PROCEEDINGS
JOINT CONVENTION BANDUNG (JCB) 2021
November 23rd – 25th 2021

ANALYZE THE POTENTIAL OF OFFSHORE TIGHT GAS CARBONATE RESERVOIR USING MULTI LAYER RATE TRASIENT ANALYSIS

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Abstract

X field is an offshore gas field located in North of Bali. X field is currently developed by 1 subsea deviated well with open hole gravel pack and consist of two reservoir layers. Based on static model, this reservoir has OGIP ratio of around 59% in Layer A and 41% in Layer B and now has recovered 8.6 % of total OGIP. Layer A is known as tight carbonate reservoir with net pay 98–103 ft, and based on core data permeability ranging from 0.2–30 md, meanwhile layer B has better quality of reservoir properties with net pay 53-75 ft, and permeability ranging from 27–1066 md. DST result from exploration well Z-1 indicated that there is small flow from layer A. However, since well Z-1 is commingled, it is difficult to estimate the contribution of each layer properly.

To analyze the gas potential of this tight reservoir layer, Rate Transient Analysis (RTA) is applied in this study. By using this method, production data can be utilized to get estimates of OGIP, production allocation and reservoir properties (skin and permeability) for each layer. Various RTA techniques are used as a default workflow which are Flowing Material Balance, Type-curve analysis, and History matching at multi-well multi-layer model. Result from this study will be used for further development plan of X field.

Keywords: Multilayer Reservoir, Rate Transient Analysis, Tight Gas Reservoir, Flowing Material Balance.

Introduction

X Field was discovered in 1991, approximately 210 miles east of Surabaya and 87 miles north of Bali. It was discovered in 1991 by the drilling of Z exploration well which discovered gas in Paciran Carbonate. A second well, Z-1 was drilled in 2018 as a development well.

Z-1 is deviated subsea commingle well completed with Open Hole Gravel Pack System consist of reservoir layer A and B that produced dry gas. Based on current static model this reservoir has Original Gas in Place (OGIP) ratio of around 59% in Layer A and 41% in Layer B and now has recovered 8.6 % of total OGIP.

Data and Method

Concept of Modern Production Analysis

Modern production analysis method adapted in this study was introduced by Mattar and Anderson (2003) which is known later as Rate Transient Analysis (RTA). Equation behind RTA are combining static material balance with Darcy's flow equation which have same concept of diffusivity equation to perform material balance calculation from production data. This could maximize the utilization of rate and flowing pressure in during reservoir surveillance.

The workflow' employs the method of Flowing Material Balance (FMB), Type curve analysis, and concluded with multilayer model. Through FMB analysis, current connected HC in-place estimation, productivity index, well drainage areas, reservoir pressure trend, and reservoir/well condition can be monitored by flowing production data. Since FMB requires no shut-in pressure data, reservoir performance can also be monitored periodically without shutting the well. To confirm the result from FMB, Type Curve Analysis is conducted to get the dynamic properties of the reservoir such as current permeability, skin, and to identify the flow regime whether it is boundary dominated or still in transient. Both analysis are complimentary and can be used as a basis in multilayer model analysis to obtain production allocation from each layer followed by history matching with commingle historical data.

Fundamental Theory of Multi-Layer Model

Adopted from IHS Markit Harmony Enterprise Manual Book, multilayer material balance and Darcy's flow equation is the main formula behind the RTA for Multi-Layer model. Grid cells are used in the simulation to represent flow in reservoir based on material balance formula.

To define components of mass balance for cell *i* at timestep *n+1*, Mass in place (MIP) for cell *i* at timestep *n+1* can be calculated as:

$$MIP_i^{n+1} = MIP_i\left(p_i^{n+1}\right) = V_{bi}\varphi\left(p_i^{n+1}\right)\rho\left(p_i^{n+1}\right) \quad \text{….(1)}$$

where:
V_{bi} = bulk volume for cell *i*
p_i^{n+1} = pressure for cell *i* at timestep *n+1*
φ = porosity
ρ = density

Then, combined with the Darcy flow formula it become:

$$m_{i,j}^{n+1} = \rho\left(p\right) q_{i,j}^{n+1} \Delta t = \frac{A_{i,j}k}{L_{i,j}} \frac{\rho(p)k_m(p)}{\mu(p)} \left(p_i^{n+1} - p_j^{n+1}\right) \Delta t \quad .(2)$$

where:

$q_{i,j}^{n+1}$ = flow rate from cell *i* to cell *j* at timestep *n+1*
$A_{i,j}$ = cross-section area between cells *i* and *j*
$L_{i,j}$ = distance between the centers of cells *i* and *j*
μ = viscosity
k = permeability at the initial pressure
$k_m(p)$ = permeability multiplier (permeability at a certain pressure is calculated as $k_{effective} = k \cdot k_m(p)$).

