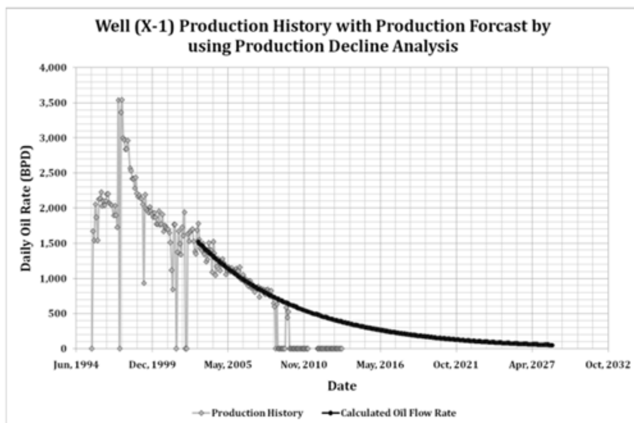

Figure 13- Well X-1, Production History with Production Forecast by using Production Decline Analysis Linear Plot. (Actual and Calculated Oil Rate)