# The Integration of Rate Transient Analysis in Dynamic Material Balance Simulation to Predict Reservoir Performance in an Oil Field

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*Abstract:* Estimation of hydrocarbon in place and remaining reserves as well as being able to predict future reservoir performance for oil and gas reservoirs is extremely needed from time when such reservoirs are first discovered to future times when they are being developed. To achieve this purpose, Dynamic material balance simulation is one of good solution as this method is an advanced application of material balance method as well as integrated to production and system performance analysis. However, a lack of information or data in particularly reservoir characteristics is mainly become one of issue in performing production and system performance analysis. Consequently, it will affect the results will be not valid. Integration of rate transient analysis in dynamic material balance simulation could be an alternative solution in dealing with this issue. In this paper, the integration method is applied in an onshore oil field which is “X” Field. Material balance method is used in evaluating reservoir pressure and drive mechanism analysis. Type curve methods as application of rate transient analysis are performed to estimate reservoir characteristics which are permeability and skin factor. These results are used to support in modeling and obtaining production performance of the wells. Afterwards, integrated of these methods are performed in conducting dynamic material balance simulation for estimating remaining reserves and forecasting future reservoir performance. In summary, Reservoir drive mechanism in “X” Field is strong water drive mechanism as depletion of reservoir pressure is relatively low as well as currently it is still above the bubble point pressure and there is support from aquifer influx. The remaining reserves in “X” Field at end of prediction is around 705.80 MSTB based on existing artificial lift production method.

*Key-Words:* Dynamic material balance simulation, material balance method, production and system performance analysis, Reservoir characteristics, Rate transient analysis, Type curve methods.

## 1 Introduction

Estimation of hydrocarbon-in-place and reserves for oil and gas reservoirs is needed from the time when such reservoirs are first discovered to future times when they are being developed by drilling step-out wells or infill wells. These estimates are needed to determine the economic viability of the project development as well as to book reserves required by regulatory agencies. The material balance method is one of method to estimate the original hydrocarbon in place and reservoir drive mechanism. The material balance equation is zero-dimensional, meaning that it is based on a tank model and does not take into account the geometry of the reservoir, the drainage areas, the position and orientation of the wells, etc.

In order to do production forecasting for obtaining the future reservoir performance, a numerical simulation should be performed. Application of numerical simulation in material balance is called by dynamic material balance simulation, as the material balance method is integrated with production and system performance analysis. However, a lack of information or data in particularly reservoir characteristics is mainly become one of issue in application of production system performance analysis. Thus, when the results of production and system performance analysis will be integrated to material balance method to perform dynamic material balance simulation, the results will not be valid. Consequently, a new way or methodology is extremely needed to deal with this issue.

Rate Transient Analysis (RTA) is a method to evaluate the reservoir using combined rate and pressure data without the need to shut in wells. This method involves the interpretation of characteristic flow-regimes, which evolve during production of a well, to extract quantitative information about reservoir properties. The procedure and theory for rate-transient analysis is analogous to pressure-transient analysis; in fact, the modern concept of rate-transient analysis is to analyze production data like one would a long-term drawdown test, which is a classic well-test procedure. Thus, the integration of rate transient analysis in dynamic material balance simulation could be an alternative solution to obtain accurate and valid results.

This study will focus on the application of material balance method in evaluating reservoir pressure and drive mechanism analysis. A field case study is used to perform the study. Analytical method as function of reservoir pressure and calculated oil production was used to identify if there is aquifer influx or not. The reservoir characteristics include reservoir drainage area, permeability, and skin factor were estimated by using rate transient analysis. These data are integrated and used in production and system performance analysis in the wells. This analysis was performed to obtain the well performance with current production method and valid well models as constraint in conducting dynamic material simulation for estimating remaining reserves and future reservoir performance.

## 2 Methodology

The integration of rate transient analysis in dynamic material balance simulation is performed in an onshore oil field. Methods implemented is consisted of the following sequential steps:

### 2.1 Material Balance Method

Material balance equation is derived as a volume balance which state that cummulative production recorded as underground withdrawal is equivalent to the changes of volume due to fluids expansion in a reservoir as caused by reservoir pressure declined. The equation is written as follows:

$$Np(Bo+(Rp-Rso)Bg) = NBoi\left[\frac{(Bo-Boi)+(Rsoi-Rso)Bg}{Boi} + m\left(\frac{Bg}{Bgi}-1\right)+(1+m)\left(\frac{SwcCw+Cf}{(1-Swc)}\right)\Delta P\right]+(We-Wp\,Bw) \quad (1)$$

If pore compressibility and connate water are neglected, the question is then become:

$$Np(Bo+(Rp-Rso)Bg) = NBoi\left[\frac{(Bo-Boi)+(Rsoi-Rso)Bg}{Boi} + m\left(\frac{Bg}{Bgi}-1\right)\right]+(We-Wp.Bw) \quad \text{.....................} (2)$$

Subsequently, the right side is divided by the left side, thus it becomes:

$$1 = \underbrace{N\frac{(Bo-Boi)+(Rsoi-Rso)Bg}{Np(Bo+(Rp-Rso)Bg)}}_{\text{DDI}} + \underbrace{\frac{NmBoi(\frac{Bg}{Bgi}-1)}{Np(Bo+(Rp-Rso)Bg)}}_{\text{SDI}} + \underbrace{\frac{(We-Wp.Bw)}{Np(Bo+(Rp-Rso)Bg)}}_{\text{WDI}} \quad \text{..................................} (3)$$

From equation (3), it can be defined the driving index as follows:

DDI = Depletion Drive Index
SDI = Segregation (gas cap) index
WDI = Water drive index

The material balance equation can be written as a simple way as follows:

F = N (Eo + m Eg + Ef, w) + We ........................ (4)

Then, if the value of (Eo + m Eg + Ef, w) is simplified to be total expansion Et, thus equation (4) become:

F = N.Et + We ........................................... (5)

F/ Et = N + We/ Et .......................................... (6)

From equation (6), it can be generated a linear graph with x-axis is (We/ Et) and y-axis is (F/ Et). The line will be result in an angle of 45o and the cross section on y-axis is the value of N or original oil inplace (OOIP).
According to Campbell, the equation (5) can be modified as:

(F – We)/ Et = N ................................................. (7)

If the equation (7) is made a linear graph with x-axis is F and y-axis is (F – We)/ Et, thus, it will be result in a straight line with gradient 0 and intercept with y-axis is the value of OOIP.