And then, Mass produced at the well during timestep *n+1* (if well penetrates cell *i*) can be calculated as:

$$m_{i,w}^{n+1} = \rho\left(p\right)\, q_{i,w}^{n+1} \Delta t \ = WI \frac{\rho(p)k_m(p)}{\mu(p)} \left(p_i^{n+1} - p_{wb}^{n+1}\right)\, \Delta t \quad (3)$$

where:

WI = wellbore index (as per Peaceman 1978 or Babu and Oden, 1989)
p_{wb}^{n+1} = pressure at the wellbore at timestep *n+1*

Material balance for cell *i* at timestep *n* can be written as:

$$\underbrace{\sum_j m_{i,j}^{n+1}}_{flow\ to\ other cells} + \underbrace{m_{i,w}^{n+1}}_{flow\ to\ the\ well} = \underbrace{MIP_i\left(p_i^{n+1}\right) - MIP_i\left(p_i^n\right)}_{change\ in\ mass\ inplace} \quad .(4)$$

Since the multiple layers assumption are connected through the wellbore, additional modifications are made to model flow in a vertical direction. Refer to equation 2, to account for the fact that the direction of flow may have a vertical component, the equation should be adjusted as:

$$\frac{m_{x\,i,j}}{\Delta t} = \frac{A_{i,j}k_{abs}}{L_{i,j}} \frac{\rho_x(p)k_{rx}(S_x)k_m(p)}{\mu_x(p)} \left(p_i - p_j - \rho_x(p)gh\right) \quad .....(5)$$

Where *h* is a vertical distance between the centers of *cells i and j*. It is also important to note that each phase is in hydrostatic equilibrium.

Remember that wellbore cells are also connected to each other, but this connection is different, because flow in this connection represents flow of the fluid in the pipe, not in the porous media. Phases inside the wellbore are assumed to be mixed and to flow as a single homogeneous fluid. Therefore, pressure drop across the wellbore calculated using this approach:

$$p_i - p_j = \rho_{mix}(p)gh + \frac{q_{mix}\mu_{mix}}{T_m} \approx \rho_{mix}gh \quad ....(6)$$

Where T_m is a high number to represent the high conductivity of the pipe.

Field X Case Study Analysis Workflow

Field X is developed with 1 subsea gas well that produce from layer A and B with commingle completion. Reservoir properties value gap between layer A and B make it difficult to specifically understand the layer proportion. RTA methods is utilized to answer those challenge.

A comprehensive approach in this paper explained details below:

1. Data input: production data (gas rate and calculated sandface pressure from WHP), wellbore diagram, reservoir properties initial (porosity, saturation, thickness, reservoir pressure initial), and welltest result (if any for matching point).
2. Data quality control (QC): Synchronizing sandface pressure calculation and production rate, should follow the relationship between rate and pressure (if the flowrate increase, pressure should be decrease).
3. Perform RTA in an individual well. Trends of FMB and Type curve could estimate connected volume, k, S, well condition, boundary dominated flow identification.
4. History matching in Multilayer Model by changing dynamic properties of reservoir will be confirming k, s, reservoir pressure, and production allocation of each layer.
5. Rate and sand face pressure from each layer will be input back to a new imaginary well for each layer representatively.
6. Conduct Flowing Material Balance analysis using allocated production data for each layer's representative model to validate multilayer result.

Result and Discussion

Due to the nature of Z-1 well (subsea well, commingled, and without downhole gauge) Multi layered material balance could provide the solutions to understand and estimate the reservoir's contribution. According to publication develop by Kuppe, Frank et al (1) about "Layered Material Balance" method, there are various advantages which can be summarized as below:

- Good diagnostic tool to determine OGIP in multi-layered reservoirs.
- Accounts for operational effects (i.e. compression, stimulation or re-perforation) on production decline and material balance curves.
- Enables user to QC pressure data.
- Can be used to allocate production between commingled layers (over time).

