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Integrated Reservoir Characterization for Field Development

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Abstract

Reservoir Characterization is a process of modeling a reservoir by incorporating an understanding of its various properties and attributes. It gets continuously updated throughout the lifecycle of the field at different stages. When the field becomes a mature brown-field, the best dependable data is the production data. The reservoir has been well established by now and the magnitude of the range of uncertainty has been brought down to a very narrow scale. The wells later face water production problems. Chan, in 1995 proposed the use of a particular set of diagnostic plots that can be used to identify the water production problem. Also, Bondar and Blasingame proposed a pseudo-steady state model to precisely model the fluid behavior from the very early stage to the decline phase.

The work shown in this study briefly describes the various techniques that are adopted to achieve a better global reservoir model. Two approaches have been followed:

- Integration of different data for a field evaluation and field development planning.
- Analysis of different diagnostic plots of production data to determine the water production problem and estimate the ultimate recoverable reserves.

Introduction - Reservoir Characterization

Reservoir Characterization deals with the modeling of a reservoir. It incorporates various characteristics of the reservoir related to its storing and producing ability. Data from different sources is acquired and interpreted for this purpose. This model is continuously updated throughout the life of the field. The main use of this model is in simulating the fluid behavior and prediction of the future performance of the field and corresponding wells. It helps in optimizing the production and managing the assets.

Methodology

In this work, two approaches have been followed:

- Integration of different data for a field evaluation and field development planning: A work flow is followed to characterize the target zone and estimate its various properties. A case study is provided to give a better understanding of each step described in the work.
- Analysis of different diagnostic plots of production data to determine the water production problem and estimate ultimate recoverable reserves: Simulation of the present reservoir conditions is done to test different methods of recovery. Incorrect decisions may lead to heavy financial losses. A case study from the Bombay High Offshore Filed Data is provided to understand the working and analysis of the different diagnostic plots.

First approach: Reservoir characterization for FDP

This approach uses all set of available data to efficiently characterize the reservoir, subsequently helping in good decision making and good management of the reserves and resources.

To illustrate this approach, we have considered a case study as an example. **This case study was presented at the "Schlumberger Field Development Case Study Challenge – UPES SPE Fest, 2014".** The following workflow was followed:

I. Interpretation of the Structural Contour Map

The structural contour map of the reservoir top (Fig. 1) and bottom was given and the location of all the wells was provided. Other relevant locations such as processing platforms (SP1, SP2, and SP3) were provided for other analysis which is beyond the scope of this work. From the contour map of the field, it was inferred that the reservoir system was an anticline with no fault trapping mechanism.

The area of the map was calculated to be 90 km^2 = 22239 acres.

II. Basic open hole log analysis

Four basic conventional open-hole logs were provided, namely, Gamma ray, Resistivity (Deep, Shallow), Neutron Log & Density Log (Fig. 2). At 3009 meters – 3026 meters, Clean Sandstone formation was identified from gamma ray log. The resistivity from the deep resistivity log reads 700 ohm meter, which is very high, indicating the presence of hydrocarbons. From the Neutron density log, cross over was identified, indicating the presence of oil zone. The empirical formula for the calculation of the Initial Oil in Place is given by,

$$\text{Initial Oil in Place} = \frac{(\text{7758*Area*height*porosity*Initial Water Saturation})}{\text{Oil Formation Volume Factor}}$$

i.e.,

$$IOIP = \frac{7758*A*h*\varphi*(1- S_{wi})}{B_o}$$

Where, Initial Oil in Place, IOIP is in the units STB ; Area, A is in acres ; Height, h is in feet

III. Calculation of porosity:

The porosity can be calculated by: $ø_D = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_{fluid}}$

Where, $\rho_{ma} = 2.65$; $\rho_{log} = 2.2$; $\rho_{fluid} = 0.85$ (Assumed for medium to heavy oil)

Hence, $ø_D = 0.25$

IV. Calculation of Water Saturation:

Using Archie's equation, $S_{wi}^n = \frac{a * R_w}{Ø^m * R_T}$

Where, m = 2.2 ; n = 2 ; a = 1 ; $R_w = 0.08$ ohm m ; $R_T = 700$ ohm-m ; Ø = 0.25 i.e. 25%

