Application of Decline Curve Analysis on Some Wells in X&Y Libyan Oil Fields Using Analytical Method & OFM Software

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Abstract

Production decline curve analysis extrapolation is one of the oldest and most often used tools of the petroleum engineer. The various methods used always have been regarded as strictly empirical and generally not scientific.

This work presents basic concepts and applications of decline curve analysis (DCA) in determining the remaining, total reserves and forecasting future production rate. Details of comprehensive conventional analysis techniques of the production history data using excel spreadsheets are conducted. The main objective of this study is to make a comparison between Arps method and OFM software used in decline curve analysis.

Decline curve analysis was applied on seven oil vertical wells namely X-01, X-02, X-04, Y-01, Y-02, Y-03 and Y-04, X & Y oil fields belonging to Zueitina Oil Company.

Decline curve analysis has been used to provide a best-fit equation for series of data point by least squares method. This method has been proved useful for decline curve analysis to evaluate the initial decline rate (ai), initial rate (qi) and the decline exponent (b), which can be used to plot the declining rate versus time after calculating the future rate at any desired time and calculating the reserves from certain time to an economic limit.

The remaining reserve obtained from analytical method for Y field is about 2.64 MMstb for all the four wells and the remaining for X field is about 2.7 MMstb, and the results are closer to remaining reserve that gotten from OFM software. Also, the results obtained from RAMA

method is near from the results from the Excel and OFM. The best wells in productions are well X-02, Y-02 and Y-04. For both in production and remaining maybe due to the location and reservoir rock properties. Well Y-01, Y-03 and X-01 they have the lowest remaining and oil production.

الملخص

يعد تحليل منحنى الانحدار الإنتاجي من أقدم الأدوات وأكثرها استخدامًا لدى مهندس البترول. لطالما اعتبرت الطرق المختلفة المستخدمة تجريبية بحتة وغير علمية بشكل عام.

يقدم هذا البحث المفاهيم الأساسية وتطبيقات تحليل منحنى الانحدار (DCA) في تحديد الاحتياطيات الإجمالية المتبقية والتنبؤ بمعدل الإنتاج المستقبلي. يتم إجراء تفاصيل تقنيات التحليل التقليدية الشاملة لبيانات تاريخ الإنتاج باستخدام جداول بيانات Excel. الهدف الرئيسي من هذه الدراسة هو إجراء مقارنة بين طريقة Arps وبرامج OFM المستخدمة في تحليل منحنى الانحدار.

تم تطبيق تحليل منحنى الانحدار على سبع آبار نفطية عمودية وهي X-01 و X-02 و X-04 و Y-01 و Y-02 و Y-03 و Y-04 ، حقول النفط X و Y التابعة لشركة الزويتينة للنفط.

تم استخدام تحليل منحنى الانحدار لتوفير أفضل معادلة ملائمة لسلسلة من نقاط البيانات بطريقة المربعات الصغرى. وقد ثبتت فائدة هذه الطريقة في تحليل منحنى الانحدار لتقييم معدل الانحدار الأولي (ai) والمعدل الأولي (qi) وأس الانحدار(b) ، والتي يمكن استخدامها لرسم معدل الانحدار مقابل الوقت بعد حساب المعدل المستقبلي في أي وقت مرغوب وحساب الاحتياطيات من وقت معين إلى حد اقتصادي.

الاحتياطي المتبقي الذي تم الحصول عليه من الطريقة التحليلية لحقل Y هو حوالي 2.64 MMstbلجميع الآبار الأربعة والاحتياطي المتبقي لحقل X هو حوالي MMstb2.7 ، والنتائج أقرب إلى الاحتياطي المتبقي الذي تم الحصول عليه من برنامج OFM. أيضًا، النتائج التي تم الحصول عليها من طريقة RAMA قريبة من النتائج من Excel و OFM. أفضل الآبار في الإنتاج هي البئر X-02 و Y-02 و Y-04. بينما البئر Y-01 و Y-03 و X-01 لديها أقل إنتاج متبقي ونفط.

Nomenclature

pi	Initial reservoir pressure, psi
tablp	Volumetric average reservoir pressure
Δp	Change in reservoir pressure = pi - p, psi
pb	Bubble point pressure, psi
N	Initial (original) oil-in-place, STB
Np	Cumulative oil produced, STB
GP	Cumulative gas produced, scf
WP	Cumulative water produced, bbl
RP	Cumulative gas-oil ratio, scf/STB

GOR	Instantaneous gas-oil ratio, scf/STB
Rsi	Initial gas solubility, scf/STB
Boi	Initial oil formation volume factor, bbl/STB
Bo	Oil formation volume factor, bbl/STB
Bgi	Initial gas formation volume factor, bbl/scf
Bg	Gas formation volume factor, bbl/scf
We	Cumulative water influx, bbl
G	Initial gas-cap gas, scf
P. V	Pore volume, bbl
Cw	Water compressibility, psi-1
Cf	Formation (rock) compressibility, psi-1

Introduction

Decline curves are one of the most extensively used forms of data analysis employed in evaluating oil and gas reserves and predicting future production. The decline-curve analysis technique is based on the assumption that "past production trends and their controlling factors will continue in the future" and, therefore, can be extrapolated and described by a mathematical expression [1].

The method of extrapolating a "trend" for the purpose of estimating future performance must satisfy the condition that the factors that caused changes in past performance, for example, decline in the flow rate, will operate in the same way in the future. These decline curves are characterized by three factors:

- Initial production rate or the rate at some particular time,
- Curvature of the decline.
- Rate of decline.

The basis of decline curve analysis is to match past production performance histories or trends (i.e., actual production rate/time data) with a "model". Assuming that future production continues to follow the past trend, these models can be used to estimate original oil/gas in place and to predict ultimate oil/gas reserves at some future reservoir abandonment time or economic production rate. Alternatively, the remaining productive life of a well or the entire field can be determined. In addition, the individual well flowing characteristics, such as formation permeability and skin factor, can be estimated with decline-type-curve

analysis techniques. Decline-curve methods, however, are applicable to individual wells or an entire field [2].

The most common conventional decline-curve analysis technique is a linear semi log decline curve, sometimes called exponential or constant-percentage decline. Subsequent work, however, showed that the production performance of all wells cannot be modeled with exponential decline. Arps (1945) recognized that the decline characteristics also could be harmonic or hyperbolic. Most conventional decline-curve analysis is based on Arps empirical rate/time decline equation [2].

Objectives of the Study

The main objectives of this study are listed below:

- ✓ Estimate the ultimate recovery (reserve) for the reservoir.
- ✓ Predicting the future production rate and the production life of a reservoir and wells.
- ✓ Analyze the field's performance in order to better understand its behavior.
- ✓ Compare between lateral well with the other horizontal wells.

Methodology

It was selected seven wells from two field located in concessions 103 oil field to be a real case in this study, these wells are “X-01, X-02, X-04, Y-01, Y-02, Y-3 and Y-04”. Perform Decline Curve Analysis, DCA technique in order to estimate decline rate and ultimate recovery for each well by using both Excel sheet and OFM software and compared with each other.

The following procedure is implemented to estimate the Initial Decline Rate (a_i), the Initial Rate (q_i), which can be used to calculate the future rate and reserves at any desired time:

1. Plot q vs. time and allocate decline interval to be analyzed.
2. Assume the value of “b” is equal to zero.
3. Calculate the values of (a_i) and (q_i) by using equations for Exponential Decline.

$$a_i = \left(\frac{\sum t_k \sum \ln(q_k) - n \sum t_k \ln(q_k)}{n \sum t_k^2 - \sum t_k \sum t_k}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$q_i = \exp\left(\frac{\sum \ln(q_k) + a_i \sum t_k}{n}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

4. Calculate the new values of (q).
5. Calculate the sum of squares of the difference between the actual data points and the points calculated ($q_{\text{-actual}}$ and $q_{\text{-calculated}}$).
6. Repeat these steps by using different values of "b" in incremental steps of (0.001) by using equations for Hyperbolic Decline.

$$a_i = \left(\frac{q_i^b \sum \frac{1}{q_i^b} - n}{b \sum t_k}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$q_i = \left(\frac{n \sum t_k^2 - \sum t_k \sum t_k}{\sum t_k^2 \sum \frac{1}{q_k^b} - \sum t_k \sum \frac{t_k}{q_k^b}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

7. For Harmonic Decline equations, when the value of "b" is equal to (1).

$$a_i = \left(\frac{q_i \sum \frac{1}{q_k} - n}{\sum t_k}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$q_i = \left(\frac{n \sum t_k^2 - \sum t_k \sum t_k}{\sum t_k^2 \sum \frac{1}{q_k} - \sum t_k \sum \frac{t_k}{q_k}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

8. Choose the values of (a_i), (q_i) and "b" which give a minimum SD_{min}.
9. Calculate the economic reserves by substituting the calculated parameters (a_i, q_i, q_e and b) into one of the lasts equations.

Analytical Method

In this section, it presents the decline curve analysis by using Arbs technique for the wells.

Well X-01

This well includes one decline periods; the period starts from 2005 until end of 2009 and. **(Figure 1)** illustrates the production history for well X-01.

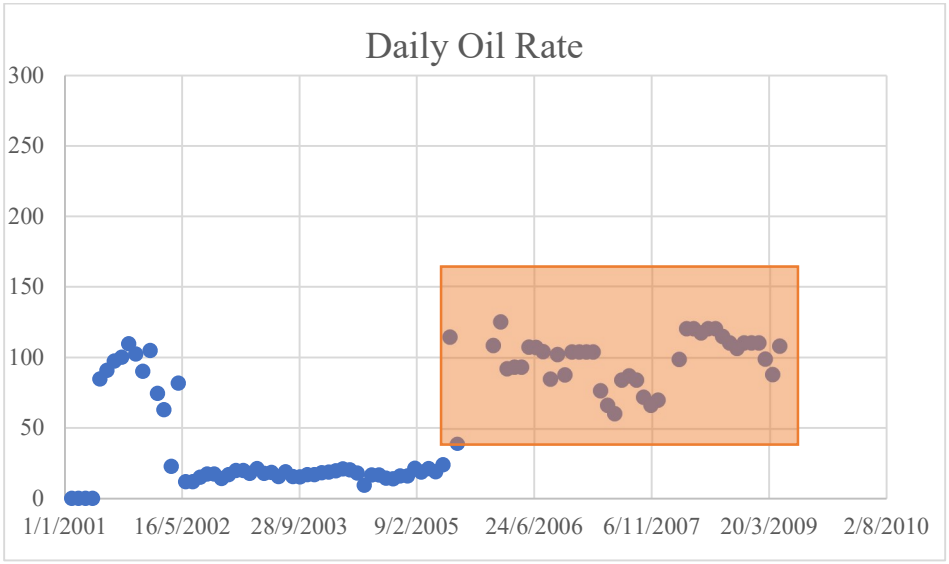

Figure 1. Production history for well X-01.

To know the type of decline, we use the technical and graphical method. The following figures shows the graphical method for this well.

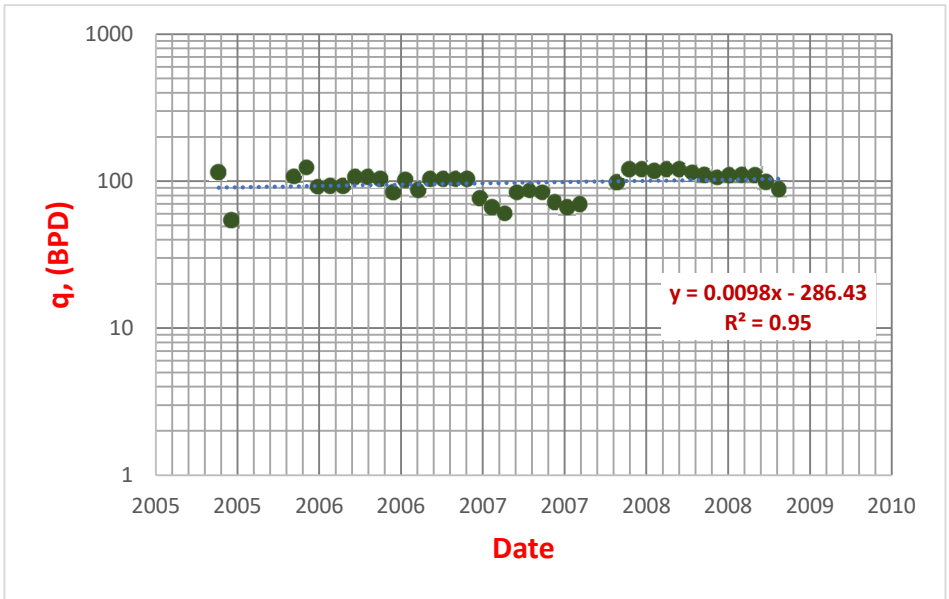

Figure 2. Graphical plot for well X-01 "Semi-log plot between Rate and Time".

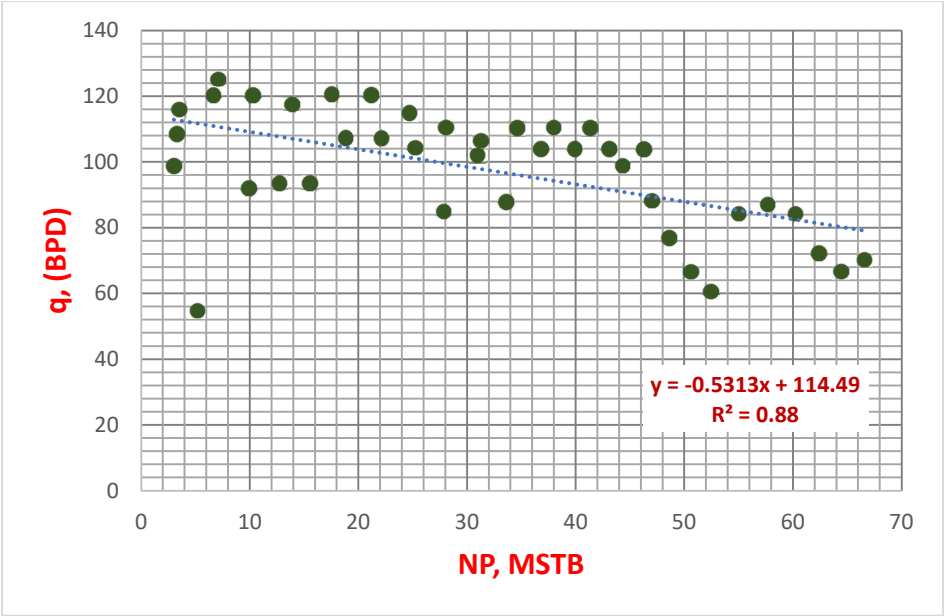

Figure 3. Graphical plot for well X-01 "Linear plot between Rate and Np".

From graphical method the decline type is exponential.

(Figure 4) shows the late period which was selected to perform DCA technique.

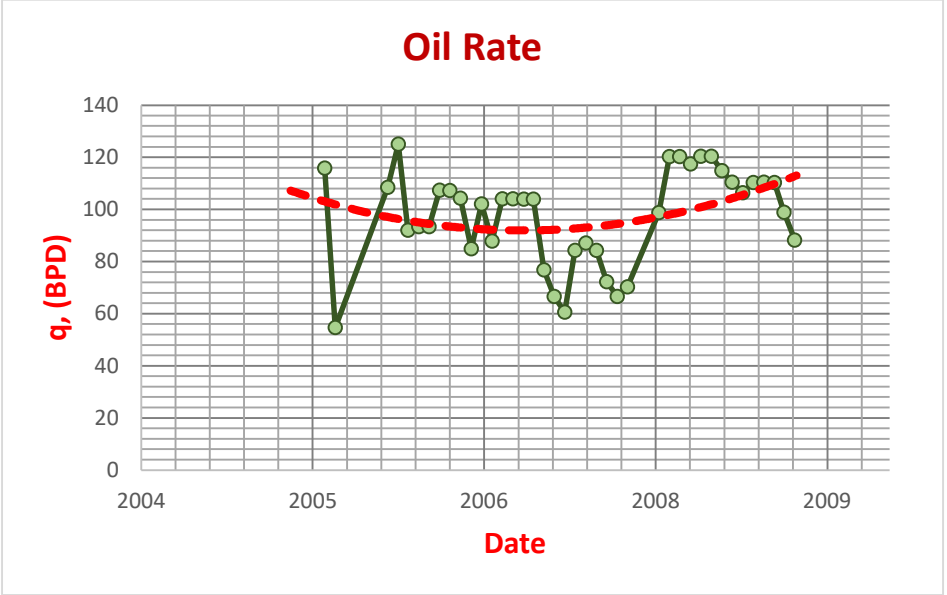

Figure 4. The late period of production history for well X-01.

The decline curve analysis was applied on the late period of production data for well X-01. The results obtained from analysis; it summarizes in the **Table 1**.

Table 1. DCA results for well X-01.

Type of plot	Analyzed Period	b	a, Year^{-1}	q_i, BPD	e^2	R^2	b, (least of error squared)	Np $_{remaining}$, (MMbbl)
q vs t	2005 until end of 2010	0	-0.0554	100	1.2021E+04	0.984	0	0.231
		0.1	-0.0554	87.93	1.2054E+04	0.934	Not least of error squared	N/A
		0.2	-0.0555	87.69	1.2069E+04	0.884	Not least of error squared	N/A
		0.3	-0.0556	87.45	1.2086E+04	0.834	Not least of error squared	N/A
		0.4	-0.0556	87.21	1.2106E+04	0.784	Not least of error squared	N/A
		0.5	-0.0557	86.97	1.2128E+04	0.734	Not least of error squared	N/A
		0.6	-0.0557	86.72	1.2143E+04	0.684	Not least of error squared	N/A
		0.7	-0.0557	86.48	1.2170E+04	0.634	Not least of error squared	N/A
		0.8	-0.0558	86.23	1.2190E+04	0.584	Not least of error squared	N/A
		0.9	-0.0558	85.97	1.2203E+04	0.534	Not least of error squared	N/A
		1	-0.0433	85.72	1.2219E+04	0.484	Not least of error squared	N/A

The best decline of X-01 is exponential decline, because it has the least sum of square error, it is about 1.2 E+04. After it had selected type of decline, it analyzed exponentially in order to predict the production performance for this well until economic limit.

(Figure 5) illustrates the least sum of square error versus reservoir constant.

