

Original article

## Decline Curve Analysis for Farrud Reservoir in Zenad Oil Field

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### Abstract

Decline curve analysis (DCA), in petroleum engineering, is a tool being used to do many calculations, for instance: to estimate original oil in place, to estimate ultimate oil reserve (EUR) at initial reservoir conditions, to estimate remaining oil reserves from certain time to the end of reservoir age (that to be at future reservoir abandonment pressure or economic production rate), to forecast future production rate at any desired time and predict the reservoir performance. The basis of decline curve analysis (DCA) 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. The decline-curve methods apply to individual wells or an entire reservoir. This project presents basic concepts and applications of decline curve analysis using OFM software. Well-testing data from ten producer-wells in the Farrud reservoir were collected and subjected to DCA calculations through OFM software. The results showed that, for the whole Farrud reservoir, the economic flow rate was about 300 STB/D of oil, the recoverable reserves at initial reservoir conditions (EUR) were 80.2 MMSTB oil, and the remaining reserves at the time of study were 19.96 MMSTB oil, with an expected abandonment date of November- 2058. The decline curve analysis for the entire field is more reliable than for the wells, and the remaining reserve for the entire reservoir is very close to the summation of the remaining reserves for the ten well producers. Finally, it is preferable to evaluate the reserves with other methods, such as the MBAL software or utilizing the Petrel software to conduct the reservoir simulation study, in order to ensure that the results that have been obtained are dependable.

**Keywords.** Oil reserve, Decline Curve Analysis, Recovery factor.

### Introduction

Decline curve analysis (DCA) is the most current method for reserve estimation when historic production data are available and sufficient. It is traditionally used to provide deterministic estimates for future performance and remaining reserves. It is an analysis of past trends of declining production performance and expressed in two types of plots: Production rate vs. Time and Production rate vs. Cumulative Production [1].

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 [2].

Certain conditions must prevail before applying the decline curve technique [3], such conditions are:

- Sufficient production data to allow reasonable extrapolation
- The production must have been stable over the period before declining.
- The production decline observed should truly reflect reservoir productivity
- The decline flow rate data points that resulted from external causes should be excluded [4], such external causes as well as damage, equipment failure, and "human-enforced" flow rates (e.g., shut-in periods for pressure testing, maintenance, workover jobs, and reduced rate periods due to company reservoir strategy)

The decline Curve analysis plots are characterized by three factors [5], as follows:

1. Initial production rate
2. The curvature of the decline
3. The rate of decline

The value of these factors is a complex function of the reservoir parameters, such as porosity, permeability, fluid saturation, and driving/producing mechanism [6].

### Study Objectives

Using DCA, the objectives of this study can be summarized as follows:

- a) Determination of original recoverable reserves (or provides a check on reserves figures determined by other methods) [7].
- b) Predict the ultimate oil reserve of oil wells in the Farrud reservoir at the economic production rate, or, in other words, at the abandonment pressure [5].
- c) Predict ultimate oil reserve for the whole Farrud reservoir at the economic production rate, or, in other meaning, at the abandonment pressure [5].
- d) Prediction of future production rates for each well individually and for the whole reservoir.
- e) Perform well by well curve analysis in Farrud reservoir.
- f) Perform Farrud (the whole reservoir) analysis <sup>1</sup>
- g) Determine the remaining productive life of oil production wells and entire field.

**Methodology**

Well-testing data from nine producer-wells, in Farrud reservoir, were collected and subjected to DCA calculations through OFM software.

**Screening and selecting of production data:**

The proper selection of production data necessitates that the reservoir and / or well condition is recorded together with the flow rate readings. Calibration of meters has to be conducted on regular basis [7].

All wells and the entire field will be analysed separately to determine their depletion rate, decline rate, cumulative production and much more [8].

The official data from the Zenad Oil Field is used. The total oil production is divided into several subclasses. This is to improve display the different behaviour and properties of the different oil types and field sizes.

The overall aim is to analyse the production behaviour of Zenad crude oil. From this, a possible future production profile will be created, where the historical experience is applied to future development.

**Applying the Least Sum of Squares Method,**

The following procedure is implemented to estimate the Initial Decline Rate (ai), the Initial Rate (qi), which can be used to calculating the future rate and reserves at any desired time [10].

If the Least Sum of Squares Method is Applied to the General Hyperbolic Form of the production decline equation, then the following two simultaneous equations are obtained [5]:

$$q_i = \left( \frac{n \sum t_k^2 - \sum t_k \sum t_k}{\sum t_k^2 \sum \frac{1}{q_k^b} - \sum t_k \sum \frac{t_k}{q_k^b}} \right)^{(1/b)} \dots\dots\dots \text{Equation 1}$$

$$a_i = \left( \frac{q_i^b \sum \frac{1}{q_k^b} - n}{b \sum t_k} \right) \dots\dots\dots \text{Equation 2}$$

Equations (1) and (2) are used for Hyperbolic decline in general, and they can also be used for Harmonic decline simply by setting (b=1).

For the Exponential decline where (b=0), the above equations cannot be applied directly. Instead, the following equations should be used:

$$a_i = \left( \frac{\sum t_k \sum \ln q_k - n \sum t_k \ln q_k}{n \sum t_k^2 - \sum t_k \sum t_k} \right) \dots\dots\dots \text{Equation 3}$$

$$q_i = \exp \left( \frac{\sum \ln q_k + a_i \sum t_k}{n} \right) \dots\dots\dots \text{Equation 4}$$

So, the values of (b) as follows:

At exponential decline the b = 0, at Harmonic decline the b=1, whereas at Hyperbolic 0 < b < 1

**Numerical Methods**

<sup>1</sup> . Farrud reservoir locates in Zenad field, which is a one of Al-Harouge Oil Company fields.

In order to surpass the problem of uniqueness, a numerical approach can be programmed to obtain the “Best Fit” according to some numerical criteria. The suggested numerical model used for production decline analysis is a trial-and-error technique based on the theory of the (Least Squares Best Fit) [2]. The procedure can be carried out by developing a simple computer program [11] which can be summarized as follows:

- 1) Assume a certain value for (b) (e.g., 0).
- 2) Using the equations of the least sum of squares methods given to evaluate (ai) and (qi).
- 3) Write the production decline equation using the values of (ai) and (qi) calculated in step (2) and the assumed value of (b).
- 4) Substitute the original data values of (t) in the equation and evaluate the “calculated rate, (q)”.
- 5) Calculate the sum of squares of the discrepancies between the calculated rate values and measured rate values, i.e.,  $\sum_{k=1}^n (q_{cal} - q_k)^2$
- 6) Repeat steps (1-5) for different values of (b), preferably increments of (0.1), and calculate the sum of the squares of the discrepancies in each case.
- 7) Compare the sum values calculated, and choose the smallest sum. This will define the most appropriate values of (b), (qi), and (ai) which can be used for reserve calculation and future prediction.