Hence, $S_{wi} = 0.0491$

V. Saturation of Oil:

The Saturation can be calculated by, $S_{oi} = 1 - S_{wi} = 0.9509$

VI. Height of the Reservoir Zone:

Height, h = 15 m = 49.21 feet

VII. Initial Oil in Place

From the data given, reservoir is a heavy oil reservoir, thus, the B_0 was assumed to be 1.2 (average for low-shrinkage heavy oil). Substituting all the values calculated above in the empirical formula for volumetric estimate of Initial oil in place, we get,

The initial oil in place, IOIP = 1681.98 MmSTB

VIII. Drive Mechanism

The production data provided shows only water being produced along with Oil with consistent low GOR. The drive mechanism thus, inferred is water drive mechanism. Also, wells drilled on the anticline fold will experience gravity drive mechanism. It is a combined gravity-water drive mechanism. In this scenario, the recovery factor can be assumed to be 40%, i.e. $E_R = 40\%$

Hence, The amount of recoverable oil = E_R*IOIP = 0.40 * 1681.98 = 672.792 MMSTB

IX. Formation Pressure Acquisition Data

Formation pressure acquisition data for various depth intervals was provided. From this, pressure gradients at each depth interval was calculated (Table 1). At 3032 meters, the pressure gradient changed from 1 psi/meter to 1.4 psi/meter. The change in the pressure gradient within the same formation marks a change in the fluid type. Since, from the well logs, no gas zone was identified, only the presence of an oil zone was indicated (Fig. 2), this analysis confirms the presence of two different fluids, i.e. oil and water.

The change of gradient marks the oil water contact at 3032 meters. Thus, the wells that can be seen in the contour map (Fig. 1) below this OWC are all dry wells.

X. Well Test Data

Well Test Data was provided with different pressure and corresponding flow rates of the well head. From these the Inflow performance relationship (IPR) curve (Fig. 3) was plot, i.e. the relation between flow rate and pressure. The trend line is a straight line signifying the pseudo steady state condition and the wells are not encountering any formation damage or near wellbore problem. The value of P_i equals the reciprocal of the slope, which is equal to 4.70. Using this, the absolute open flow potential (AOFP) of the well is calculated,

AOFP = Pi x (Initial Pressure –Atmospheric Pressure)

Given, initial pressure = 4350 psi, hence, AOFP = 20219 STB/day

This AOFP is the maximum flow rate of a well which is a hypothetical case. From this value a draw-down of upto 2000 psi can be taken. Taking 40% of this maximum draw-down rate, draw-down of 800 psi is chosen.

XI. Production Data

Production data comprising of the sum of oil produced, sum of water produced, and number of days for different months was provided. From this data, the water oil ratio (WOR) and water oil ratio derivative (WOR'), i.e. simple time derivative of WOR, was calculated. The plots of WOR v/s time and WOR' v/s time, were plot. For wells in the southern part of the field, the WOR derivative plot (Fig. 4) gave a positive slope indicating water channeling problem being encountered by the wells. However, in the northern part of the field, the WOR was very low and correspondingly, the WOR derivative was again near zero. Explanation to such interpretation is provided in the second approach mentioned later in the paper.

The Second approach

In this approach, the use of WOR and Water cut function plots to estimate EUR and the use of diagnostic plots to discern the different water production problems have been discussed.

Diagnostic Plots

The three water production problems are, water coning, multilayer channeling and near wellbore problems. Earlier water cut v/s reservoir saturation plots were used to predict the reservoir flow performance. This was not practical since the values of saturation are continuously changing and with the water cut plots, it was not possible to differentiate among the different production problems. Chan in 1995 proposed the use of WOR and semi log WOR plots to evaluate the past and predict the future performance of the well. These results were based on numerical calculations and simulations.

In figure 5, the two different trends for coning and channeling are identified. Coning has a gradual slope, whereas channeling effect shows a steeper constant slope. Three different periods in the plot of WOR can be seen. The beginning of the second period is the first departure point which is the time when water breakthrough. First departure point is shorter for coning. The beginning of the third period is the second departure point. Channeling has a constant slope therefore the second departure point cannot be easily differentiated. The second departure point for coning marks the pseudo steady state where the water cone becomes a high water conductivity channel.

Chan also proposed the use of WOR derivatives for differentiating coning and channeling. The figures 6 and 7 show the WOR derivatives depicting multilayer channeling and bottom water coning respectively. A positive slope is obtained for channeling which is constant throughout. A changing negative slope is obtained for coning.

