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Maximizing Production Data to Understand Well Connectivity, Connected Volume, and Drainage Area for Future Prediction of Reservoir

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Abstract.

Field C is located at Cepu Block, East Java. This structure is observed as a small closure reservoir with 1347 acre-ft net volume which discovers in 2012 and starts to put on production in 2017. There are 2 production wells (well-1 and well-2) and 1 suspended well (well-3) that drilled to the L layer with oil production. The recovery factor from this layer was predicted around 31.79% of OOIP. After producing for 9 months, the flowrate and flowing pressure from existing wells starting to decline followed with a significant increase of water. Investigation of this performance is conducted in order to evaluate well and reservoir surveillance as part of Layer L development plan.

The objectives of this study to obtain drainage area from two wells (Well-1 & Well-2), investigate well connectivity and discover potential of layer L for production optimization. Updating dynamic model of reservoir to do monitoring of performance becomes a challenge because lack of reservoir data such as static pressure data that rarely collect. Rate transient analysis method becomes an alternative method to help overcome those challenge by maximizing production data analysis from rate and tubing head pressure to perform well and reservoir surveillance. Workflow in this analysis using the method of flowing material balance to define connected volume, typecurve analysis to define reservoir properties, and validate using multiwell models with history matching.

Analysis is focusing first on a well basis to determine well connectivity. Then continue to the reservoir basis using a multi-well model to understand the drainage at the reservoir level. So that it can be used as a reference to predict reservoir potential in layer L. The result said that from the well basis observation there's water breakthrough from well-2 also interference indication between Well-1 and Well-2 so that connected volume from well basis need to validate to multi-well model. Analyzing to multi-well model brings a clue that those existing well have not reach their boundary yet during their production, the drainage area also has not reach Well-3 (suspended well) area located in the edge of reservoir. Further observation from well-3 production data can help to validate this study.

Keyword: Rate transient analysis; Modern Production Analysis; Oil Potential; Reservoir Surveillance

1 Introduction

Field C is located at Cepu Block, East Java and has been producing from Bulu and Ngrayong formation since 2015. The initial oil rate was around 170 BOPD, while peak production was reached in 2018 at around 500 BOPD. There are 6 wells drilled, 4 wells production, 1 well suspended and 1 dry well as shown in figure 1.

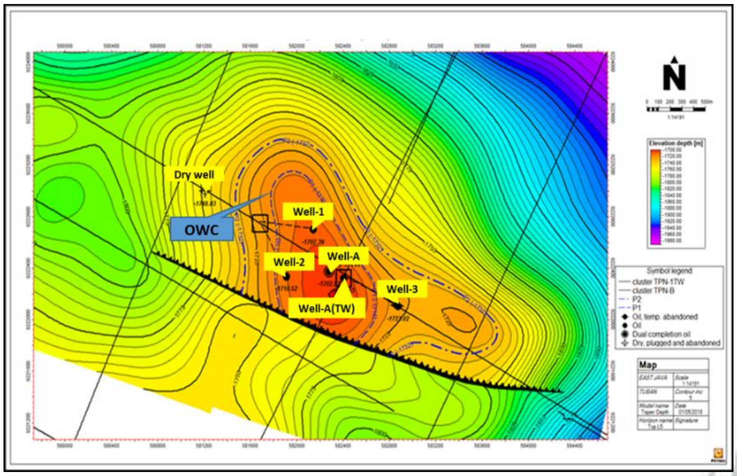

Figure 1. Well Location

In the current condition, there are 2 wells produce from L formation which is Well-1 and Well-2, with initial reservoir pressure is 2200 Psi with reservoir temperature of 215 degF at reservoir depth of around 1800 mMD. Well-1 start production at 16 Nov 2017 with Qoi 146 bopd, water cut tend to be constant around 5 %, cumulative production until Des 2019 is 85.91 Mstb, Well-2 start production at 27 Des 2017 with Qoi 187 bopd, Water cut initial around 5% and increasing periodically until 30% at Oct 2018 and significantly after installing ESP at Jan 2019 until 58% and still increase simultaneously, cumulative production until Des 2019 is 75.83 Mstb. Production performance of Well-1 and Well-2 can be seen below in Figure 2.