### Results and Discussion

This section presents the results that have been obtained from the comprehensive decline curve analysis technique of the production history data using OFM Software

Decline curve analysis was conducted (run) for nine producing wells individually in the Farrud reservoir, and for the entire Farrud reservoir, as follows:

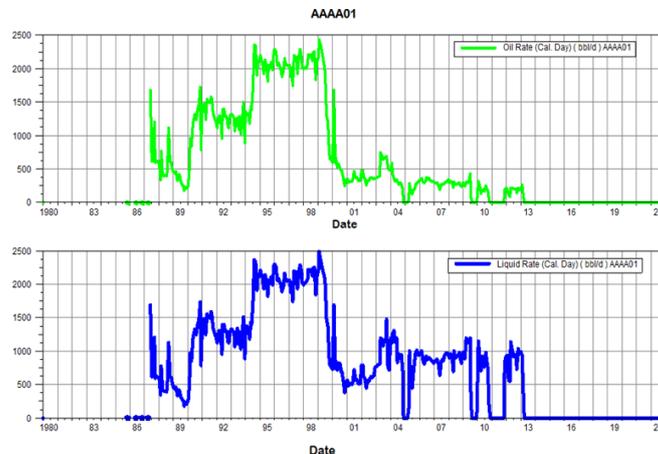


Fig 1 : Oil & Liquid Rate vs. Date for well no (AAAA01)

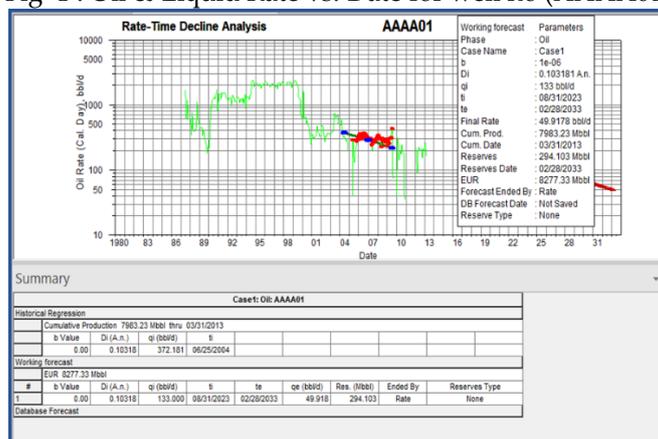


Fig 2: Decline Curve Analysis by OFM for well no (AAAA01)

Table 1: Decline Curve Results by OFM for no (AAAA01)

Decline period / From: 2004				
To: 2008				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.103	133	8.277	0.294

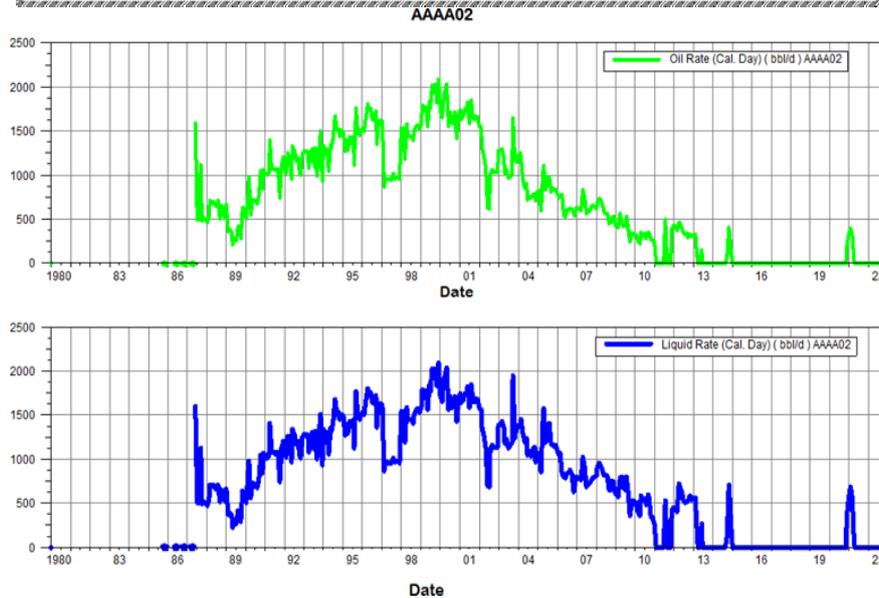


Fig 3 : Oil & Liquid Rate vs. Date for well no (AAAA02)

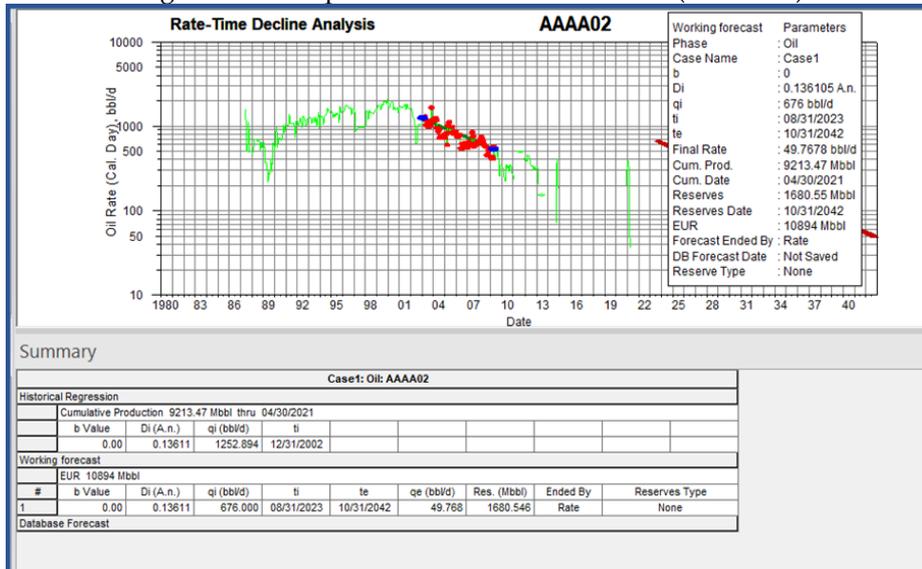


Fig 4: Decline Curve Analysis by OFM for well no (AAAA02)

Table 2 : Decline Curve Results by OFM for well no (AAAA02)