The third period, starting from second departure point, marks late water channeling from coning behavior. This is not easily identified in WOR plot but in a WOR' plot (Fig. 8), the negative slope behavior changes to a positive slope indicating late time channeling. Similarly for gas coning in an oil well, water coning or channeling in a gas well, or gas and water coning in an oil well, GOR or WGR and their derivatives can be used to indicate different mechanisms. Similar trends are obtained, i.e. positive slope for channeling and negative slope for coning.

Over the large period of time, different production techniques are applied with varying draw down rate and available technology. This results in a change in the production and correspondingly a change in the WOR. Therefore, it is recommended to always analyze the production data from the diagnostic plots along with the well test data and the information about the production mechanisms applied. With the correct diagnosis of the water production problem, it helps to effectively select the method for water control.

Estimation of Recoverable Oils

Extrapolation technique is adopted to estimate ultimate recoverable reserves from the production plots. The method is very easy and uses only the production data. However, this can also be a disadvantage of this method. The techniques use the following plotting functions,

- $1/f_w$ v/s N_p
- f_w v/s N_p
- f_o v/s N_p
- q_o v/s N_p

These different plotting functions should be applied simultaneously to ensure consistency in results as misinterpretation from any one plotting function my lead to over or under estimation of the reserves.

Pseudo Steady State Model

The previous techniques are empirical and require many assumptions to be taken such as for multi layer channeling, the saturation distribution is taken to be uniform and no cross flow is assumed with high horizontal to vertical permeability ratio. Similar assumptions are taken for coning cases also. Other approach has been adopted as suggested by V.V. Bondar and T. A. Blasingame, 2002.

A multivariate relation was developed by them to represent WOR function. First, separate relationships were developed for water cut and oil cut functions assuming the conditions to be of pseudo steady state flow. Then, recalling the relationship between water cut and oil cut with WOR, equation for WOR pseudo steady state model was formed. The objective was to develop a pseudo steady state model of WOR which can represent the WOR behavior in the early stages also, which was not possible in the conventional Chan plots. However, this method does not throw any light on the diagnosis of water cut problems but can be used to estimate the ultimate recoverable reserves.

The proposed pseudo steady state water cut model is defined by the following equation,

$$fw = \frac{1}{1 + \frac{(m_w t_w + b_{pssw})}{(m_o t_o + b_{psso})}}.$$

And the pseudo steady state oil cut model is defined by the following equation,

$$fo = \frac{1}{1 + \frac{(m_o t_o + b_{psso})}{(m_w t_w + b_{pssw})}}.$$

Substituting the above models in the WOR equation we get,

$$WOR = \frac{(m_o t_o + b_{psso})}{(m_w t_w + b_{pssw})}$$

Where, m is the pss slope term $\Delta p/q$
b_{pss} is the pss intercept term
t_w is the water material balance time i.e. W_p/q_w
t_o is oil material balance time i.e. N_p/q_o

For this calculation, a set of production data along with the well test data is required to calculate the pss slope and intercept term. Due to limited access of the actual field data, the pss model is only suggested and could not be validated. An example (Fig. 9) is cited below from the work of Bondar and Blasingame, 2002. It shows a comparison in the WOR trends from the conventional and pss model. A very good correlation can be seen between the two models during the late time production, but, the conventional method is not successful in describing the reservoir flow behavior during the early stages. The pseudo steady state model fits the WOR trend very well, even during the early stage.

Bombay Offshore Field Production Data Analysis

Data Available

Five different wells from the offshore field were taken. Their names have been kept confidential and hence, they will be named as Wells A, B, C, D and E.

Production Data Analysis

The production data was taken for all five wells. The data comprises of the log of the quantity of the produced fluids for each month along with the number of days the well was in production. From these figures, various calculations were done: Oil Flow Rate (qo), Water Flow Rate (qw), Water cut (fw), Oil Cut (fo), Water Oil Ratio (WOR), Water Oil Ratio Derivative (WOR'), Cumulative Oil Produced (Np), Cumulative Water Produced (Wp), Gas Oil Ratio (GOR), Cumulative Time, Oil Material Balance Time (to) and Water Material Balance Time (tw). Along with these calculations, some other operations were also done on these results which were required for further analysis. These include: 1/fw, 1/fo, log (fo), 1/qo.