### 2.2 Rate Transient Analysis

The modern production data analysis method is known as rate transient analysis. It is an extension of well testing. It combines Darcy’s law with the equation of state and material balance to obtain a differential equation, which is then solved analytically. The solution is usually presented as a “dimensionless type curve,” one curve for each of the different boundary conditions, such as: vertical well, horizontal well, hydraulically fractured well, stimulated or damaged well, bounded reservoir, etc.

In this study, type curve methods will be used to estimate hydrocarbon inplace and reservoir characteristics. These are Blasingame type curve, Agarwal and Gardner (A&P) type curve and Normalized Pressure Integral (NPI) type curve.

#### 2.1.1 Blasingame Type Curve

Blasingame typecurves have identical format to those of Fetkovich. The Fetkovich analytical typecurves can be used to calculate three parameters: permeability, skin and reservoir radius.

$$k = \frac{141.2\mu B}{h(p_i - p_{wf})}\left[\ln\left(\frac{r_e}{r_{wa}}\right) - \frac{1}{2}\right]\frac{q}{q_{Dd_{match}}} \quad \text{.................... (8)}$$

$$r_{wa} = \sqrt{\frac{0.00634k}{\phi\mu c_t}\left.\frac{1}{\frac{1}{2}\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2}\right]\left[\left(\frac{r_e}{r_{wa}}\right)^2 - 1\right]}\frac{t}{t_{Dd}}\right|_{match}} \quad \text{.... (9)}$$

$$s = \ln\left(\frac{r_w}{r_{wa}}\right) \quad \text{........................................................ (10)}$$

$$r_e = \sqrt{2\frac{141.2B}{h(p_i - p_{wf})}\frac{0.00634}{\phi\mu c_t}\frac{q}{q_{Dd_{match}}}\frac{t}{t_{Dd_{match}}}} \quad \text{........... (11)}$$

However, there are three important differences in presentation; models are based on constant rate solution instead of constant pressure, exponential and hyperbolic stems are absent, only harmonic stem is plotted, rate integral and rate integral - derivative typecurves are used (simultaneous typecurve match).

Blasingame type curve method uses the normalized rate (q/dP) and the material balance pseudotime (tca) and plots those values to be matched against type curves of dimensionless rate and dimensionless time (constant rate type curves in Fetkovich dimensionless format). Then the integrals defined in the equations below (rate-integral and rate-integral derivative) are plotted.

The rate integral is:

$$q_{Ddi} = \frac{1}{t_{DA}}\int_0^{t_{DA}} q_{Dd}(t)dt \quad \text{.......................................... (12)}$$

The derivative of the rate integral is:

$$q_{Ddid} = t_{DA}\frac{dq_{Ddi}}{dt_{DA}} \quad \text{................................................ (13)}$$

#### 2.1.2 Agarwal and Gardner Type Curve

The Agarwall and Gardner typecurves are all derived using the well testing definitions of dimensionless rate and time. The models are all based on the constant rate solution. Three sets of type curves; rate vs time typecurves (qD and tDA format), inverse of pressure derivative (1/pDd) vs tDA, and inverse of pressure integral-derivative (1/ pDid) vs tDA.

The Agarwal and Gardner type curve method is quite similar to that presented by Palacio and Blasingame, only after matching the normalized rate (q/dP) and the material balance pseudotime against constant rate typecurves in well test format (Agarwal-Gardner type curves), an estimate of a value named the Inverse Pressure Derivative (IPD) is made. The IPD is given by

$$IPD = \left[t_{ca}\frac{d(\Delta P_p / q)}{dt_{ca}}\right]^{-1} \quad \text{........................................... (14)}$$

#### 2.1.3 Normalized Pressure Integral Type Curve

This method uses a normalized pressure (dP/q) instead of a normalized rate as shown in the previous methods (Palacio and Blasingame and Agarwal and Gardner). Again, the method tries to match the normalized pressure versus the material balance pseudo time (tca) data to a plot of dimensionless pressure (Pd) versus dimensionless time (tda), which is a constant rate type curve in well test format. Once the match is performed, the pressure integral is plotted as well as the pressure-integral derivative.

Pressure integral:

$$p_{Di} = \frac{1}{t_{DA}}\int_0^{t_{DA}} P_p(t)dt \quad \text{.............................................. (15)}$$

Pressure integral – derivative:

$$P_{Did} = t_{DA}\frac{dP_{Di}}{dt_{DA}} \quad \text{................................................... (16)}$$

### 2.3 Production and System Performance Analysis

This analysis is designed to allow the building of reliable and consistent well models, with the ability to address each aspect of wellbore modeling, PVT (fluid characterization), VLP correlations (for calculation of flow-line and tubing pressure loss) and Inflow Performance Relationship (IPR).

The analysis is beginned by defining the well type which is consisted by fluid description, well type, production and completion methods; PVT modeling; then, modeling the IPR of the wells uses Vogel method (if there is well test data) and Darcy method (if there is no well test data) by inputing reservoir characteristics from rate transient analysis; subsequently, construction of the well model by inputing the deviation survey, downhole equipment, geothermal gradient, and average heat capacities; afterwards, determine the flow correlation based on well test data, select the best correlation using correlation comparison and VLP/ IPR quality check; finally, generate the VLP sensitivity analysis with three (3) or four (4) variables (well head pressure, gas-oil ratio, and water cut).

### 2.4 Dynamic Material Balance Simulation

Dynamic material balance is performed to do production forecasting in order to obtain the future reservoir performance. The analysis is beginned by matching the fractional flow (Fw), set-up the prediction, set the production constraint, define the well type by inputing the well model from production and system performance analysis, and finally running simulation to get future production performance.