Decline period / From: 2002				
To: 2008				
Decline Exponent (b)	Decline Factor	Initial Decline Rate	Economic Recoverable	Remaining
	Di (A.n.)	(BBL/D)	Reserves (MMSTB)	Reserves (MMSTB)
0	0.136	676	10.894	1.68

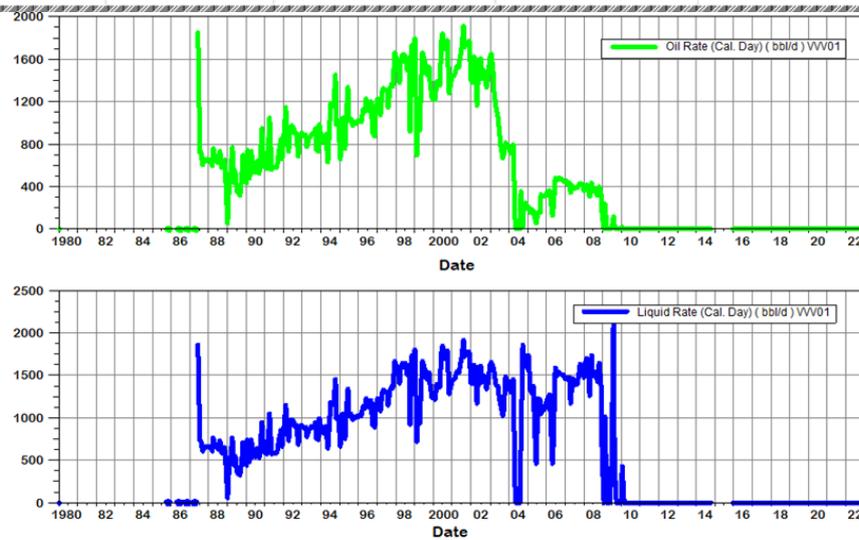


Fig 5: Oil & Liquid Rate vs. Date for well no (VVV01)

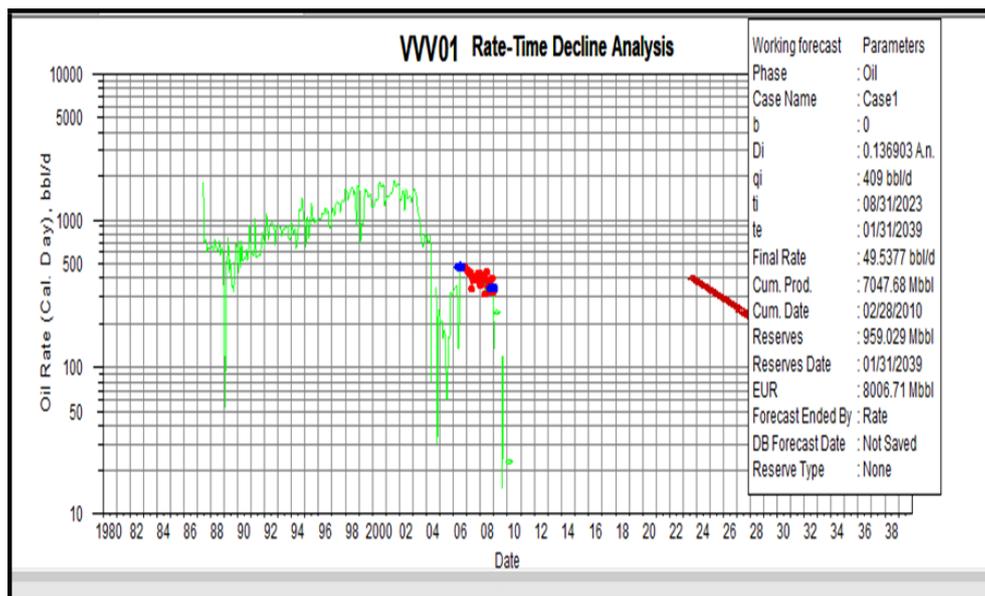


Fig 6: Decline Curve Analysis by OFM for well no (VVV01)

Table 3: Decline Curve Results by OFM for well no (VVV01)

Decline period / From: 2006				
To: 2008				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.135	409	7.997	0.95

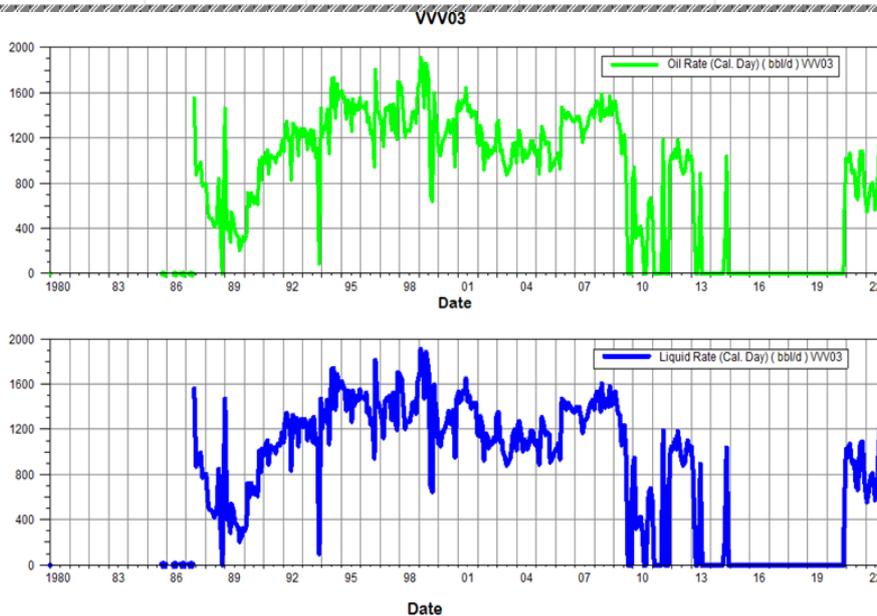


Fig 7: Oil& Liquid Rate vs. Date for well no (VVV03)

