# Application of Volumetric, Material Balance and Decline Analysis Methods for Gas Initially in Place Estimation

by

Leong Sau Hong
14931

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr M. Mahbubur Rahman)

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January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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LEONG SAU HONG

# ABSTRACT

Initial estimate of GIIP by volumetric method needs to be validated with independent methods in order to gain confidence. Flowing material balance ( $p/z$ vs cumulative production), Fetkovich type curve and Blasingame type curve matching were used for verification. When the GIIP estimated by these three methods do not converge to one another, it yielded uncertainties in the GIIP estimated by many oil and gas operators. When the GIIP estimated were reasonably close to one another, then operators can proceed with the development plan as the confidence in getting the GIIP right was high. A comparison study of these three methods suggested that volumetric method, material balance, Fetkovich type curve and Blasingame type curve yielded 634 BCF, 585 BCF, 567 BCF and 557 BCF respectively. These three independent methods have been tested with real field data and the results were close enough. With only differences of 7%, 11% and 12 % from the volumetric method, the results were within the limits of 14% and the confidence of initial estimate was high.

# ACKNOWLEDGEMENT

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# ABBREVIATIONS AND NOMENCLATURES

Abbreviations

| | |
|---|---|
| AUPM | = Analytical uncertainty propagation method |
| BCF | = Billion cubic feet |
| GIIP | = Gas initially in place |
| HIIP | = Hydrocarbon initially in place |
| PA | = Production analysis |
| PVT | = Pressure, volume & temperature |
| RVP | = Reserve variability potential |

Nomenclatures

| | |
|---|---|
| $A$ | = Area |
| $b$ | = Formation volume factor |
| $B_g$ | = Gas formation volume factor |
| $B_{gi}$ | = Initial gas volume factor |
| $B_o$ | = Oil formation volume factor |
| $B_{oi}$ | = Initial oil formation volume factor |
| $B_w$ | = Water formation volume factor |
| $c_f$ | = Formation rock compressibility |
| $c_t$ | = Total compressibility |
| $c_w$ | = Water compressibility |
| $D_i$ | = Initial decline rate |
| $G$ | = Gas-initially-in-place |
| $G_p$ | = Cumulative gas production |
| GRV | = Gross rock volume |
| $h$ | = Reservoir thickness |
| $m$ | = Ratio of gas cap HCPV to oil column HCPV |
| $N$ | = Oil-initially-in-place |
| $N_p$ | = Cumulative oil production |
| NTG | = Net-to-gross |
| $p$ | = Reservoir shut-in pressure |
| $p_i$ | = Initial reservoir pressure |
| $\Delta P$ | = $p_i$ - $p_{wf}$ , Change in pressure |
| $p_{pi}$ | = Initial pseudo pressure |
| $p_{sc}$ | = Pressure at standard condition |

| | |
|---|---|
| $p_{wf}$ | = Wellbore flowing pressure |
| $q$ | = Flow rate |
| $q_D$ | = Dimensionless rate |
| $q_{Dd}$ | = Decline curve dimensionless rate |
| $q_i$ | = Initial surface rate |
| $q(t)$ | = Surface rate of flow at time t |
| $r_e$ | = External radius |
| $R_p$ | = Cumulative or average GOR since start of production |
| $R_s$ | = Solution gas-oil ratio |
| $R_{si}$ | = Initial solution gas-oil ratio |
| $r_w$ | = Wellbore radius |
| $S_h$ | = Saturation of hydrocarbon |
| $S_w$ | = Water saturation |
| $S_{wi}$ | = Initial water saturation |
| $S_{wc}$ | = Connate water saturation |
| $t$ | = Time for $t_{Dd}$ |
| $T$ | = Temperature |
| $t_c$ | = Material balance time |
| $t_D$ | = Dimensionless time |
| $t_{Dd}$ | = Decline curve dimensionless time |
| $T_{sc}$ | = Temperature at standard condition |
| $V_p, V_{pF}$ | = Reservoir pore volume |
| $W_e$ | = Water influx |
| $W_p$ | = Cumulative water production |
| $z$ | = Gas compressibility factor |
| $z_i$ | = Initial gas compressibility factor |
| $\phi$ | = Porosity |
| $\mu$ | = Viscosity |
| $\mu_o$ | = Oil viscosity |

Subscripts

| | |
|---|---|
| g | = Gas phase |
| i | = Initial stage |
| o | = Oil phase |
| sc | = Standard condition |
| w | = Water phase |
| wf | = Wellbore flowing |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

There are three ways of estimating the hydrocarbon GIIP in the reservoir namely the volumetric, material balance and the decline curves analysis. These three methods are independent of each other and when they yield reasonably close results, we have more confidence in the GIIP estimation.

GIIP estimation started back when the oil and gas operator started to plan for the development of the reservoir interested. With all the static data that is obtained from the reservoir, the volumetric GIIP estimation started with the volumetric calculation. Volumetric calculation was the driving force of developing the field when economical and profitable GIIP was reported from the earlier estimate. Volumetric estimation is dependent on the geological, petrophysical and PVT data which were applied at the early stage of the reservoir life. The volumetric method is static in nature and recovery factor is determined arbitrarily.

Material balance has been neglected by most of the engineers when numerical simulation was being introduced to the industry. In fact, material balance has been the root of reservoir studies since it does not require geological models for the analysis. Material balance utilized the production, reservoir pressure and PVT data which were applicable after a while of production where 20% of pressure depletion or 10% of initial fluids produced can be observed. Thus, it is able to calculate the hydrocarbon in place and describe the drive mechanism of the reservoir with sufficient production data and average reservoir pressure decline data. The material balance is dynamic and its recovery factor can then be calculated.

Decline curve analysis was found by Arps in 1940 when he introduced the three declines theory which were the exponential, hyperbolic and harmonic to forecast the recoverable reserves from the plots. The decline prediction was considered empirical with no theoretical basis on that. Since then, the type curves decline analysis have been introduced with dimensionless variables plotted on the semi-log and log-log scale to improve on the empirical solutions introduced by Arps. Rate decline curves analysis utilized declining production data which are applicable at the later stage of reservoir's life when it goes into natural decline in production rate.

Fetkovich and Blasingame type curves have been utilized for estimating the fluids in place for the reservoir by matching the type curves. Other reservoir parameters like the skin, permeability and radius of investigation can be estimated through these type curves matching exercise. With different ways of estimating the GIIP using the material balance equation and the type curves decline analysis matching method, this project will see how each method varies from each other when reporting the volume of hydrocarbon GIIP.

## 1.2 Problem Statement

GIIP estimation is the most important factor which decides all other activities about the reservoir such as budget allocation and decision for investment for development, contracts and etc. Due to geological uncertainties and complexities happening in the subsurface, it has been a challenging task to estimate the GIIP of the reservoir.

There is a need for independent methods to verify the volumetric GIIP estimate and to increase the level of confidence. Volumetric GIIP estimate from volumetric method utilized static data. After some production, other methods become applicable which incorporated the production-pressure data (dynamic). Techniques available are:

i. Material balance
ii. Decline curve analysis

Volumetric estimate is the initial stage of GIIP estimation which rely mainly on the geological and petrophysical inputs of the reservoir is able to provide an estimation to the GIIP. Nonetheless, this method is significant in providing the guidelines for the estimation of the GIIP when there is no production and pressures declining data from the reservoir. Initial estimate must be revised as our knowledge of the reservoir increases.

