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A Novel Approach for New Well Placements Using Dynamic Data and Flowing Material Balance

Ricardo*, Azalea Hidayat, Faisal Muhammad, Wahyu Agung Rahmanto, and Avep Disasmita
Saka Energi Indonesia
* Email: ricardo@sakaenergi.com

Abstract.
W Field is a carbonate reservoir which produced on a thin oil rim with a gas cap. The W field is one of the newest fields in UP area and producing from 4 wells within 1-year production period. The adjacent field with similar features with W field shows challenging in field development with low recovery factors, especially in selecting new well proposed locations. Furthermore, dynamic simulation couldn't be used, since history matching always become problems in this field where fracture and vugs have big contributions to well performances. Even generating bubble maps using decline curve analysis will give high uncertainty since well recovery factor is unknown. Therefore, reliable methods to determine each well connecting volume is needed.
Flowing material balance (FMB) as a new approach in Production data analysis and Rate Transient Analysis (RTA) with a type curve will be used as the basis to determine the connecting volume from each well. Compared with conventional material balance where shut in is required to get the average reservoir pressure, FMB will use historical rate and flowing pressure to derive average reservoir pressure and determining connected Original Hydrocarbon in Place. By using FMB, it can also be seen whether the wells that have been producing interfere with each other thus have connecting volume between wells. All above solutions were preferable since no shut in is required.
The results show Flowing Material Balance and Rate Transient Analysis give reliable connecting volume. The derived connecting volume then used to generate bubble maps as a guidance for estimating new well placements. The resulted maps, guided with the static model volumetric show the estimated drainage area and possible additional drainage from new wells to increase hydrocarbon recovery. Therefore, in W field 2 new wells have been proposed to be drilled in the following years.
Keyword(s): Connected Volume, Improve Recovery Factor, Flowing Material Balance, Field Development

1 Introduction

W field is located in offshore North-East Java and its Plan of Development (POD) was approved by Government of Indonesia in 2018 with the objective is to drill 4 new development wells from Kujung Formation and produced on a thin oil rim with a gas cap. The first well, W-1 well, was drilled in end of 2020 with its first production started in February 2021. Currently, all 4 wells have been drilled and produce.

The depositional environment shows W Field is located in the shelf margin carbonate complex (Figure 1). Shelf margin structure is along east west trend. HC accumulation is producing from early Miocene carbonate. In specifically, most of production well is located in the back reef – crestal reef and carbonate is well developed in this area. Additional notes, fracture and vugs were identified from core and image logs and have high contribution for the production in W fields.

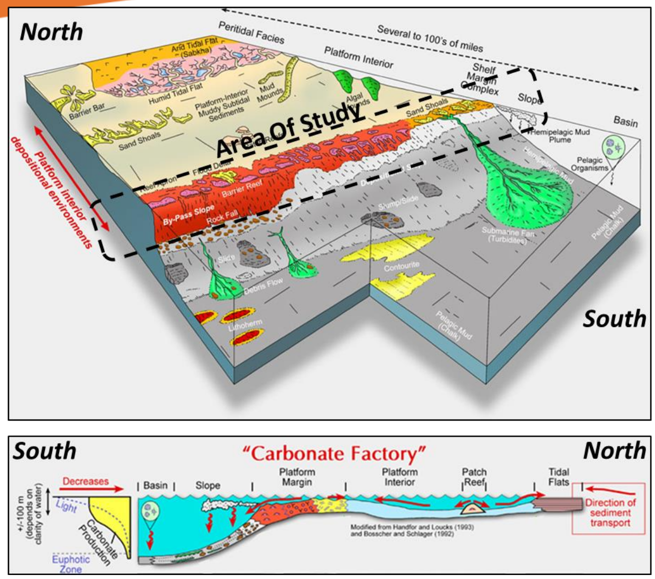

Figure 1 Depositional Environment of W Field.

A continuous effort has been made to evaluate newly acquired data from each drilling results in order to update hydrocarbon in place as the basis for full field development planning. One approached to increase recovery factors is by increasing number of wells. However, the adjacent field with similar features still showing low recovery factors even with many numbers of wells. Furthermore, dynamic simulation couldn't be used, since history matching become problems in this field where fracture and vugs have big contributions to well performances and it is difficult to have good understanding of its distribution. Therefore, it is always becoming a challenge to determine new well placements.