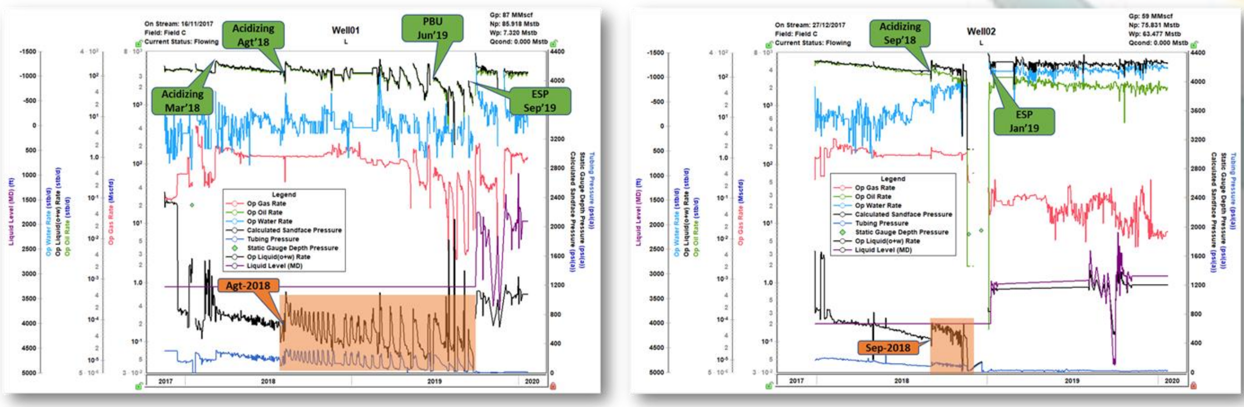

Figure 2. Production History Well-1 and Well-2

After 9 months of production oil rate and pressure starting to decrease both from Well-1 and Well-2. From PTA result of Well-1 in Jun-2019, permeability around 3.98 md with skin 2.42 . Because of low performance in those wells, then acidizing job was done to help increase productivity, also ESP has been installed at Well-1 since Sep-2019 and well-02 since Jan-2019. The performance of those wells needs to be observed, in order for further development of production optimization.

The challenges in this reservoir are starting from its structure. From GnG interpretation, Tapen structure bulk volume around 15.75 km2, which consists of 5 layers. Layer L becomes a focus in this study which has the smallest net volume around 1347 acre-ft compared with other layers. OOIP volumetric from P1 plus P2 of Layer L estimated around 1800 MSTB with RF from POD report is 31.79%. Current cumulative production already covered 8.9% of OOIP. Reservoir surveillance for better understanding of the performance can lead to planning an effective production optimization of Layer L. In this layer there's Well-3 as a suspended well that already considered to open in the development plan. Worth to produce or not is still uncertain due to the difficulties in updating dynamic model of reservoir. Updating the dynamic model of reservoir to do monitoring of performance becomes a challenge because of the lack of reservoir data such as static pressure data that rarely to collect. It is very difficult to shut-in the wells for long periods due to low permeability reservoir to get reliable data. Rate Transient Analysis (RTA) method become an alternative method to help overcome those challenges by maximizing production data analysis from rate and tubing head pressure to perform well and reservoir surveillance.

2 Methodology

2.1 Concept of Modern Production Analysis

Modern production analysis method that adapted in this study was introduced by Mattar and Anderson (2003). Modern production analysis is also called Rate Transient Analysis (RTA). Concept of RTA is maximizing production data which are rate and flowing pressure in conducting reservoir surveillance. Equation behind RTA are combining static material balance, flow equation which have same concept of diffusivity equation that makes this method can performing material balance from production data.