Material balance analysis can be used to determine the GIIP and drive mechanism from the production and pressure data of the reservoir. However, adequate data collection and a defined average pressure decline trend has to be determined prior to any material balance analysis. Material balance analysis will compute a volume of fluids in place based on the data and is independent of other methods in determining the GIIP.

Type curve decline analysis is a production analysis which is based on constant pressure solution for Fetkovich type curves and constant rate solution for Blasingame type curves. These analyses are able to estimate the fluids in place after matching them on the type curves. This method yields another fluids in place volume which is different from the material balance analysis.

Volumetric, material balance and type curves decline analysis yield different amount of fluids in place in the reservoir. Both methods are independent of each other as both are equally important to evaluate the fluids in place. These three methods will be a powerful tools to justify our GIIP in the reservoir as they should support and validate each other when independent investigations were being employed. When independent methods yield reasonably close results, the confidence in the GIIP estimate is high which help in sound development plan of the field.

## 1.3 Objectives

In completing the project, the following objectives were set to reach the outcome of this project.

i. To estimate gas initially in-place by using the three independent methods from a real field data

There are three ways of estimating the GIIP of a reservoir which were the volumetric, material balance and type curves decline analysis. These three methods which were independent of each other can be used to estimate GIIP depending on the time frame and the data availability of the reservoir.

ii. To compare the variation in the hydrocarbons in place from the initial estimates

During the initial field development plan, the volumetric estimate was made to give an approximation on the GIIP that are present in the reservoir. GIIP estimated by the material balance analysis and type curves decline analysis methods are being used to compare the variation in GIIP estimated by the volumetric method in order to validate the reported GIIP by each method.

iii. To build confidence in the estimates

When the GIIP estimated using the three methods are reasonably close to each another, then the level of confidence in reporting the numbers are higher. On the other hand, when these three methods do not converged to one another, then a recommended plan will be made to justify the reason for the differences which exist.

## 1.4 Scope of Study

The scope of study reflects the constraints which were imposed on this project to keep the study on track during the period of research. In this project, the following scopes were being listed as part of the limitations.

i. Volumetric: Deterministic method

In estimating volumetric hydrocarbons in place, there are namely two methods which are the volumetric and probabilistic methods. In this project, only volumetric method is being considered for simplification purposes when comparing with a single value. In deterministic estimation, only single value of the estimate is being produced to represent the whole reservoir instead of a range of values used by probabilistic methods. Due to the data availability, only deterministic calculation can be carried out in this project.

ii. Material balance: Flowing material balance

Flowing material balance is an alternative to the classical material balance when the reservoir pressure data are not available. As the wellhead pressure data are available in this study, the flowing material balance has been employed to estimate the GIIP. Therefore, flowing material balance technique will be used for this project when material balance method is concerned.

iii. 2 decline curve analysis techniques: Fetkovich & Blasingame type curves

The reservoir that is studied has to be of declining in production trend in order to carry out the type curves decline analysis. There are many decline type curves analysis available for example the Arps and the Agarwal-Gardner type curves. However, this project is constrained to advanced decline curve analysis rather than the conventional Arps decline. The software’s limitation in performing the decline curve analysis has also prevented the use of Argarwal-Gardner decline curve analysis in this project.

iv. Real data from gas field A

The data of this project utilised real field data from a gas field to increase the confidence of the results obtained in this project. Instead of using virtual data for studying purposes, the real field data can provide us an insight into the behavior and connectivity of the reservoir. This real data should prove, validate and support the findings of the project if questions were to be asked on the validity of this project.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Volumetric

Ogbalor *et al*. (2013) in their studies defined deterministic as a method which estimated fluids in place by using a single value for every variable in Equation 1 and the resulting volume was then acquired. They described deterministic as some times over-predicting and under-predicting the volumes as the input parameters may contain uncertainties which affected the accuracy of reserves calculations.

Araujo & Rattia (2011) illustrated that volumetric estimate was a static method which was utilised at the early stages of development plan when reservoir contained insufficient production data and no clear information on how the reservoir will go into decline and depletion. Deterministic volumetric method could be computed based on three categories which were the low, most likely and high cases when comparing with probabilistic method.(Karra *et al*., 1995)They added that deterministic estimation played a vital role in reserves estimation during the exploration, pre-development and development phase of a reservoir.

Karacaer & Onur (2012) discussed that the uncertainties in the volumetric method for estimating hydrocarbon in place were due to the insufficient information in the variables present in the volumetric formula in Equation 1 and it could be demonstrated by the method of analytical uncertainty propagation (AUPM) where the uncertainty of each variable is exhibited.

$$\text{HIIP} = \frac{\text{GRV} \times \text{NTG} \times \phi \times S_{\text{h}}}{b} \quad \text{(Equation 1)}$$

According to Worthington (2005), the uncertainties in the volumetric calculation were prioritized from the greatest which were the gross volume of the rock, geophysics seismic analysis, procedure of converting depth, free water level determination and the net-to-gross value. Volumetric could be evaluated by either deterministically or probabilistically where two methods have different approaches.

Holtz (1993) in his work introduced the RVP method which represented quantify reserve variability potential to reduce the gap between deterministic and probabilistic method using the probability distribution function from these two methods with more confidence where geological uncertainties existed.

## 2.2 Material Balance

Material balance could be utilized to determine the volume of fluids in place and the drive mechanism with the presence of the average reservoir pressure in a reducing pattern, production and the PVT data. (Dake, 2001) The fundamentals concept involving the volumetric material balance was the volume of fluids production was equivalent to the sum of the reservoir expansion in the system and the summation of water influx. The material balance equation accounted for the increment in the oil column (total difference in volume), increment in gas cap size, connate water effect, reservoir rock pore compaction and the water influx which yielded the general equation stated as below:

$$N_p\left[B_o + (R_p - R_s)B_g\right] + W_p B_w = N\left[(B_o - B_{oi}) + (R_{si} - R_s)B_g\right] + mNB_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) + \frac{(1+m)NB_{oi}(c_w S_w + c_f)\Delta P}{1 - S_{wc}} + W_e B_w \quad \text{(Equation 2)}$$

Havlena & Odeh (1963) discussed the straight line methods which plotted the parameters of the material balance equation. The methods were able to determine the fluids in place and the drives of the reservoir according to the parameters plotted on the axes.

In a gas reservoir, material balance equation predicted the gas initially in place (GIIP) from the declining reservoir pressure data, evaluated the presence and efficiency of the water drive mechanism and forecasted the performance of the reservoir. (Ikoku, 1984) Besides, this method could validate the GIIP calculated by the volumetric equation. Material balance method offered an independent inspection on the volumetric method. The material balance equation for gas is as shown

$$\frac{p}{z} = -\left(\frac{p_i}{z_i}\frac{1}{G}\right)G_p + \frac{p_i}{z_i} \quad \text{(Equation 3)}$$

Equation 3 above assume only gas expansion as the only drive of the reservoir with no external pressure maintenance into the system which yielded a linear relationship of $p/z$ versus cumulative production.