The simplest approach to select new well location is using bubble maps by calculating well connected volume continued by identify the undrained area. Bubble maps could be derived using decline curve to calculate Estimated Ultimate Recovery (EUR) then transform to well-connected volume by divide EUR by the expected recovery factors. However, the expected recovery factors typically become one of the biggest uncertainties in the calculations. Although bubble map derived from EUR might not also the true drainage area, since the true drainage area is the total area that the pressure could be reached from well.

In this paper, a new approach to calculated well connected volume using Production Data Analysis and Rate Transient Analysis is used to minimize the error and identify the undrained area which shows better well placement locations for the upcoming drilling campaign.

2 Basic Theory

Flowing Material Balance (FMB) was first introduced by Mattar and McNeil[1] by calculating volumetric of gas reservoir without shut in wells. The author shows that reservoir pressure could be obtained from the flowing pressure for wells producing at a constant rate. The methods then optimized by Mattar and Anderson[2] which is referred as Dynamic Material Balance that applicable to both constant rate and variable rate production by converts the flowing pressure at any time point to the average reservoir pressure, while in the conventional material balance the average reservoir pressure is obtained by shut in the wells. The final equation proposed is simplified into:

$$\overline{p_R} = p_{wf} + b_{pss}q \tag{1}$$

The equation illustrates how the Dynamic Material Balance can be applied to a well with varying production rate, where the conversion from flowing pressure (p_{wf}) to average reservoir pressure ($\overline{p_R}$) must take into account the varying flow rate (q). Since the flow rate and flowing pressure is known, the value of b_{pss} should be determined by using some independent method. Mattar and Anderson[2] propose to plot $(p_i - p_{wf})/q$ with material balance time where the intercept on the y-axis give b_{pss}. Afterwards, the connected volume could be calculated based on conventional material balance concept using the calculated average reservoir pressure.

Agarwal-Gardner[3] FMB proposed more direct methods to calculate inplace which use the normalized rate and normalized cumulative productions. The methods provide clearer boundary between transient and boundary dominated flow. The step-by-step procedure for generating the Agarwal-Gardner analysis for a gas well with varying flow rate described as below:

1. Assume a value for OGIP.
2. Calculate p/z from the general material balance equations.
3. find the corresponding average reservoir pressure.
4. Plot a graph of normalized rate versus normalized cumulative.
5. Draw a straight line through the best-fit of the data points. (The intercept on the x-axis gives OGIP.)
6. Using this new value for OGIP, repeat steps until the OGIP converges.

The straight line in number 5 indicated that the flow regime already in boundary dominated flow. The flow regime could not be seen if general material balance (p/z) is used which make this method more preferable. Although, the methods directly calculate the inplace, it also measures the b_{pss} which is the reciprocals of the intercept of the normalized rate and normalized cumulative on the y-axis.

3 Methodology

In this paper, all the existing 4 four wells in W field will utilize Agarwal-Gardner FMB procedure combined with Rate Transient Analysis (RTA) type curve to estimate the connected well volume that will be used to generate bubble maps. Based on the remaining un-drained area, the possibility for new well placements will be determined. RTA also used to check whether the well already in pseudo steady state conditions, since if the well still in transient period over time the inplace value will still getting bigger until it reached pseudo steady state conditions. The FMB and RTA type curve calculation will be applied through Harmony Enterprise™ software.

The input for production data is taken from daily welltest and during Drill Stem Test (DST) after the well is drilled. Each well have downhole gauge installed that will be used as the input for the bottom hole pressure after corrected to sandface pressure. The initial condition that was used for all the calculation is shown in Table 1 which derived from the exploration well UPW-1 and the latest drilling campaign. All well haven't been shut in since opened in 2021 and have variable rates.

Table 1. Basic Rock and Fluid Properties in W field.