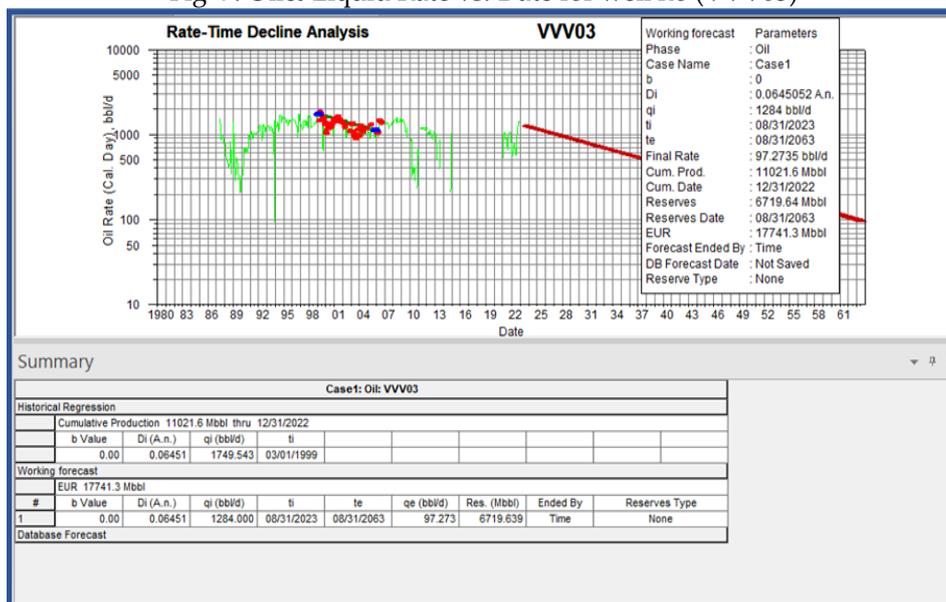


Fig 8: Decline Curve Analysis by OFM for well no (VVV03)

Table 4: Decline Curve Results by OFM for well no (VVV03)

Decline period / From: 1998				
To: 2007				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.0645	1284	17.741	6.719

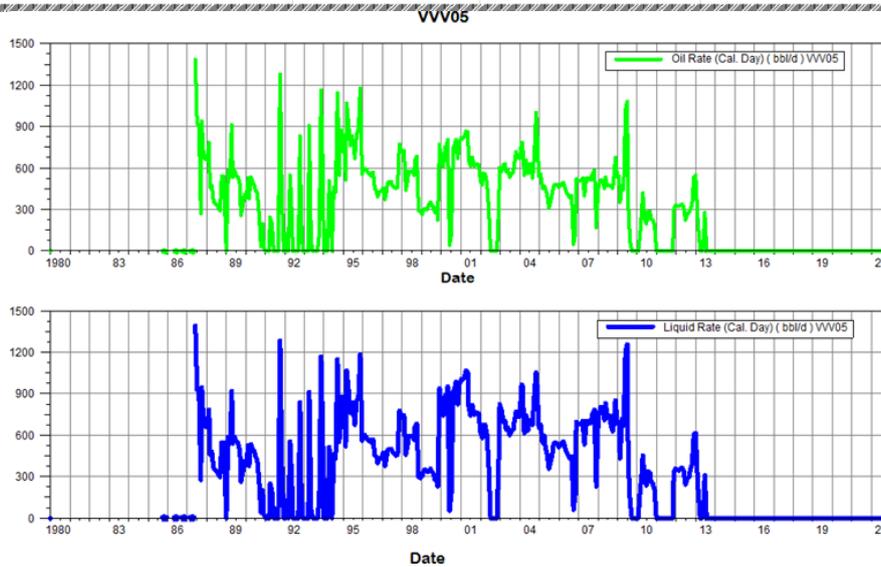


Fig 9: Oil & Liquid Rate vs. Date for well no (VVV05)

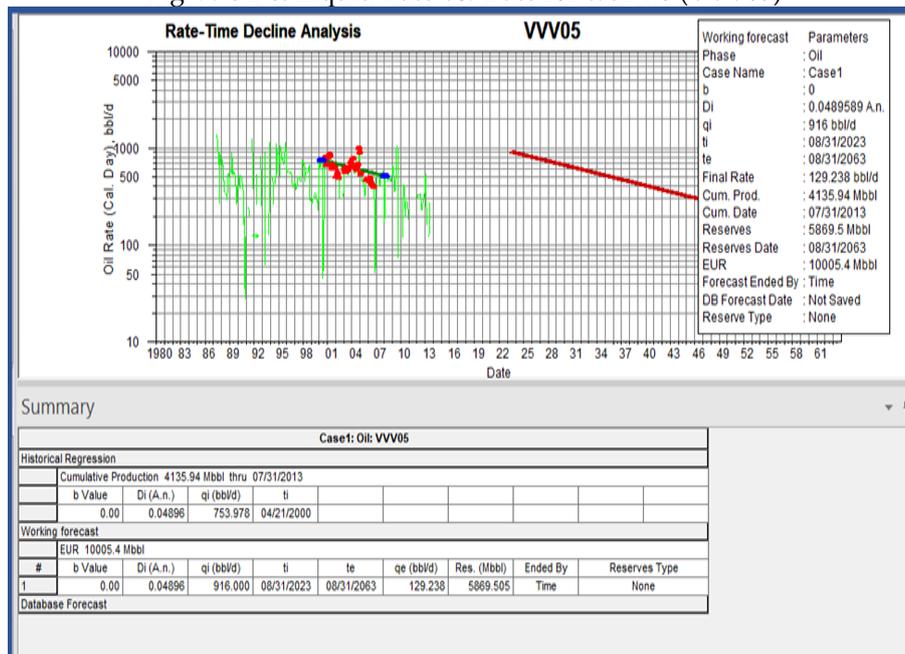


Fig 10: Decline Curve Analysis by OFM for well no (VVV05)

Table 5: Decline Curve Results by OFM for well no (VVV05)

Decline period / From: 2001				
To: 2008				
Decline Exponent (b)	Decline Factor	Initial Decline Rate	Economic Recoverable	Remaining
	Di (A.n.)	(BBL/D)	Reserves (MMSTB)	Reserves
0	0.0489	916	10.005	5.869

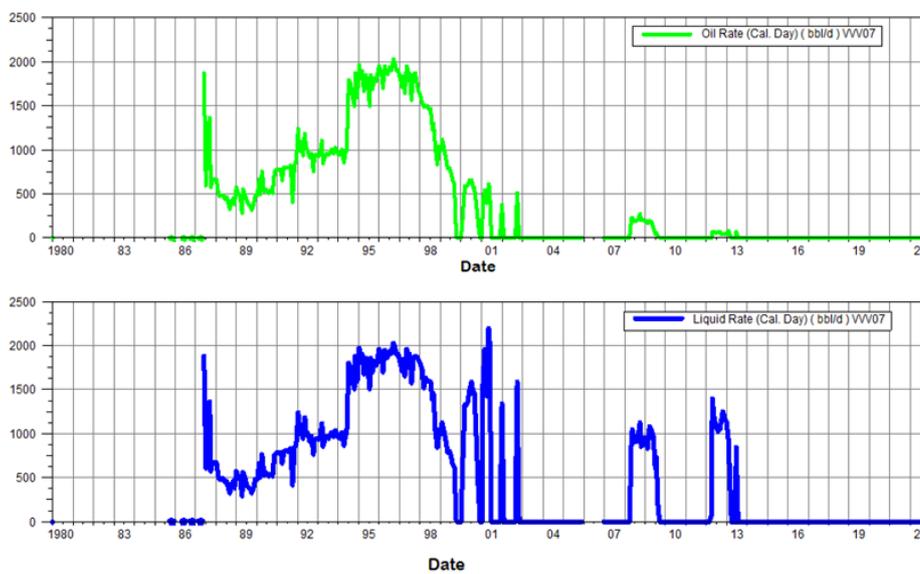


Fig 11: Oil & Liquid Rate vs. Date for well no (VVV07)