- Can be used to forecast total or individual layer production

In this paper, Rate Transient Analysis (RTA) is applied as an alternative method to do material balance technique.

Rate Transient Analysis Single Well

Z-1 FMB and type curve result plotted in figure 1. The value of connected pore volume from Layer A and Layer B is determine by FMB result and confirm the boundary in type curve which will be utilized as allocation's reference. FMB plot shows there are two trend data in FMB followed by Productivity Index (PI) plot as well. This condition shows there is PI changing during the production which cannot be fully addressed because the FMB theory is based on Pseudo Steady State condition that have constant PI. Therefore, the stabilized PI trend chosen as matching point, followed by FMB trend, rate and pressure matching. This connected pore volume value is justified by type curve analysis to guarantee that this well has reached the boundary which allowing us to lock the connected gas volume. This means we could only match the data until during the stabilized PI number is achieved in multilayer analysis.

Multilayer Model

Layer A is known as tight carbonate reservoir with net pay 98–103 ft, permeability ranging from 0.2– 30 md meanwhile layer B has better quality of reservoir properties with net pay 53–75 ft, permeability ranging from 27–1066 md refer to core data. Well log of Z-1 and Z well can be seen on figure 2. DST result from exploration well (Z well) indicated that there is small flow from layer A. Multilayer model from RTA method is utilized to obtain the allocation because there is no PLT data in Z-1.

History matching in multilayer model is build using commingled connected volume result and k h range from core data. The result of multilayer history matching showed in figure 3 and figure 4. There are 4 cases that shows the most reasonable matching of layer A and layer B. Based on the outcome of multilayer model, layer A contributes around 0.95% – 9.74% of total production while layer B contributes around 90.26% – 99.05% of total production. The details shown in table 1. This result must be verified using single layer model on the next step.

The result of multilayer model based on several assumption as follows:

- Layers are communicating with each other only through wellbores.
- Gas rate is used as control parameter.
- Not considering the effect of relative permeability because it is single phase (dry gas).
- Initial reservoir pressure of each layer is assumed to be reliable.
- Only consider single value of Productivity Index
- The skin factor from history matching result represents average skin across all layers.

Result Validation

Single layer model of FMB is developed to verify the rate and allocation result. Data input of this model is gathered from production data of each layer, while other properties are based on the average value from all layer. If the connected volume value difference between multilayer model and single layer model is less than 5%, the result stated to be valid. The FMB validation result of each case can be seen on figure 5 for Layer A and figure 6 for Layer B.

Conclusions

- This method can be adopted as an empirical approach to determine production allocation for commingle well.
- Based on best match cases, the range of allocation result are between 0.95 – 9.74% from layer A while layer B contributes around 90 – 99% of total production. Layer A's OGIP is ranging from 11.9% - 13.3% while layer B is ranging from 86.7% - 88.1%
- Simultaneous matches of the material balance and production trend (rate or cumulative production vs. time) are obtained to ensure a representative value of OGIP and k h is generated for each of the two layers.
- Based on the result, Layer A still have potential undrained gas which cannot flow due to tight reservoir properties. This can be used as a reference for production forecasting and planning although it needs PLT data for validation.

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Acknowledgements

The author would like to thank Kangean Energy Indonesia to give permission to publish this paper.