## 3 Results and Discussion

### 3.1 Material Balance Analysis

Application of the integration of rate transient analysis in dynamic material balance simulation is performed in an onshore oilfield which is X Field. “X” oil reservoir is a single reservoir, which is X Sand. In this case there will be no inter-reservoir allocation factor issue. Construction of reservoir tank modeling in “X” Field needs original oil inplace (OOIP) data from the results of static modeling used volumetric method, fluid and petrophysical properties, production and reservoir pressure data.

According to production data history (**Fig. 1**), “X” Field began production on 31 May 1973 untill 31 August 2014, cummulative oil production of about 20.092 MMSTB with water cut of 98.72%. Currently, this field producing with oil rate of 365.60 bopd from three (3) active wells.

On pressure data, there are only a very limited data recorded in this field. **Fig. 2** shows the pressure data, which will be used for the history matching. Note that the term ‘other data’ means the pressure data from build up which only noted in the wellfile’s workover tour reports, there are no full data of these build up pressure.

None of wells having PVT data. So, for the purpose of simulation study of “X” field, on X sand only, we will use analog from the closest field, “Y” Field. PVT data was derived from “Y” #1 sampled at depth of 3623 ft. This PVT data was chosen after compared and validated with theoritical/ calculation using basic known properties of the oil i.e. API gravity, Gas gravity, Reservoir temperature and Solution Gas-Oil ratio. **Table 1** shows basic fluid properties of X Sand. PVT properties; Solution Gas Oil Ratio (Rs), Oil Formation Volume Factor (Bo), Oil Viscosity (μo), Gas Formation Volume Factor (Bg), and Gas Viscosity (μg) are shown in **Fig. 3 – Fig. 7**.

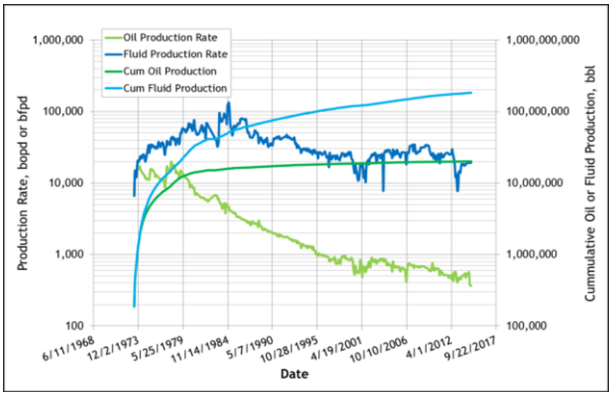

**Fig. 1** “X” Field Production rate and cummulative

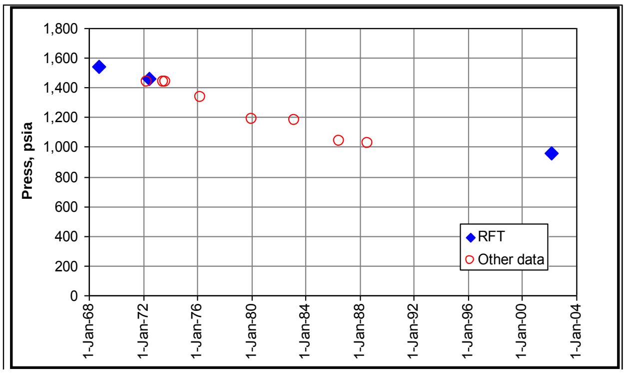

**Fig. 2** “X” Field Reservoir pressure data

Relative to the sample’s bubble point pressure data, the reservoir pressure in this field has never got anywhere near the low values of bubble point pressure, so there will be no free gas in the reservoir in the development stage. The values of these fluid properties below its bubble point pressure, also will take no effect on the reservoir simulation as the pressure has never been below any the bubble point pressures.

**Table 1.** “X” Field Basic Fluid Properties

| Basic Properties | Value |
|---|---|
| Reservoir temperature ($^{o}$F) | 232 |
| Reservoir pressure (psia) | 1541.7 |
| API oil gravity ($^{o}$) | 35.4 |
| GOR (SCF/ STB) | 22 |
| Bubble point (psia) | 159.7 |
| Oil FVF at $P_{sat}$ (Rb/ STB) | 1.095 |
| SG gas | 1.092 |