Mattar & McNeil (1998) expressed the flowing material balance which was based on flowing bottom-hole pressure as oppose to shut-in average reservoir pressure used in classical material balance. A straight line drawn parallel to the flowing bottom hole pressure data intercepted with the initial reservoir pressure on the y-axis could also provide an estimate on the gas-initially-in-place (GIIP). In addition to the flowing pressure, wellhead pressure data like the tubing head pressure and the casing pressure could also yield the gas in place estimation but the parallel line has to intercept the initial wellhead pressure data instead of initial reservoir pressure.

## 2.3 Fetkovich Type Curve

Fetkovich (1980) in his study discussed that analytical constant-pressure solution and the empirical rate-time equations by Arps (exponential, hyperbolic and harmonic decline) could be fitted into a log-log plot of dimensionless variables. The dimensionless analytical rate, $q_{Dd}$ against dimensionless time, $t_{Dd}$ by (Fetkovich, 1980) are shown in the equations below.

$$t_{\mathrm{Dd}} = \frac{t_{\mathrm{D}}}{\frac{1}{2}\left[\left(\frac{r_{\mathrm{e}}}{r_{\mathrm{w}}}\right)^{2} - 1\right]\left[ln\frac{r_{\mathrm{e}}}{r_{\mathrm{w}}} - \frac{1}{2}\right]} \text{ ..........(Equation 4)}$$

$$q_{\mathrm{Dd}} = \frac{q(t)}{q_{\mathrm{i}}} = q_{\mathrm{D}}\left[ln\frac{r_{\mathrm{e}}}{r_{\mathrm{w}}} - \frac{1}{2}\right] \text{ ..........(Equation 5)}$$

While the empirical rate-time equation introduced by Asps (1945) based on production data of 149 oil fields are as shown:

For $b = 0$,

$$q_{\mathrm{Dd}} = \frac{q(t)}{q_{\mathrm{i}}} = \frac{1}{e^{D_{\mathrm{i}}t}} \text{ ..........(Equation 6)}$$

For $b > 0$,

$$q_{\mathrm{Dd}} = \frac{q(t)}{q_{\mathrm{i}}} = \frac{1}{[1 + bD_{\mathrm{i}}t]^{1/b}} \text{ ..........(Equation 7)}$$

$$t_{\mathrm{Dd}} = D_{\mathrm{i}}t \text{ ..........(Equation 8)}$$

Figure 6.1 takes into account of the analytical and empirical solutions of a series of type curves. Fetkovich *et al*. (1996) discussed in their studies that there were two periods which existed in the composite log-log type curve of Fetkovich which was the transient period and the depletion period. To the left of $t_{\mathrm{D}} = 0.3$, transient period could be used to match the production data for determining the reservoir parameters like skin, s and kh. On the other hand, the depletion period (to the right of $t_{\mathrm{D}} = 0.3$) could be used for determining the hydrocarbon in place.

Fetkovich *et al*. (1987) in their studies elaborated on the techniques of computing the hydrocarbon in place using the following equations:

$$V_{\mathrm{p}} = \pi r_{\mathrm{e}}^{2} h\phi = \left[ \frac{2000 p_{\mathrm{sc}} T}{(\mu c_{\mathrm{t}})_{\mathrm{i}} T_{\mathrm{sc}} (p_{\mathrm{pi}} - p_{\mathrm{wf}})} \right] \left( \frac{t}{t_{\mathrm{dD}}} \right) \left[ \frac{q(t)}{q_{\mathrm{dD}}} \right] \text{..........................(Equation 9)}$$

$$G = V_{\mathrm{p}} (1 - S_{\mathrm{w}}) B_{\mathrm{g}} \text{.........................................................(Equation 10)}$$

$$V_{\mathrm{pF}} = \left[ \frac{(\overline{\mu_{\mathrm{o}} B_{\mathrm{o}}})}{(\mu c_{\mathrm{t}})_{\mathrm{i}} (p_{\mathrm{pi}} - p_{\mathrm{wf}})} \right] \left( \frac{t}{t_{\mathrm{dD}}} \right) \left[ \frac{q(t)}{q_{\mathrm{dD}}} \right] \text{......................................(Equation 11)}$$

$$N = \frac{V_{\mathrm{pF}} (1 - S_{\mathrm{w}})}{B_{\mathrm{o}}} \text{..........................................................(Equation 12)}$$

## 2.4 Blasingame Type Curve

To overcome the limitations of Fetkovich type curve using a constant pressure solution, Blasingame has been able to solve the changing gas properties with pressure and used material balance time which produced result of a constant rate solution in Figure 6.2. (Palacio & Blasingame, 1993) The graph contained the transient flow region at the initial stage of the plot and a harmonic decline curve pattern in the later stage which was used to produce analytical solutions. Besides, it used the concept of normalized rate, rate integral and rate integral derivative on the McCray type curve as shown in the following equations:

$$\frac{q}{\Delta P} \text{.......................................................................(Equation 13)}$$

$$\left( \frac{q}{\Delta P} \right)_{\mathrm{i}} = \frac{1}{t_{\mathrm{c}}} \int_{0}^{t_{\mathrm{c}}} \frac{q}{\Delta P} dt \text{......................................................(Equation 14)}$$

$$\left( \frac{q}{\Delta P} \right)_{\mathrm{id}} = t_{\mathrm{c}} \frac{d \left( \frac{q}{\Delta P} \right)_{\mathrm{i}}}{dt_{\mathrm{c}}} \text{......................................................(Equation 15)}$$

To calculate the fluids in place for oil or gas, the following equations were incorporated:

$$N = \frac{1}{c_{\mathrm{t}}}\left[\frac{t_{\mathrm{e}}}{t_{\mathrm{Dd}}}\right]_{\mathrm{MP}}\left[\frac{\frac{q}{\Delta P}}{q_{\mathrm{Dd}}}\right]_{\mathrm{MP}} \quad \text{(Equation 16)}$$

$$G = \frac{2p_{\mathrm{i}}}{(z\mu c_{\mathrm{t}})_{\mathrm{i}}}\left[\frac{t_{\mathrm{e}}}{t_{\mathrm{Dd}}}\right]_{\mathrm{MP}}\left[\frac{\frac{q}{\Delta P_{\mathrm{p}}}}{q_{\mathrm{Dd}}}\right]_{\mathrm{MP}} \quad \text{(Equation 17)}$$

In the case of inconsistent rate and pressure drop monitored during production, Blasingame *et al*. (1991) method could be employed to solve the problems using the boundary dominated flow method to obtain the constant pressure from the constant rate as a function of analog time.