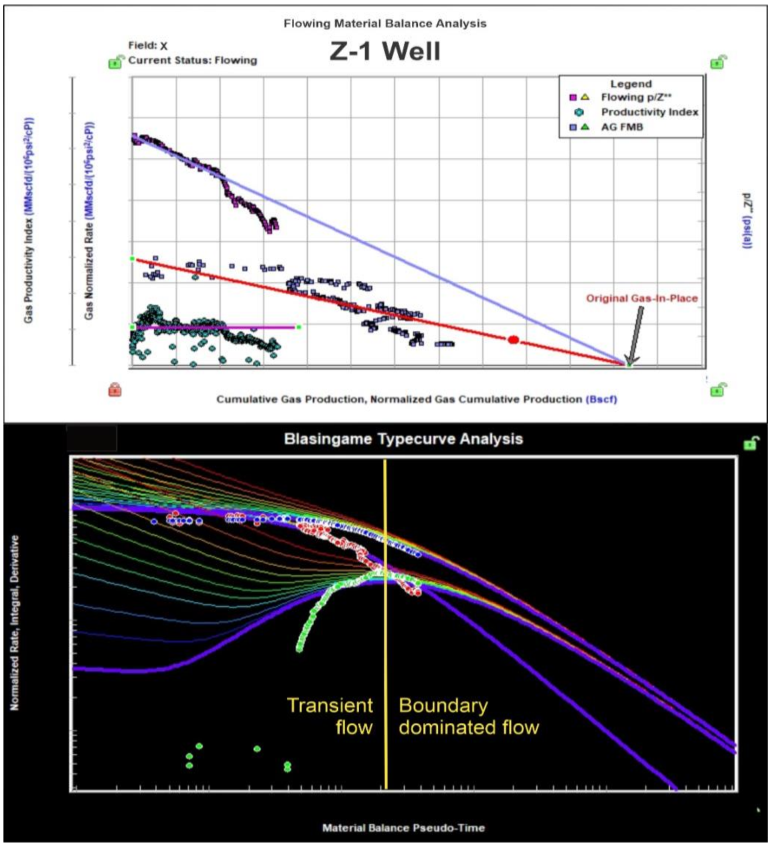

Figure 1: Z-1 Well FMB and Typecurve Result

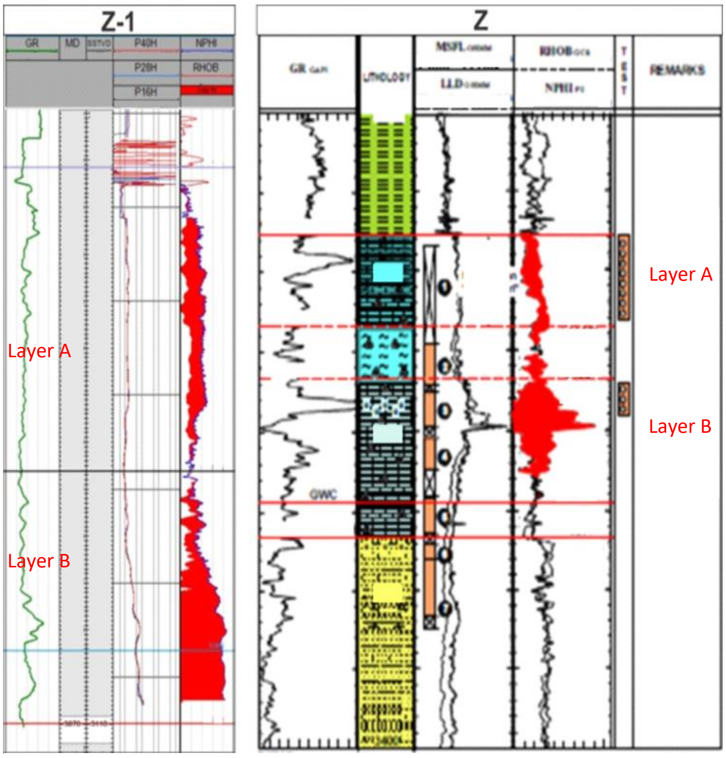

Figure 2: Log Z-1 and Z

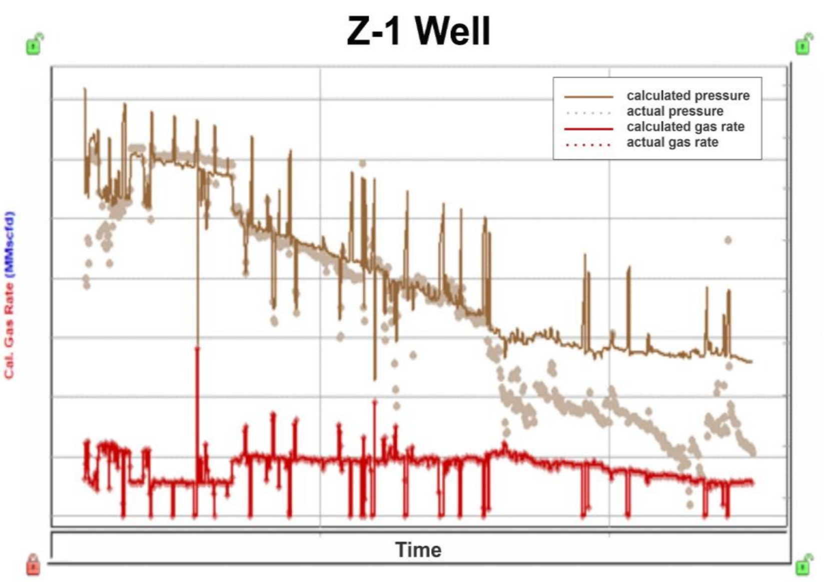

Figure 3: History Matching Z-1 Commingle

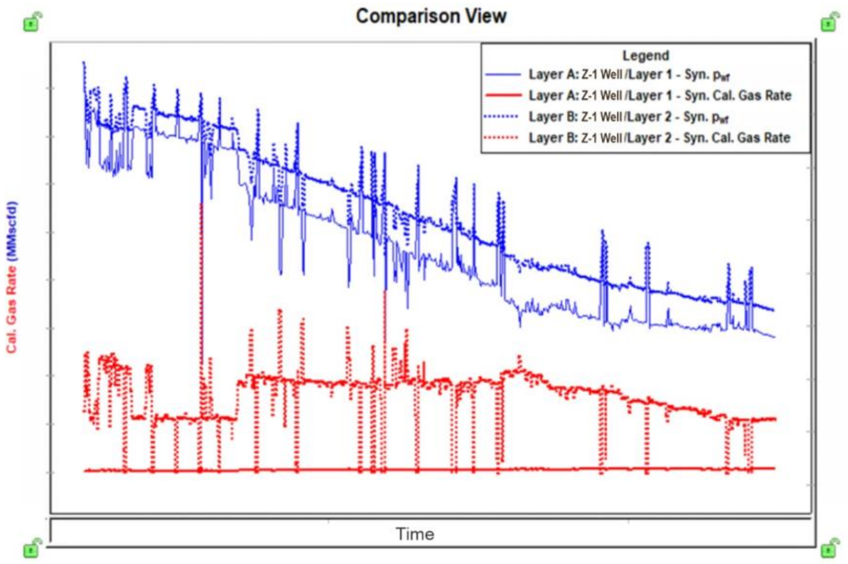

Figure 4: Multilayer Model Result

Layer	Case	Pay zone (ft)	Permeability (md)	Skin factor	OGIP (%)	Flow Contribution (%)
A	1	98	53	15	11,9%	9,74%
	2	103	55	13,5	12,46%	2,55%
	3	103	53	15	12,27%	0,95%
	4	102	57	17	13,33%	5,40%
B	1	64	600	16	88,1%	90,26%
	2	75	530	15	87,54%	97,45%
	3	75	520	15	87,73%	99,05%
	4	59	640	13	86,67%	94,60%