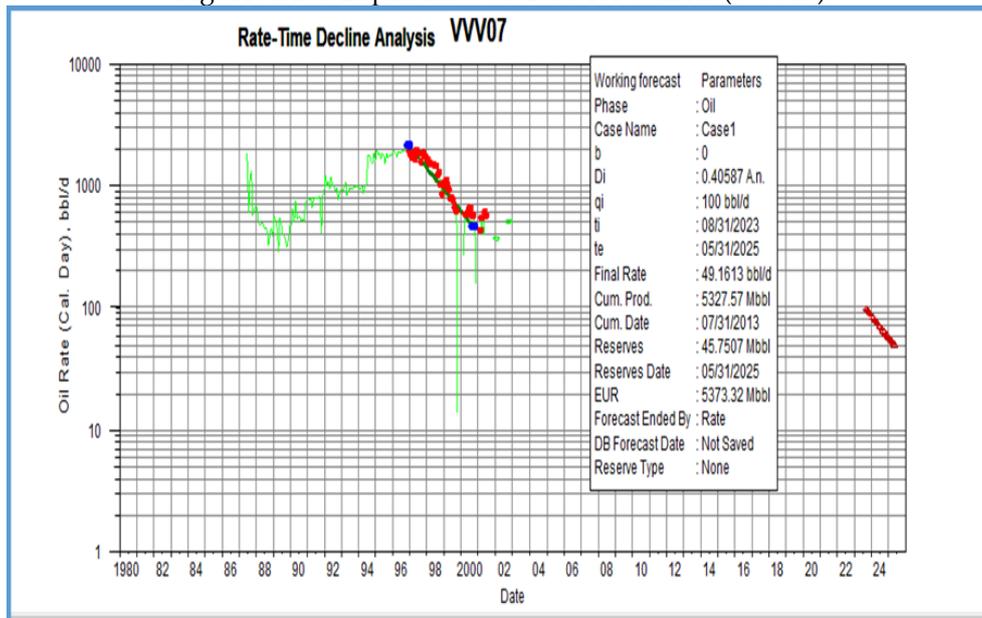


Fig 12: Decline Curve Analysis by OFM for well no (VVV07)

Table 6: Decline Curve Results by OFM for well no (VVV07)

Decline period / From: 1996 To: 2001				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.411	100	5.367	0.0455

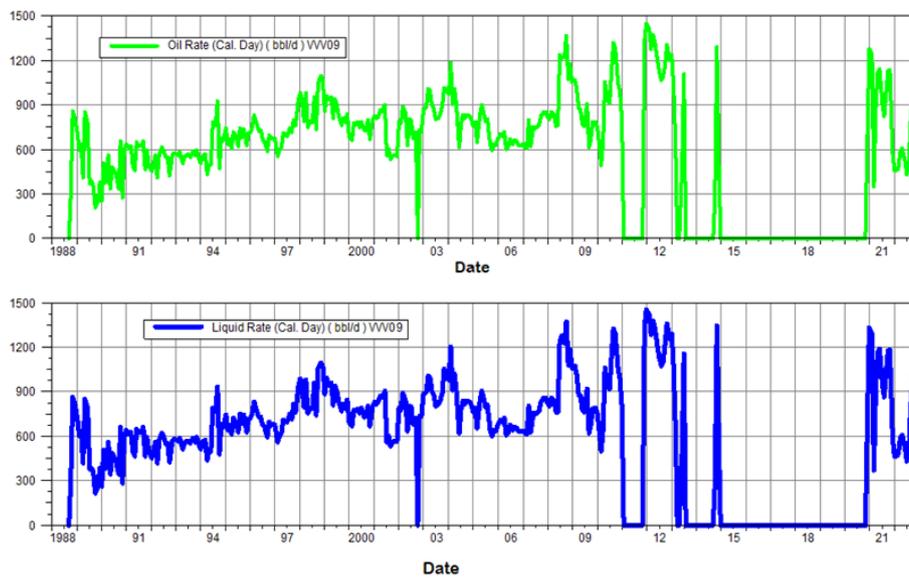


Fig 13: Oil & Liquid Rate vs. Date for well no (VVV09)

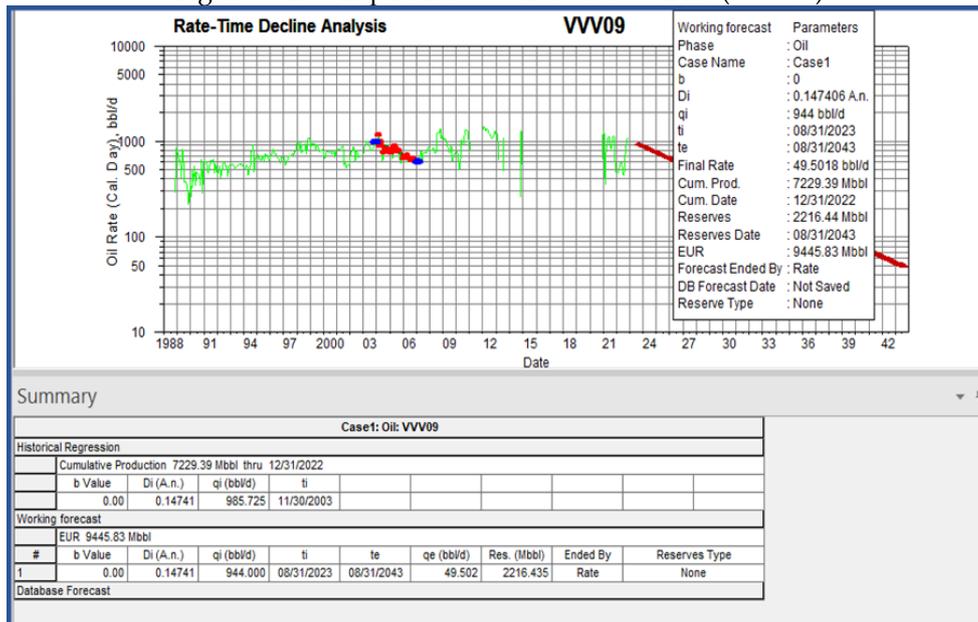


Fig 14: Decline Curve Analysis by OFM for well no (VVV09)