Diagnostic Plots

Following plots as suggested by Chan and other research works were plot:

- qo v/s Time
- qo v/s Np
- fo v/s Np
- fw v/s Np
- GOR v/s Np
- WOR and WOR' v/s Time

All the above mentioned calculations and plots were made and done for each of the five wells taken for the study. The following results were obtained:

1. A clear identification of the water production problem was done in the WOR and WOR' plot. A positive slope seen in the WOR' (derivative) plot (Fig. 10) clearly marks a multilayer channeling condition. This validates the Chan's suggestions provided to identify the water production problem, which was earlier not possible by water cut and flow rate plots.
2. The GOR v/s Np plot (Fig. 11) was used to identify the presence of a secondary gas cap formed later due to the dissolved gas solution after the reservoir pressure declined below the bubblepoint pressure.
3. Plots of qo v/s Np (Fig. 12), fo v/s Np (Fig. 13) and fw v/s Np (Fig. 14) were used to calculate the Ultimate Recoverable Reserves. The three plots gave close results, but reliable results were obtained from fo v/s Np and fw v/s Np plots. This is because these plots are independent of the drawdown pressure and flow-rate. Change in drawdown pressure or pump size will not change the water cut, but will affect the flow rate. Water-cut and Oil-cut are volume/volume ratio in terms of percentage.
4. A pseudo steady model proposed by Bondar and Blasingame was acknowledged. Although due to limited access to data, it was not validated. But an example was cited to show its results. However, a plot between the reciprocal of oil flow rate v/s oil material balance time (Fig. 15) was generated. A linear relationship with a slope of unity was formed. It is an approach to only model the flow behavior and cannot be used as a diagnostic plot. This approach is not meant for extrapolation to estimate the ultimate recoverable reserves. Therefore, a lot more research needs to be done in this field.

Estimated Ultimate Recovery (EUR)

Straight line extrapolation technique was adopted to calculate the ultimate recoverable reserves. This technique was applied in all the five wells in the following plots, namely, qo v/s Np ; fo v/s Np ; and fw v/s Np (Fig. 12, 13 & 14). Results from fo v/s Np and fw v/s Np are more consistent and also reliable because a change in the draw down pressure will not affect the volume/volume ratio but will impact the flow rate. However, results from the qo v/s Np plot are also close and thus can be used as an approximate. The results obtained are given in table2.

Results and Conclusions

In today's economy, a well developed reservoir model is important that can help in quick decision analysis and efficient management of resources. For any field development planning, there is a need for a good oil field asset management where selecting the right method at the right time becomes very important.

Moreover, all simulation results are dependent on two factors: the probabilistic approach of the range of uncertainty in each of the variables; the accuracy in the reservoir model which has to be simulated. Any simulation done on an incorrect reservoir model will yield incorrect results.

Furthermore, any project is made live only after being passed by a series of appraisals. A full economic evaluation is done keeping in mind, all the required facilities and installments. An accurate estimate of the initial oil in place is very essential. Only once, the project seems to be economically viable, it comes into existence.

The first approach discusses the following:

- Interpretation of structural contour maps;

- Use of basic open-hole well logs for quick-look evaluation of hydrocarbon-bearing zones;
- Calculation of parameters like area, reservoir height, porosity to calculate the initial oil in place;
- Use of well testing data for assessing the reservoir producing potential and in evaluating any near-wellbore problem, if any;
- Use of production data identifying the drive mechanism and water production problems.

The second approach discusses the following:

- Different diagnostic plots for well performance evaluation and assessment;
- Chan's WOR and WOR' (derivative) plots to diagnose different water production problems;
- Conventional Straight-line extrapolation to estimate ultimate recoverable reserves;
- Discussed Pseudo-steady state model to characterize the reservoir fluid behavior.