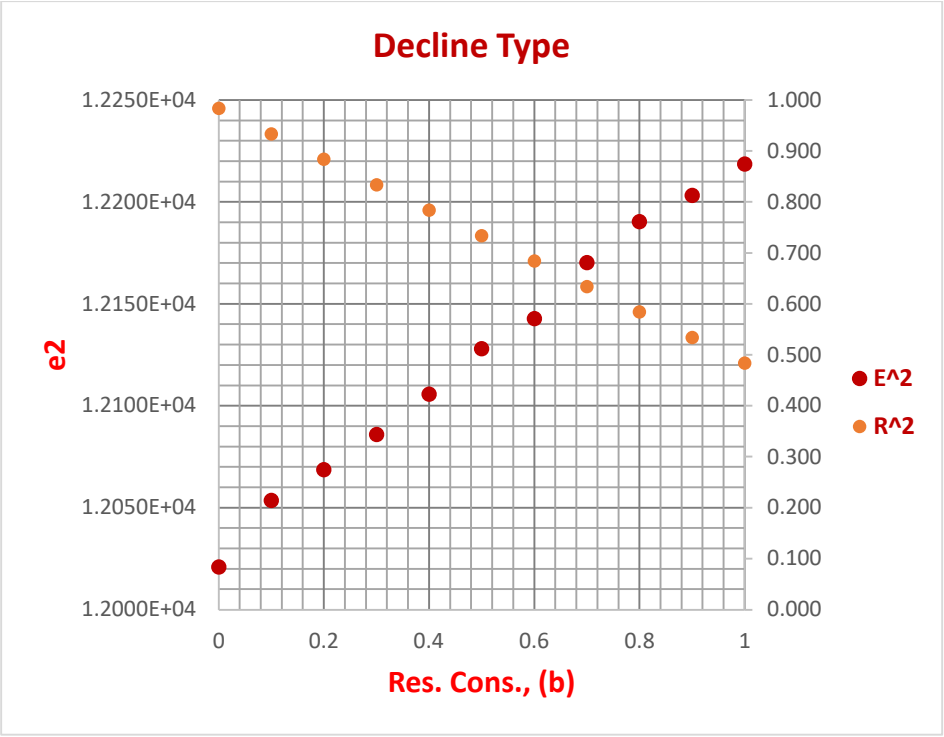

Figure 5. Error Analysis for well X-01

Table 2 shows the main results for well X-01.

Table 2. Summary of results for well X-01.

	History	Forecast
	31-3-2009	Until q_e
	Actual	
NP, (MMSTB)	0.46	0.231
Rama Method	0.46	0.18

DCA for well X-01 gave the initial rate about 100 bpd, and the decline rate is -about -0.0554 1/year. The Enhanced Ultimate Recovery, EUR for this well is 0.231 MMstb.

- **RAMA Method**

Rama Method was used to determine the ultimate reserve and the decline parameter. The following figure introduces the decline results for the Rama Method.

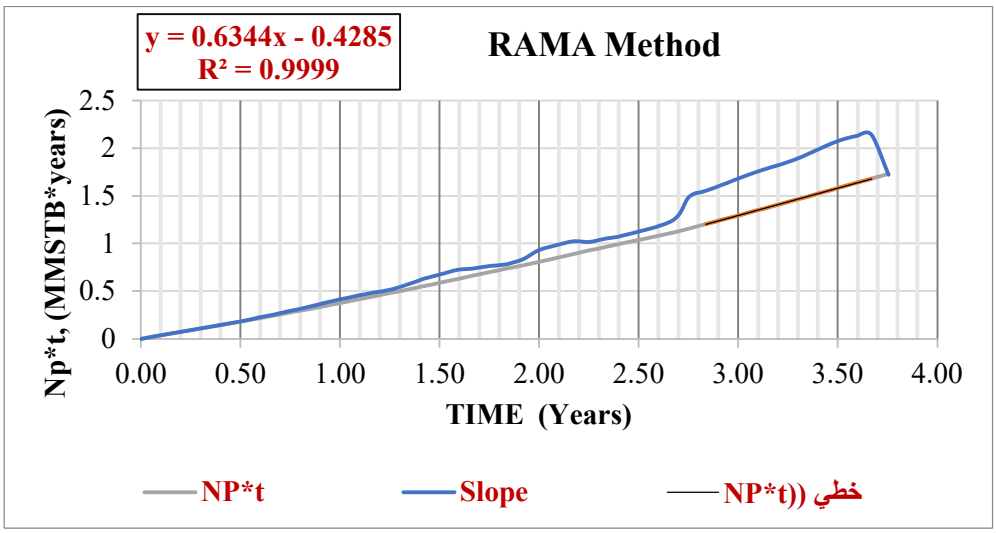

Figure 6. Rama Method plot for well X-01.

The ultimate reserve for well X-01 around 0.64 MMSTB and the remaining about 0.18 MMSTB to the economic rate.

4.2.2. Well X-02

This well includes one decline periods; the period starts from 1991 until end of 2009 and. **(Figure 7)** illustrates the production history for well X-02.

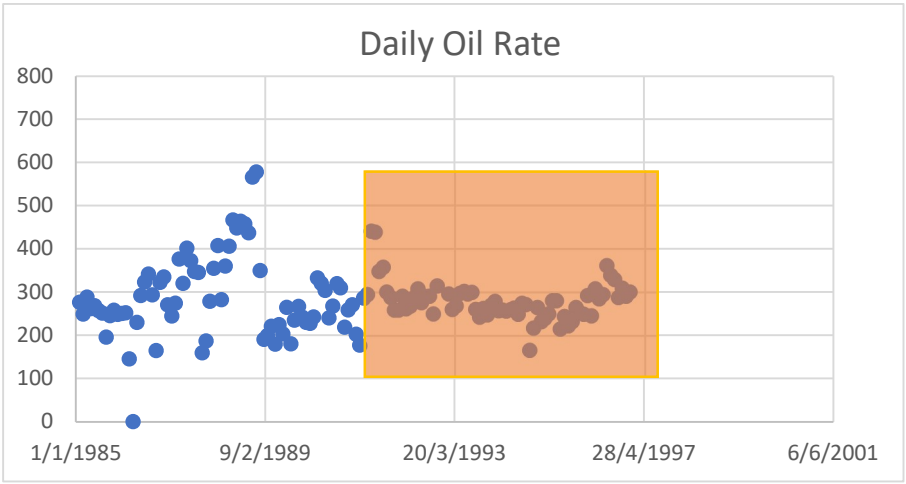

Figure 7. Production history for well X-02.

The Graphical method for this well is illustrated below:

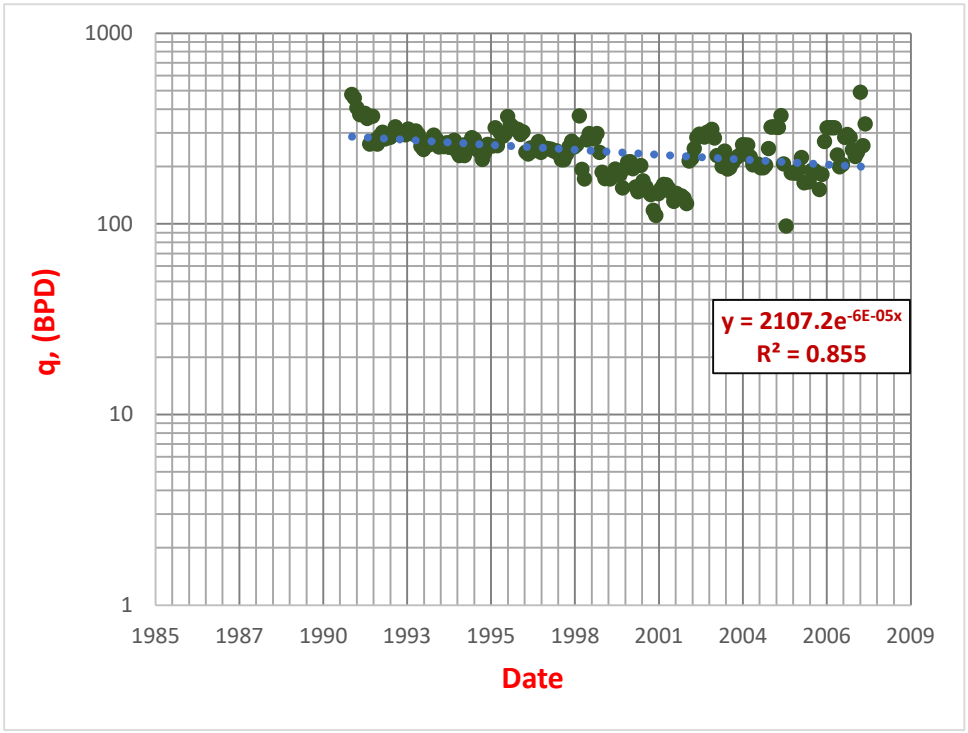

Figure 8. Graphical plot for well X-02 "Semi-log plot between Rate and Time".

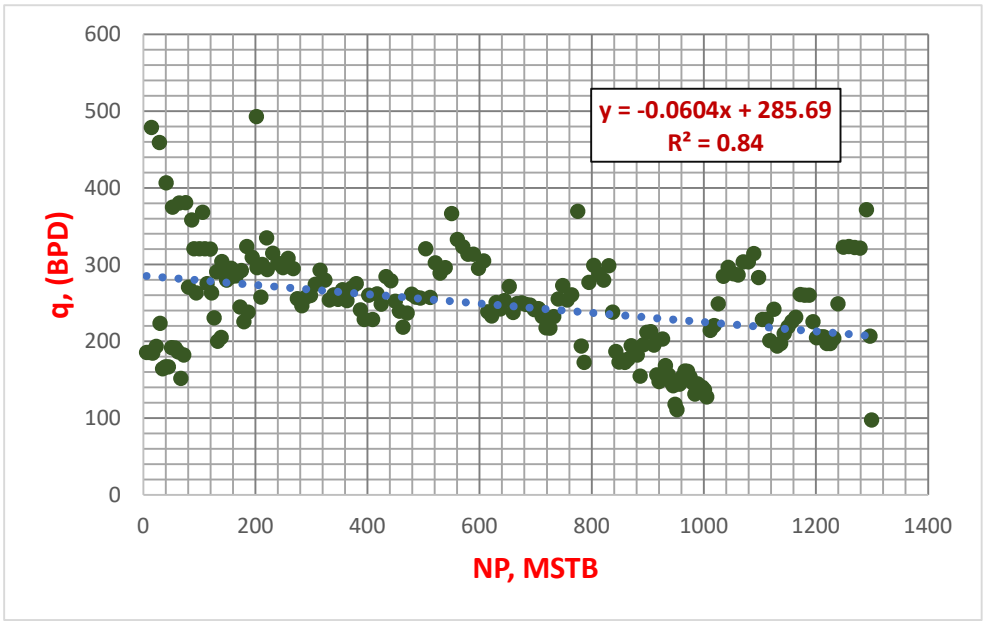

Figure 9. Graphical plot for well X-02 "Linear plot between Rate and Np".

From graphical method the decline type is exponential.

(Figure 10) shows the late period which was selected to perform DCA technique.

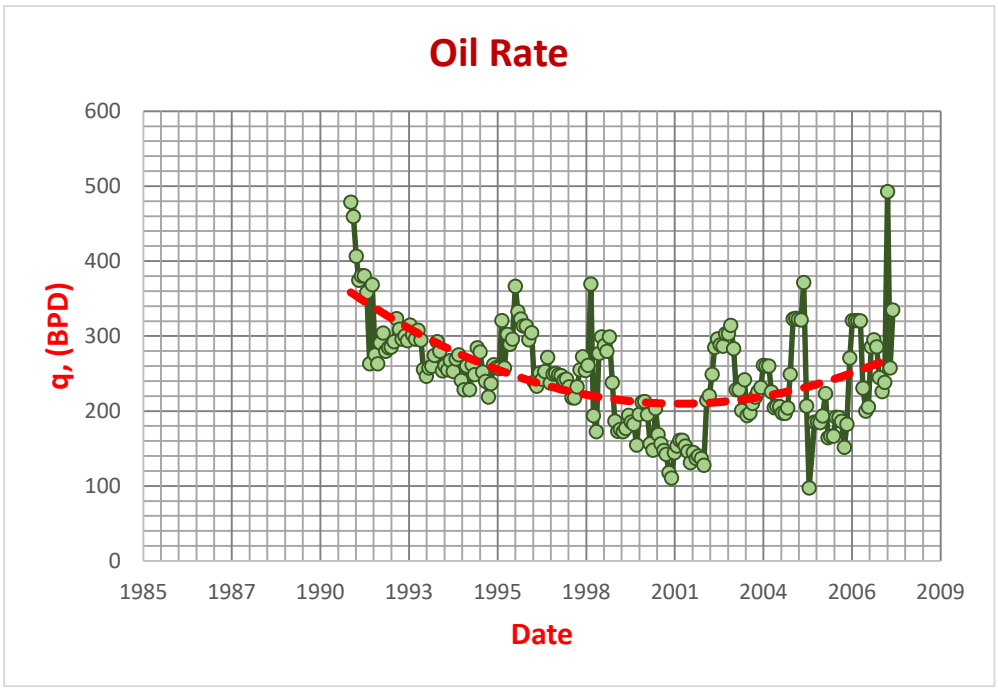

Figure 10. The late period of production history for well X-02

The decline curve analysis was applied on the late period of production data for well X-02. The results obtained from analysis; it summarizes in the **Table 1**.

Table 3. DCA results for well X-02.

Type of plot	Analyzed Period	b	a, Year^{-1}	q_i, BPD	e^2	R^2	b, (least of error squared)	$Np_{remainings}$, (MMbbl)
q vs t	1991 until 2009	0	0.03302	306.90	5.25E+05	0.95	0	1.66
		0.1	0.03409	307.03	5.25E+05	0.85	Not least of error squared	N/A
		0.2	0.03522	307.20	5.25E+05	0.8	Not least of error squared	N/A
		0.3	0.03641	307.41	5.25E+05	0.75	Not least of error squared	N/A
		0.4	0.03769	307.67	5.25E+05	0.7	Not least of error squared	N/A
		0.5	0.03904	307.98	5.26E+05	0.65	Not least of error squared	N/A
		0.6	0.04049	308.34	5.26E+05	0.6	Not least of error squared	N/A
		0.7	0.04203	308.75	5.27E+05	0.55	Not least of error squared	N/A
		0.8	0.04368	309.23	5.28E+05	0.5	Not least of error squared	N/A
		0.9	0.04546	309.77	5.29E+05	0.45	Not least of error squared	N/A
		1	0.04825	310.38	5.30E+05	0.4	Not least of error squared	N/A

The best decline of X-02 is exponential decline, because it has the least sum of square error, it is about 5.25 E+05. After it had selected type of decline, it analyzed exponentially in order to predict the production performance for this well until economic limit.

(Figure 11) illustrates the least sum of square error versus reservoir constant.

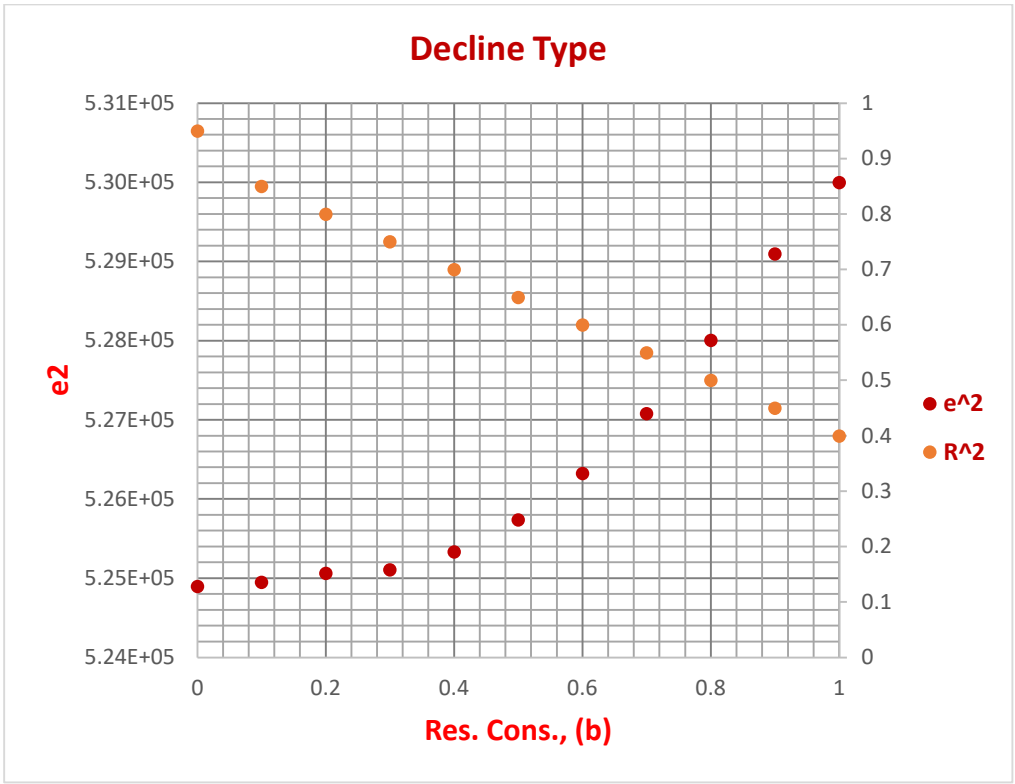

Figure 11. Error Analysis for well X-02

Table 4 shows the main results for well X-02.

Table 4. Summary of results for well X-02.

	History	Forecast
	31-3-2009	Until q_e
	Actual	
NP, (MMSTB)	3.24	1.66
Decline Model	Exponential	

DCA for well X-02 gave the initial rate about 306 bpd, and the decline rate is -about -0.0330 1/year. The Enhanced Ultimate Recovery, EUR for this well is 1.66 MMstb.

RAMA Method

Rama Method was used to determine the ultimate reserve and the decline parameter. The following figure introduces the decline results for the Rama Method.

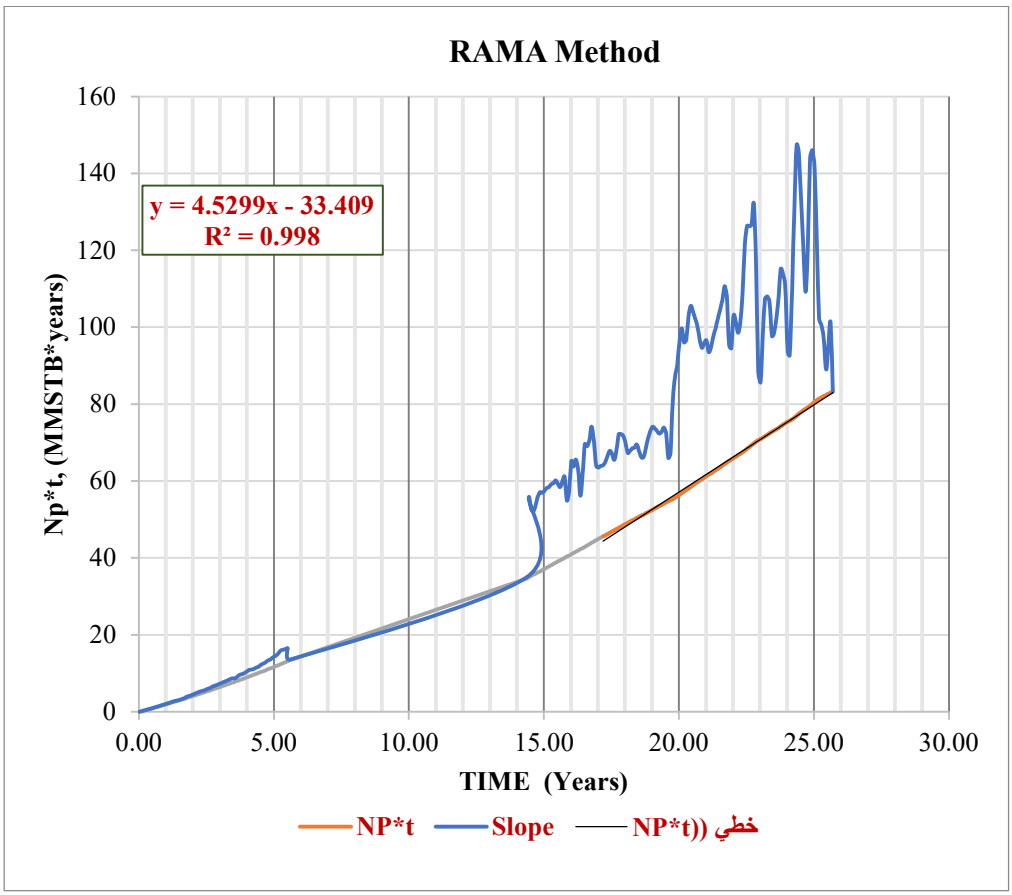

Figure 12. Rama Method plot for well X-02.