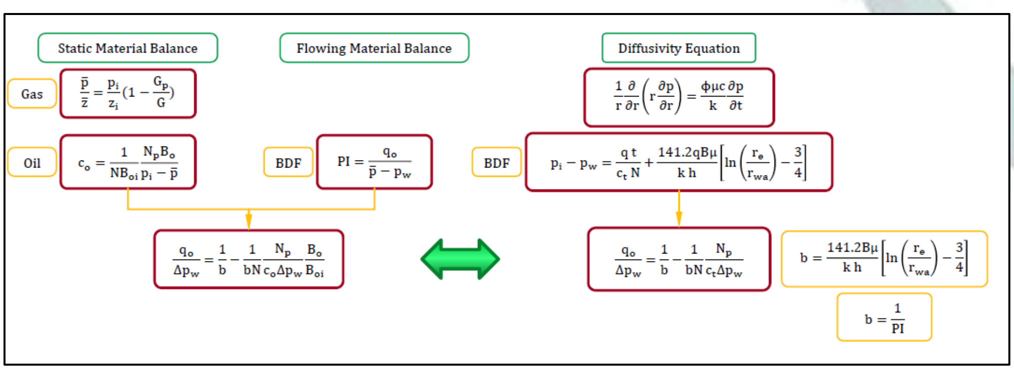

Figure 1. The Equation behind RTA

Workflow in this analysis use the method of Flowing Material Balance (FMB), Type curve analysis, and completed with history matching in numerical models. Analysis with FMB plots to understand connected HC in-place information, productivity index, well drainage areas, reservoir pressure trend and understand whether there is a change in reservoir/well condition. Flowing Material Balance requires no shut-in pressure data, with this advantage engineers can monitor the reservoir performance periodically without often shut-in the well. Then proceed with Type Curve Analysis to help find out the dynamic properties of the reservoir such as permeability and skin also identify the flow regime whether it is boundary dominated or still in transient. The results from the FMB and type curve then proceed to history matching with the numerical model to match with historical data. This method can perform in well basis and tank basis.

2.2 Field C Case Study Analysis Workflow

Field C was identified as small closure reservoir from GnG interpretation. This field is producing oil from layer L and from volumetric data has OOIP P1 550 Mbbl and P2 1250 Mbbl. Performing RTA using IHS Harmony Enterprise software in this paper might bring an insight about the potential of layer L and its further development strategy with fast and simple method. A comprehensive approach in this paper explained details below (Figure 3):

1. Data input: production data (rate and tubing pressure), fluid level, wellbore diagram, reservoir properties initial (porosity, saturation, thickness, reservoir pressure initial), BHP survey (if any for matching point)
2. Data quality control (QC): calculating sandface pressure by converting FTHP to FBHP using Hagedorn & Brown equation (applicable for oil well). Synchronizing sandface pressure calculation and production rate, it should follow the relationship between rate and pressure (if the flowrate increase, pressure should be decrease). It is preferable to identify and eliminate inconsistent data before the analysis is undertaken.
3. Performing RTA in an individual well. Looking to the trend of FMB and Type curve could estimate connected volume, k, S, well condition, boundary dominated flow identification. Inconsistencies of the trend may lead to back again in data QC. If there's possibility of well connection between 2 existing wells, for better interpretation, RTA should be perform in tank basis.
4. Applying RTA in the tank basis to understand widerange of pressure respond that already performed by existing wells. Well drainage area from material balance performance of existing well can be seen from FMB and Typecurve group basis. It helps to confirm the boundary and connected volume.
5. History matching in Multiwell Model by changing dynamic properties and relative permeability of reservoir will be confirming k, s, reservoir pressure. Then proceed to prediction of reservoir performance.