# CHAPTER 3

# METHODOLOGY

## 3.1 Research Methodology

In completing this project, the following steps were incorporated to achieve the result of this project:

i. Data gathering for a period of five years from Field A

Firstly, in computing the volumetric GIIP estimation, the following data were collected:

a) Gross rock volume
b) Net-to-gross
c) Porosity
d) Water saturation
e) Oil saturation
f) PVT data
g) Initial pressure

For the material balance analysis the following data were collected for a period of five years:

a) Field production history (rate vs time)
b) Average reservoir pressure
c) PVT data

While the decline analysis data collected for a period of 5 years were as followed:

a) Field production history (rate vs time)
b) Wellhead pressure
c) PVT

The period of data collection for material balance and decline analysis might be different as long as the duration of the data is five years long.

ii. Screening of data if material balance and decline analysis were applicable

For the material balance analysis, the pressure data has to be in declining trend in order for the material balance analysis to work. Whilst for the decline analysis method, the production of the field has to be in natural decline. The raw data collected has to be filtered and screened to confirm if the pressure and production data were undergoing a declining trend. This was why screening the data was important because the pre-requisite of both methods have to be met before these two methods could be used to estimate the fluids in place.

iii. Volumetric calculation of Field A

The volumetric estimate of Field A was calculated using the Equation 1 which utilized all the data collected for volumetric calculation. It could be done in the Microsoft® Excel by importing all the important parameters of volumetric calculation and be computed.

iv. Application of material balance to evaluate fluids in place (N)

The material balance of Field A was done by plotting the $p/z$ against cumulative gas production on the Microsoft® Excel to estimate gas-initially-in-place (GIIP). The intercept of the straight line plot on the x-axis will give the estimation of GIIP of the reservoir.

v. Determination of fluids in place (N) from type curves decline analysis

The type curves decline analysis was done by loading the required data into the commercial software, Topaze and then, plotted the Fetkovich and Blasingame decline curve in the software. Matching exercise was required for both analyses to come out with a matched gas initially in place estimation.

vi. Compare the difference in the GIIP and analyze the data

The GIIP estimated by the three independent methods were being tabulated into the Microsoft® Excel and computed for the percentage differences between the three methods. The percentage differences were being studied whether these three methods were reasonably small or vice versa.

vii. Validate the fluids in place determined

If the three methods did not converge to each other, the reason which caused the disparity in the GIIP reported will be studied and analyzed. The final resolution to these findings will be pointed out by making recommendations on the possibility of these differences. If the three methods gave reasonably close reading, then the confidence of initial estimate is high and further improvements will be made in the recommendations.

## 3.2 Key Milestone

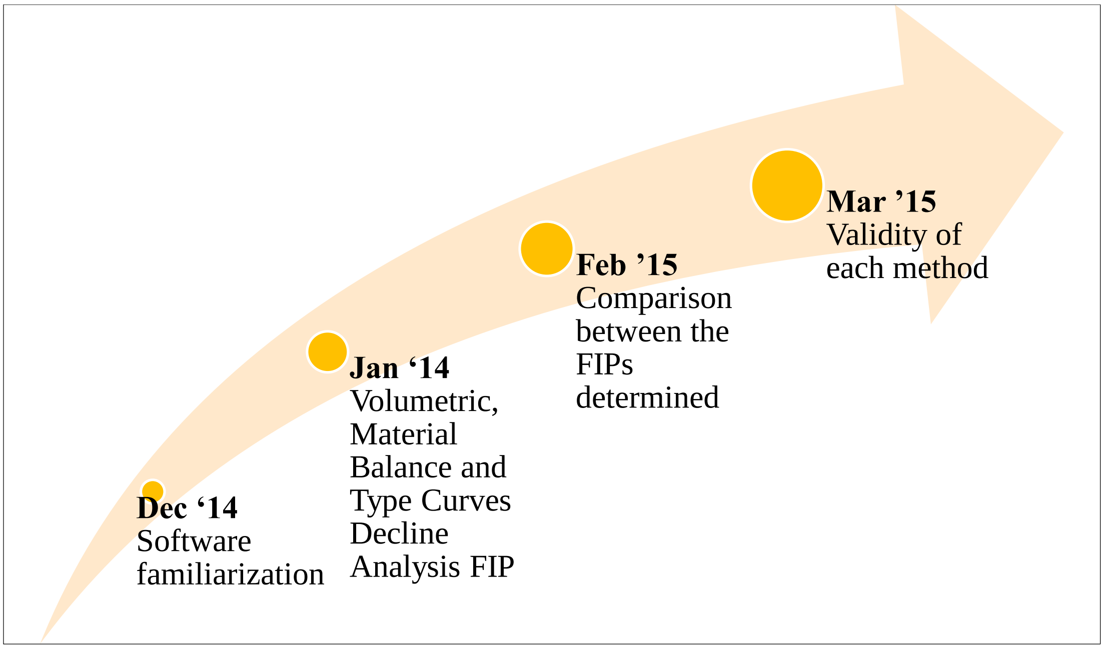


Figure 3.1: Key Milestone

## 3.3 Gantt Chart

Table 1: Gantt Chart of Final Year Project I

| Final Year Project I | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task \ Week** | **W1** | **W2** | **W3** | **W4** | **W5** | **W6** | **W7** | **W8** | **W9** | **W10** | **W11** | **W12** | **W13** | **W14** |
| Selection of project topic | | | | | | | | | | | | | | |
| Literature review findings | | | | | | | | | | | | | | |
| Extended Proposal preparation | | | | | | | | | | | | | | |
| Reservoir data (PVT, production, pressure) gathering | | | | | | | | | | | | | | |
| Proposal defense | | | | | | | | | | | | | | |
| Software Familiarization | | | | | | | | | | | | | | |
| Interim Draft Report preparation | | | | | | | | | | | | | | |
| Draft Report preparation | | | | | | | | | | | | | | |

Table 2: Gantt Chart of Final Year Project II

| Final Year Project II | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task \ Week** | **W1** | **W2** | **W3** | **W4** | **W5** | **W6** | **W7** | **W8** | **W9** | **W10** | **W11** | **W12** | **W13** | **W14** |
| Type Curves Analysis: Determination of fluids in place | | | | | | | | | | | | | | |
| Volumetric analysis: Determination of fluids in place | | | | | | | | | | | | | | |
| Material balance analysis: Determination of fluids in place | | | | | | | | | | | | | | |
| Comparison and validate the fluid in place volume between three methods | | | | | | | | | | | | | | |
| Progress report preparation | | | | | | | | | | | | | | |
| Pre-SEDEX preparation | | | | | | | | | | | | | | |
| Draft report | | | | | | | | | | | | | | |
| Dissertation | | | | | | | | | | | | | | |
| Technical paper | | | | | | | | | | | | | | |
| Oral presentation | | | | | | | | | | | | | | |

## 3.4 Software Required

The following software were vital in completing the project:

1. Microsoft® Office

It is considered one of the basic requirement for the project as preparation of reports is an important part of the project requirements. Microsoft® Word serves the purpose of documenting all the pertinent resources into the report. Nevertheless, Microsoft® Excel is significant in computing the mathematical equations of the material balance and plotting the results into the graphs. Excel will be an excellent tool to evaluate the fluids in place based on the production, PVT and pressure data.