Properties	units	Value
Initial reservoir pressure	psia	1750
Reservoir temperature	F	175
Porosity	fraction	0.26
Gas gravity	fraction	0.698
Oil density	degAPI	37
Condensate density	degAPI	64

4 Results and Discussion

Connected volume was calculated for all four wells in W field using FMB based on normalized rates and normalized cumulative. Figure 2 and Figure 3 show the example for FMB in oil well and gas well results which produces good straight line and the intercept with x-axis will give the expected of connected volume. Rate history-match and the flowing pressures history-match was used to ensure the final connected volume will give good history match. For oil well, W-1 and W-2, produces significant number of waters therefore the material balance must be corrected for water influx effect. However, the aquifer strength impact is not visible in RTA type curve (Figure 4) where at the end of production the data point still following PSS declining line. The connected volume results are differs as shown in Table 2 since in those 2 oils well the gas cap also being produces together with the oil zones where type curve couldn't account for multiphase fluid, the analysis for oil and gas reservoir couldn't be done altogether. On the other hand, FMB could handle multiphase flow thus resulting more robust and reliable connected volume.

Gas Well, W-3 and W-4, give more consistent connected volume results based on FMB and RTA type curve as shown in Table 3, since their only produces single zone only on gas cap. Rate history-match and the flowing pressures history-match also used to ensure connected volume was reliable as shown in Figure 3 while RTA type curve also give good matching in most of the data points as shown in Figure 5. Further analysis also considered whether W-3 and W-4 had interference, by combining the production analysis in group. The analysis show both wells had interference recently and had joined connected volume. However, at the moment only limited numbers of rate and pressure data shows interference thus need to further observation.

