# Reservoir Performance Prediction using Integrated Production Modelling (MBAL Software)

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***Abstract:*** ***Reservoir performance prediction is important aspect of the oil & gas field development planning and reserves estimation which depicts the behavior of the reservoir in the future. Reservoir production success is dependent on precise illustration of reservoir rock properties, reservoir fluid properties, rock-fluid properties and reservoir flow performance. Petroleum engineers must have sound knowledge of the reservoir attributes, production operation optimization and more significant, to develop an analytical model that will adequately describe the physical processes which take place in the reservoir. Reservoir performance prediction based on material balance equation which is described by Several Authors such as Muskat, Craft and Hawkins, Tarner's, Havlena & odeh, Tracy's and Schilthuis. This paper compares estimation of reserve using dynamic simulation in MBAL software and predictive material balance method after history matching of both of this model. Results from this paper shows functionality of MBAL in terms of history matching and performance prediction. This paper objective is to set up the basic reservoir model, various models and algorithms for each technique are presented and validated with the case studies. Field data collected related to PVT analysis, Production and well data for quality check based on determining inconsistencies between data and physical reality with the help of correlations. Further this paper shows history matching to match original oil in place and aquifer size. In the end conclusion obtained from different plots between various parameters reflect the result in history match data, simulation result and Future performance of the reservoir system and observation of these results represent similar simulation and future prediction plots result.***

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## I. INTRODUCTION

The activities of reservoir engineering fall into three general categories like Reserve estimation, development planning and production operation optimization [1]. A reservoir engineer roles to continuously monitor the reservoir, data acquisition, data analysis to validate and interpretation of these data which is able to characterize the corresponding reservoir system, evaluate past, present and forecast future reservoir performance to control the flow of fluids inside the reservoir with aimed to increase cumulative oil production, ultimate oil recovery and accelerate oil recovery under various types of natural driving mechanism [2]. Reservoir simulators are used for analyzing the reservoir performance and reserve estimation. Various study shows Reservoir simulator play crucial role in implementing initial development plans, history matching, optimization study, planning and evaluating the reservoir system performance [3].

In this paper, a software suit called Integrated production modeling (IPM) by petroleum experts was developed based on material balance to forecast the performance of hydrocarbon reservoir whereas simulation method of prediction is very complex, requiring a geologic model, populating the model with rock, fluid, historical production data and all events that have occurred in the reservoir. Though the simulation method is a more accurate technique but a rigorous exercise which requires carrying out a material balance on each of the grid blocks. Tarek stated that material balance equation is an analytical tool of reservoir engineers for interpreting and predicting the performance of the given hydrocarbon system. When MBE properly applied, can be used to estimate the initial hydrocarbon in place, predict the future performance and ultimate hydrocarbon recovery for various driving mechanisms[4]. In context with technical details material balance model considered as a tank model for a given hydrocarbon system. There were certain advantage of material balance model where they could address average reservoir pressure for given quantities of production and water influx from initial quantiles and pressure [5]. Havlena & Odeh described the techniques of interpreting material balance as an equation of straight line which had a capability to estimate three unknowns like the original oil in place, cumulative water influx, original size of a gascap as a compared with oil zone size and driving mechanism. This linear solution required to plot variant group against another variant group which was selected based on the reservoir drive mechanism and it was observed if actual plots turnout to be non-linear then deviation could itself be diagnostic to estimating the actual drive mechanism [6]. Once linearity achieved based on field production history data and pressure data a suitable mathematical model developed to predict the future reservoir performance.

The initial reservoir model could be found wrong before history matching because of unaccounted energy water influx helping to maintain system pressure. To deal with this issue where greatest uncertainty lied to the determination of water influx. To the determination of water influx required a mathematical model which relies on aquifer properties. To build a correct aquifer model required 'try and see it' for correct matched with field history data. There were various models like pot-aquifer, Van Everdingen & Hurst. The Van Everdingen & Hurst unsteady state model is based on the superposition principle [7]. There were serval models, such as Carter & Tracy [8], Fetkovich [9], and Leung [10], which tried to abolish the drawback of the desired computing power, and hence became alternative solution in commercial flow simulators [11].