2. Ecrin Topaze or equivalent

Topaze is the software endorsed by many oil and gas industry in carrying out their Production Analysis (PA) or also known as Production Decline Analysis. In this project, Topaze will operate as a platform for the type curves analyses namely the Fetkovich type curves and Blasingame type curves. It is a significant tool for the decline curve analysis part of this project.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Results

### 4.1.1 Volumetric

The reservoir parameters of gas field A are as shown in Table 3 and determinisitic calculation can be determined from the equation below.

$$\text{GIIP} = 43560 Ah\phi(1 - S_{wi})\frac{1}{B_{gi}} \text{ .............................................(Equation 18)}$$

Table 3: Volumetric Reservoir Parameters

| Parameters | Unit | Value |
|---|---|---|
| Area, $A$ | acre | 3249 |
| Thickness, $h$ | ft | 280.4 |
| Porosity, $\phi$ | | 0.17 |
| Gas Saturation, $S_g$ | | 0.73 |
| Gas formation volume factor, $B_g$ | cu ft/scf | 0.00445 |
| Net-to-gross, NTG | | 0.573 |
| Gas-initially-in-place, GIIP | scf | 6.341E+11 |
| Gas-initially-in-place, GIIP | Bcf | 634.1 |

From the calculation of deterministic GIIP, the resulting estimates was 634.1 BCF. This showed the intial estimate of the reservoir when volumetric method was applicable at the early life of the reservoir. As observed, the deterministic estimation utilised a single value for every parameters required to produce a single value of GIIP estimate. This GIIP estimate was a valuable information as we were able to quantify the volumes of gas present in the reservoir.

### 4.1.2 Material Balance

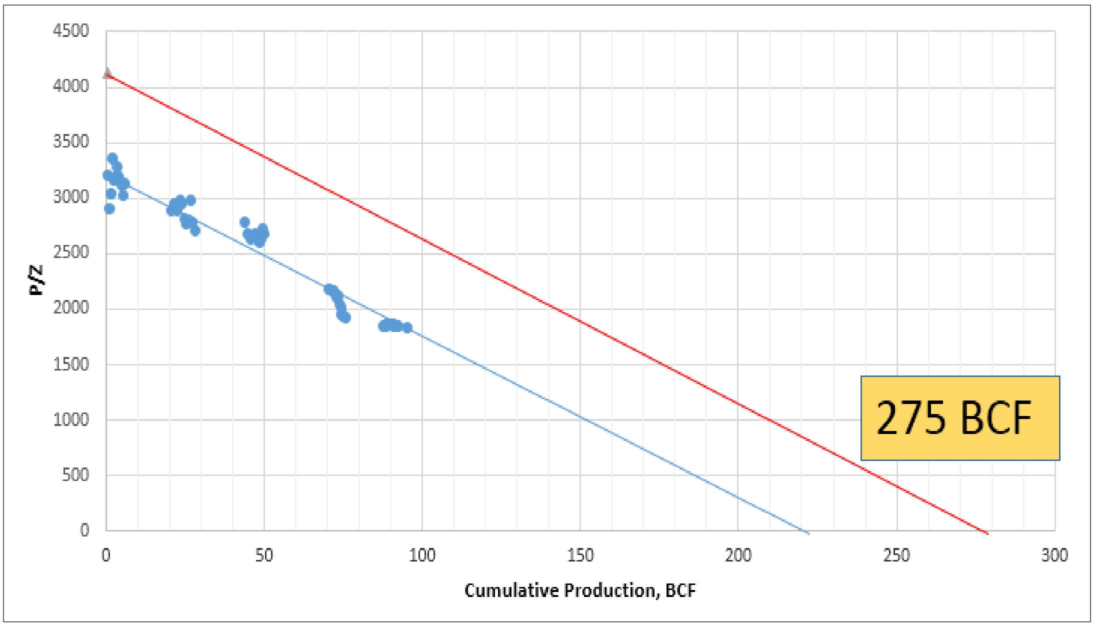


Figure 4.1: Flowing Material Balance of Well A

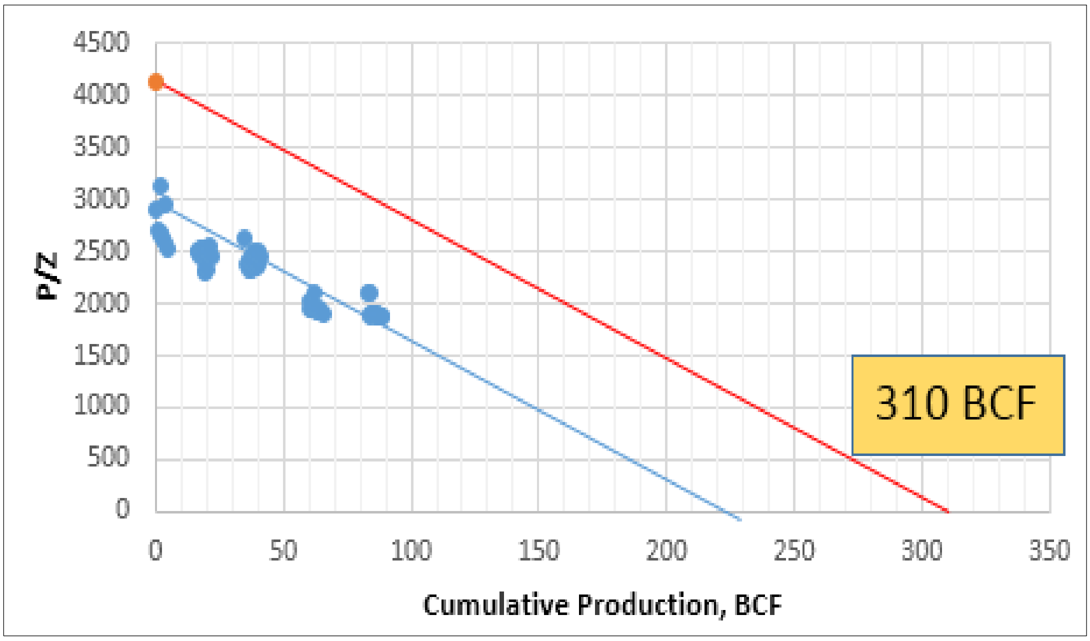


Figure 4.2: Flowing Material Balance of Well B

The flowing material balance is used in the absence of the shut-in reservoir pressure data in this project. Therefore, classical material balance ( $p/z$ vs cumulative production) could not be used as only flowing wellhead pressure data are available. Flowing material balance was conducted on two wells (Well A and B) and it appeared that summation of both GIIP were close to the initial estimate of volumetric deterministic method determined earlier. The GIIP estimated by Well A was 275 BCF while Well B estimated 310 BCF as shown in Figure 4.1 and Figure 4.2. The summation of both GIIPs added up to a total 585 BCF.