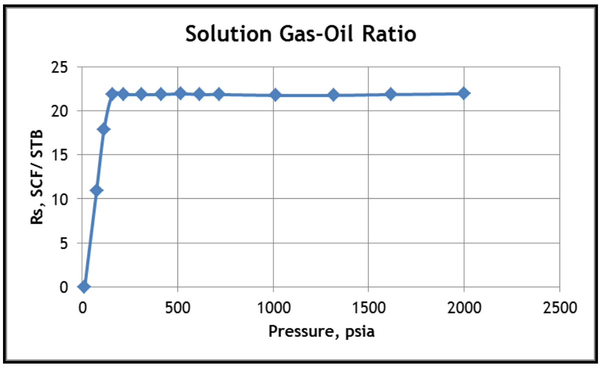


**Fig. 3** Solution Gas – Oil Ratio

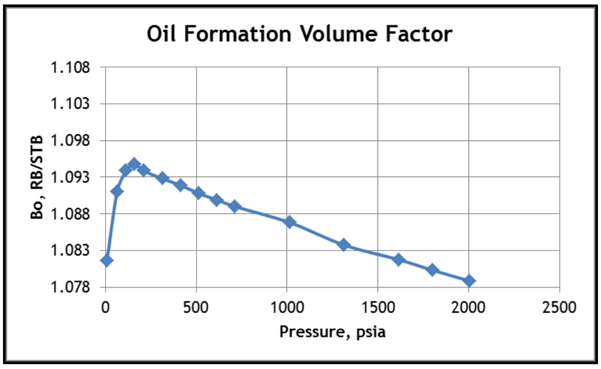


**Fig. 4** Oil Formation Volume Factor

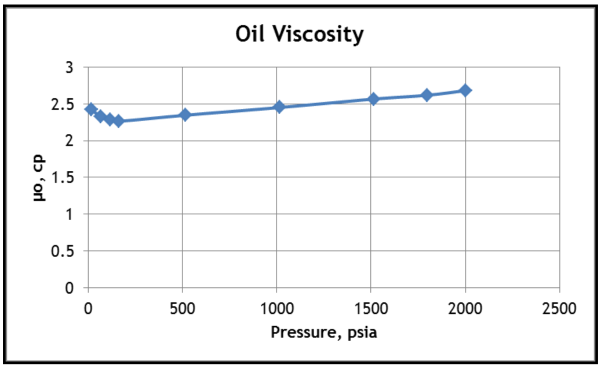


**Fig. 5** Oil Viscosity

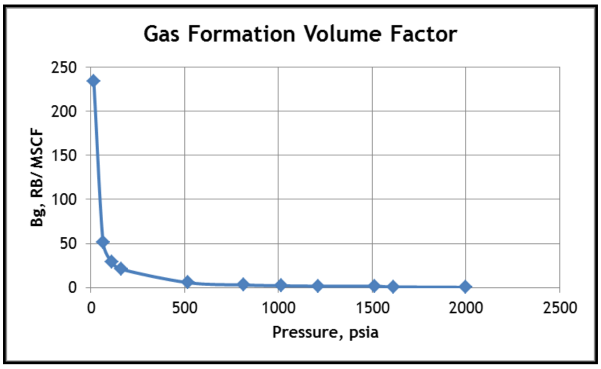


**Fig. 6** Gas Formation Volume Factor

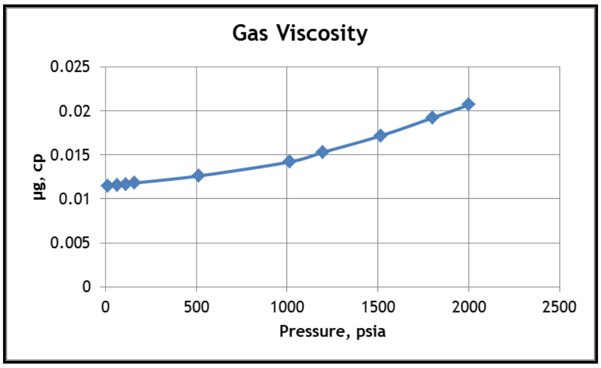


**Fig. 7** Gas Viscosity

In order to initialize the reservoir simulation, we generated the series of oil-water and oil-gas relative permeability based on the data samples of four wells from other fields. There was no special core analysis (SCAL) performed in any wells. With the assumption that X sand in this field has the similarity of properties with the same sand in different field, we have gathered the X Sand SCAL data from wells in other fields. **Fig. 8** and **Fig. 9** are relative permeability curves for water oil and gas-oil systems.

For rock compressibility data, sample from X Sand at ST#1 (sample depth 4197 ft) will be used for rock compressibility input for material balance simulation. X Sand's rock compressibility of ST#1 is shown in **Fig. 10**.

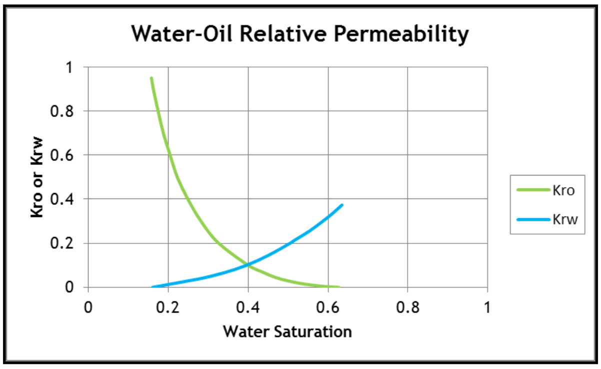


**Fig. 8** X Sand's Water-Oil relative permeability

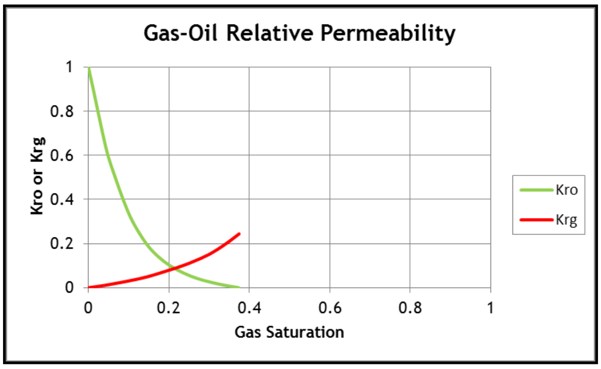


**Fig. 9** X Sand's Gas-Oil relative permeability

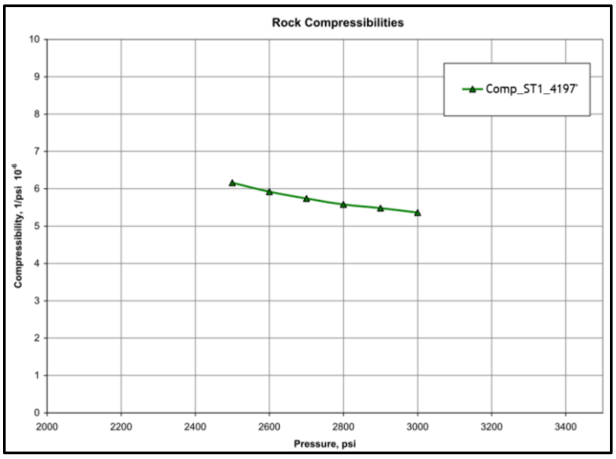


**Fig. 10** X Sand's Rock Compressibility of ST#1

Identification of original oil inplace (OOIP) and reservoir drive mechanism used Campbell Plot method (F/Et vs F). From the results of this plot, it is identified that reservoir drive mechanism of "X" Field is strong water drive and OOIP of about 33.75 MMSTB (**Fig. 11**). The differences OOIP value from the material balance and the volumetric method of about 0.73%. Subsequently, analytical method was conducted to validate tank model towards actual data, which is the cross-plot between reservoir tank pressure vs calculated oil production from tank model and actual data. From the result shows that the tank model has not validated yet due to the result of cross-plot not matched (**Fig. 12**). Thus, it is required to model the aquifer in "X" Field in order to obtain a valid tank model which is matched to the reservoir actual condition.