The ultimate reserve for well X-02 around 4.52 MMSTB and the remaining about 1.28 MMSTB to the economic rate.

Well X-04

This well includes one decline periods; the period starts from 2005 until end of 2009 and. **(Figure 13)** illustrates the production history for well X-04.

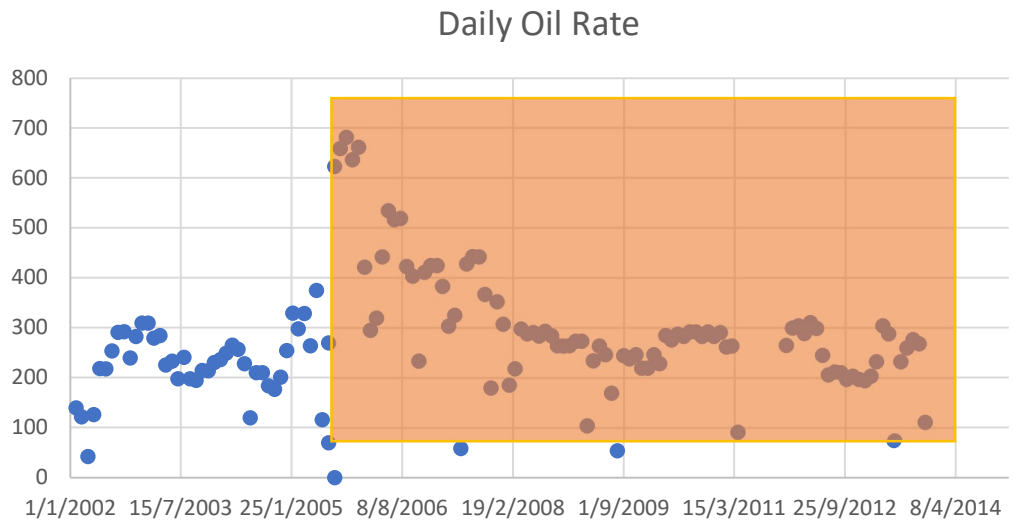

Figure 13. Production history for well X-04.

The Graphical method for this well is illustrated below:

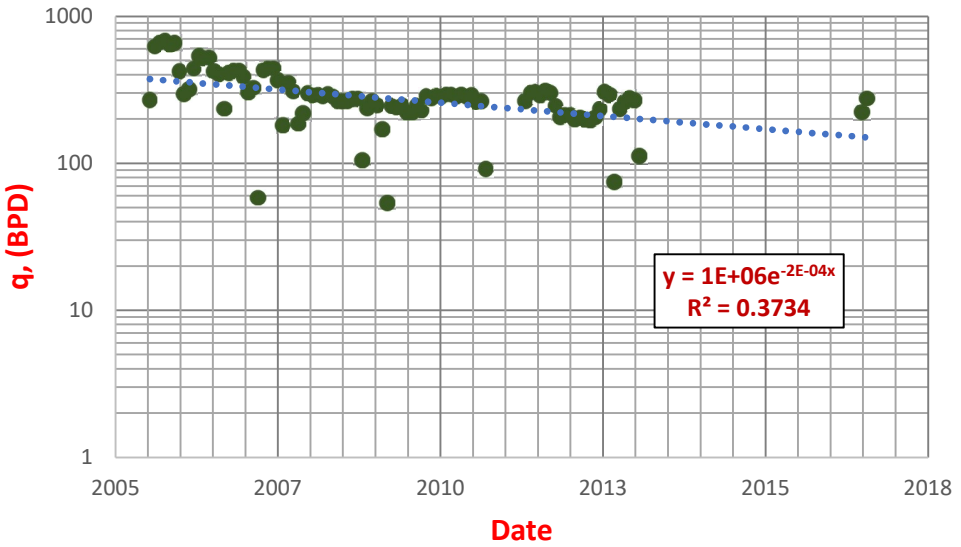

Figure 14. Graphical plot for well X-04 "Semi-log plot between Rate and Time".

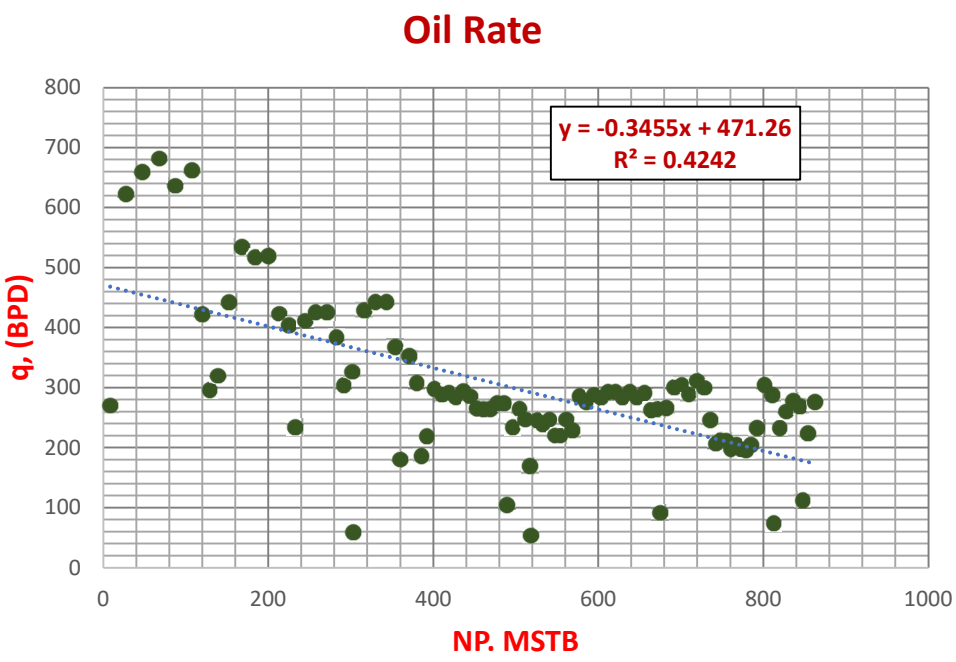

Figure 15. Graphical plot for well X-04 "Linear plot between Rate and Np".

From graphical method the decline type is exponential.

(Figure 16) shows the late period which was selected to perform DCA technique.

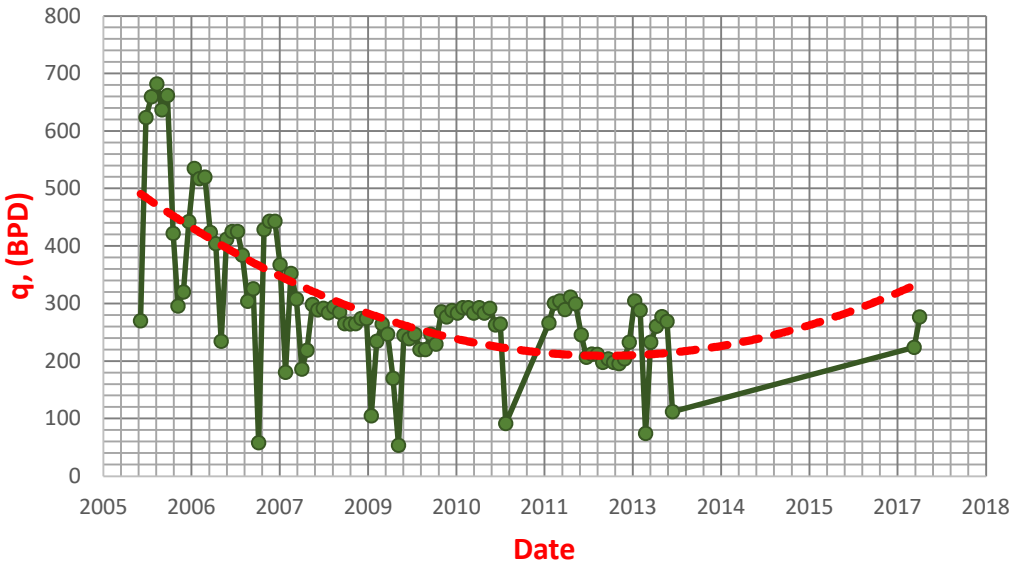

Figure16. The late period of production history for well X-04.

The decline curve analysis was applied on the late period of production data for well X-02. The results obtained from analysis; it summarizes in the **Table 5**.

Table 5. DCA results for well X-04.

Type of plot	Analyzed Period	b	a, Year^{-1}	q_i, BPD	e^2	R^2	b, (least of error squared)	Np $_{remaining}$, (MMbbl)
q vs t	2005 utill 2017	0	0.07773	374.55	9.86E+05	0.91	0	1.06
		0.1	0.07870	370.52	9.99E+05	0.90	Not least of error squared	N/A
		0.2	0.07958	366.27	1.01E+06	0.88	Not least of error squared	N/A
		0.3	0.08036	361.79	1.03E+06	0.87	Not least of error squared	N/A
		0.4	0.08100	357.06	1.05E+06	0.86	Not least of error squared	N/A
		0.5	0.08146	352.05	1.08E+06	0.85	Not least of error squared	N/A
		0.6	0.08173	346.75	1.10E+06	0.84	Not least of error squared	N/A
		0.7	0.08176	341.12	1.13E+06	0.84	Not least of error squared	N/A
		0.8	0.08151	335.17	1.17E+06	0.83	Not least of error squared	N/A
		0.9	0.08094	328.86	1.21E+06	0.82	Not least of error squared	N/A
		1	0.07879	322.21	1.25E+06	0.80	Not least of error squared	N/A

The best decline of X-04 is exponential decline, because it has the least sum of square error, it is about 9.86 E+05. After it had selected type of decline, it analyzed exponentially in order to predict the production performance for this well until economic limit.

(Figure 16) illustrates the least sum of square error versus reservoir constant.

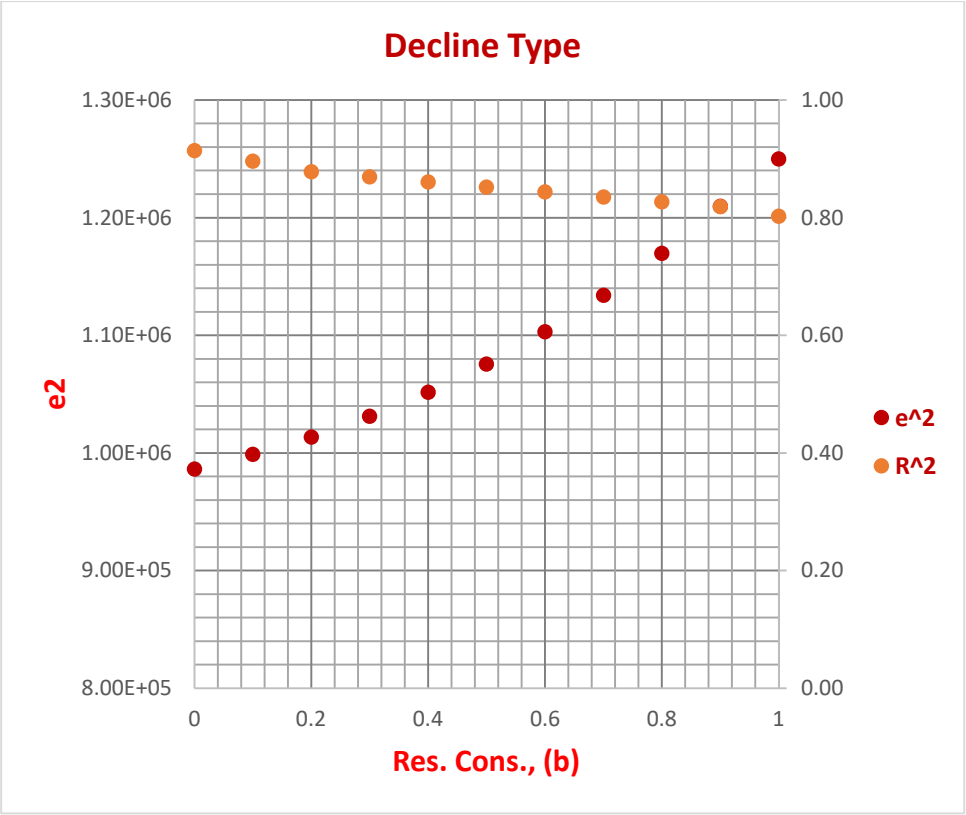

Figure 17. Error Analysis for well X-04

Table 6 shows the main results for well X-04.

Table 6. Summary of results for well X-04.

	History	Forecast
	31-3-2009	Until q_e
	Actual	
NP, (MMSTB)	0.87	1.06
Decline Model	Exponential	

DCA for well X-04 gave the initial rate about 375 bpd, and the decline rate is -about -0.077 1/year. The Enhanced Ultimate Recovery, EUR for this well is 1.06 MMstb.

RAMA Method

Rama Method was used to determine the ultimate reserve and the decline parameter. The following figure introduces the decline results for the Rama Method.

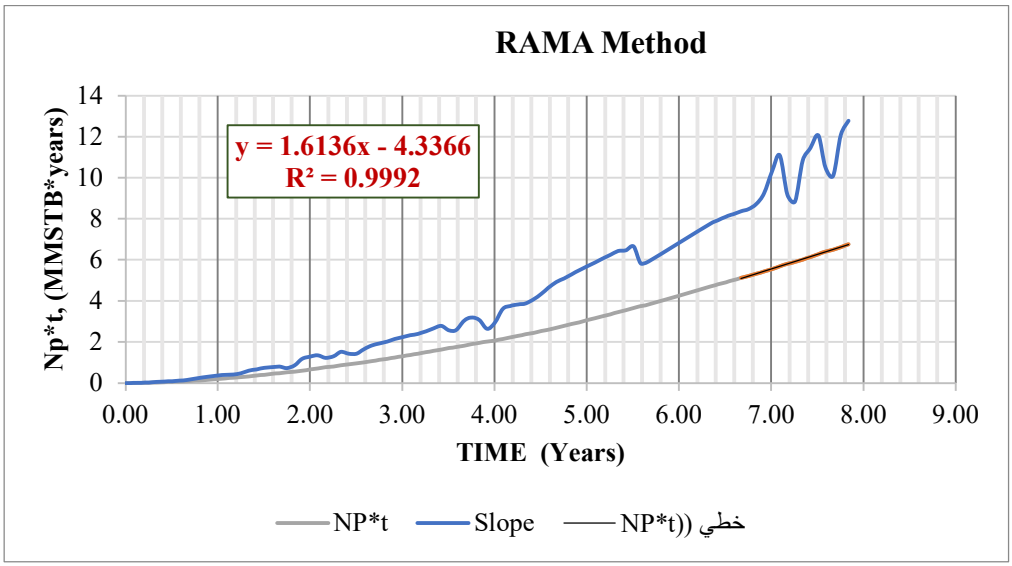

Figure 18. Rama Method plot for well X-04.

The ultimate reserve for well X-04 around 1.62 MMSTB and the remaining about 0.75 MMSTB to the economic rate.

Well Y-01

The decline period that selected to execute DCA technique. **(Figure 19)** illustrates the production history for well Y-01.

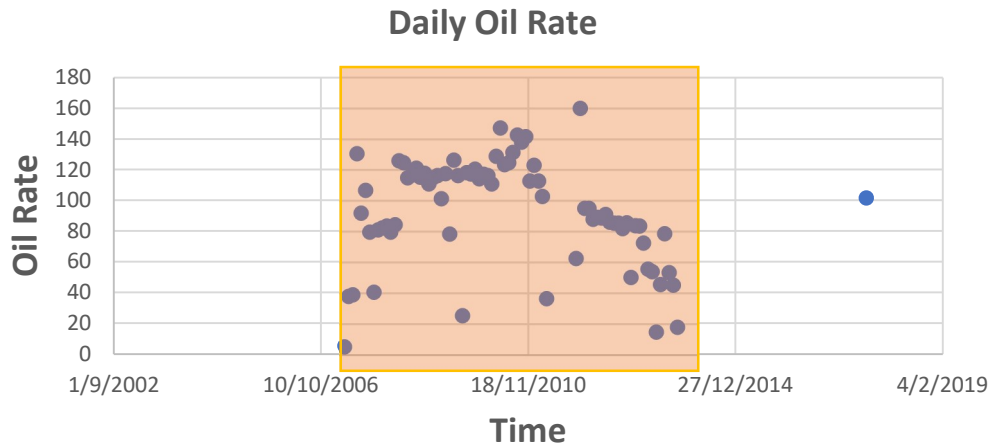

Figure 19: Production history for well Y-01

The following figures introduce the graphical results for this well.

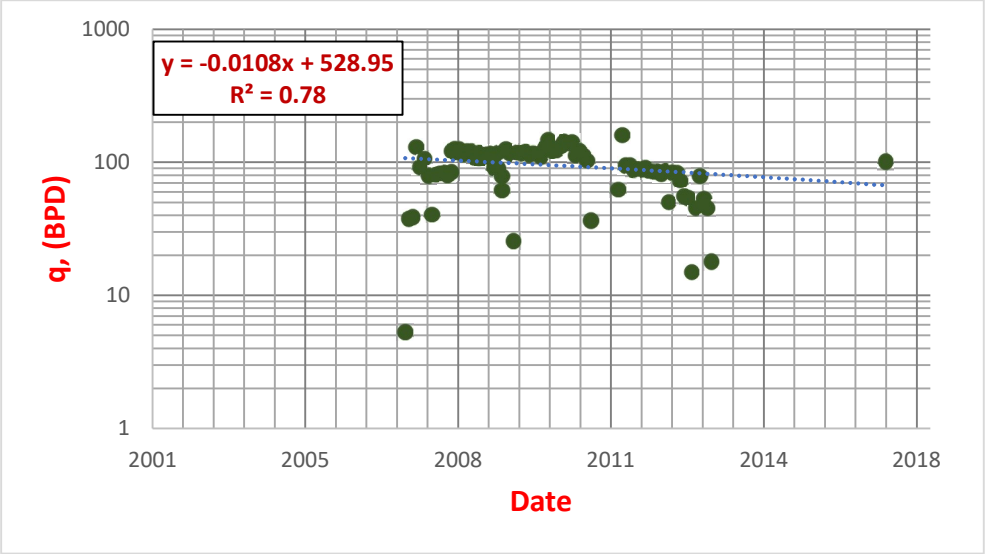

Figure 20. Graphical plot for well Y-01 "Semi-log plot between oil rate and time".