Table 1: Multilayer History Matching Result

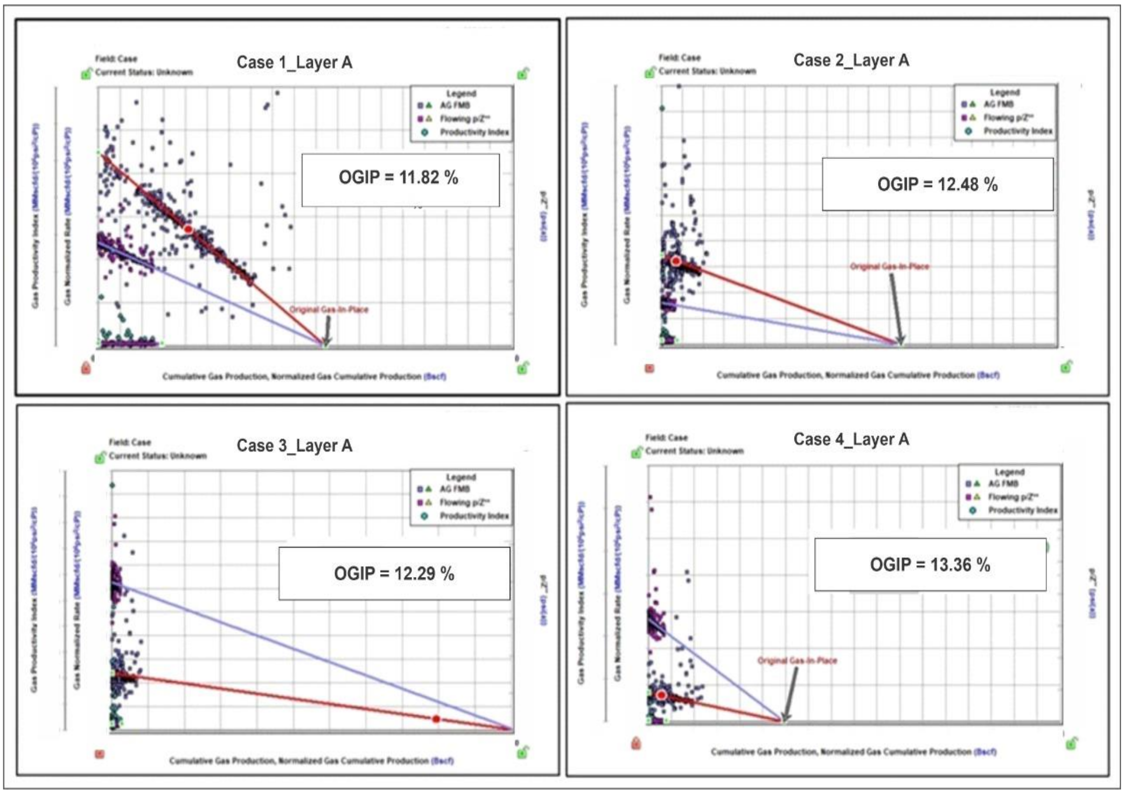

Figure 5: FMB Result Validation Case 1-4 Layer A

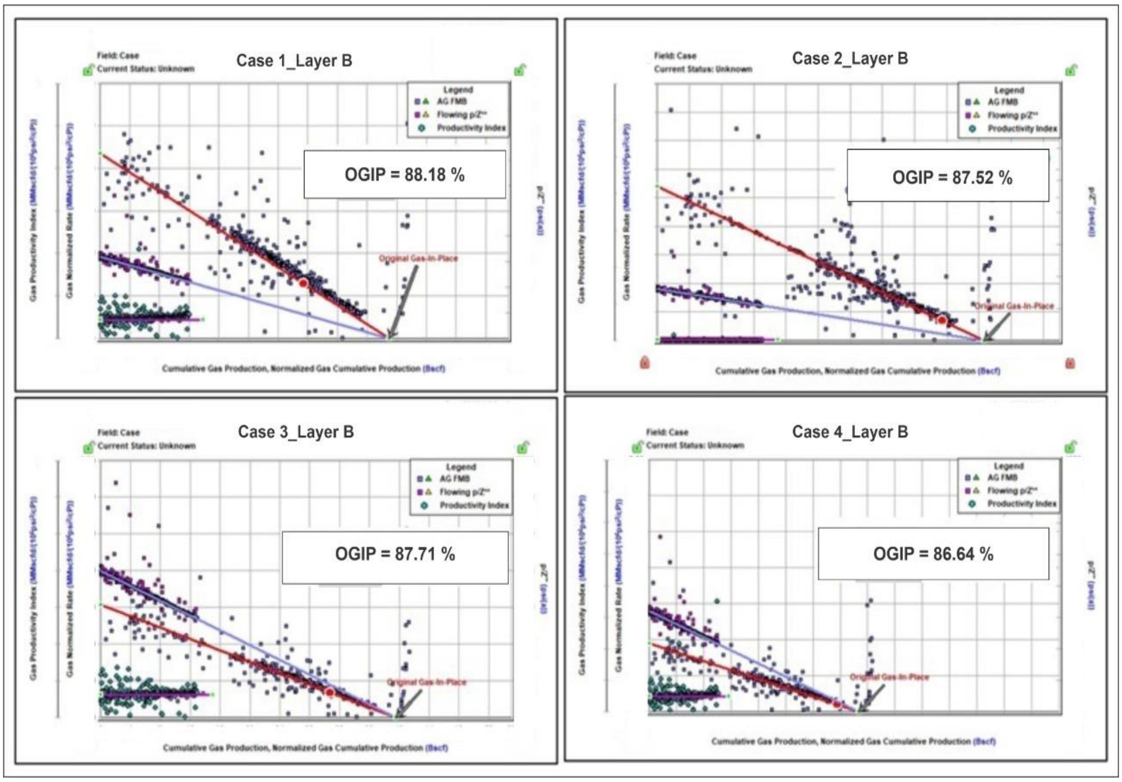

Figure 6: FMB Result Validation Case 1-4 Layer B