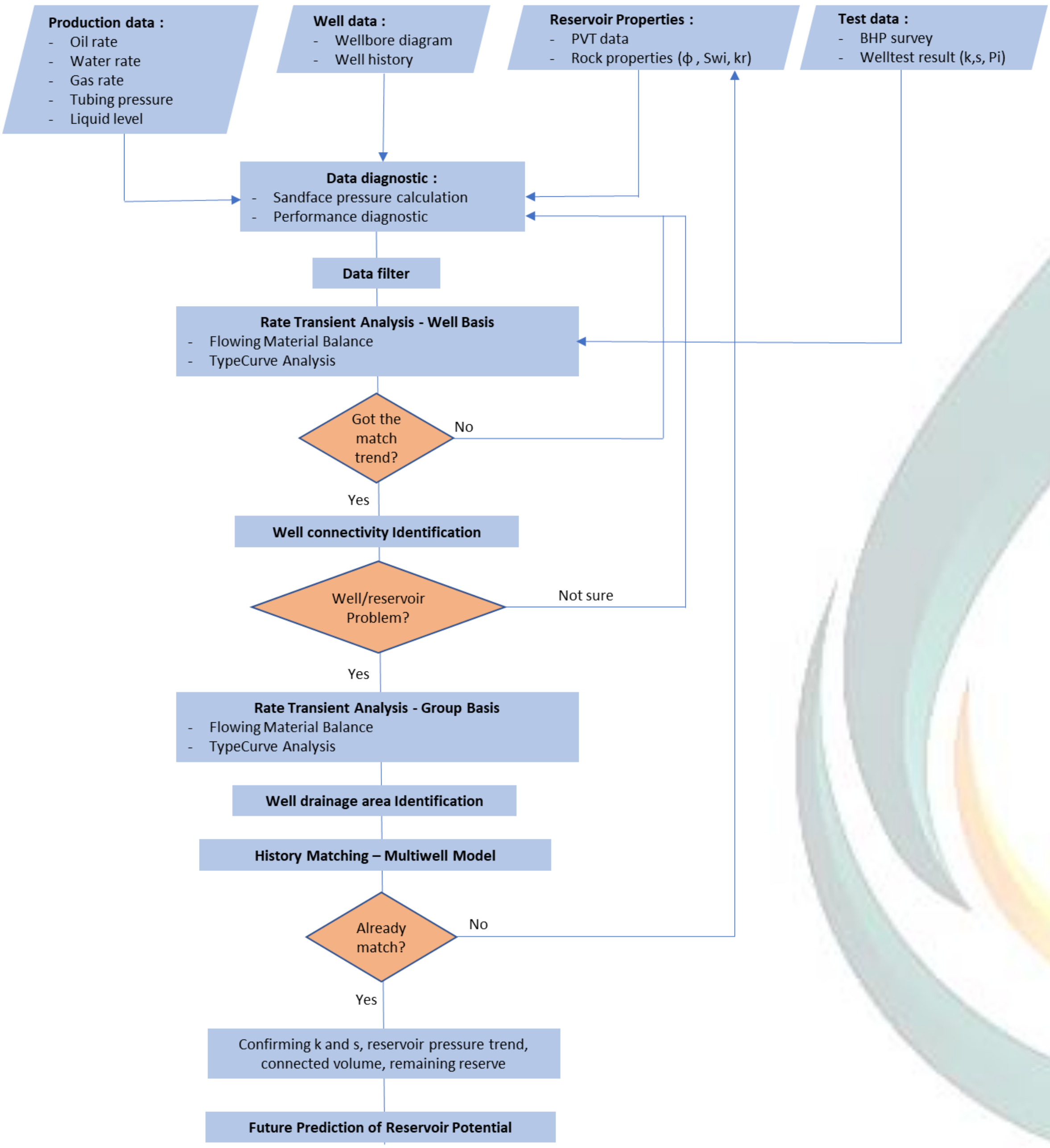

Figure 3. Analysis Flowchart

3 Result and Discussion

In this discussion, production data analysis in conducting to do Rate Transient Analysis method. Data availability that already explained in the workflow are inputed to the software. Higher density on rate and tubing head pressure data are important to run this analysis.

3.1 Well Connectivity Identification

Flowing Material Balance (FMB) and Agarwal-Gardner typecurve plot was done well by well as shown in the Figure 4,5,6,7. Using production data analysis, FMB can deliver some of result which are connected volume, well performance that can be seen from productivity index plot, well connectivity, and reservoir performance. Then completed with typecurve analysis give some output like flow regime identification, permeability, skin, and current reservoir pressure.