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Figures and Tables

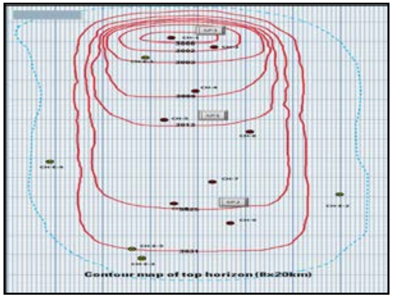


Fig. 1: Structural Contour Map

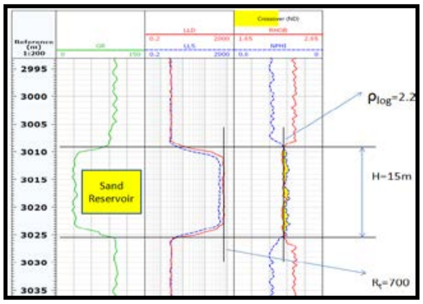


Fig. 2: Open hole well log data

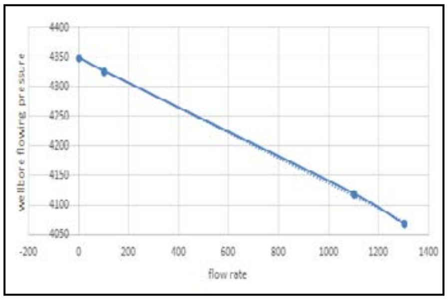


Fig. 3: IPR Curve

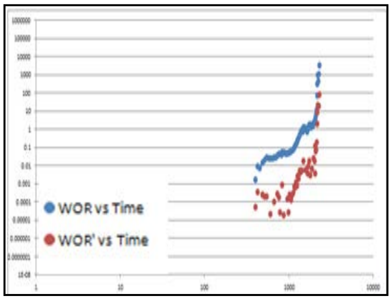


Fig. 4: WOR and WOR' v/s time

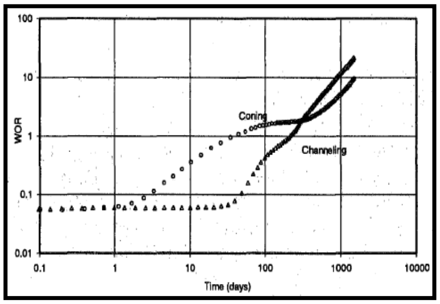


Fig. 5: Coning and Channeling trend

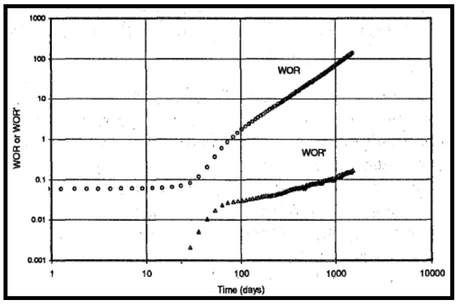


Fig. 6: Multilayer Channeling

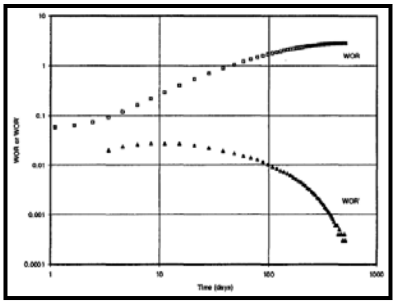


Fig. 7: Bottomwater Coning

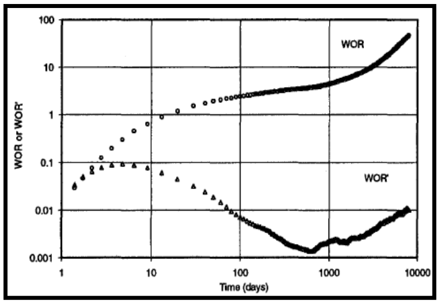


Fig. 8: Coning with late time channeling behavior

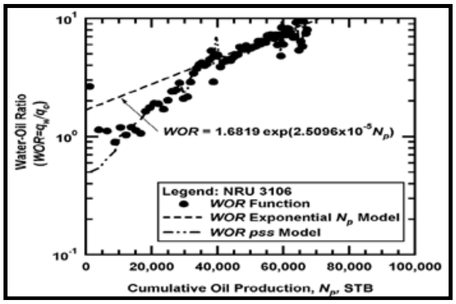


Fig. 9: Example of WOR v/s Cumulative oil production showing WOR and WORpss

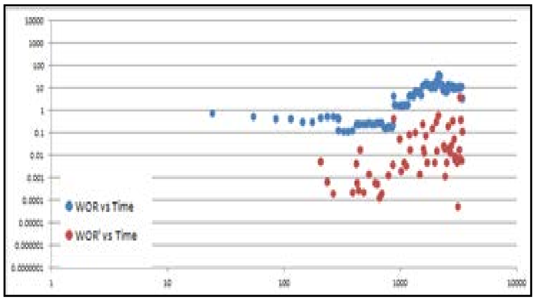


Fig. 10: Log-log plot of WOR and WOR'(Positive Slope in WOR' signifies Channeling problem)