### 4.1.3 Decline Curve Analysis: Fetkovich Plot

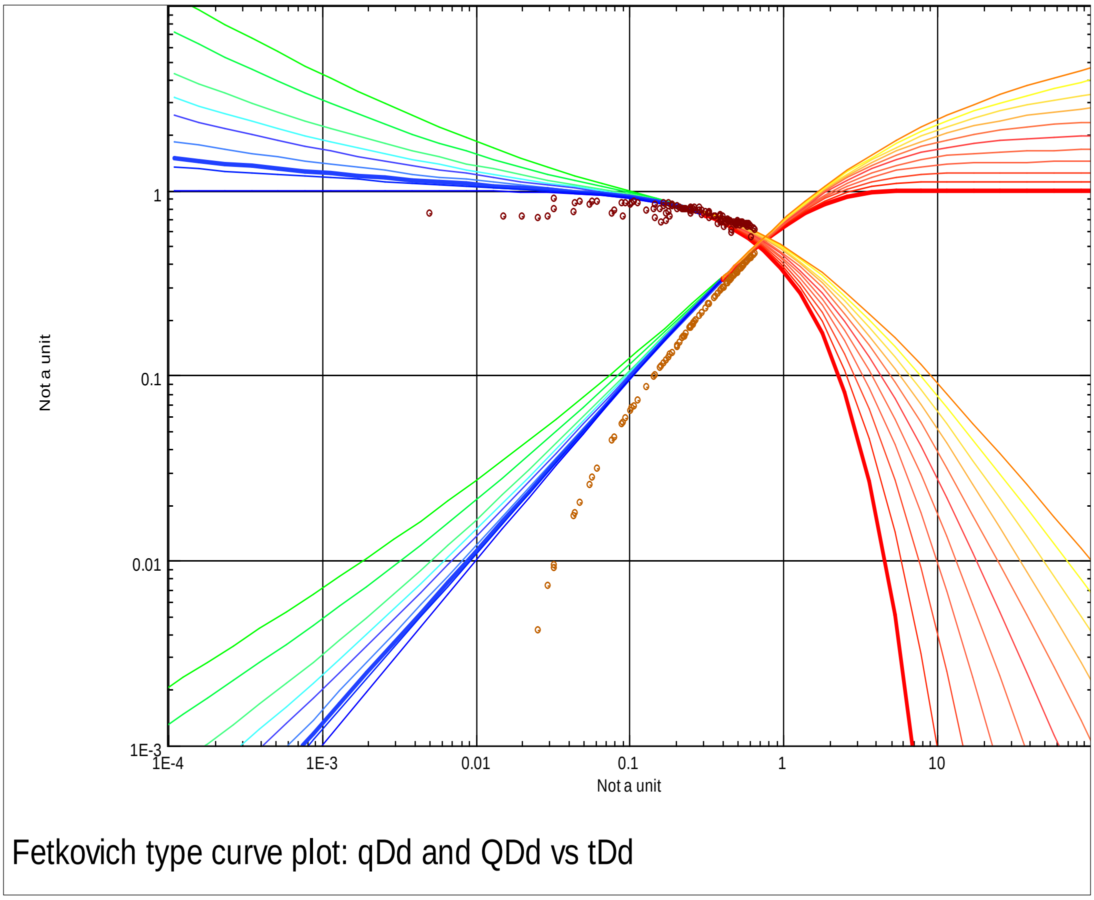


Figure 4.3: Fetkovich Plot of Field A

The Fetkovich type curve matched the dimensionless rate, dimensionless cumulative production and dimensionless time from the historical production data input. Fetkovich type curve provided an independent estimates of the GIIP by matching the above parameters. The result of the matching from Figure 4.3 yielded an estimate GIIP of 567 BCF.

### 4.1.4 Decline Curve Analysis: Blasingame Plot

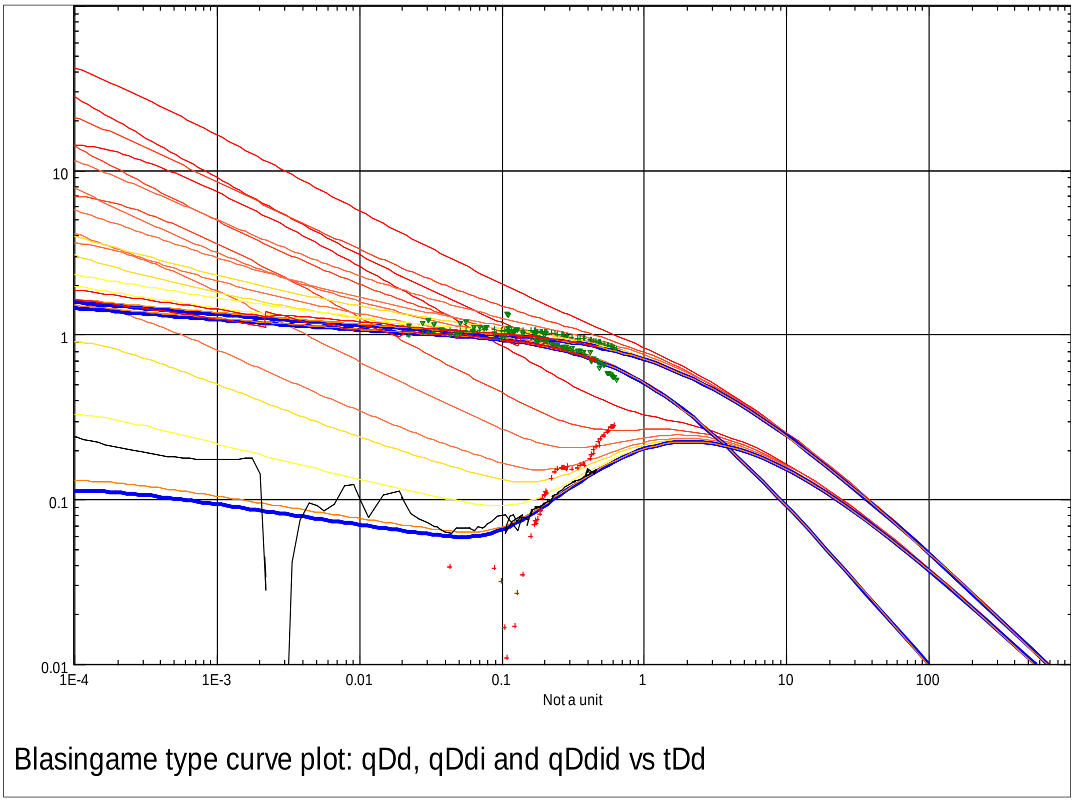


Figure 4.4: Blasingame Plot of Field A

Blasingame type curve is an independent analysis of GIIP estimation which provides a standalone gas in place. Three parameters were being matched as shown in Figure 4.4 in order to get a good estimation of the GIIP. The lines were being dragged to match with the points on the log-log plot of Blasingame. The matching of rate integral, rate and rate integral derivative on the Blasingame plot gave an estimate GIIP of 557 BCF.