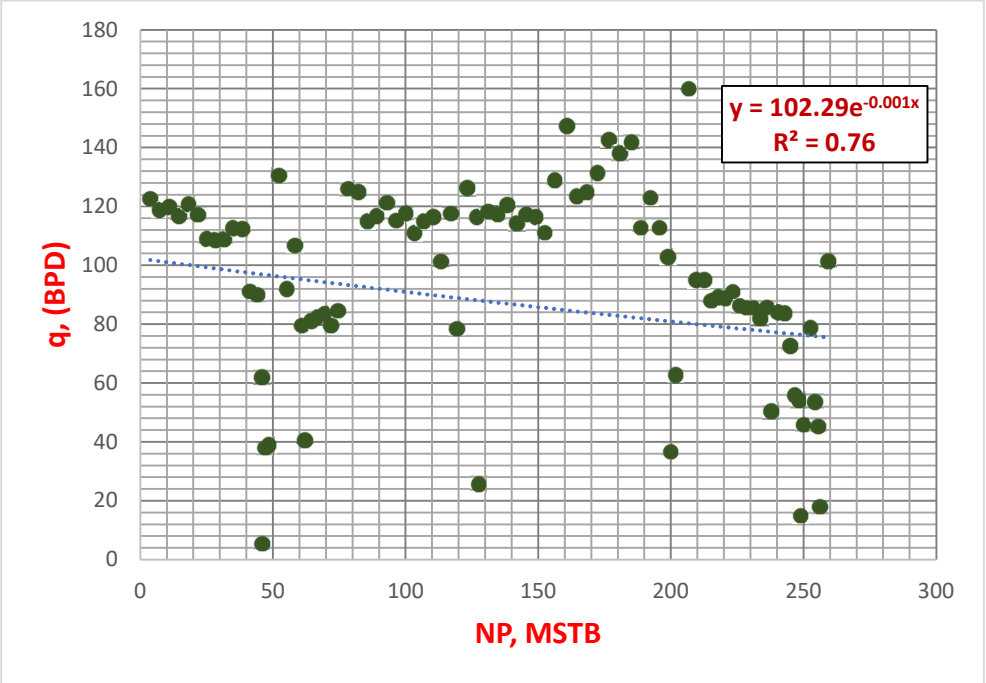

Figure 21. Graphical plot for well Y-01 "Linear plot between oil rate and Np".

The results from the graphical method are exponential decline.

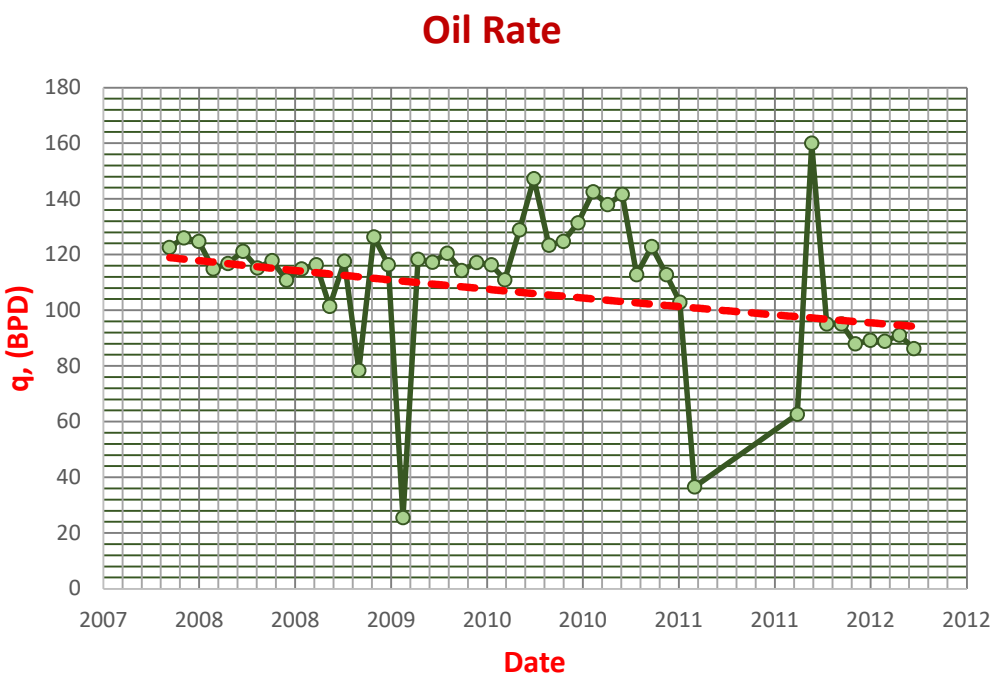

Figure 22. The late period of production history for well Y-01.

The decline curve analysis was applied on the late period of production data for well Y-01. The results obtained from analysis; it summarizes in the **Table 7**.

Table 7. DCA results for well Y-01.

Type of plot	Analyzed Period	b	a, Year^{-1}	q_i, BPD	e^2	R^2	b, (least of error squared)	$Np_{remaining}$, (MMbbl)
q vs t	2008 until 2013	0	0.05148	120	9.07E+04	0.92	0	0.18
		0.1	0.05079	94.77	9.27E+04	0.88	Not least of error squared	N/A
		0.2	0.04941	92.96	9.53E+04	0.84	Not least of error squared	N/A
		0.3	0.04715	90.89	9.85E+04	0.79	Not least of error squared	N/A
		0.4	0.04379	88.51	1.02E+05	0.76	Not least of error squared	N/A
		0.5	0.03911	85.81	1.08E+05	0.72	Not least of error squared	N/A
		0.6	0.03286	82.74	1.14E+05	0.68	Not least of error squared	N/A
		0.7	0.02488	79.32	1.22E+05	0.65	Not least of error squared	N/A
		0.8	0.01506	75.54	1.32E+05	0.62	Not least of error squared	N/A
		0.9	0.00346	71.45	1.44E+05	0.59	Not least of error squared	N/A
		1	0.00689	67.10	1.60E+05	0.56	Not least of error squared	N/A

The best decline of Y-01 is exponential decline, because it has the least sum of square error, it is about 9.07E+04. After it had selected type of decline, it analyzed exponentially in order to predict the production performance for this well until economic limit.

(Figure 23) illustrates the least sum of square error versus reservoir constant.

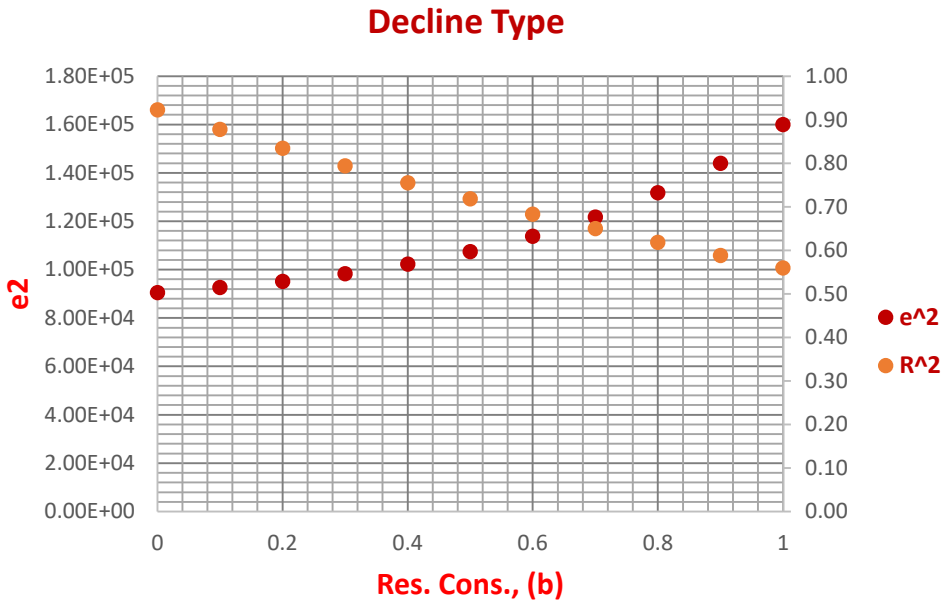

Figure 23. Error Analysis for well Y-01

Table 8 shows the main results for well Y-01.

Table 8. Summary of results for well Y-01.

	History	Forecast
	30-11-2013	Until q_e
	Actual	
NP, (MMSTB)	0.64	0.18
Decline Model	**Exponential**	

DCA for well Y-01 gave the initial rate about 132.67 bpd, and the decline rate is -about -0.0514 1/year. The Enhanced Ultimate Recovery, EUR for this well is 0.169 MMstb.

RAMA Method

Rama Method was used to determine the ultimate reserve and the decline parameter. The following figure introduces the decline results for the Rama Method.

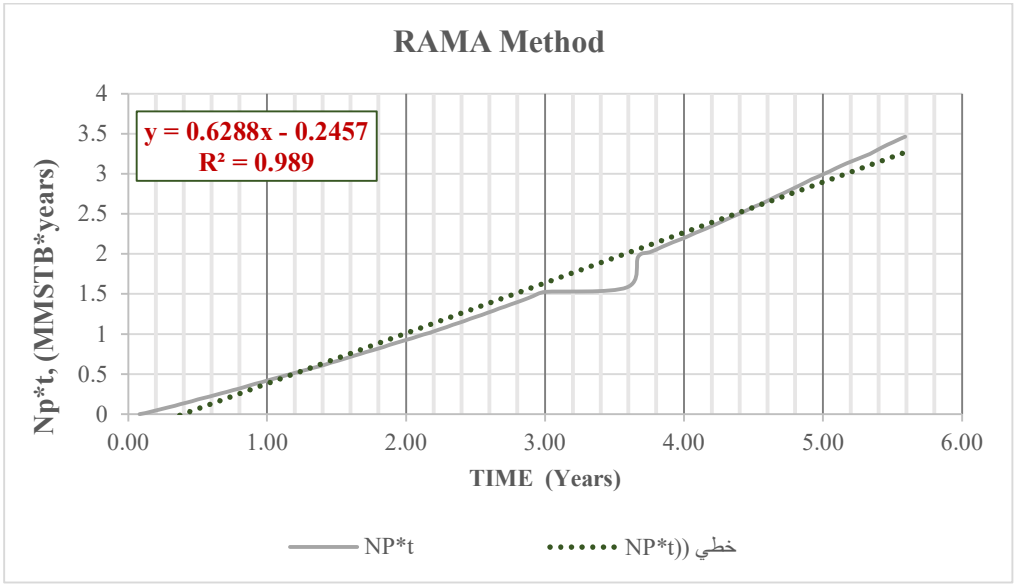

Figure 24. Rama Method plot for well Y-01.

The ultimate reserve for well Y-01 around 0.63 MMSTB and the remaining about 0.15 MMSTB to the economic rate.

Well Y-02

The decline period that selected to execute DCA technique. **(Figure 4.25)** illustrates the production history for well Y-02.

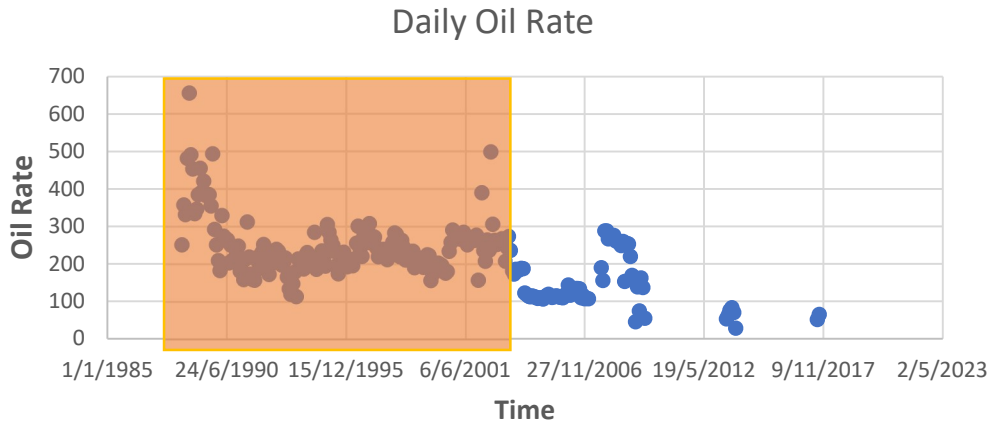

Figure 25: Production history for well Y-02

The following figures introduce the graphical results for this well.

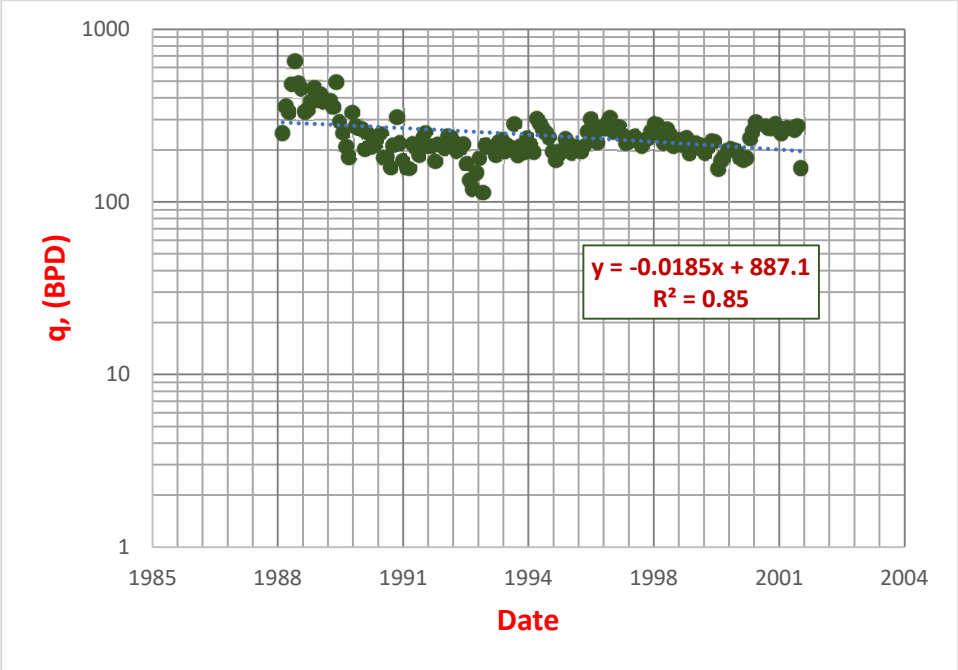

Figure 26. Graphical plot for well Y-02 "Semi-log plot between oil rate and time".

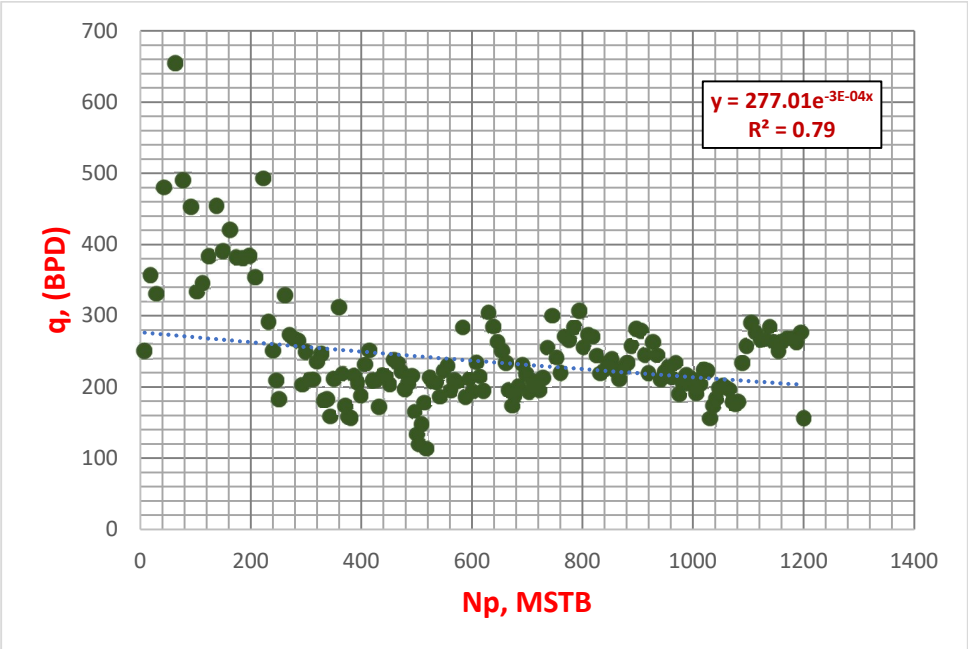

Figure 27. Graphical plot for well Y-01 "Linear plot between oil rate and Np".

The results from the graphical method is exponential decline.

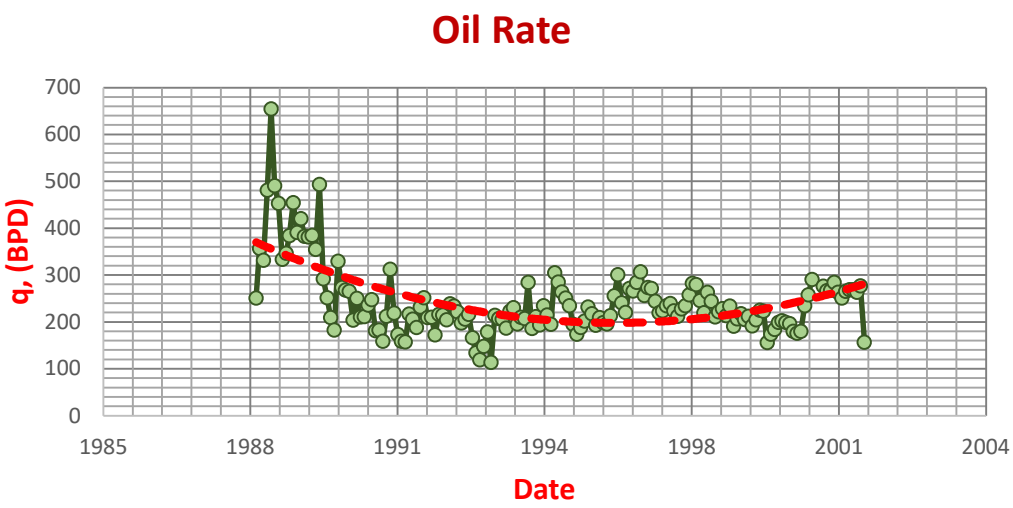

Figure 28. The late period of production history for well Y-02.