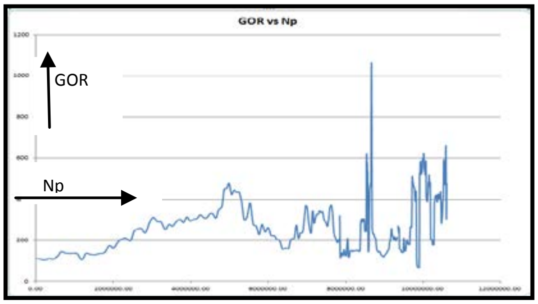


Fig. 11: Plot of GOR v/s N_p

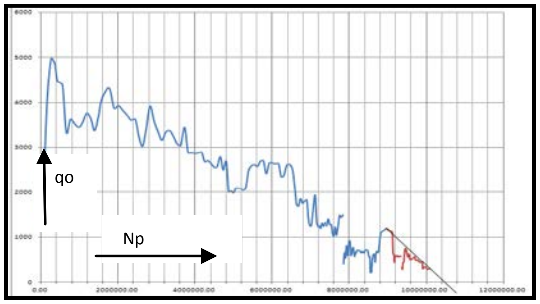


Fig. 12: Plot of q_o v/s N_p

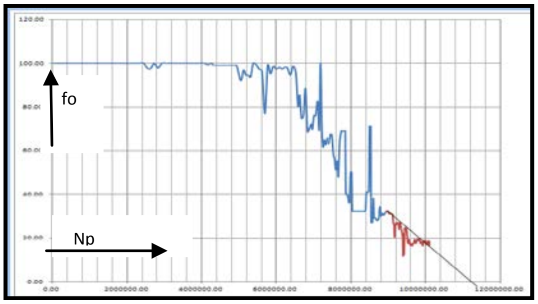
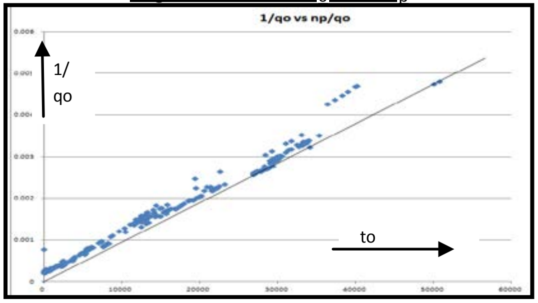


Fig. 13: Plot of f_o v/s N_p



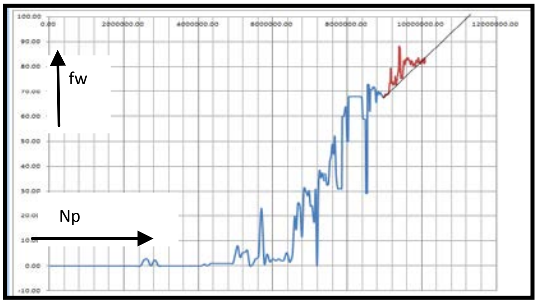


Fig. 14: Plot of f_w v/s N_p

Fig. 15: Plot of $1/q_o$ v/s N_p/q_o

Well: 1		Pressure Gradient (psi/m)
Depth (m)	Pressure (psi)	
3008.0	4348	
3012.0	4351.9	0.975
3015.0	4354.9	1
3018.0	4357.9	1

Well: 2		Pressure Gradient (psi/m)
Depth (m)	Pressure (psi)	
3032.0	4372.2	
3033.5	4374.4	1.466667
3035.0	4376.5	1.4
3035.5	4377.2	1.4
3036.0	4377.9	1.4
3038.0	4380.8	1.45

Well: 3		Pressure Gradient (psi/m)
Depth (m)	Pressure (psi)	
3028.5	4368.3	
3029.0	4368.8	1
3029.5	4369.3	1
3030.5	4370.3	1
3032	4372.239	1.292965
3034	4375.08	1.42024
3035.5	4377.21	1.42024
3036	4377.92	1.42024

Table 1: Pressure Gradient at regular depth interval (Case study)

Well	Plot	EUR (MM STB)
A	qo v/s Np	3.31
	fo v/s Np	3.60
	fw v/s Np	3.63
B	qo v/s Np	4.29
	fo v/s Np	5.20
	fw v/s Np	5.20
C	qo v/s Np	4.23
	fo v/s Np	4.445
	fw v/s Np	4.51
D	qo v/s Np	0.44
	fo v/s Np	0.45
	fw v/s Np	0.45
E	qo v/s Np	10.50
	fo v/s Np	11.20
	fw v/s Np	11.20

Table 2: Ultimate recoverable reserves from diagnostic plots using straight line extrapolation