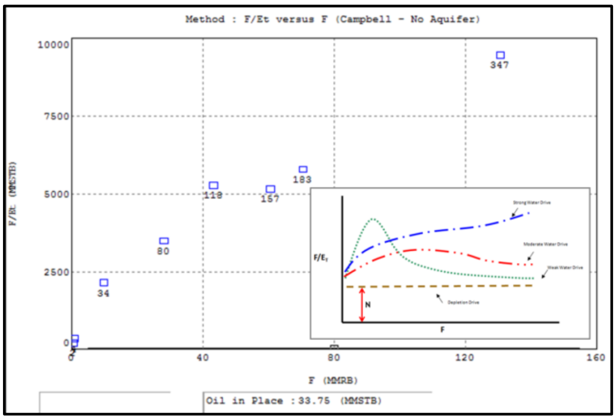


**Fig. 11** Campbell Plot analysis

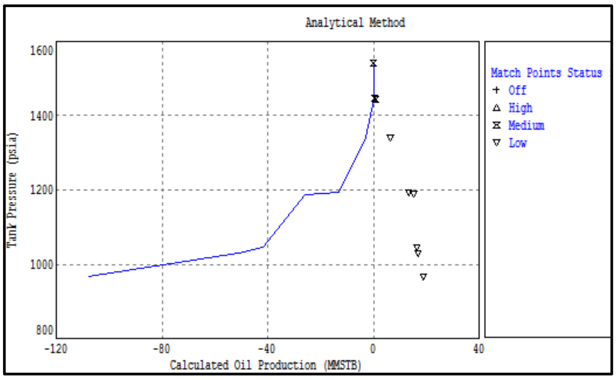


**Fig. 12** Analytical Method

The Hurst-Van Everdingen Modified was used to modeling the aquifer with radial system model. This method was applied due to more accurate compared to other methods, such as Fetkovich, Carter-Tracy, Schiltuis, Wogt-Wang, etc. From the results of aquifer modeling, it was obtained aquifer permeability of about 60 mD and reservoir tank model matched with actual data (**Fig. 13**). Thus, the current reservoir tank model is valid.

The Energy plot was then conducted to identify the reservoir drive mechanism in the "X" Field. The result shows that drive mechanism which dominates by Water Drive (**Fig. 14**), it could be seen clearly that effect of the water influx at the initial production till present.

History matching analysis was performed to match reservoir performance of the tank model with actual reservoir performance. The result of history matching analysis is shown in **Fig. 15**, the main parameter to be matched are pressure and production data. Cummulative fluid and oil production were obtained from simulation matched to actual production, with cummulative oil production at end of production history of about 20.092 MMSTB and recovery factor of 59.1%. Cumulative fluid production from this field is very large, while the observed pressure depletion is relatively low. This would also indicate that the reservoir has a strong water drive mechanism. The wells in "X" Field are high fluid producing wells, with such high PI wells from this field, it is expected that the reservoir in this field, which is X Sand, have high permeability. These will be proven in rate transient analysis and production & system performance analysis.

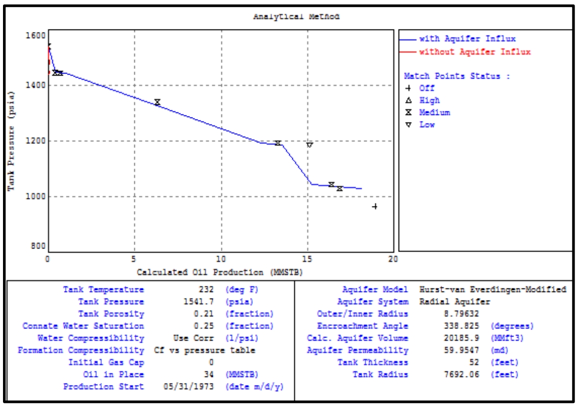


**Fig. 13** Analytical method with Aquifer Influx

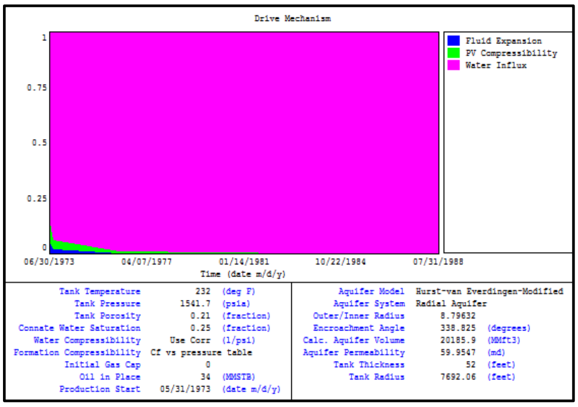


**Fig. 14** Identification of the reservoir drive mechanism used the Energy Plot

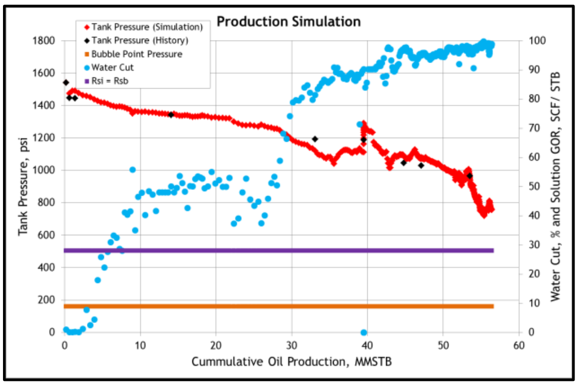


**Fig. 15** History matching analysis

## 3.2 Rate Transient Analysis

Modern production data analysis or rate transient analysis was performed by using types curve and non-type curve methods. This method was beginned by selecting a key well which represents field production performance. Key well selecting criteria based on the long time period of production, the well still active, and the well represents the field production performance. Acoording to these criteria, the Well #1 was chosen as the key well as this well meets the requirements.