## II. METHODOLOGY

An abstract idea about material balance was exhibited by Schilthuis in 1941 which was based on the mass conservation law. There was certain assumption made in this technique where reservoir considered as a homogenous tank model [12]. The material balance used for history match and past performance for estimation volume of reservoir and prediction of future performance. MBAL software based on this concept while using minimum data the reservoir engineer can be used this tool for reservoir analysis throughout the life of the field. Basic equation used in MBAL software i.e.

$$F - W_e = N [E_o + mE_g + Ef_w)$$

### A. Workflow Procedure

In analytical reservoir engineering tool kit MBAL software is progressive option for running a simulation based on historical data which should be matched with analytical model. MBAL provides substantial matching facilities and aquifer modelling which advances research about pressure support response and forecasting. There were certain steps followed during this research study to forecast the performance for selected reservoir [19].

i. PVT, cumulative oil Production and pressure depletion data were entered while considering a tank model.
ii. The matching amenities available in MBAL were used to adjust the empirical fluid property correlations to fit PVT laboratory data. To foremost fit for the measured data, correlations were modified using non-linear regression techniques then selected for use in the model.
iii. Glaso-correlation [13] was selected for saturation pressure, Gas-oil ratio and Formation volume factor; and beggs-correlation [14] selected for viscosity.
iv. Tank data included for further reservoir model development like Initial pressure, porosity, Reservoir Temperature, Initial hydrocarbon in place, connate water saturation and production start date data. Initial hydrocarbon in place calculated based on Geological data. History matching requires past production data along with pressure declination. Reference data is obtained from L.P. Dake [15].
v. After matching, three graphical plots were developed which used to determine reservoir and aquifer parameter. The energy plot was used to observe driving mechanism and Campbell plot was a diagnostic tool to identify the reservoir type based on the sign of pressure and production behavior. Analytical method shows the variation between model and historical data which indicate the unaccounted energy. Based on Campbell plot, the presence of aquifer was likely [16].
vi. Non-linear regression method was employed to evaluate the unknown aquifer potential and reservoir parameter then tuned the data related to pressure and production. Various aquifer models choose and selected best fit matched aquifer model [17].
vii. Precision of the model was validated with historical data like pressure, cumulative oil and gas production data [18].

### B. Input Parameter

The input data into MBAL model consist PVT properties, Oil and gas Production data, aquifer parameter, relative permeability data, reservoir thickness. Porosity and Permeability data were obtained from well logs [20]. Correlation were used to evaluate relative permeability. A summary of input PVT data, Reservoir Tank data and relative permeability data shown in Table 1, Table 2 and Table 3 respectively. Additional Water influx data which is shown in Table 4 required during the Campbell plot shows variation which shows that an unaccounted energy source was contributing to the historical production [21].

**Table 1. Summary of input PVT data.**

| Parameter | Input data |
|---|---|
| Temperature (°F) | 250 |
| Bubble point pressure, (Psig) | 2200 |
| Solution GOR (scf/stb) | 500 |
| Oil FVF $B_O @ P_b$ (RB/STB) | 1.32 |
| Oil viscosity @ $P_b$ (cp) | 0.4 |
| Oil gravity ($^o API$) | 39 |
| Gas gravity (Specific gravity) | 0.798 |
| Mole percentage $H_2S$ | 0 |
| Water salinity (PPM) | 1,00,000 |
| Mole percentage $CO_2$ | 0 |
| Mole percentage $N_2$ | 0 |

**Table 2. Summary of Reservoir Tank input data**

| Parameter | Input data |
|---|---|
| Tank fluid Type | Oil |
| Temperature (°F) | 250 |
| Initial Tank Pressure (psig) | 4000 |
| Porosity (fraction) | 0.23 |
| Connate Water saturation (fraction) | 0.15 |
| Water Compressibility (1/psig) | Correlation |
| Initial Gas-cap | 0 |
| Original Oil in Place (MMSTB) | 210.867 |