Table 7: Decline Curve Results by OFM for well no (VVV09)

Decline period / From: 2003 To: 2006				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.147	944	9.446	2.216

VVV12

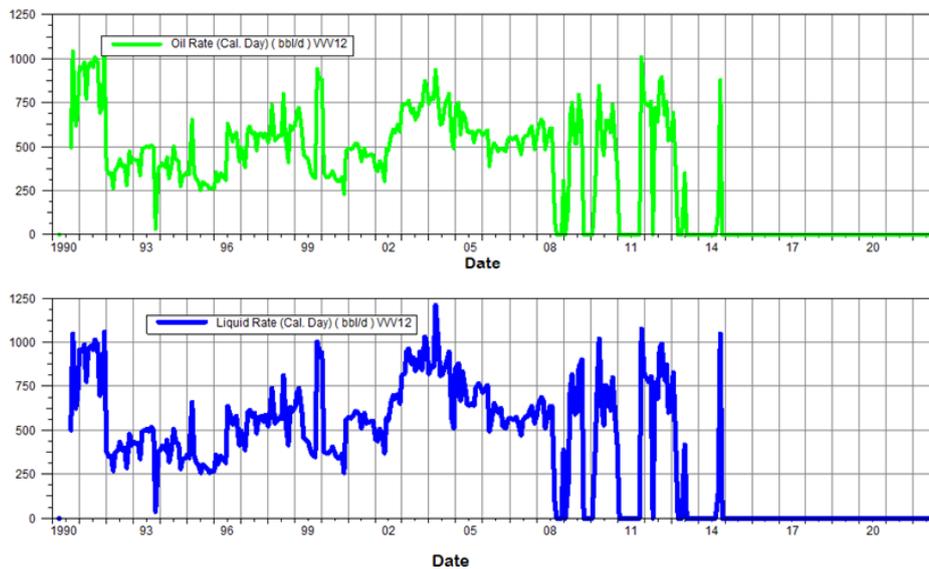


Fig 15: Oil & Liquid Rate vs. Date for well no (VVV12)

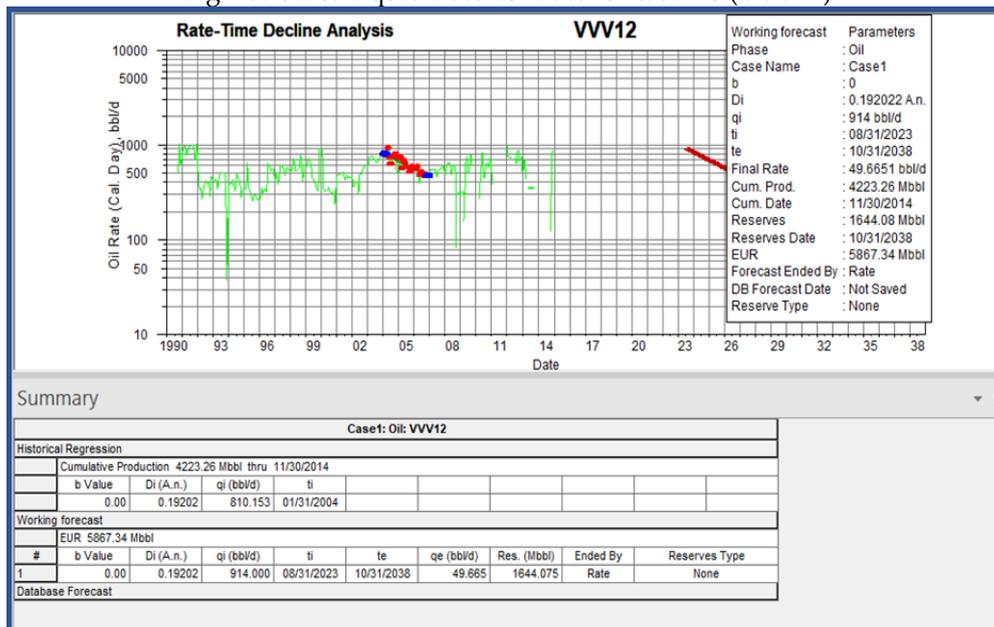


Fig 16: Decline Curve Analysis by OFM for well no (VVV12)

Table 8: Decline Curve Results by OFM for well no (VVV12)

Decline period / From: 2003 To: 2007				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.192	914	5.867	1.644

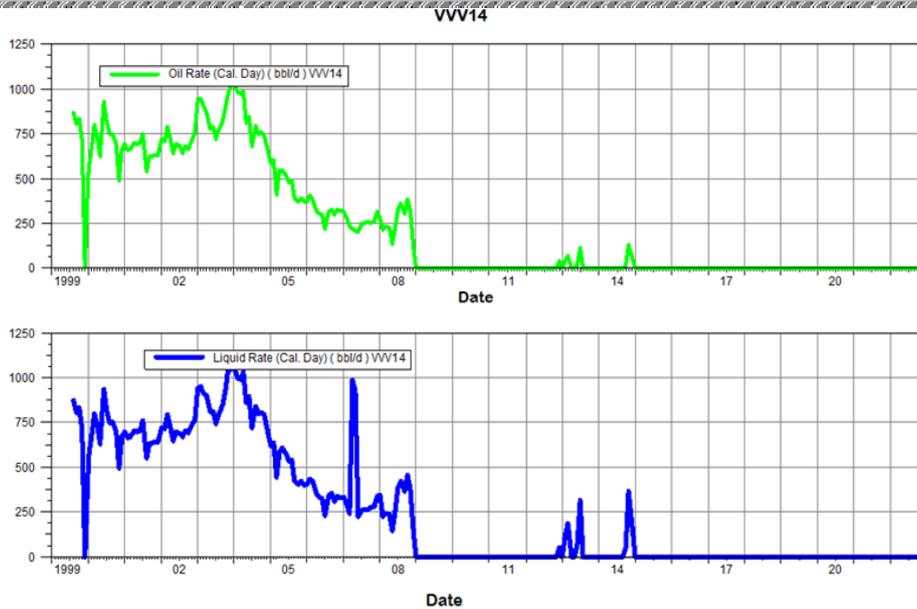


Fig 17: Oil & Liquid Rate vs. Date for well no (VVV14)