### 4.1.5 Decline Curve Analysis: Production History Plot

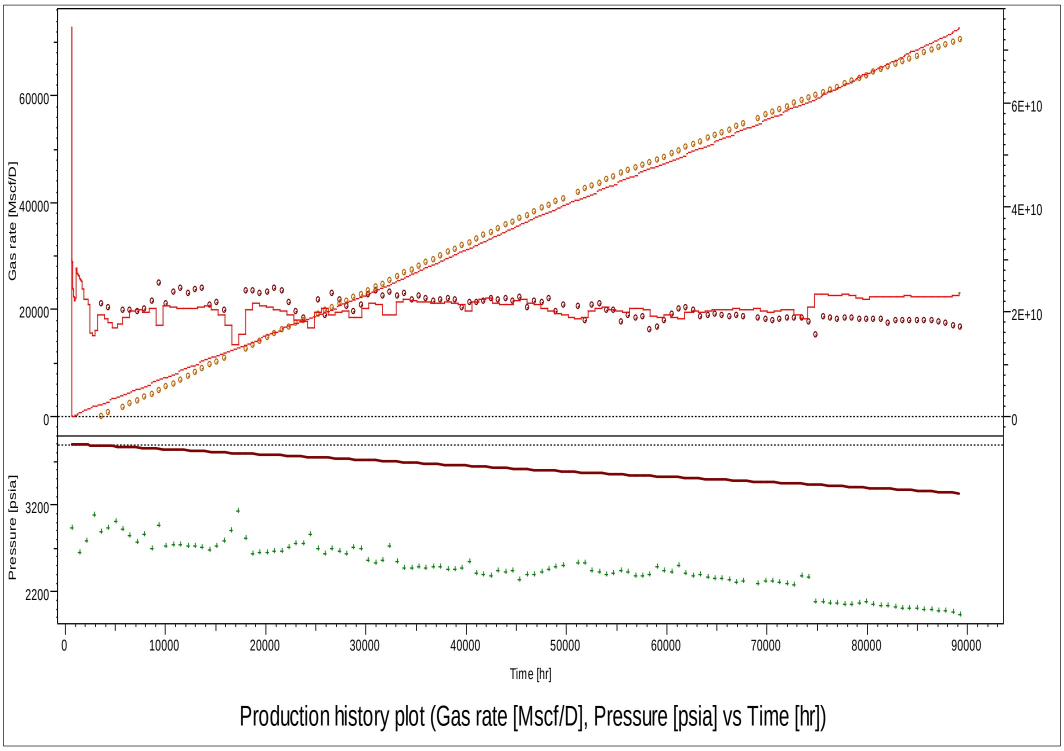


Figure 4.5: Production History Plot

After matching the Blasingame and Fetkovich plot, a simulated model was then being generated on the production history plot as shown in Figure 4.5. In Figure 4.5, the simulated model were being matched with the rate and cumulative volume from Field A. Below the production history plot was the pressure plot which was in line with the production data. No matching on the pressure plot was required. The matching of the simulated model with production history gave us a higher confidence on the GIIP estimated. The result of the simulated production history plot estimated GIIP of 593 BCF of gas.

## 4.2 Discussion

### 4.2.1 Quality of Data

The data for volumetric calculation was obtained during the development stage of Field A and it is static in nature. It was used to compute the deterministic estimation from the formula given in Equation 18. The reliability of these data depended on the early development (geological & geophysical) stages where data were acquired through logs and seismic activities. However, it would need to be validated with decline curve analysis and material balance to show that these data obtained from the geological and geophysical phase were reliable enough.

From Figure 4.1 and Figure 4.2, noise could be observed in the $p/z$ plots as not every data could be fitted on the straight line. The noise observed could not be prevented in any real field applications as operators will have regular well's intervention activities like sand clean-out, well's recompletion, wellhead maintenance and etc. when required. These activities were the main contributing factor for creating the noise which existed along the straight line of the $p/z$ plots.

In Figure 4.4 and Figure 4.3, the noise existed in the plots were due to the same reason as explained earlier before. By using these real field data, we will be expecting these kind of noises in our plots and it can hardly be prevented.

### 4.2.2 Quality of Match

The matching of flowing material balance in Figure 4.1 and Figure 4.2 were considered satisfactory as most of the data could be fitted onto the straight line. Even though there were some noise which exist along the production from both wells, the straight line were able to intercept most of the data and provided a conservative estimation GIIP.
In Figure 4.4, the matching of the data on the Blasingame type curve was considered satisfactory as the normalized rate and rate integral could be matched directly on the type curve. However, it could be observed that the rate integral derivative could not be match directly on the type curve stem. This is the drawback of the integral derivative

plot because noise will be existing in the derivative plot which was inherited from the pressure and production data.

The matching of data in Figure 4.3 was satisfactory as the dimensionless rate data and dimensionless cumulative production could not be match on the type curves at the early time. This was because the reservoir has not depleted much or there is improvement in the reservoir productivity. The improvement in the productivity has led to a slower decline in the rate and also led to some improvement in the production rates. Therefore, the data could not be matched on the type curves at early times. After some production (late time) as observed in the matching, the data could be matched with the type curves. The successful matching of the end data was due to the reservoir natural depletion which enable decline type curve analysis to be made accurately.

### 4.2.3 Uncertainties

Uncertainties existed when carrying out the flowing material balance analysis and the matching of the type curves decline curve analysis. In flowing material balance analysis, the uncertainties existed when there were distribution of noise which existed in the plot. The problem will be matching the $p/z$ data on the straight line of material balance. In doing the material balance, the straight line has to intercept the $p/z$ data as much as it could on the plot to give the best fit and the most accurate prediction of GIIP. Otherwise, poor decision on the straight line interception will result in optimistic or conservative GIIP estimation.

On the other hand, the type curve matching of Fetkovich and Blasingame was very subjective to slight changes in the matching process. A slight changes in the matching will result in different GIIP estimation. Therefore, in the process of matching Fetkovich type curve, the strategy is to match the end point data as observed in Figure 4.3. If the end point data could be match perfectly on to the type curve, then the matching process is considered successful. While Blasingame matching process prioritized on the matching the normalized rate and rate integral parameters on the type curves. Given that, both parameters could be matched on the type curves in Figure 4.4, the confidence level in the GIIP estimation is higher.

Referring to Table 4, a sensitivity analysis was run on the flowing material balance, Fetkovich type curve and Blasingame type curve GIIP estimation. A tolerance of 10% was set to account for the uncertainties which might exist during the matching process. This 10% sensitivity was calculated based on the base case for each method. The base case of each method was determined earlier in the matching process of type curves and material balance analysis.

Table 4: Sensitivity Analysis

| Sensitivity | Flowing Material Balance | Decline Curve Analysis | |
|---|---|---|---|
| | $p/z$ plot | Fetkovich type curve | Blasingame type curve |
| Base Case | 585 | 567 | 557 |
| + 10% | 644 | 624 | 613 |
| - 10% | 527 | 510 | 501 |

### 4.2.4 Comparison between Three Methods

The GIIP estimation by three methods volumetric, flowing material balance and decline curve analysis are tabulated in Table 5.

Table 5: GIIP Comparison between Three Methods

| Comparison | Methods | | | |
|---|---|---|---|---|
| | Volumetric | Flowing Material Balance | Decline Curve Analysis | |
| | Deterministic | $p/z$ plot | Fetkovich type curve | Blasingame type curve |
| GIIP (BCF) | 634 | 585 | 567 | 557 |
| Percentage Difference (%) | - | 7 | 11 | 12 |

The percentage difference of different methods was calculated based on volumetric deterministic estimation. Therefore, there will be no percentage difference computed for volumetric estimation. As shown in Table 5, the difference between $p/z$ plot and deterministic calculation was only 7% while Fetkovich and Blasingame type curves gave a difference of 11% and 12% respectively. We could say that $p/z$ plot gave a very close estimate to the volumetric method. Nevertheless, Fetkovich and Blasingame estimated a close result too with the volumetric estimates. Overall, the percentage difference for each method was less than 14% of the initial estimate which was considered good for validating the volumetric GIIP.