**Table 3. Relative Permeability data**

| | Residual saturation | End Point | Exponent |
|---|---|---|---|
| $K_{rw}$ | 0.151 | 0.631 | 0.841 |
| $K_{ro}$ | 0.151 | 0.80 | 1.547 |
| $K_{rg}$ | 0.020 | 0.90 | 1 |

**Table 4 Water influx data**

| Parameter | Input data |
|---|---|
| Model | Modified Hurst Van Everdingen |
| Reservoir Radius (ft) | 2500 |
| Reservoir Thickness (ft) | 250 |
| Outer Inner radius ratio | 5 |
| Encroachment angle (degree) | 180 |
| System | Radial Aquifer |
| Aquifer Permeability (md) | 10 |

### C. Overview of the Reservoir

The oil reservoir is under-saturated which possessed saturation pressure of 2200 psia, oil API gravity was 39, oil density 51.78 lb/$ft^3$ and rock compressibility is calculated based on the correlations. For described reservoir a single tank MBAL model was built. Aquifer influx modeled were checked from which a suitable match of reservoir trend was selected. The models used to match with the help of tuning and Regression method where pressure and Production data regressed. To build a reservoir model knowledge of the reservoir structure, aquifer support and Gas cap was necessary [22]. Those were identified based on available data which used to ensure good engineering judgment. The idea behind history matching was that the model input is adjusted to match the field pressure and production history data. Procedure should be a way of systematic where adjusting the reservoir model to agree with the field operation data. Encroachment angle and radius were regressed to obtain history matches on pressure and production data which ensure a satisfactory pressure match for the tank. In this study to get a quality history match, Different aquifer models were used in the reservoir model and their parameters were regressed [23].

Best fit aquifer was selected. This was observed when model and field pressure and production data matched together in graphical representation. In this study author find that there is no impedance between material balance and simulation, instead they were supportive of one another. Material balance is best for the history matching pressure and production performance but has disadvantage when it comes to prediction, which is strongly related to numerical reservoir simulation modelling. As in this case good history match had been achieved, MBAL model showed a good pressure and production match for the tank with historical production and pressure data. Further research shows performance prediction of the reservoir tank.

## III. RESULTS AND DISCUSSION

### A. The Energy of the system

Different driving mechanism plays a role into reservoir for providing enough energy for the system. After running history matching this was necessary to select the aquifer and for better history matching we selected suitable aquifer. The relative contributions of the different driving mechanism energy and aquifer system to the recovery from the reservoir were discovered with certainty. In figure 1 there were three driving mechanisms presents with the fluid expansion and the pore volume compressibility which can't be ignored due to enough participation to providing energy to the reservoir system. Water influxes identified as a dominated energy in the system and contribute about 50% of the total energy system while other two contribute remaining energy. The energy plot revealed the relative importance of each driving mechanism.

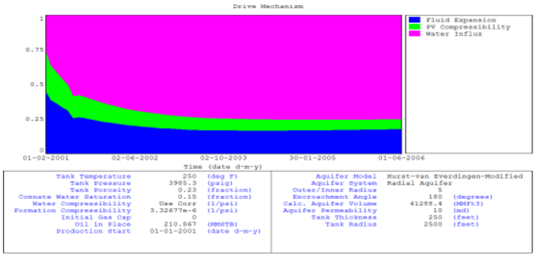


**Figure. 1 Drive Mechanism for Reservoir**

### B. Analytical Plot

The Analytical plot represents the cumulative oil production as a function of reservoir pressure decline in Figure 2. From analytical plot it was observed that with the current aquifer model, the model was predicting the cumulative oil production higher than those observed without considering water influx initially when there was uncertainty of possible energy system. Plot shows considerable deviation between history matching data and history matched simulation model result.