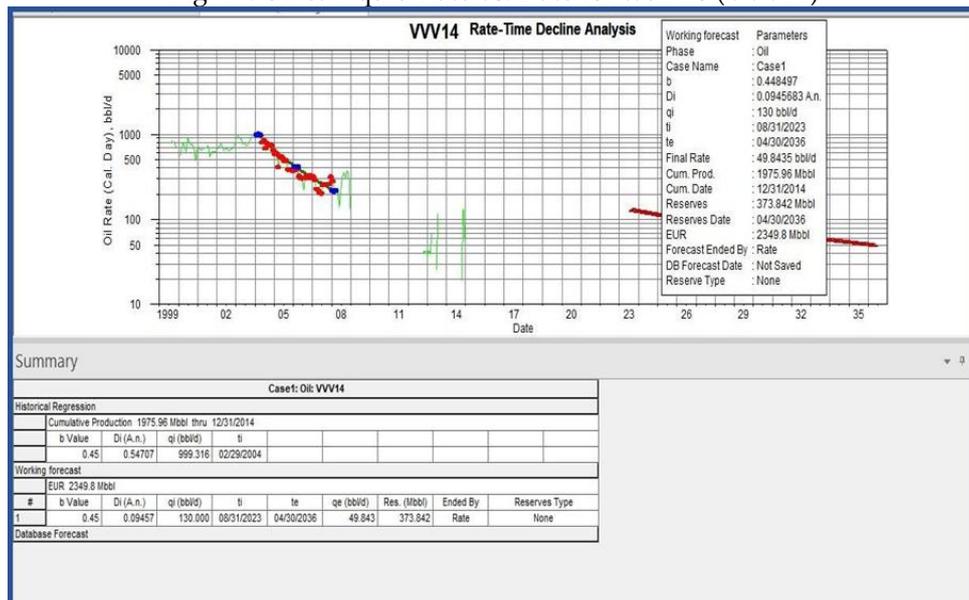


Fig 18: Decline Curve Analysis by OFM for well no (VVV14)

Table 9: Decline Curve Results by OFM for well no (VVV14)

Decline period / From: 2003 To: 2008				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.0946	130	2.349	0.374

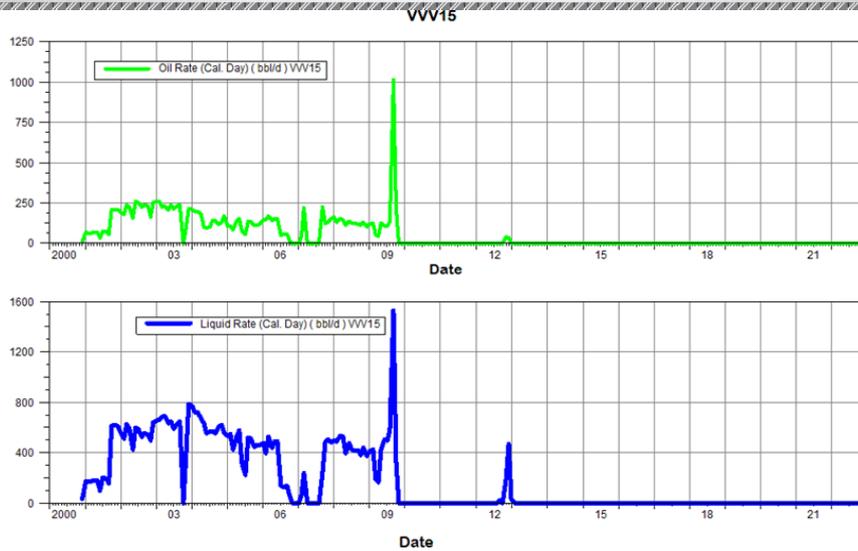


Fig 19: Oil & Liquid Rate vs. Date for well no (VVV15)

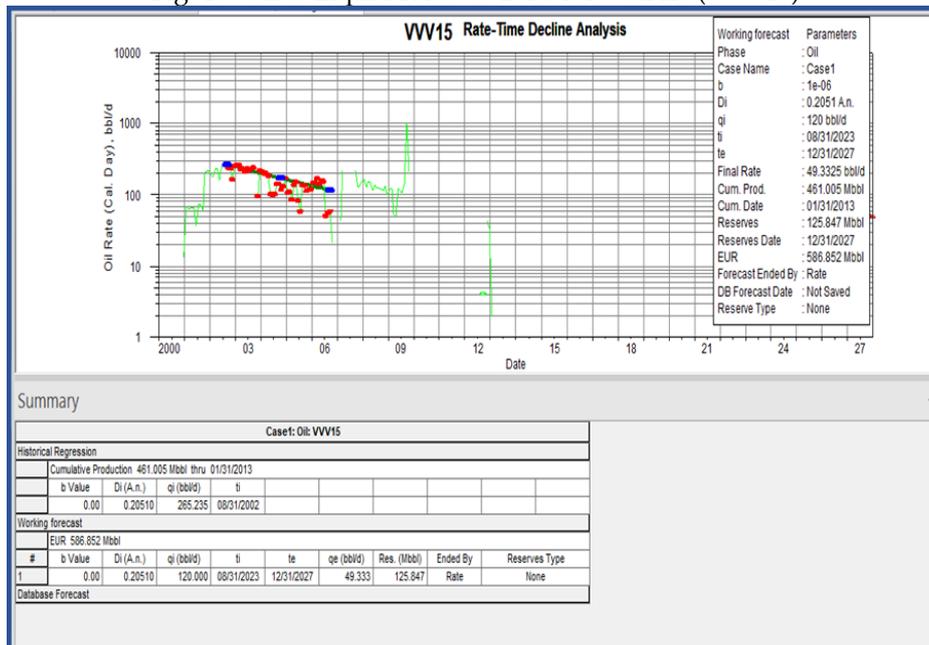


Fig 20: Decline Curve Analysis by OFM for well no (VVV15)

Table 10: Decline Curve Results by OFM for well no (VVV15)

Decline period / From: 2002 To: 2006				
Decline Exponent (b)	Decline Factor Di (A.n.)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserves (MMSTB)	Remaining Reserves (MMSTB)
0	0.205	120	0.587	0.126