The decline curve analysis was applied on the late period of production data for well Y-02. The results obtained from analysis, it summarizes in the **Table 9**.

Table 9. DCA results for well Y-02.

Type of plot	Analyzed Period	b	a, $Year^{-1}$	q_i, BPD	e^2	R^2	b, (least of error squared)	$Np_{remaining}$, (MMbbl)
q vs t	**1988 until 2001**	**0**	**0.01994**	**268.00**	**8.07E+05**	**0.93**	**0**	**1.28**
		0.1	0.01946	266.01	8.11E+05	0.89	Not least of error squared	N/A
		0.2	0.01896	264.05	8.16E+05	0.85	Not least of error squared	N/A
		0.3	0.01845	262.12	8.20E+05	0.81	Not least of error squared	N/A
		0.4	0.01793	260.21	8.25E+05	0.78	Not least of error squared	N/A
		0.5	0.01740	258.34	8.31E+05	0.74	Not least of error squared	N/A
		0.6	0.01686	256.50	8.36E+05	0.71	Not least of error squared	N/A
		0.7	0.01631	254.68	8.42E+05	0.68	Not least of error squared	N/A
		0.8	0.01576	252.90	8.48E+05	0.65	Not least of error squared	N/A
		0.9	0.01521	251.14	8.55E+05	0.62	Not least of error squared	N/A
		1	0.01466	249.42	8.61E+05	0.59	Not least of error squared	N/A

The best decline of Y-02 is exponential decline, because it has the least sum of square error, it is about 8.07E+05. After it had selected type of decline, it analyzed exponentially in order to predict the production performance for this well until economic limit.

(Figure 29) illustrates the least sum of square error versus reservoir constant.

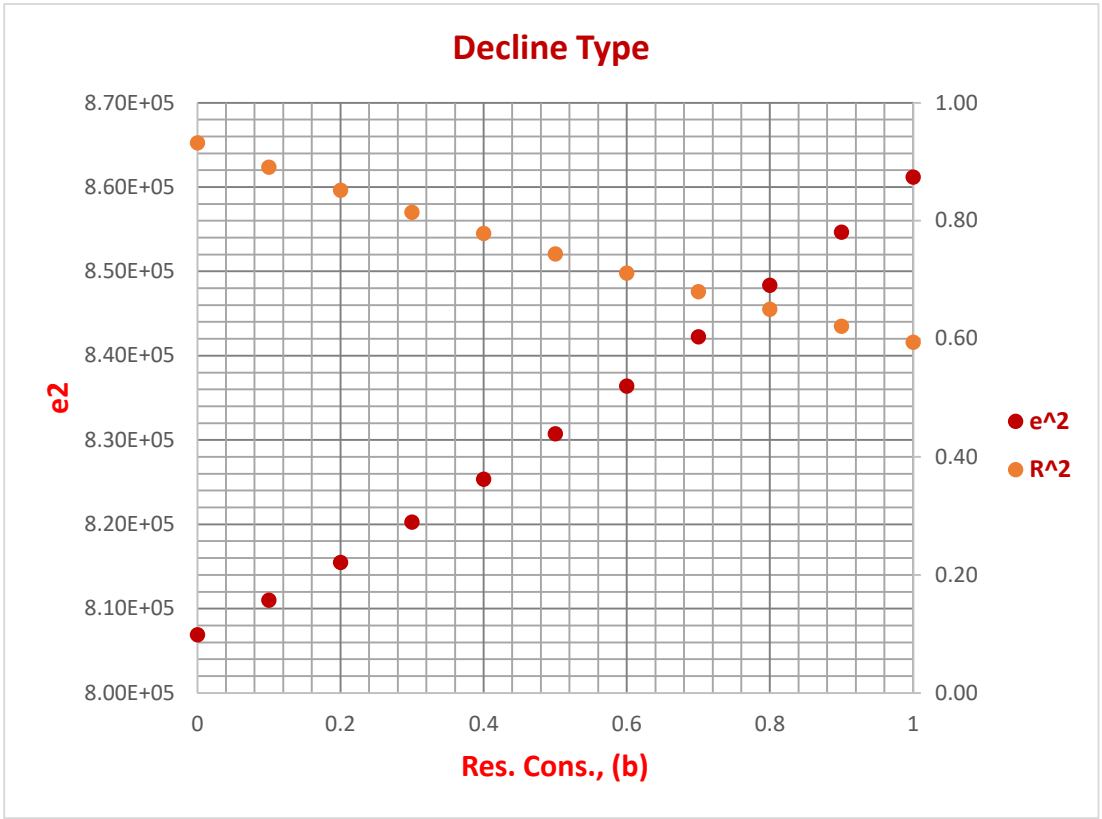

Figure 29. Error Analysis for well Y-02

Table 4.8 shows the main results for well Y-02.

Table 10. Summary of results for well Y-02.

	History	Forecast
	30-11-2013	Until q_e
	Actual	
NP, (MMSTB)	1.8	1.28
Decline Model	**Exponential**	

DCA for well Y-02 gave the initial rate about 270 bpd, and the decline rate is -about -0.0194 1/year. The Enhanced Ultimate Recovery, EUR for this well is 1.28 MMstb.

RAMA Method

Rama Method was used to determine the ultimate reserve and the decline parameter. The following figure introduces the decline results for the Rama Method.

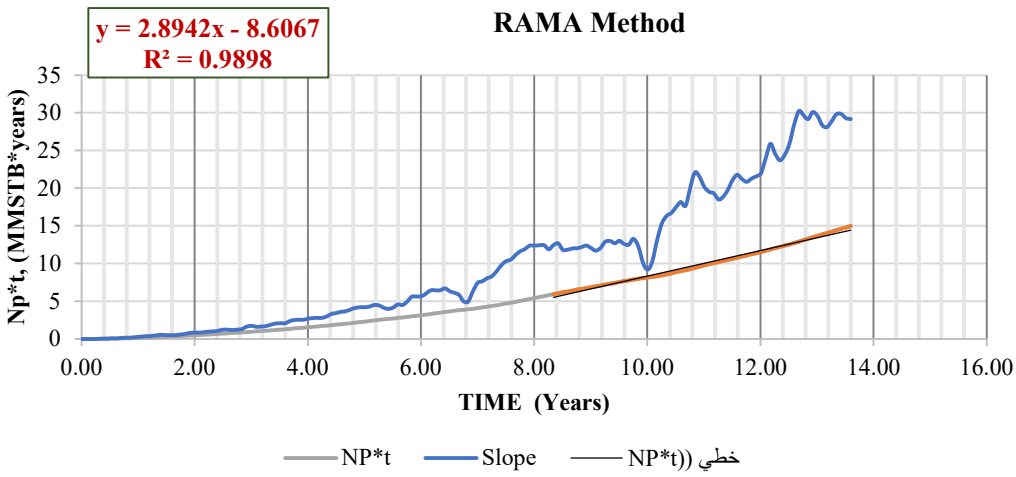

Figure 30. Rama Method plot for well Y-02.

The ultimate reserve for well Y-02 around 2.9 MMSTB and the remaining about 1.10 MMSTB to the economic rate.

Well Y-03

The decline period that selected to execute DCA technique. **(Figure 31)** illustrates the production history for well Y-03.

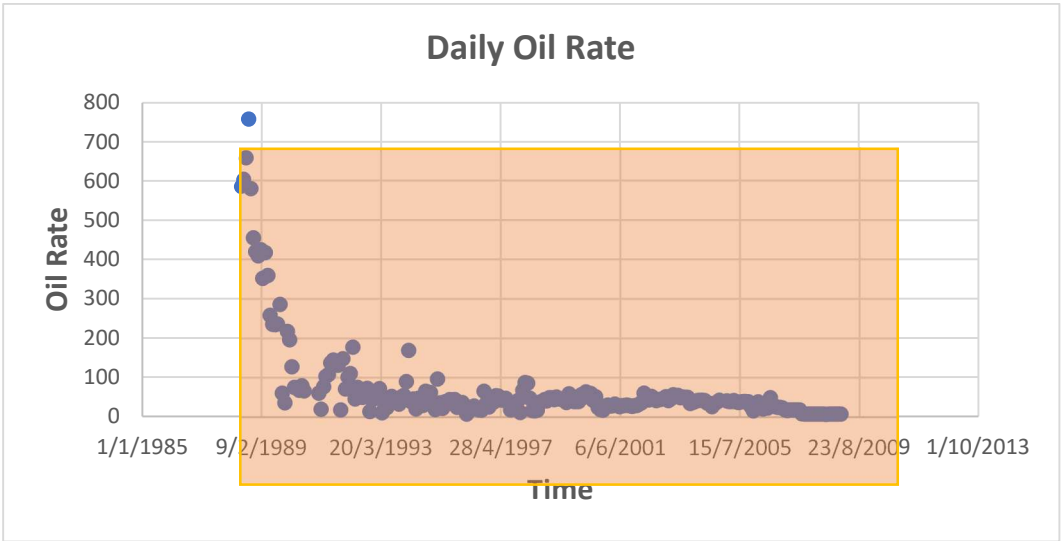

Figure 31: Production history for well Y-03

The following figures introduce the graphical results for this well.

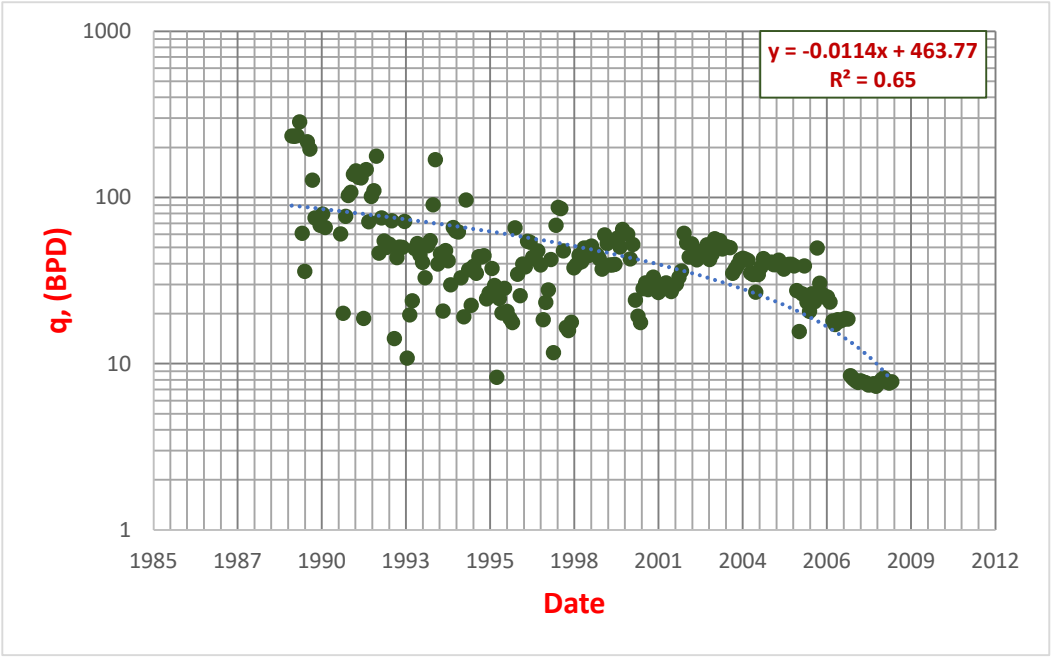

Figure 32. Graphical plot for well Y-03 "Semi-log plot between oil rate and time".

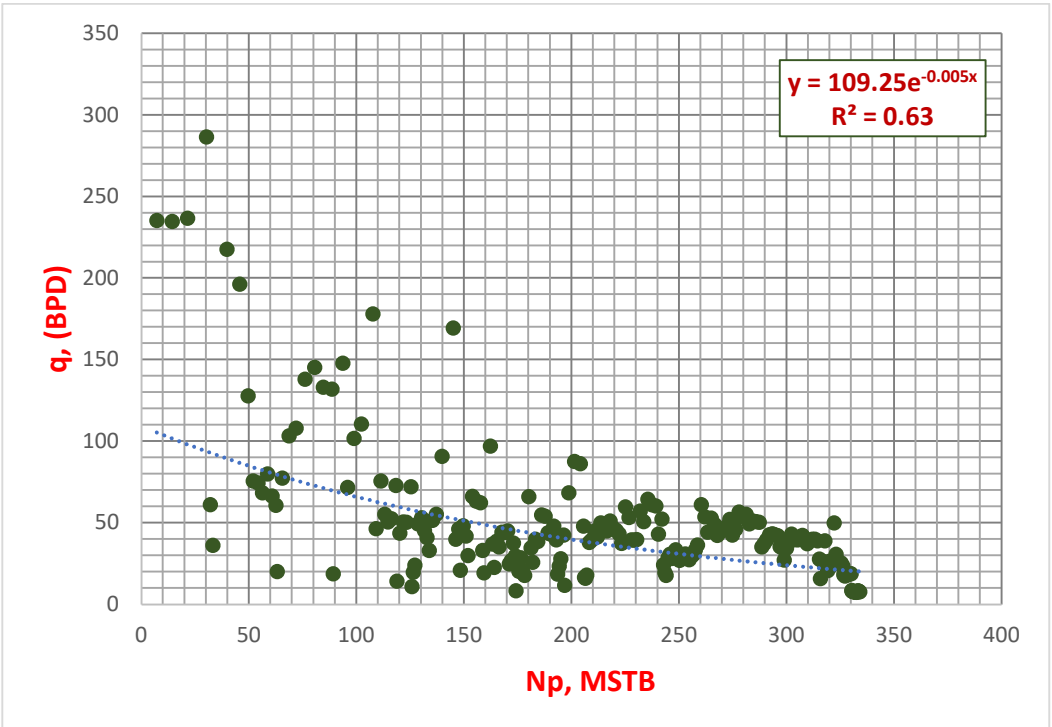

Figure 33. Graphical plot for well Y-03 "Linear plot between oil rate and Np".

The results from the graphical method are exponential decline.

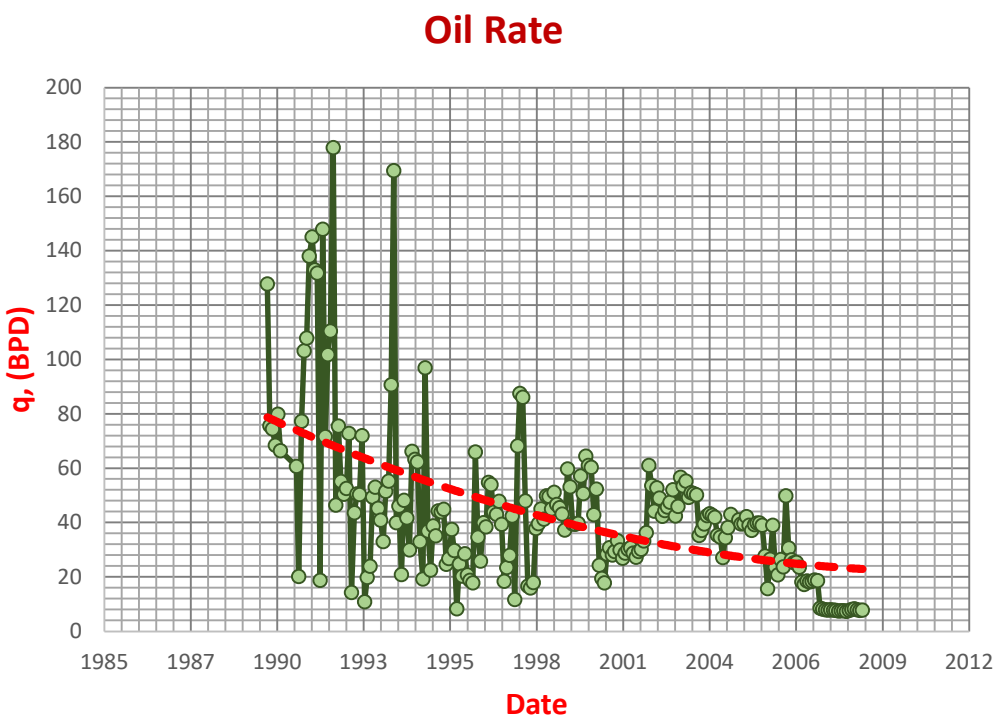

Figure 34. The late period of production history for well Y-03.

The decline curve analysis was applied on the late period of production data for well Y-02. The results obtained from analysis; it summarizes in the **Table 11**.

Table 11. DCA results for well Y-03.

Type of plot	Analyzed Period	b	a, Year^{-1}	q_i, BPD	e^2	R^2	b, (least of error squared)	Np remaining, (MMbbl)
q vs t	1988 until 2008	0	0.05426	70.08	1.13E+05	0.90	0	0.20
		0.1	0.05326	67.66	1.14E+05	0.84	Not least of error squared	N/A
		0.2	0.05197	65.27	1.15E+05	0.79	Not least of error squared	N/A
		0.3	0.05038	62.94	1.16E+05	0.75	Not least of error squared	N/A
		0.4	0.04851	60.65	1.18E+05	0.70	Not least of error squared	N/A
		0.5	0.04638	58.42	1.21E+05	0.66	Not least of error squared	N/A
		0.6	0.04400	56.26	1.23E+05	0.63	Not least of error squared	N/A
		0.7	0.04142	54.17	1.26E+05	0.59	Not least of error squared	N/A
		0.8	0.03867	52.16	1.29E+05	0.55	Not least of error squared	N/A
		0.9	0.03580	50.22	1.32E+05	0.52	Not least of error squared	N/A
		1	0.03488	48.37	1.37E+05	0.49	Not least of error squared	N/A

The best decline of Y-03 is exponential decline, because it has the least sum of square error, it is about 1.13 E+05. After it had selected type of decline, it analyzed exponentially in order to predict the production performance for this well until economic limit.

(Figure 35) illustrates the least sum of square error versus reservoir constant.