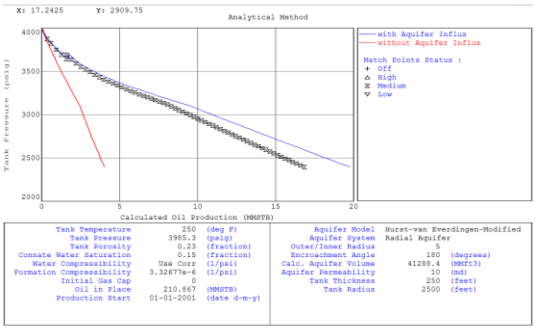


**Figure 2. Analytical Plot reservoir pressure vs cumulative oil production**

### C. Analytical Plot after regression

Regression played a constructive role for eliminating the deviation between the simulated model and historical behavior in terms of production and pressure data in figure 3.

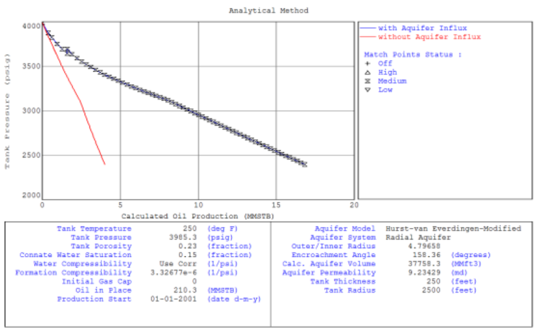


**Figure 3. Analytical plot after regression analysis**

### D. Campbell Plot

Basic material balance equation for oil reservoir

$$F = NE_t + W_e$$

Rearranging the equation, we got

$$\frac{F - W_e}{E_t} = N$$

Now, if (F -$W_e$ / $E_t$) vs F is plotted, a horizontal line with Y intercept equal to N should be obtained. We can clearly see in figure 4 history points deviates from the horizontal, it indicates the model is not able to predict the response as seen from the reservoir. The input data must be reviewed in this case.

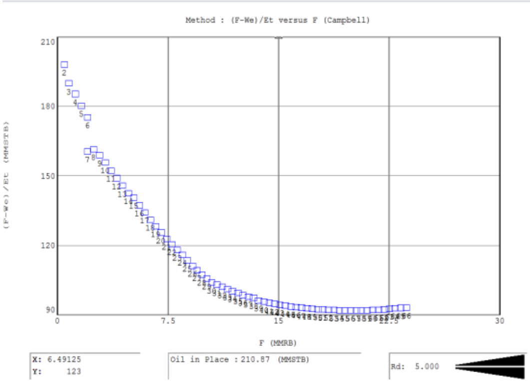


**Figure 4. Campbell Plot with aquifer (F - $W_e$ / $E_t$) vs F**

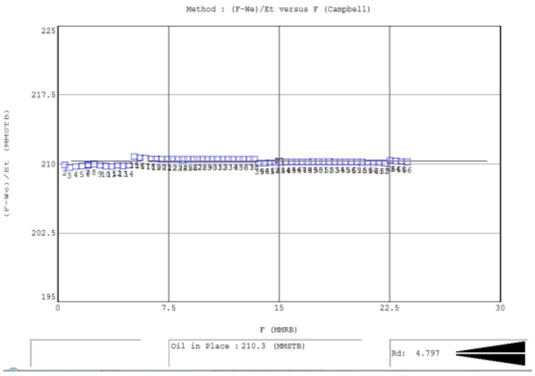


**Figure 5. After Regression Campbell Plot with aquifer (F - $W_e$ / $E_t$) vs F**

### E. Reservoir Simulation

Reservoir simulation considered as a tool for overall field development planning and used to perform reverse calculations. Simulation study in figure 6 revealed that if simulated model has been properly history matched, there should be no variance between predicted reservoir pressure as a function of time from simulation result and historical measured pressure result. After result in this case simulated and historical data matched together.