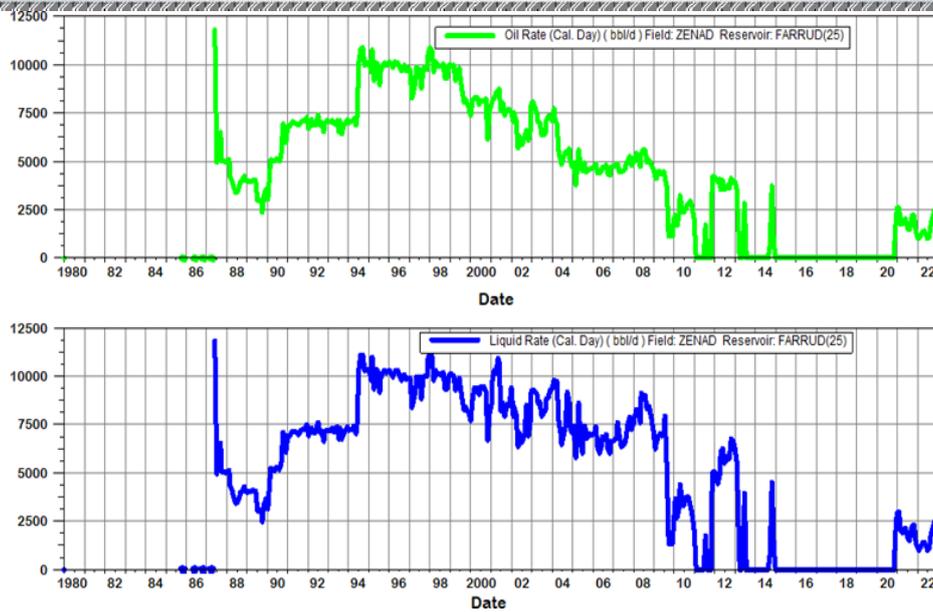


Fig 21: Oil & Liquid Rate vs. Date for the entire Farrud reservoir

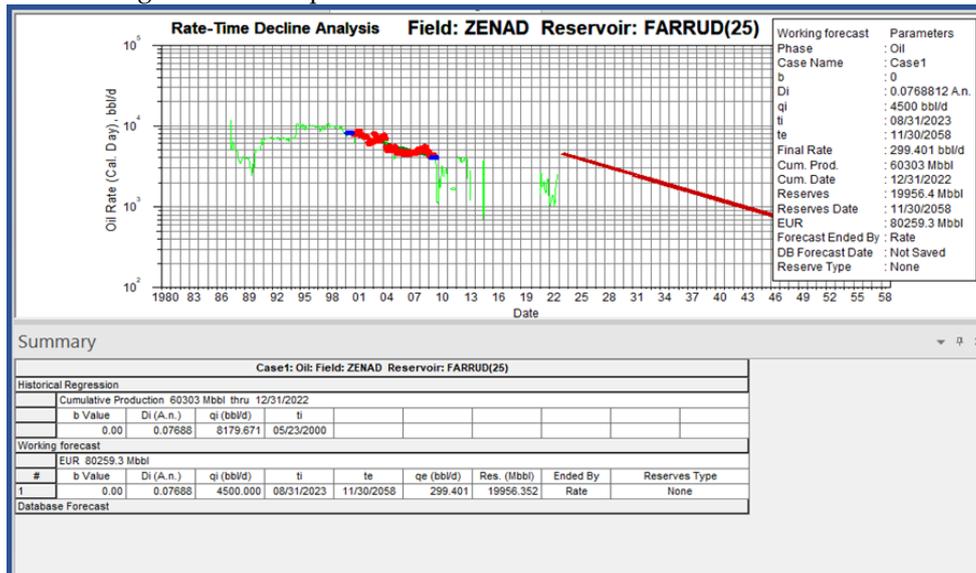


Fig 22: Decline Curve Analysis by OFM for the entire Farrud Reservoir

Table 11: Decline Curve Results by OFM the entire Farrud Reservoir

Decline Period /From		2001		
To		2007		
Decline Exponent (b)	Decline Factor Di (AN)	Initial Decline Rate (BBL/D)	Economic Recoverable Reserve (MMSTB)	Reamining Reserve (MMSTB)
0	0.077	4500	80.259	19.96

The remaining reserve - for well no (AAAA01) is calculated to be around 0.294 MMSTB, for well no AAAA02 to be around 1.68 MMSTB, for well no VVV01 to be around 0.950 MMSTB, for well no VVV03 to be around 6.729 MMSTB, for well no VVV05 to be around 5.869 MMSTB, for well no VVV07 to be around 0.0457 MMSTB, for well no VVV09 to be around 2.216 MMSTB, for well no VVV12 to be around 1.644 MMSTB and for well no VVV14 to be around 0.374 MMSTB, for well no VVV15 to be around 0.126 MMSTB, for the entire Farrud Reservoir to be around 19.96 MMSTB.

The starting decline period- for well no (AAAA01) is (2004 up to 2008) with initial flow rate 133 BOPD, for well No AAAA02 is (2002 up to 2008) with initial flow rate 676 BOPD, for well No VVV01 is (2006 up to 2008) with initial flow rate 409 BOPD, for well No VVV03 is (1998 up to 2007) with initial flow rate 1284 BOPD, for well No VVV05 is (2001 up to 2008) with initial flow rate 916 BOPD, for well No VVV07 is (1996 up to 2001) with initial flow rate 100 BOPD, for well No VVV09 is (2003 up to 2006) with initial flow rate 944 BOPD, for well No VVV12 is (2003 up to 2007) with initial flow rate 914 BOPD, for well No VVV14 is (2003 up to 2008) with initial flow rate 130 BOPD, for well No VVV15 is (2002 up to 2006) with initial flow rate 120 BOPD, for the entire Farrud Reservoir is (2001 up to 2007) with initial flow rate 4500 BOPD (Current Field Capacity).

## Conclusion

A number of conclusions can be drawn from the work outlined within this project:

- The decline curve is a basic tool for predicting future production rates, estimating oil reserves, and estimating remaining productive life.
- Decline Curve Analysis can be performed using OFM Software that usesg Arps Equation, which is a widely applicable, very useful, and highly accurate for production decline prediction of daily, monthly, and quarterly basis.
- The energy plot, which was obtained from the MBE study using MBAL software, showed that the main production driving mechanism is expansion of the reservoir fluid "gas liberation" for the primary depletion, although some PV compressibility and water influx is anticipated. After implementing the water injection project, aquifer influx is considered to be the predominant mechanism, and it is participated with highly contributing factor. We can sum up that the "b" value in most of the wells and for the entire reservoir is equal to zero, "exponential decline rate."
- The decline curve analysis for the entire reservoir is more reliable than wells; also, the remaining reserve for the entire reservoir is very close to the summation of the remaining reserve for the nine well producers.
- HOO provided us with the analysis that was conducted by the OFM software. It was observed that there is a consistency in the results between the analysis that was performed by the OFM and the conventional technique "project's analysis".

## Recommendations

It is preferable to evaluate the oil reserves with other methods, such as the MBAL software or utilizing the Petrel software to conduct the reservoir simulation study, in order to ensure that the results that have been obtained using the conventional analysis techniques, "least sum of squares method," are dependable.



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