Type curve methods that applied were Blasingame, Agarwal & Gardner, and Normalized Pressure Integral (NPI) typecurves, while for the non-type curve method was Flowing Material Balance (FMB) method**.** Blasingame type curve method uses the normalized rate (q/dP) and the material balance pseudotime (tca) and plots those values to be matched against type curves of dimensionless rate and dimensionless time**.** The Agarwall and Gardner typecurves are all derived using the well testing definitions of dimensionless rate and time. The models are all based on the constant rate solution. While Normalized Pressure Integral (NPI), this method uses a normalized pressure (dP/q) instead of a normalized rate as shown in the previous methods (Blasingame, and Agarwal & Gardner). The Flowing Material Balance uses the concept of stabilized or "pseudo-steady-state" flow to evaluate total in-place fluid volumes.

**Fig. 16 – Fig. 18** show the results of type curves analysis in the Well #1. Based on the analysis, it shows that the flow regime of reservoir has reached boundary dominated flow system. It means that original oil inplace and reservoir characteristics could be estimated because the reservoir condition has reach the reservoir boundary where pressure and production rate have stabilized at this condition/ the pseudosteady-state flow regime. The summary results of Rate Transient Analysis is given in **Table 2**. OOIP in average was obtained of about 35.81 MMSTB, average permeability of about 724.33 mD and average skin factor of about 5.31. These reservoir characteristics (permeability and skin factor) are very important in conducting production and system performance analysis, particularly in producing the inflow performance relationship (IPR) model.

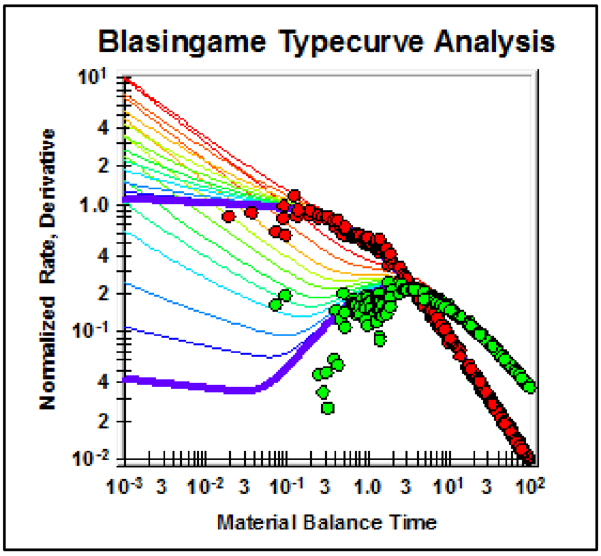


**Fig. 16** Blasingame typecurve analysis in the Well #1

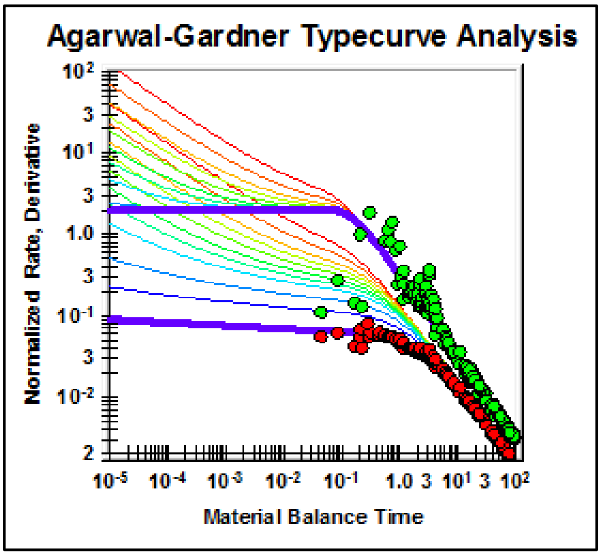


**Fig. 17** Agarwal-Gradner (A&G) typecurve analysis in the Well #1

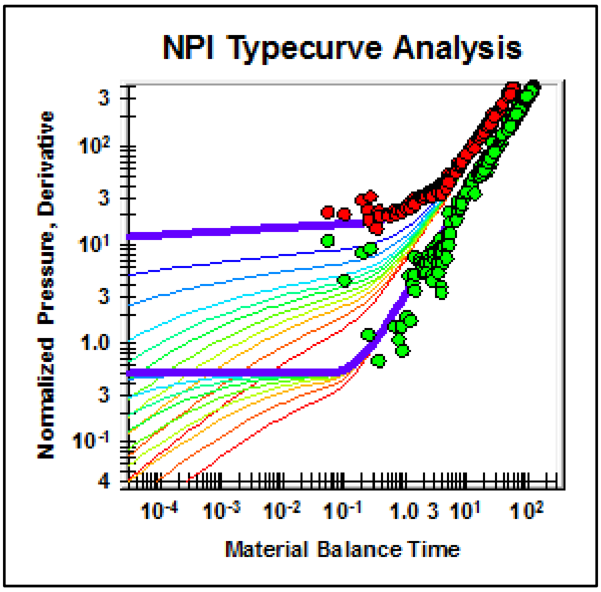


**Figure 18.** Normalized Pressure Integral (NPI) typecurve analysis in the Well #1

**Table 2.** The summary results of Rate Transient Analysis in the "X" Field

| Method | OOIP MSTB | Area Acres | Perm (k) mD | Skin |
|---|---|---|---|---|
| Blasingame | 35.95 | 14,712.8 | 715.63 | 4.93 |
| A&G | 36.16 | 14,799.7 | 659.13 | 5.50 |
| NPI | 35.32 | 14,453.2 | 798.24 | 5.51 |
| Average | 35.81 | 14,655.2 | 724.33 | 5.31 |

## 3.3 Production and System Performance Analysis

Construction of wells model was needed for inputing data to conduct dynamic material balance analysis. Construction of wells model that suitables with the actual condition will give a valid result. There are three (3) active wells in the "X" Field with artificial lift method which is the electrical submersible pump (ESP) method.

Construction of the inflow performance relationship (IPR) model used Vogel and Darcy methods, based on the availability of the test data. For Well #1, Vogel model was used to model the IPR due to this well had the well test data. This well had been testing on 09/16/1968, with flow rate of 2355 BOPD at flowing pressure (Pwf) of about 1487 psig and Productivity Index (PI) of about 19.2 STB/ day/ psi. **Fig. 19** shows IPR modeling in the Well #1 uses Vogel method, it is obtained absolute open flow (AOF) of about 30,794.1 STB/ day and PI of about 19.15 STB/ day/ psi. **Fig. 20** and **Fig. 21** shows IPR model uses Darcy method for the Well #2 and #3, respectively. From the results, Well #2 has AOF of about 8,161.2 STB/ day and PI of about 8.32 STB/ day/ psi, and for Well #3, it has AOF of about 7,773.4 STB/ day and PI of about 7.94 STB/ day/ psi.