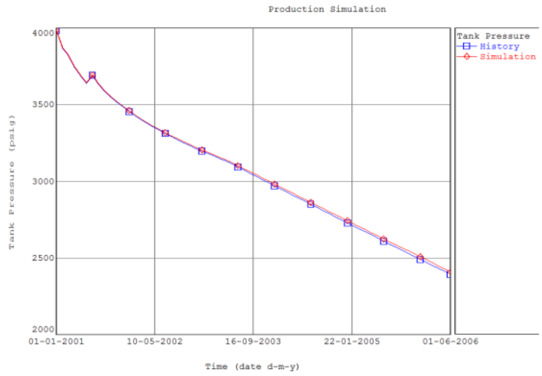


**Figure 6. Tank Pressure vs Time Reservoir Simulation Model History Match**

### F. Performance Prediction/Forecasting

After acceptable history matched obtained, prediction of cumulative oil production, oil recovery factor, water production and reservoir pressure decline are carried out.

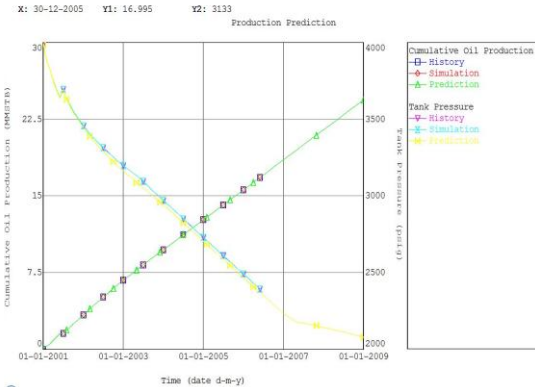


**Figure 7. Performance prediction of reservoir and History match data plotted**

Figure 7 shows that from the beginning of the production in 01/01/2001 to continuous decline of the production in plot till 01/01/2009. As we can clearly see that history model, simulated model and performance prediction fall in same line. Further cumulative oil production after 31/07/2006 will follow as an according to performance prediction plot. This will provide the information regarding water injection requirement to sustain the reservoir pressure and economic limit of the reservoir.

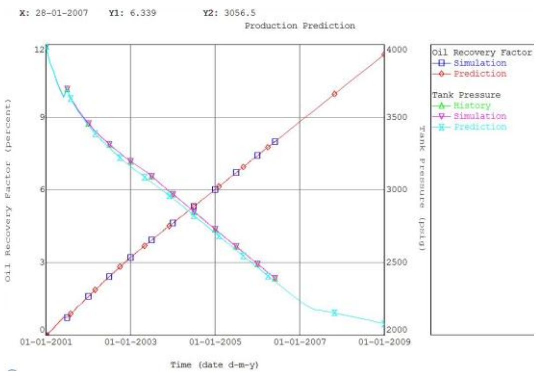


**Figure 9. Water Production along with pressure decline vs time**

In figure 9 this was illustrated that the model is ready for prediction as we can see a good agreement between the data and forecast in plot. Since we observed that reservoir most energy supplied by water influx only. After certain period this is observed that water production visible after certain time of oil production. Water cut raised from 01/01/2001 0% to 22.5% in 01/01/2009 of total production of oil according to future prediction plot.

## IV. CONCLUSION

Results obtained from different graphs the following conclusions are drawn from this research work. In reservoir engineering material balance equation is an important investigative tool when time is limited. This is very sophisticated analytical tool for evaluating reserve volume through historical production. In this study it has been proved that good data acquisition is required to carried out reserve volume evaluation with MBAL. Reservoir analysis tool MBAL is used to initialize, calibrate and benchmark the history matching.The main source of energy in reservoir was from Water influx and rock and fluid expansion drive mechanism. Water system energy provide about 50% of the reservoir energy which is required for oil recovery. The Hurst van Everdingen water influx model best describe the reservoir. The cumulative oil produced for the historical period was 16.81 MMSTB and 24.37 MMSTB for forecast period, with recovery factors of 8.22% and 11.58% respectively. The total amount of cumulative water production for the historical period was 1.88 MMSTB and 3.86 MMSTB for forecasts period. Material balance was utilized in reservoirs where enough adequate data were available for History matching and Performance prediction. Finally, central objective of this paper with the help of reservoir simulation fulfilled to produce future prediction that will lead to optimize reservoir performance which meant reservoir developed in the manner that brings utmost benefit to the commercial business.

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