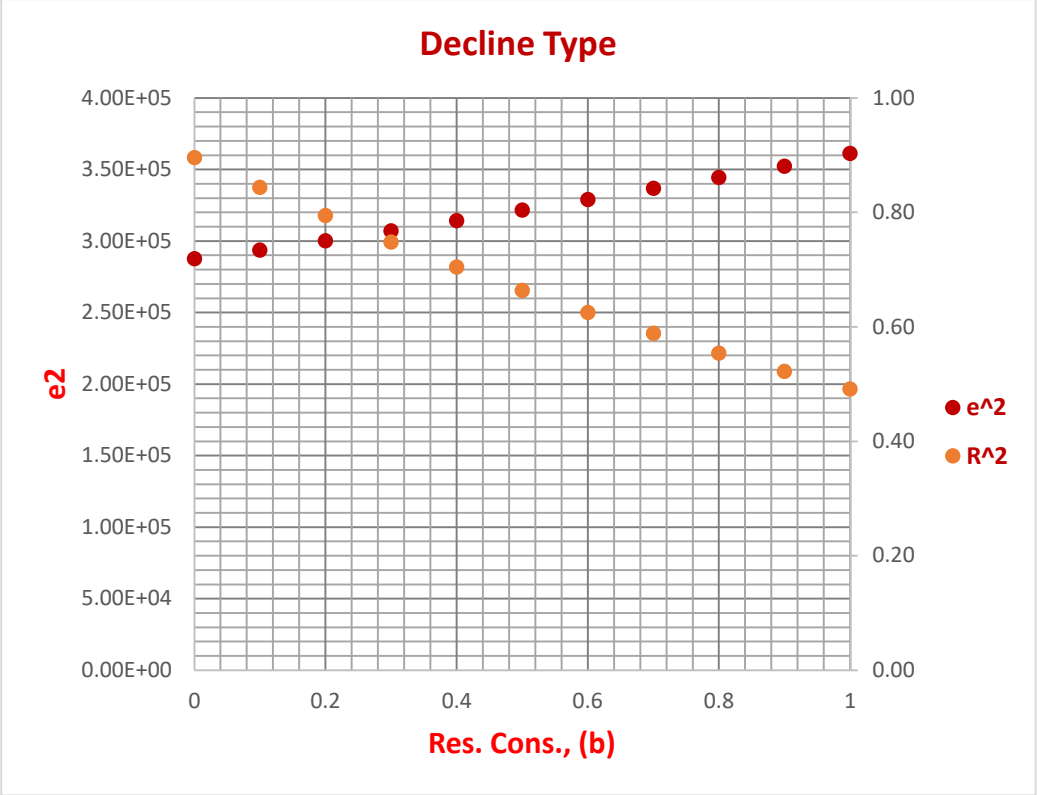

Figure 35. Error Analysis for well Y-03

Table 12 shows the main results for well Y-03.

Table 12. Summary of results for well Y-03.

	History	Forecast
	30-11-2013	Until q_e
	Actual	
NP, (MMSTB)	0.5	0.2
Decline Model	Exponential	

DCA for well Y-03 gave the initial rate about 70 bpd, and the decline rate is -about -0.0542 1/year. The Enhanced Ultimate Recovery, EUR for this well is 0.2 MMstb.

RAMA Method

Rama Method was used to determine the ultimate reserve and the decline parameter. The following figure introduces the decline results for the Rama Method.

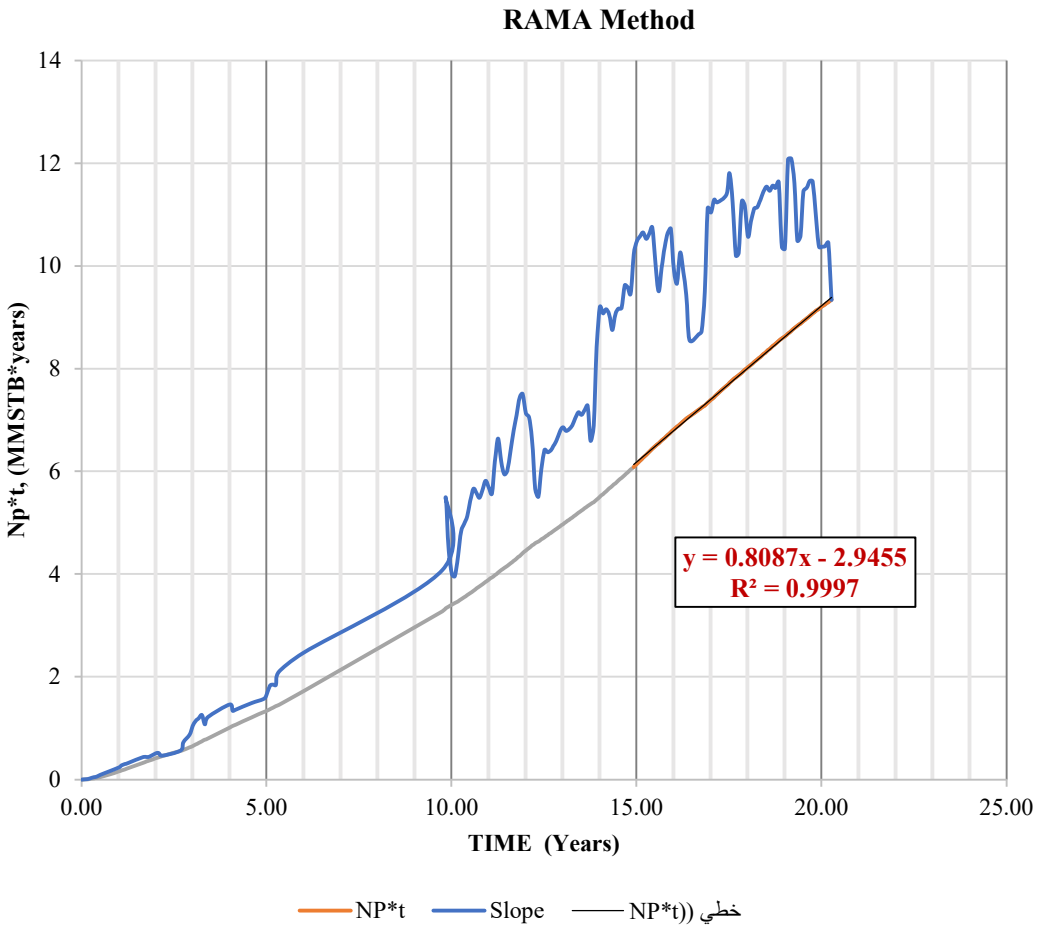

Figure 36. Rama Method plot for well Y-03.

The ultimate reserve for well Y-03 around 0.80 MMSTB and the remaining about 0.15 MMSTB to the economic rate.

Well Y-04

The decline period that selected to execute DCA technique. **(Figure 37)** illustrates the production history for well Y-04.

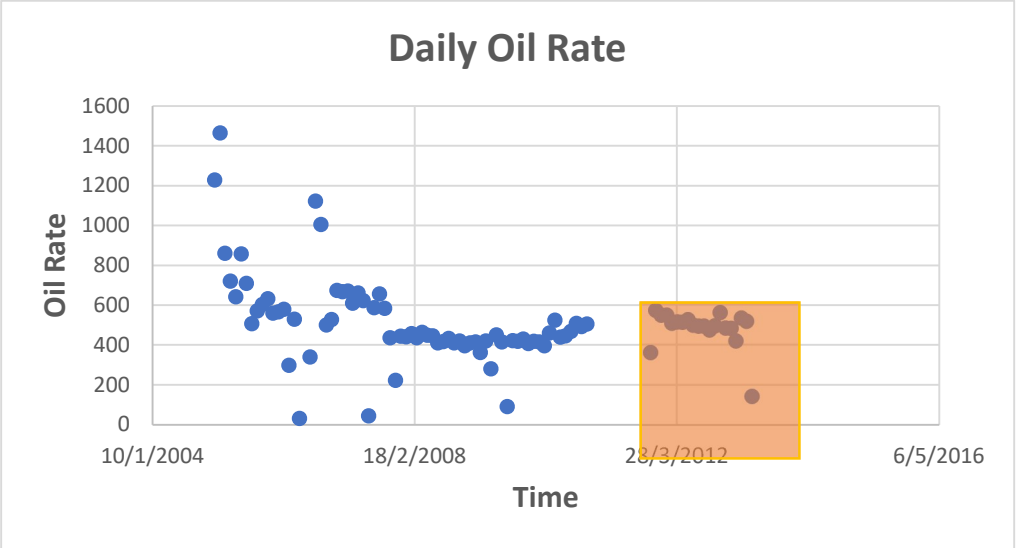

Figure 37: Production history for well Y-04

The following figures introduce the graphical results for this well.

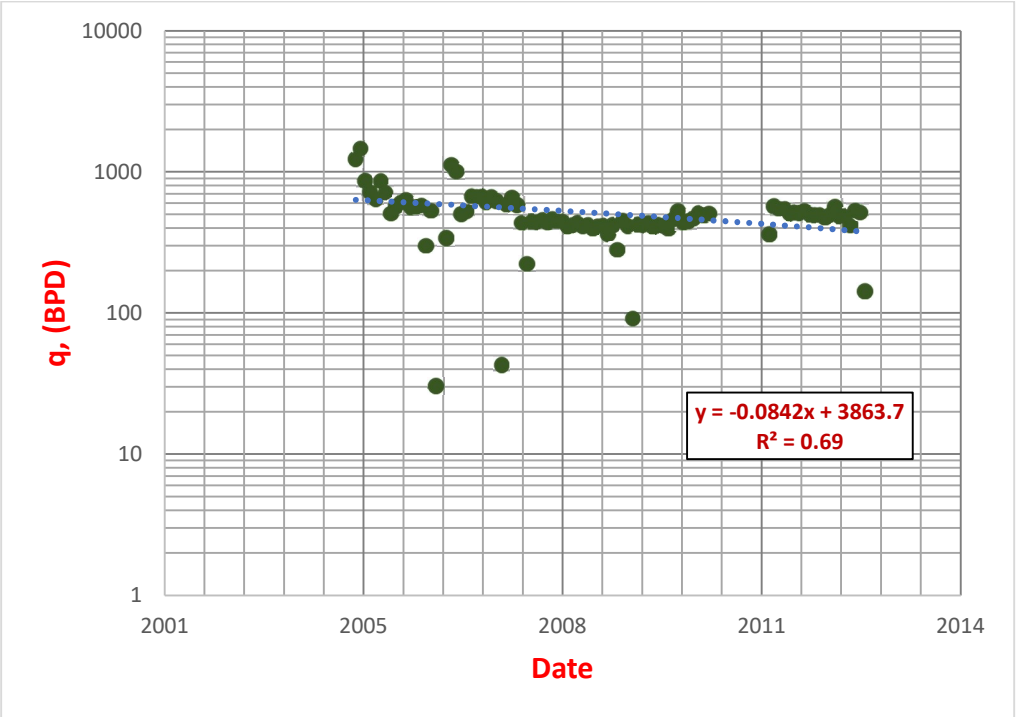

Figure 38. Graphical plot for well Y-04 "Semi-log plot between oil rate and time".

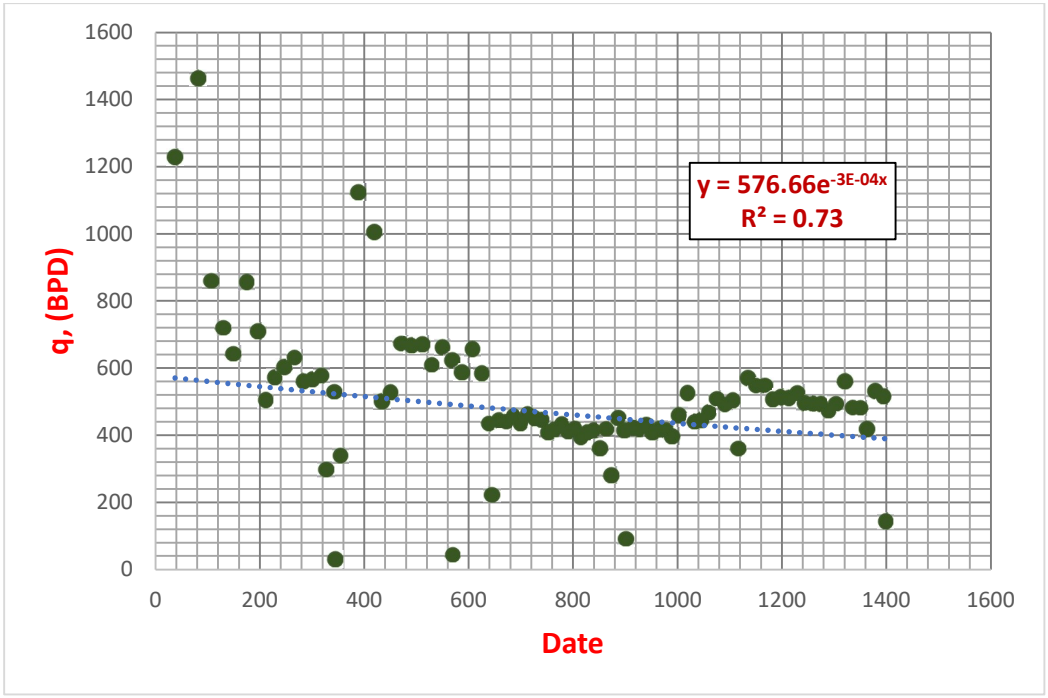

Figure 39. Graphical plot for well Y-04 "Linear plot between oil rate and Np".

The results from the graphical method are exponential decline.

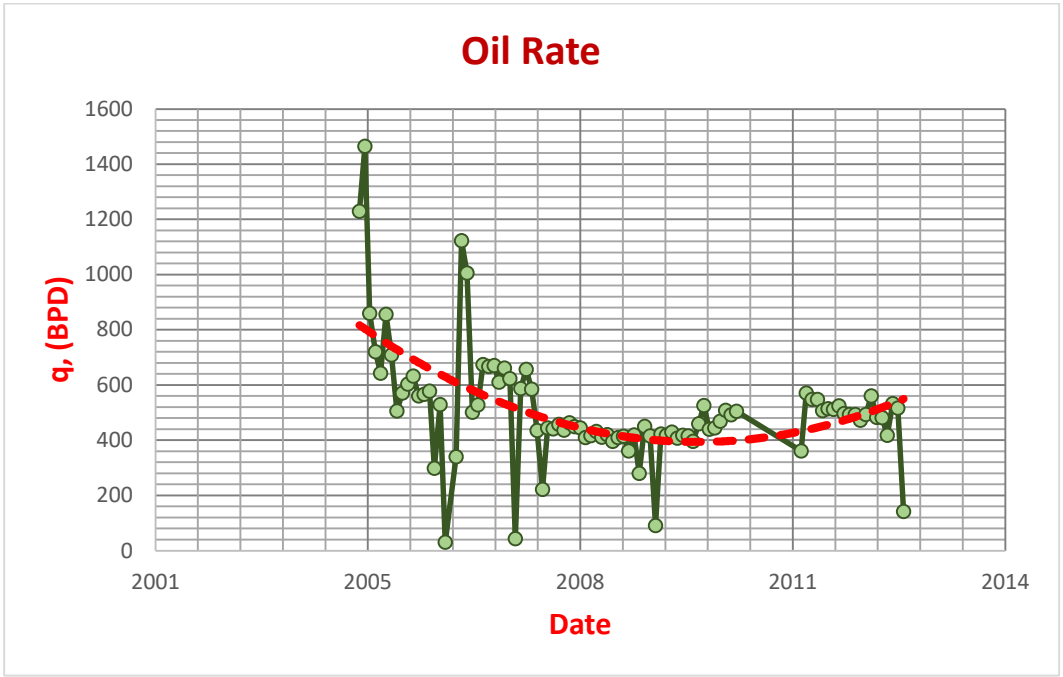

Figure 40. The late period of production history for well Y-04.

The decline curve analysis was applied on the late period of production data for well Y-04. The results obtained from analysis; it summarizes in the **Table 13**.

Table 13. DCA results for well Y-04.

Type of plot	Analyzed Period	b	a, Year^{-1}	q_i, BPD	e^2	R^2	b, (least of error squared)	Np $_{remaining}$, (MMbbl)
q vs t	2004 until 2013	0	0.02839	533.03	3.57E+06	0.96	0	1.29
		0.1	0.02495	517.66	3.66E+06	0.94	Not least of error squared	N/A
		0.2	0.02084	500.80	3.78E+06	0.91	Not least of error squared	N/A
		0.3	0.01597	482.34	3.93E+06	0.89	Not least of error squared	N/A
		0.4	0.01030	462.23	4.11E+06	0.86	Not least of error squared	N/A
		0.5	0.00382	440.50	4.33E+06	0.84	Not least of error squared	N/A
		0.6	0.00342	417.30	4.60E+06	0.82	Not least of error squared	N/A
		0.7	0.01130	392.88	4.93E+06	0.80	Not least of error squared	N/A
		0.8	0.01957	367.62	5.30E+06	0.78	Not least of error squared	N/A
		0.9	0.02796	342.02	5.73E+06	0.76	Not least of error squared	N/A
		1	0.03053	316.61	6.34E+06	0.74	Not least of error squared	N/A

The best decline of Y-04 is exponential decline, because it has the least sum of square error, it is about 3.6 E+06. After it had selected type of decline, it analyzed exponentially in order to predict the production performance for this well until economic limit.

(Figure 41) illustrates the least sum of square error versus reservoir constant.

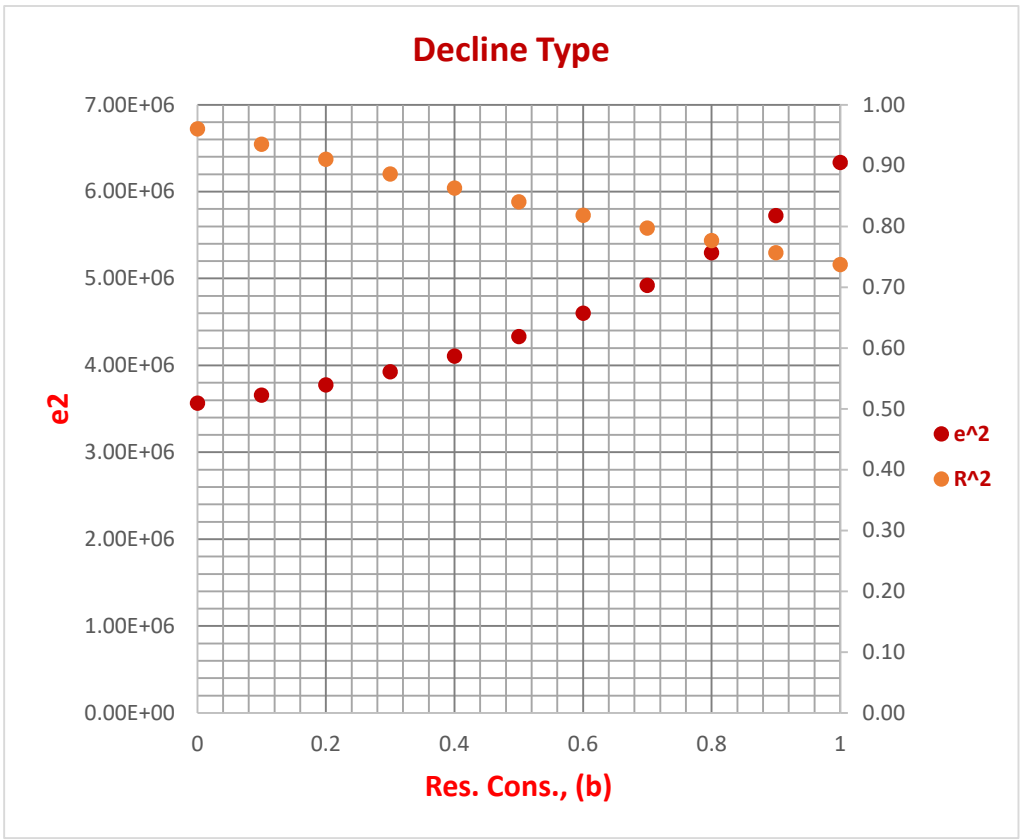

Figure 41. Error Analysis for well Y-04

Table 14 shows the main results for well Y-04.