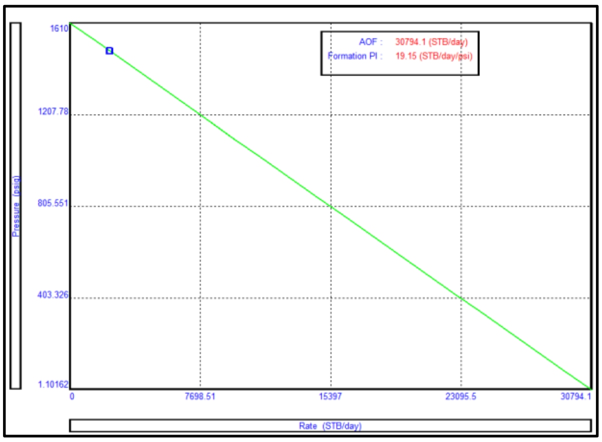

**Fig. 19** IPR plot Vogel in the Well #1

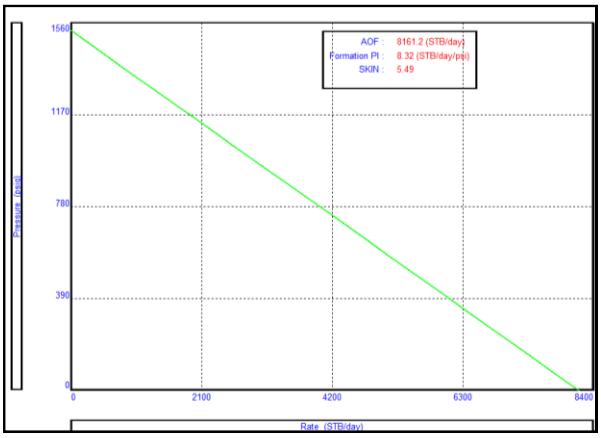

**Fig. 20** IPR plot Darcy in the Well #2

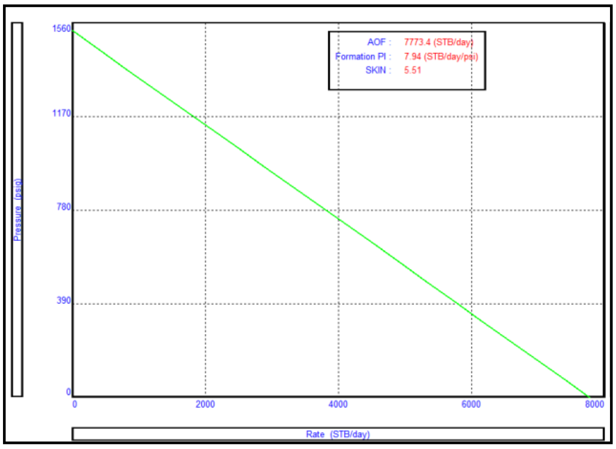


**Fig. 21** IPR plot Darcy in the Well #3

Determination of the equation for calculating the vertical lift performance (VLP) was done after all of the IPR models were obtained. The calculation was performed based on the availability of the well test data in the Well #1. Some of approach methods have been applied in calculating the VLP, these are Duns and Ros Modified, Hagedorn Brown, Fancher Brown, Mukerjee Brill, and Beggs and Brill methods. **Fig. 22** shows the comparison of the VLP calculation results from different methods. It can be seen that the VLP result from Hagedorn Brown method matched to the test data. This method more representative compared to other methods. Thus, Hagedorn Brown correlation was chosen to generate the VLP in the "X" Field wells.

Subsequently, the VLP/ IPR matching was performed to validate the well models. **Fig. 23** shows the results of the VLP/ IPR matching in the Well #1. According to this result, it was obtained the flow rate differences between model and test data of about 0.2% and the differences of bottom hole pressure between model and test data of about 0.0009%. Based on these parameter, the differences between the Well #1 model with production well test is less than 5%, thus the constructed well model has representatived or valid.

The "X" Field wells are produced with artificial lift which is Electrical Submersible Pump (ESP). Specification of the ESP for each wells is given in **Table 3**. After inputing the ESP design in the wells model, then Pump Discharge Pressure vs Vertical Lift Performance curve for each wells was generated, and the sensitivity analysis was also performed based on four (4) variables; well head pressure, operating frequency, water cut, and gas-oil ratio.

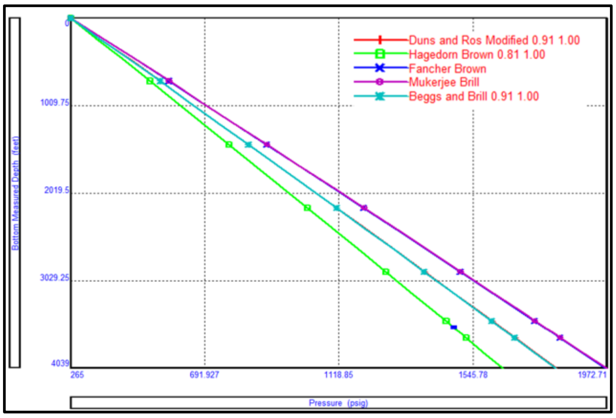


**Fig. 22** Pressure vs Measured Depth (Comparison of some correlation methods in generating the Vertical Lift Performance/ VLP) in the Well #1