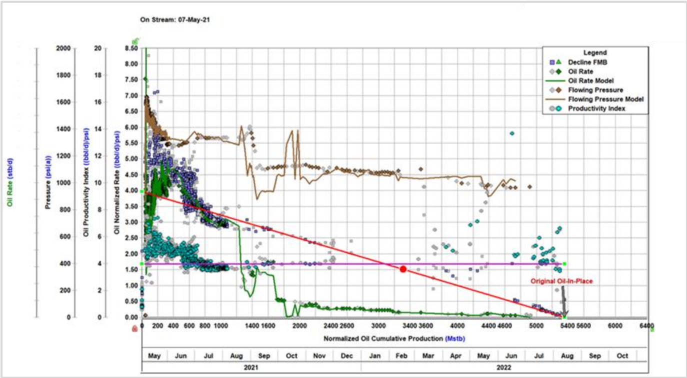

Figure 2. Final FMB W-2

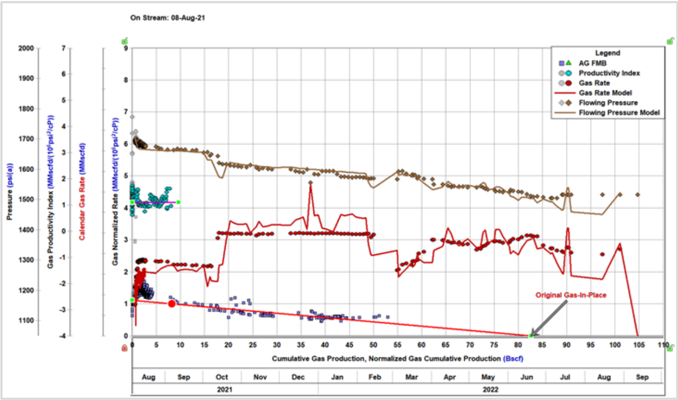

Figure 3. Final FMB W-3

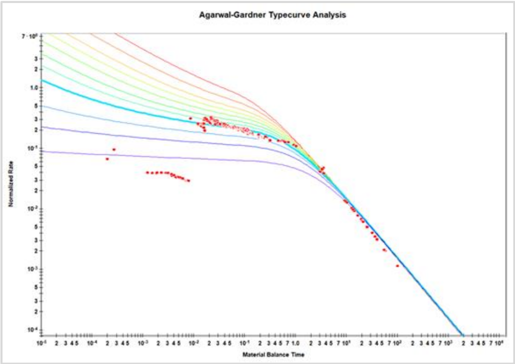

Figure 4. RTA Type curve W-2

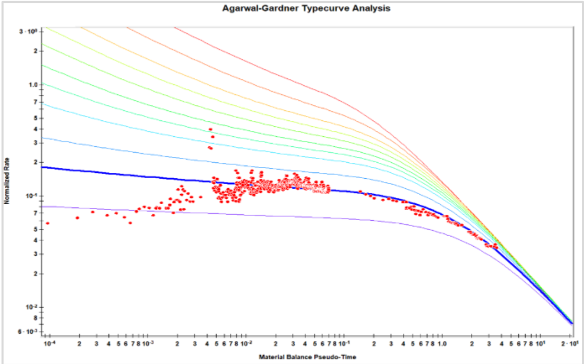

Figure 5. RTA Type curve W-3

Table 2. Comparison results FMB and RTA type curve for oil wells

Analysis	W-1	W-2
FMB, MMSTB	3.2	5.4
RTA type curve, MMSTB	0.4	0.5

Table 3. Comparison results FMB and RTA type curve for gas wells

Analysis	W-3	W-4	Combine (W-3 and W-4)
FMB, BSCF	82.5	21.3	96.6
RTA type curve, BSCF	80.8	20.3	94.7

Based on the total cumulative volume results from FMB compared with W field volumetric inplace results from static modeling, further development to increase recovery factor is still possible to be done. The further development for W field will be focusing to optimize gas production since the oil producer well heavily impacted by water breakthrough due to located in thin oil rim and the appearance of fracture and vugs. The development will be based on undrained area that plotted using the updated bubble maps. The connected volume from FMB will become the guidance to generate bubble maps that plotted in the static model. The result is shown in Figure 6 which potentially 2 well still could be drilled to improve recovery in W field.

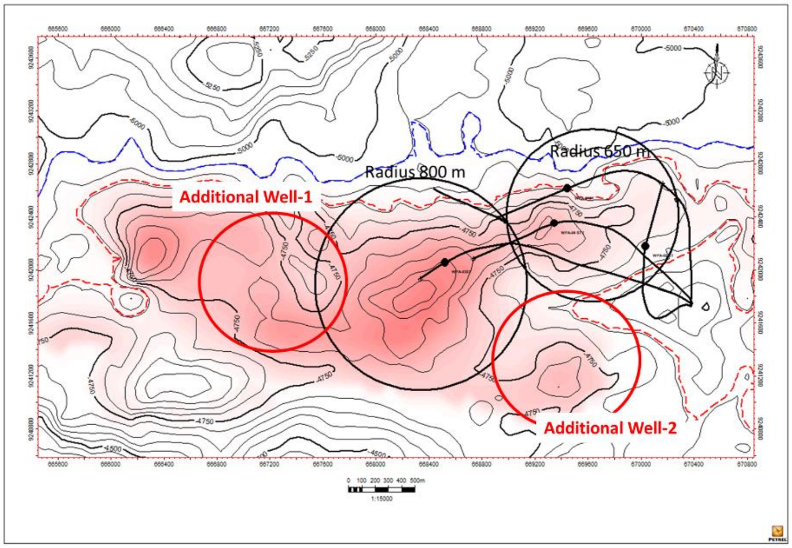

Figure 6. Bubble maps and potential new well placement.

5 Summary and Recommendations

1. FMB method with sufficient data is a very useful tool to calculate average reservoir pressure with variable production rates and to update the connected volume without having to shut in the well.
2. The estimated connected volume from FMB produce good results and comparable with the rate transient analysis type curve, even could handle multiphase flow calculations.
3. The analysis from FMB could also observe if the well had interferences.
4. Connected volume derived from FMB only valid when the well response reaches Boundary dominated flow or its behaviour is governed by the pseudo-steady state equations. While the condition still in transient period, the connected volume still tends to increase.
5. Although FMB methods is powerful, it is should not become the total replacement of PBU but as an inexpensive supplement for PBU, since PBU directly measure the average reservoir pressure.

6 Nomenclature

p_i	=	Initial pressure, psia
$\overline{p_R}$	=	Average reservoir pressure, psia
p_{wf}	=	Flowing pressure, psia
b_{pss}	=	Reservoir constant
z	=	Gas deviation factor

7 References

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