When the percentage difference for these three methods were less than 14%, the results were considered reasonably close to each other. We could justify that the amount of GIIP in the reservoir fell within the range **557 BCF** to **634.1 BCF**. The findings of these estimations have shown the importance of implementing these three independent methods to calculate the hydrocarbon in place in the reservoir as these three methods were able to validate each other. Thus, the GIIP of Field A could finally be justified after calculating with the three methods mentioned.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

Real field data has been used to test the three independent methods of estimating the GIIP in this project. We can conclude that the GIIP estimated were reasonably close to each another with 634 BCF, 585 BCF, 567 BCF and 557 BCF of gas estimated from volumetric, material balance, Fetkovich type curve and Blasingame type curve respectively. The results were within the limits of 14% percentage difference from the volumetric methods where 7% for material balance, 11 % for Fetkovich type curve and 12% for the Blasingame type curve. The percentage difference of these three independent methods show significant findings as we have more confidence in the initial estimate of the GIIP. The results of these findings showed the importance of these three independent methods in order to validate the early estimate of the GIIP.

## 5.2 Recommendation

This project could be better improved by the following recommendations:

i. Applying same methodology to other gas fields

In the interest of proving and validating the findings of this study, applying the same methodology to other gas fields could prove whether the methodology of this project works perfectly with other gas fields as well. By then, the effectiveness of these methodology can then be further justified by the outcome of the results if it produces similar results.

ii. Conduct pressure surveys and build-up test on a regular basis

There were no shut-in reservoir pressure data in this project which restricted the use of classical material balance. Conducting the pressure surveys and build-up test to obtain the shut-in pressure could allow the use of classical material balance to be conducted. Besides, obtaining shut-in pressure on a regular basis is a good practice for the operators for reservoir pressure monitoring and to check on depletion of the reservoir.

iii. Conduct classical material balance

Flowing material balance was conducted in this project in the absence of shut-in reservoir pressure data. For comparison and validating purposes, classical material balance is another tool to justify the findings of the flowing material balance. From the classical material balance, hydrocarbon estimation can be made directly from the interception of the straight line on the cumulative production axis.

iv. Study on the reservoir compartments and connectivity

If the well is only producing from one compartment, the result estimated using the material balance will differ from the volumetric estimate. Therefore, it was suggested that seismic data was being taken into account to study the geological trap and structure of the reservoir for further understanding. Besides, the connectivity of the reservoir has to be further understood by monitoring the pressure depletion of different wells.

v. Reservoir Simulation Method

Estimates the hydrocarbon in place by using the reservoir simulation method which is independent from these three methods. Reservoir simulation is another powerful tool which can estimate the fluids in place and simulate the fluids flow in the reservoir. If this method brings an estimate which is close to the earlier estimate, then the level of confidence is higher.

vi. Apply these techniques to do forecasting and compared with the simulated results

To further continue this project, the production analysis/ rate-transient analysis software is able to conduct forecasting based on the rate and pressure data that is input. This forecasted results could provide a valuable piece of information regarding the performance of the reservoir. Then, this result could then be compared with reservoir simulation result to see if there are any major differences.

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# APPENDICES

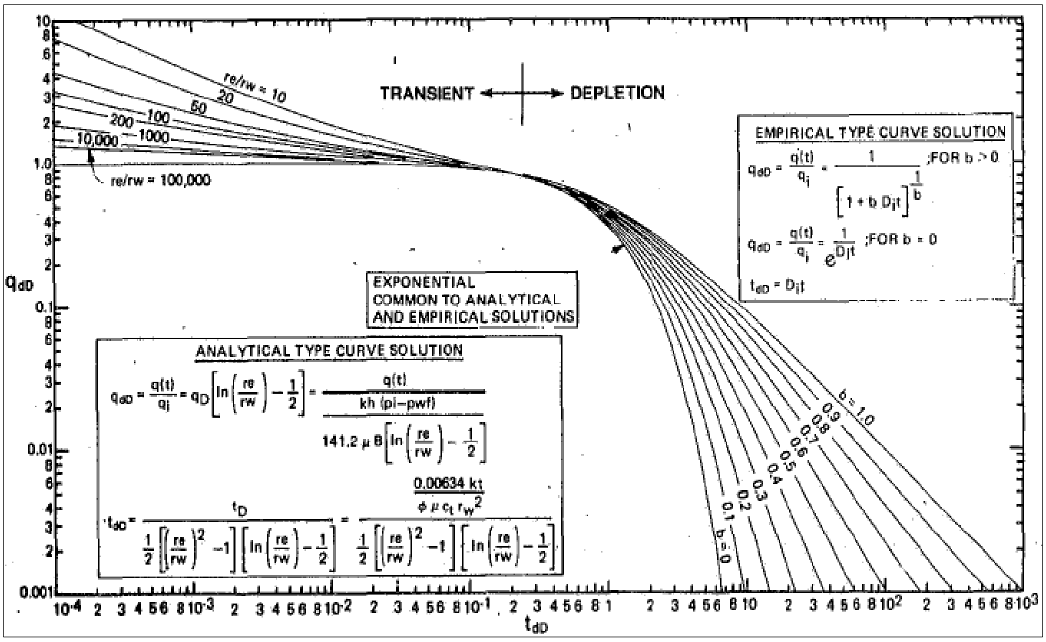


Figure 6.1: Fetkovich Plot (Fetkovich, 1980)

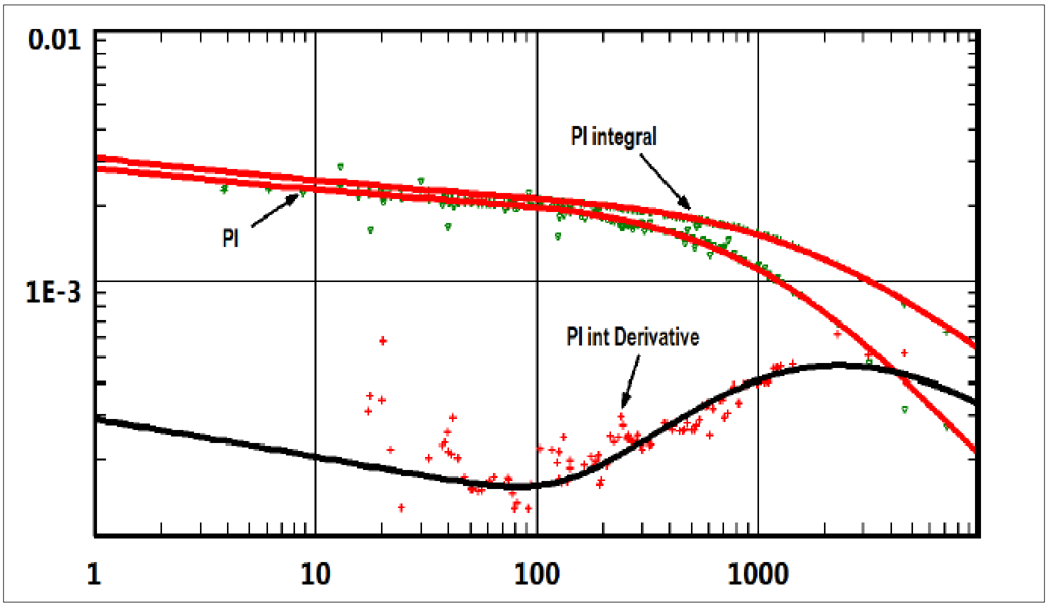


Figure 6.2: Blasingame Plot (Palacio & Blasingame, 1993)