Table 14. Summary of results for well Y-04.

	History	Forecast
	30-11-2013	Until q_e
	Actual	
NP, (MMSTB)	1.4	1.29
Rama Method	1.4	1.32

DCA for well Y-04 gave the initial rate about 533 bpd, and the decline rate is -about -0.0249 1/year. The Enhanced Ultimate Recovery, EUR for this well is 1.29 MMstb.

RAMA Method

Rama Method was used to determine the ultimate reserve and the decline parameter. The following figure introduce the decline results for the Rama Method.

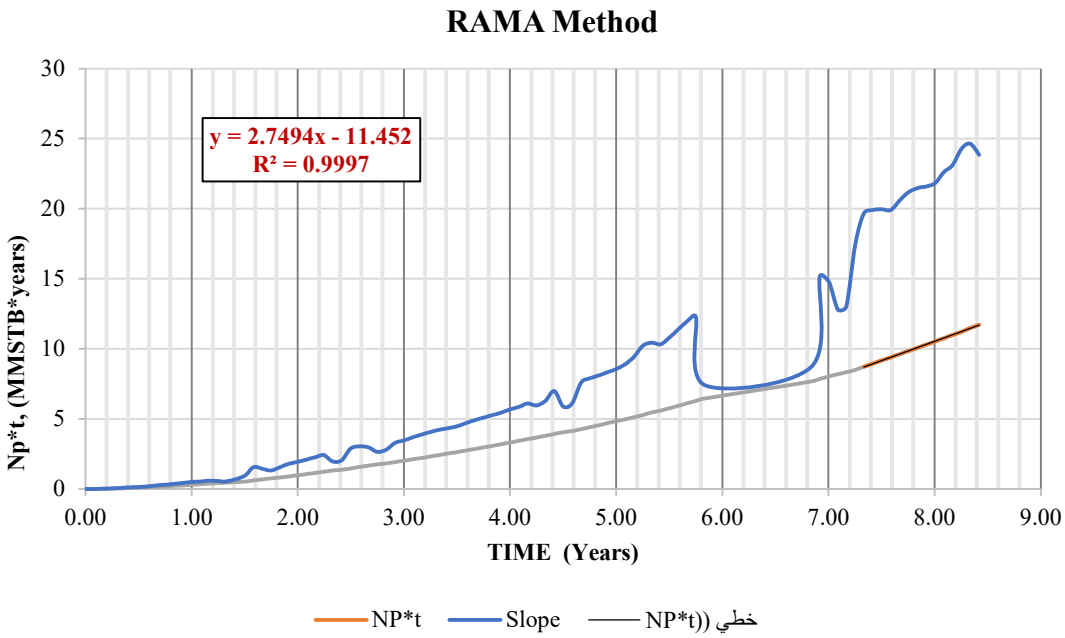

Figure 42. Rama Method plot for well Y-04**.**

The ultimate reserve for well Y-04 around 2.7 MMSTB and the remaining about 1.32 MMSTB to the economic rate.

OFM Software

In this section, it was used the Oil Field Manager, OFM software to determine decline rate and initial rate by using the following procedures:

a. The production history for specific wells on Y&L fields was collected.
b. The production history was insert to OFM in a special format.
c. The decline intervals were selected to perform the decline curve analysis.
d. Determine production decline curve parameters from OFM by edit forecasting options.

Well X-01

(Figure 43) illustrates the production performance for X-01.

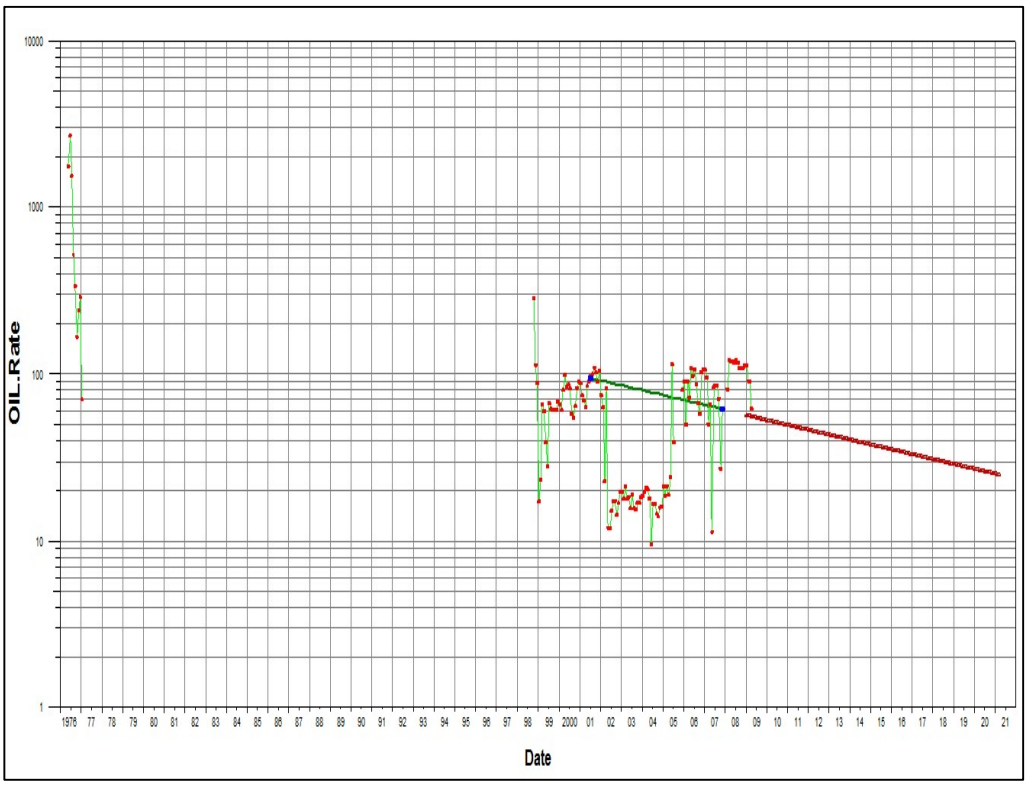

Figure 43. Production performance for well X-01 (OFM Software)

Table 15 shows the main results for well X-01 in OFM software.

Table 15. The main results for well X-01 (OFM Software)

Case1: Oil: 103L1										
Historical Regression										
	Cumulative Production 462.988 thru 04/30/2009									
	b Value	Di (M.n.)	qi ()	ti						
	0.00	0.00359	97.908	11/22/2001						
Working forecast										
	EUR 768.72									
#	b Value	Di (M.n.)	qi ()	ti	te	qe ()	Res. ()	Ended By	Reserves Type	
1	0.00	0.00359	61.891	12/31/2008	01/31/2030	24.945	313.106	Rate	None	

From table above, the decline type is exponential decline, the initial rate equals 97 bpd and the decline rate equals 0.00359 1/monthly.
The remaining reserve for this well is about 0.313 MMstb.

Well X-02

(Figure 44) illustrates the production performance for X-02.

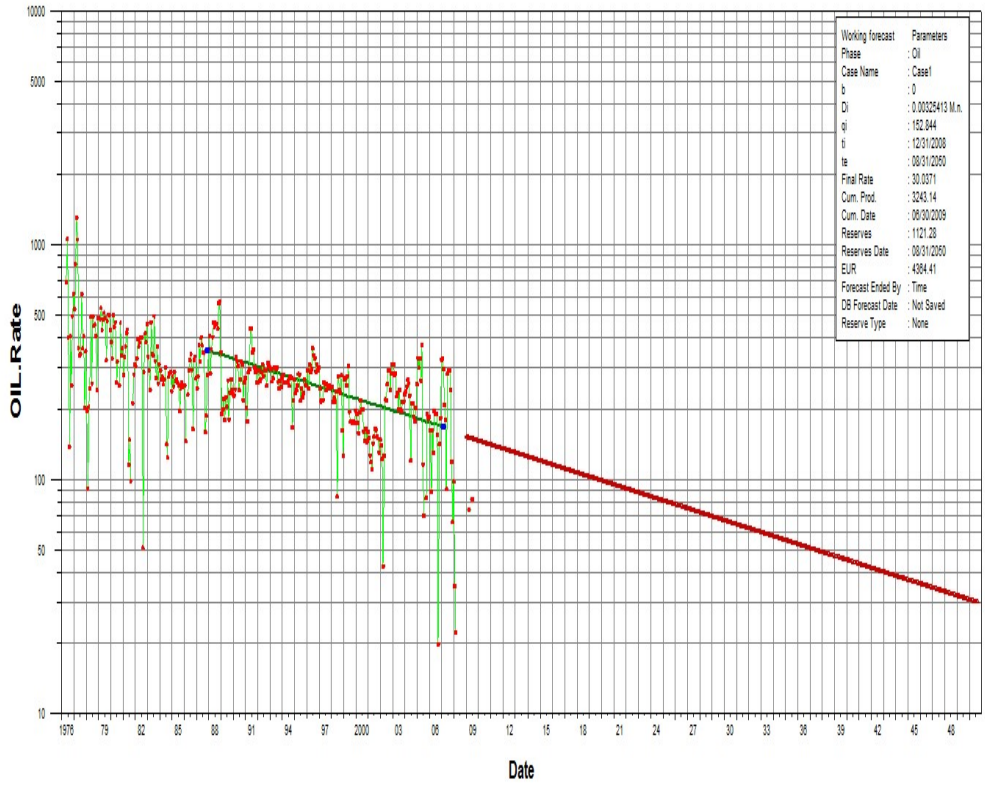

Figure 44. Production performance for well X-02 (OFM Software)

Table 16 shows the main results for well X-02 in OFM software.

Table 16. The main results for well X-02 (OFM Software)

Case1: Oil: 103L2										
Historical Regression										
	Cumulative Production 3243.14 thru 06/30/2009									
	b Value	Di (M.n.)	qi ()	ti						
	0.00	0.00325	355.791	11/10/1987						
Working forecast										
	EUR 4364.41									
#	b Value	Di (M.n.)	qi ()	ti	te	qe ()	Res. ()	Ended By	Reserves Type	
1	0.00	0.00325	152.844	12/31/2008	08/31/2050	30.037	1148.674	Time	None	

From table above, the decline type is exponential decline, the initial rate equals 152 bpd and the decline rate equals 0.00325 1/monthly.
The remaining reserve for this well is about 1.14 MMstb.

Well X-03

(Figure 45) illustrates the production performance for X-03.

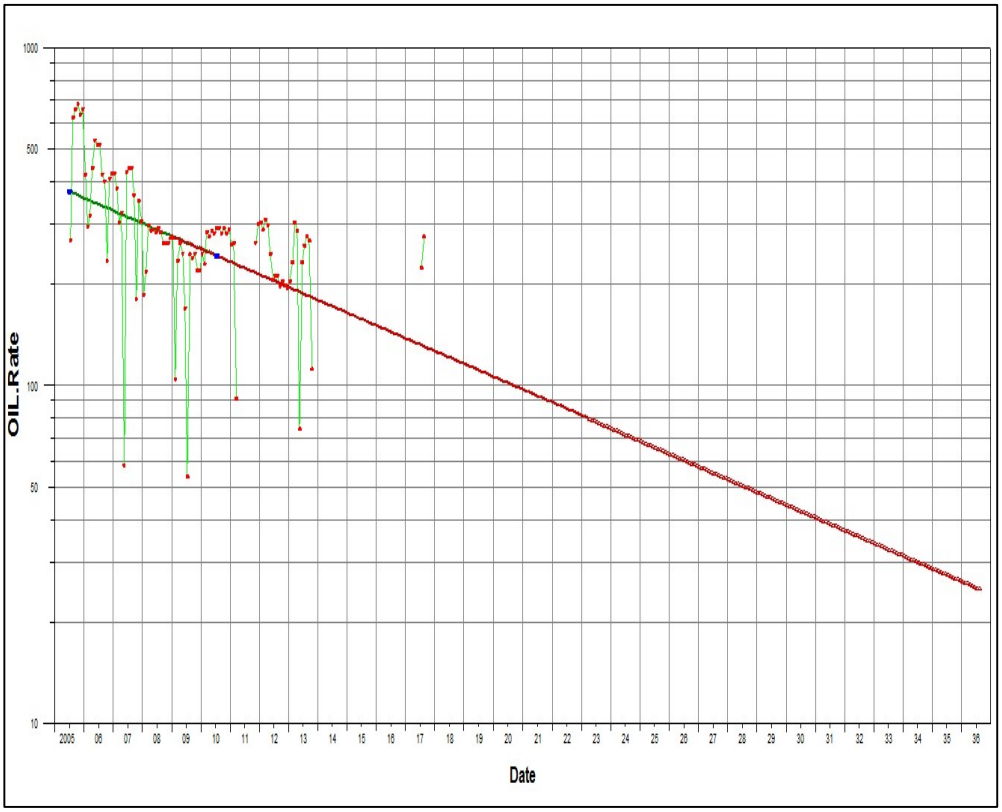

Figure 45. Production performance for well X-03 (OFM Software)

Table 17 shows the main results for well X-03 in OFM software.

Table 17. The main results for well X-03 (OFM Software)

Case1: Oil: 103L4									
Historical Regression									
	Cumulative Production 862.972 thru 08/31/2017								
	b Value	Di (M.n.)	qi ()	ti					
	0.00	0.00551	403.461	12/06/2005					
Working forecast									
	EUR 1851.07								
#	b Value	Di (M.n.)	qi ()	ti	te	qe ()	Res. ()	Ended By	Reserves Type
1	0.00	0.00551	276.612	12/31/2013	12/31/2043	37.990	1316.974	Time	None

From table above, the decline type is exponential decline, the initial rate equals 276 bpd and the decline rate equals 0.00551 1/monthly.
The remaining reserve for this well is about 0.98 MMstb.

Well Y-01

(Figure 46) illustrates the production performance for Y-01.

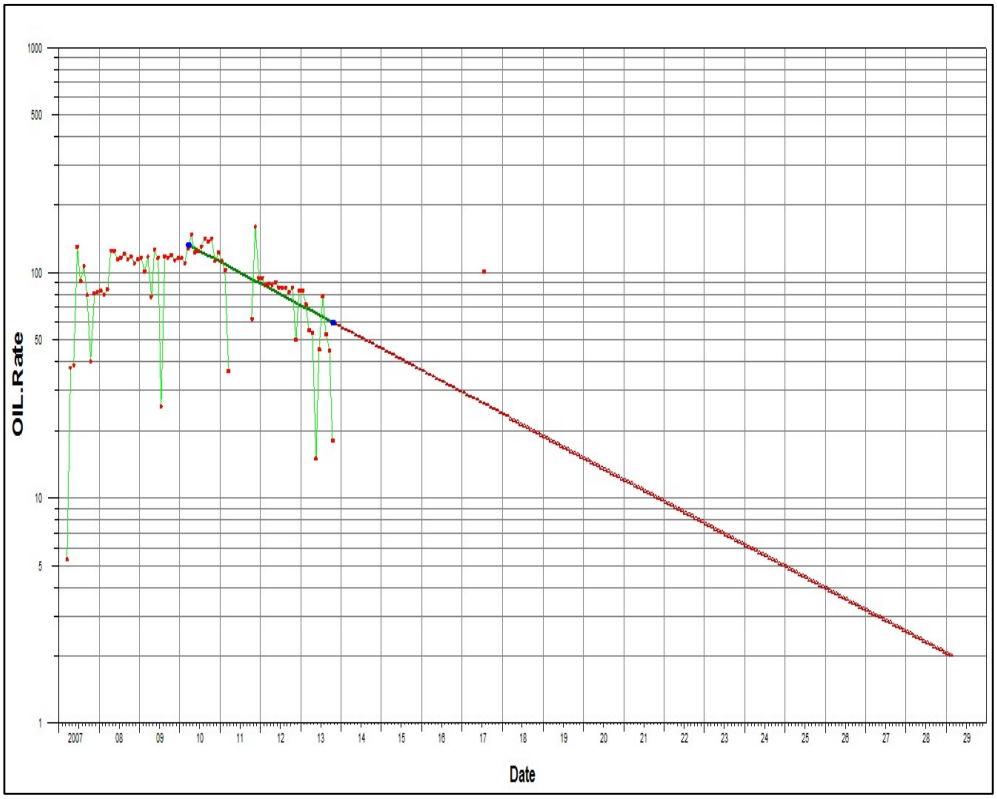

Figure 46. Production performance for well Y-01 (OFM Software)

Table 18 shows the main results for well Y-01 in OFM software.

Table 18. The main results for well Y-01 (OFM Software)

Case1: Oil: 103N1										
Historical Regression										
	Cumulative Production 213.426 thru 07/31/2017									
	b Value	Di (M.n.)	qi ()	ti						
	0.00	0.01412	120.875	09/23/2009						
Working forecast										
	EUR 279.315									
#	b Value	Di (M.n.)	qi ()	ti	te	qe ()	Res. ()	Ended By	Reserves Type	
1	0.00	0.01412	101.487	12/31/2013	04/30/2022	24.740	165.400	Rate	None	

From table above, the decline type is exponential decline, the initial rate equals 120 bpd and the decline rate equals 0.01412 1/monthly.
The remaining reserve for this well is about 0.165 MMstb.

4.3.5. Well Y-02

(Figure 47) illustrates the production performance for Y-02.