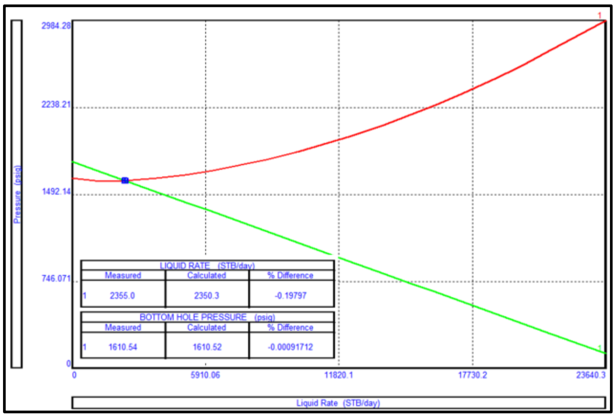


**Fig. 23** VLP/ IPR matching in the Well #1

**Table 3.** The ESP design in the "X" Field wells

| Design | The "X" Field Wells | | |
|---|---|---|---|
| | Well #1 | Well #2 | Well #3 |
| Date of ESP setting | 1/31/2013 | 1/16/2006 | 3/10/2013 |
| Pump type | Reda GN2500 5.13" | Reda GN4000 5.13" | Reda GN2000 5.13" |
| Pump setting depth | 3404 ft | 3495 ft | 2019 ft |
| Motor | Reda 540_90-0_Std 87.5 Hp 430V/ 124A | Reda 540_90-0_Std 175 Hp 1070V/ 99.5A | Reda 540_90-0_Std 87.5 Hp 430V/ 124A |
| Cable | #Al 0.84 volt/ 1000ft | #Al 0.84 volt/ 1000ft | #Al 0.84 volt/ 1000ft |

## 3.4 Dynamic Material Balance Simulation

Dynamic material balance simulation was performed by combining the results of material balance analysis till validation at end of production history with production and system performance analysis for each wells model. The simulation was beginned by doing Fractional flow (Fw) matching due to forecasting process will be constrained by the fractional flow. The results of well modeling were generated into the simulator as the constraints for the active wells in the “X” Field.

**Fig. 24** shows the simulation result in the “X” Field untill 01/01/2035. At the end of prediction, it was obtained cumulative oil production of about 20.8 MMSTB with recovery factor of about 61.17%. According to the value of ultimate recovery that was obtained, the “X” Field has remaining reserves of about 705 MSTB. Thus, the recovery factor of the “X” Field could be increased by doing production optimisation or further field development. For further study, an economic analysis is needed to perform in order to make the decision for increasing the recovery factor in the “X” Field.

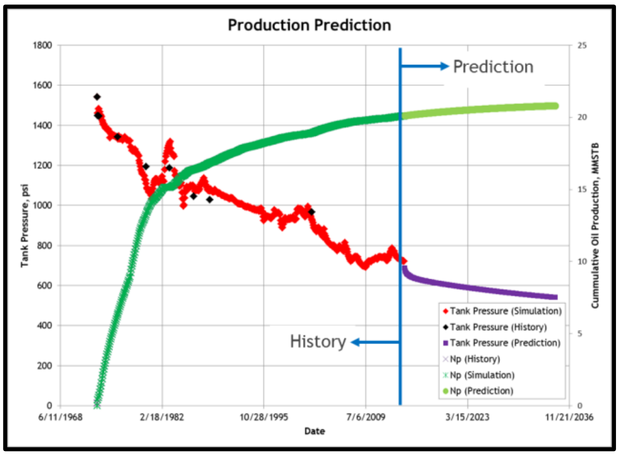


**Fig. 24.** Production forecasting in the “X” Field till 01/01/2035

## 4 Conclusion

From this study, it has been shown that the integration of rate transient analysis in performing dynamic material balance simulation is extremey important to predict reservoir performance. Key well selection is one of the main key for successful of rate transient analysis. The information that provides from rate transient analysis which is reservoir characteristics that include permeability and skin factor is crucial of important to perform dynamic material balance simulation.

A field example in an oil “X” Field, it is obtained that reservoir drive mechanism in the “X” Field is strong water drive. “X” oil sand reservoir is fully supported by Aquifer Influx as the high aquifer permeability of about 60 mD. In addition, there is no gas effect since reservoir pressure never fall below bubble point pressure.

The wells in “X” Field are high fluid producing wells, with such high productivity index wells from this field, it is caused by the reservoir in this field, which is X Sand, have high permeability around 724.33 mD. From simulation that was performed, remaining reserves in the “X” Field at end of prediction (01/01/2035) is about 705.80 MSTB based on the existing production method (Electrical Submersible Pump/ ESP)

## Acronyms and Nomenclature

OOIP = Original oil-in-place, MMstb
h = reservoir thickness, ft
Np = cummulative oil production, STB
Wp = cummulative water production, STB
B = formation volume factor
Bgi = initial gas formation volume factor
Bo = oil formation volume factor
k = permeability, mD
Pi = Initial reservoir pressure, psi
Ti = Initial reservoir temperature, oF
Bo = Oil Formation Vol Factor, bbl/STB
Rs = Gas Solubility, SCF/ STB
μo = Oil viscosity, cp
GOR = Gas-Oil Ratio
SG = Specific Gravity
RCAL = Routine core analysis
SCAL = Special Core analysis
Kro = Oil Relative Permeability
Krw = Water Relative Permeability
Sw = Water Saturation, fraction
Swi = Initial water saturation, fraction
Sor = Residual oil saturation, fraction
$P_o$ = reference pressure, psi
$P_D$ = dimensionless pressure
$P_{Dd}$ = dimensionless pressure derivative
$P_{Di}$ = dimensionless pressure integral
$P_{Did}$ = dimensionless pressure integral-derivative
$P_i$ = initial reservoir pressure
$P_p$ = pseudo-pressure
$P_{wf}$ = well flowing pressure
q = flow rate, STB/ day
$q_D$ = dimensionless rate
$q_{Dd}$ = dimensionless rate
$q_{Ddi}$ = dimensionless rate integral
$q_{Ddid}$ = dimensionless rate integral-derivative
$r_e$ = exterior radius of reservoir
$r_{eD}$ = dimensionless exterior radius of reservoir
$r_w$ = wellbore radius
$r_{wa}$ = apparent wellbore radius
s = skin factor
t = flow time
$t_a$ = pseudo-time

$t_c$ = material balance time
$t_{ca}$ = material balance pseudo-time
$t_D$ = dimensionless time
$t_{DA}$ = dimensionless time
$t_{Dd}$ = dimensionless time

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