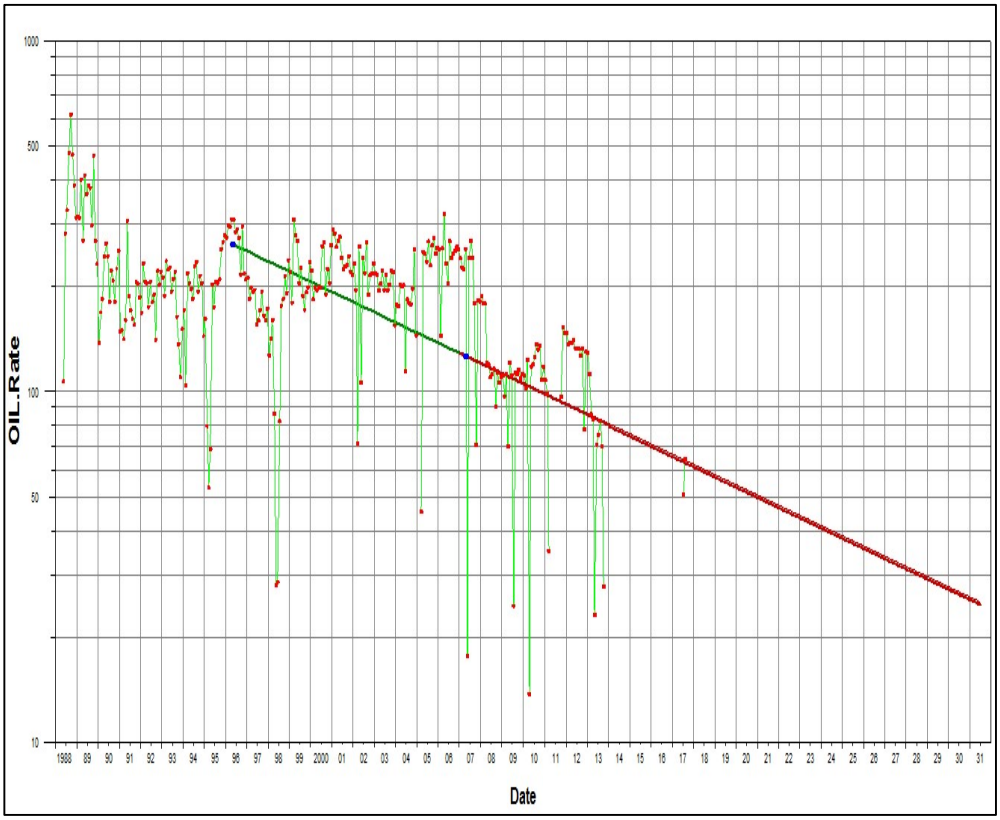

Figure 47. Production performance for well Y-02 (OFM Software)

Table 19 shows the main results for well Y-02 in OFM software.

Table 19. The main results for well Y-02 (OFM Software)

Case1: Oil: 103N2										
Historical Regression										
	Cumulative Production 1766.63 thru 08/31/2017									
	b Value	Di (M.n.)	qi ()	ti						
	0.00	0.00061	183.868	07/28/1991						
Working forecast										
	EUR 2618.12									
#	b Value	Di (M.n.)	qi ()	ti	te	qe ()	Res. ()	Ended By	Reserves Type	
1	0.00	0.00061	100.000	12/31/2013	12/31/2043	80.261	983.600	Time	None	

From table above, the decline type is exponential decline, the initial rate equals 184 bpd and the decline rate equals 0.0061 1/monthly.
The remaining reserve for this well is about 0.983 MMstb.

Well Y-03

(Figure 48) illustrates the production performance for Y-03.

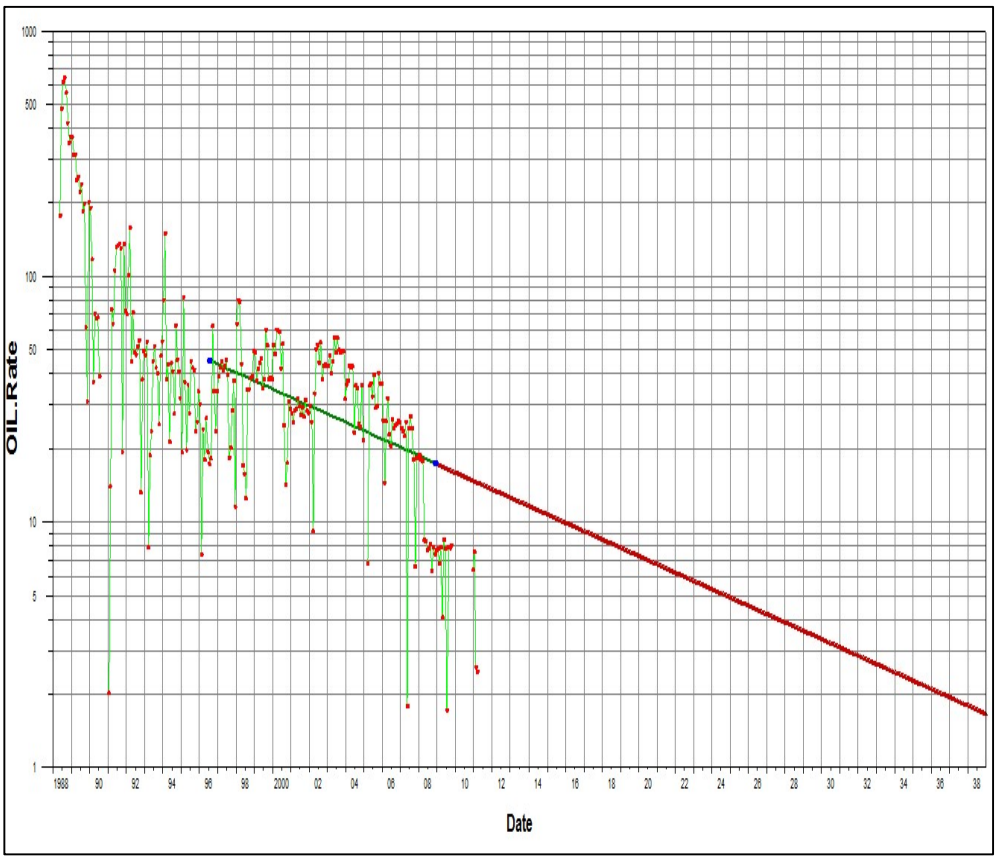

Figure 48. Production performance for well Y-03 (OFM Software)

Table 20 shows the main results for well Y-03 in OFM software.

Table 20. The main results for well Y-03 (OFM Software)

Case1: Oil: 103N3									
Historical Regression									
	Cumulative Production 464.559 thru 03/31/2011								
	b Value	Di (M.n.)	qi ()	ti					
	0.00	0.00511	72.171	04/26/1991					
Working forecast									
	EUR 510.276								
#	b Value	Di (M.n.)	qi ()	ti	te	qe ()	Res. ()	Ended By	Reserves Type
1	0.00	0.00511	10.000	12/31/2009	12/31/2039	1.589	50.098	Time	None
Database Forecast									

From table above, the decline type is exponential decline, the initial rate equals 72 bpd and the decline rate equals 0.00511 1/monthly.
The remaining reserve for this well is about 0.1 MMstb.

Well Y-04

(Figure 49) illustrates the production performance for Y-04.

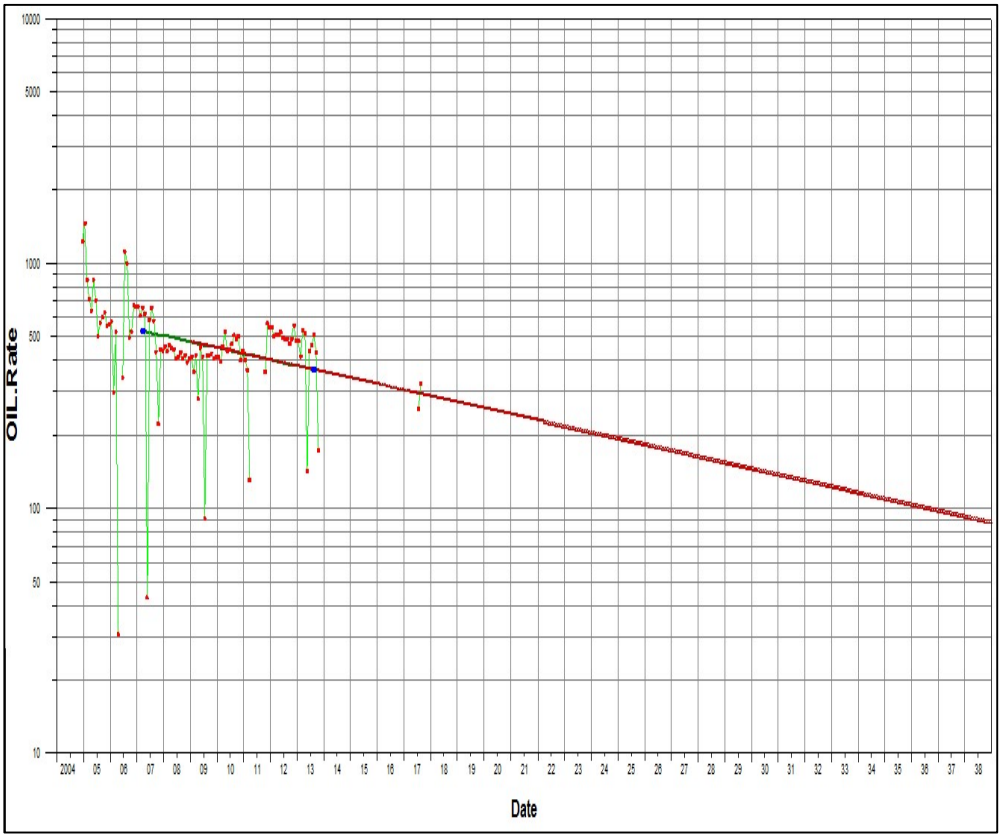

Figure 49. Production performance for well Y-04 (OFM Software)

Table 21 shows the main results for well Y-04 in OFM software.

Table 21. The main results for well Y-04 (OFM Software)

Case1: Oil: 103N4										
Historical Regression										
	Cumulative Production 1535.2 thru 08/31/2017									
	b Value	Di (M.n.)	qi ()	ti						
	0.00	0.00731	641.457	04/21/2005						
Working forecast										
	EUR 2401.39									
#	b Value	Di (M.n.)	qi ()	ti	te	qe ()	Res. ()	Ended By	Reserves Type	
1	0.00	0.00731	321.484	12/31/2013	02/28/2043	24.859	1234.262	Rate	None	

From table above, the decline type is exponential decline, the initial rate equals 641 bpd and the decline rate equals 0.00731 1/monthly.
The remaining reserve for this well is about 1.23 MMstb.

Discussion of Results

Table 22 shows the summary of results in this study.

Table 22: Summary of Results

Well NO	Analytical			OFM software		
	qi	Di	$Np_{rem.}$	qi	Di	$Np_{rem.}$
	bpd	1/year	MMstb	bpd	1/year	MMstb
X-01	100	0.055	0.231	97	0.043	0.31
X-02	306	0.033	1.66	152	0.039	1.14
X-03	375	0.077	1.06	276	0.066	0.98
Y-01	120	0.051	0.18	120	0.170	0.165
Y-02	268	0.019	1.28	184	0.019	0.98
Y-03	70	0.0542	0.2	72	0.061	0.1
Y-04	533	0.028	1.29	641	0.088	1.23

From table above, the remaining reserve obtained from analytical method for Y field is about 2.64 MMstb for all the four wells and the remaining for X field is about 2.7 MMstb, and the results are closer to remaining reserve that gotten from OFM software. Also, the results obtained from RAMA method is near from the results from the Excel and OFM.

The next plot introduces the oil production rate for the wells from X field.

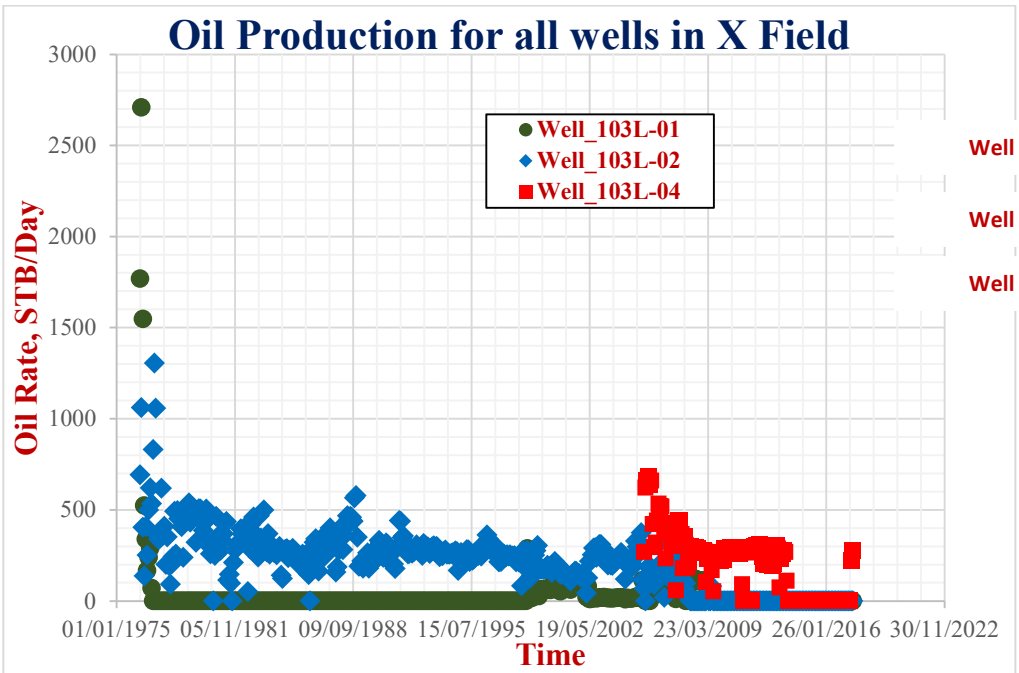

Figure 50. Oil production rate for each well in X field.

The next plot introduces the oil production rate for the wells from Y field.

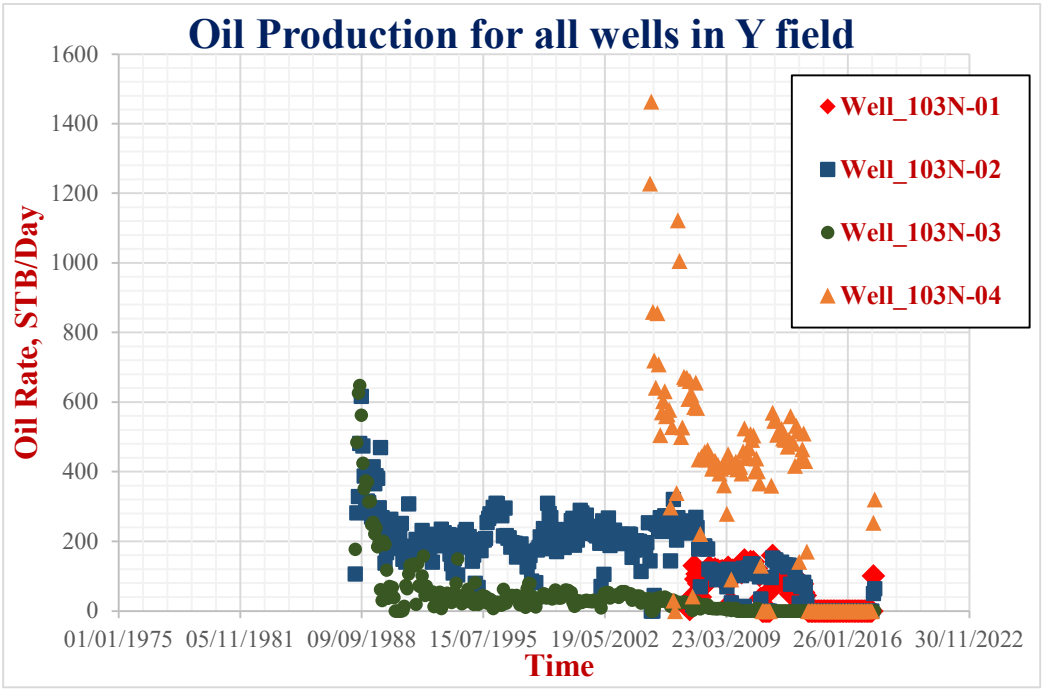

Figure 51. Oil production rate for each well in Y field.

The next plot introduces the produced oil and the remaining for the wells from the two selected fields.

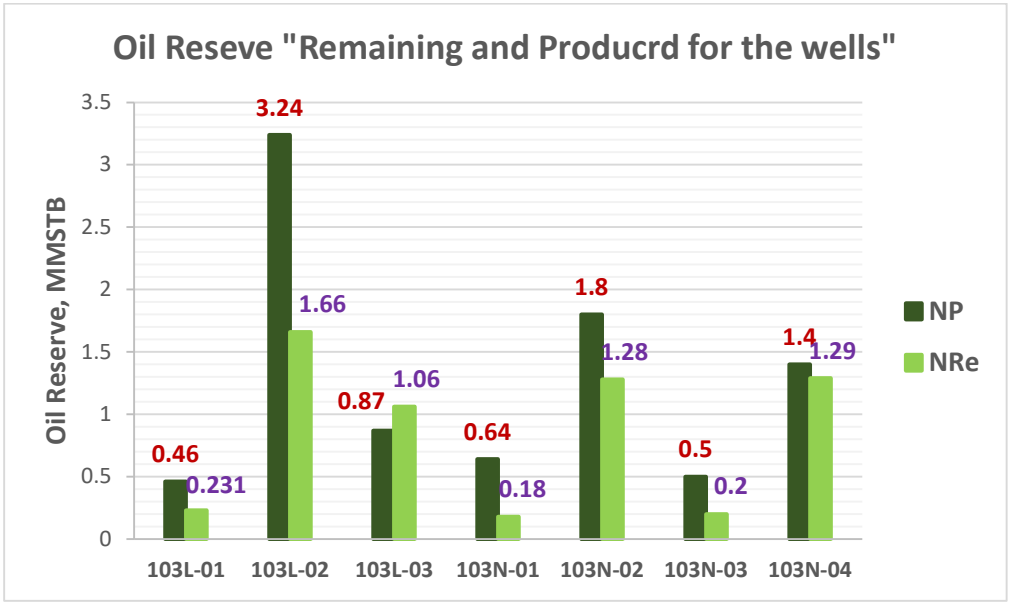

Figure 52. The produced and remaining oil for each well in X&N fields.

From the plot the best wells in productions are well X-02, Y-02 and Y-04. For both in production and remaining maybe due to the location and reservoir rock properties. Well Y-01, Y-03 and X-01 they have the lowest remaining and oil production.

Conclusions

1. A comparison between the Arps model and OFM Software is approved that Arps is a widely applicable, very useful and highly accurate for production decline prediction of daily, monthly and quarterly basis.
2. The basic methodology of decline curve analysis involves fitting an empirical model to the historical data using least squares techniques. the reserve obtained from this method for X field is around 2.72 MMSTB and for Y field is around 2.64 MMstb.
3. The value of reservoir factor (b) is almost equal to zero which means the drive mechanism of the reservoir is water drive mechanism.
4. Based on the analysis of the reservoir parameters, it is clear that the value of reservoir factor (b) is not affected by the reservoir parameters. However, these factors affected the oil recovery and ultimate reserve.
5. Quick analysis was performed using OFM software in order to evaluate the results that have been obtained from Arp's method and ensure their reliability

Recommendations

1. It is preferable to evaluate oil reserves with other methods such as the MBE technique or utilizing the Petrel program to conduct a reservoir simulation study in order to assure that the results obtained using conventional analysis techniques "least squares method" are dependable.
2. It is recommended to use another decline curve analysis such as Wc or WOR method.

3. The difference in reserve estimation using different types of DCA needs to be verified and confirmed using representative simulation modeling.

References

[1] J. J. Arps, "Analysis of Decline Curves," 1945.

[2] W. Lyons, Standard Handbook of Petroleum and Natural Gas Engineering, Taxes: Gulf Publishing Company, Houston, 1996.

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