3.1.1 FMB and Typecurve analysis Well-1

Well-1 FMB result plotted in figure 4. The Oil FMB plot shows there are 2 trends in this FMB confirmed by changing Productivity Index (PI) plot as well. The best match of FMB should follow straight line trend on Oil FMB plot as match as constant productivity index (PI) plot. If it shows as Well-1's FMB, this condition might be due to changing of reservoir condition or changing of well condition. Re-QC data from Well-1's history must be review to help the interpretation. From the sequence of well history, there's acidizing job at Aug-2018 and ESP installation at Sept 2019. This activity impacted the changing of well condition caused by flow regime disturbance followed by changing well PI. The flow of the well become not constant and come back to transient flow after acidizing was done so it creates an individual plot same as after ESP installation. Multiphase FMB is implemented to be able to do history matching with pressure and rate in the FMB plot. As seen in the FMB plot, pressure and rate matching depends on PI plot, first match before ESP installation, and second match after ESP installation. Estimating the connected volume come up from intersection of FMB lines with x-axis. One static pressure data is used here as matching point for average reservoir pressure trend to lock the connected volume estimation. Both trend of Oil FMB and PI shows the same connected volume come up with ±711.7 Mstb, so it doesn't matter to follow which trend. It means that different trend is caused by changing well condition not affected to the reservoir.

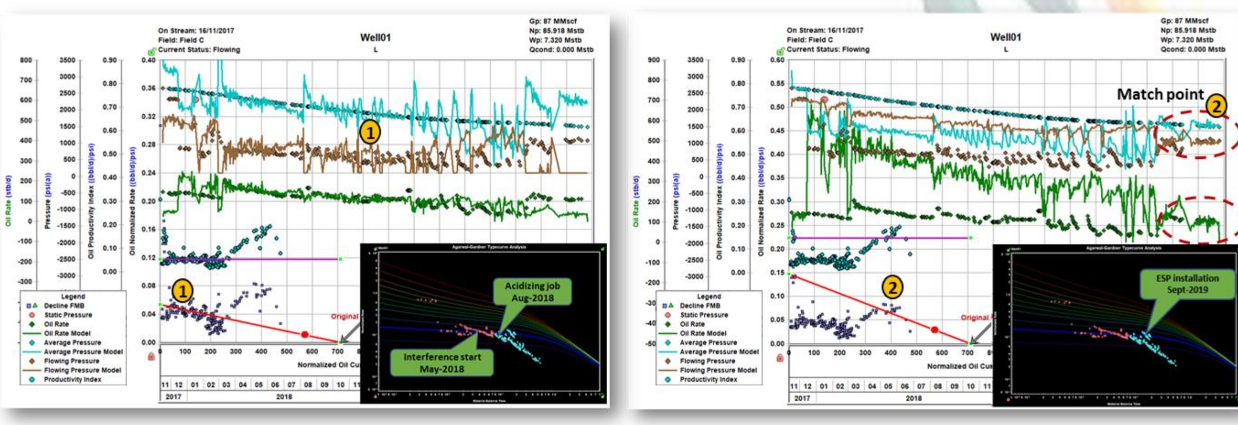

Figure 4. FMB and Typecurve Analysis Well-01

To support justification from previous analysis, typecurve analysis in details also shown in figure 5. Typecurve analysis can help to identify the flow regime clearer than FMB plot. At the green border line at the left side is transient flow area that will deliver signal from early time that will result dynamic reservoir properties such as permeability, skin, and current reservoir condition, beside at the right side is boundary dominated flow line can help to confirm connected volume and drainage area. The best match of typecurve should follow the transient trend and finalize in boundary dominated flow (BDF) trend. Well-1 typecurve result shows the declining plot which has not continue to BDF line yet. There are 3 sequences of declining trend that shows from this typecurve plot. The interpretation referring to previous FMB, there's acidizing job and ESP installation, it also confirmed changing trend from typecurve at the date of those activity was done. But there's a declining trend at around May-2018 that clearly seen in this plot, there's no activity was done at that time based on well history data. Preliminary interpretation it can happen caused by decreasing energy of the reservoir felt by Well-1, might be interference start or lack of energy. This condition needs to be confirmed by analyzing Well-2, if it's come up with the same trend in the same date, interference may happen between Well-1 and Well-2.

The dynamic reservoir properties result from typecurve estimation give permeability 4.4 md with skin 5.6, this is supported by PTA data of well-1 at Jun-2019 permeability value is 3.98 md and skin 2.42 at that time. However, this result should be validated in the history matching.

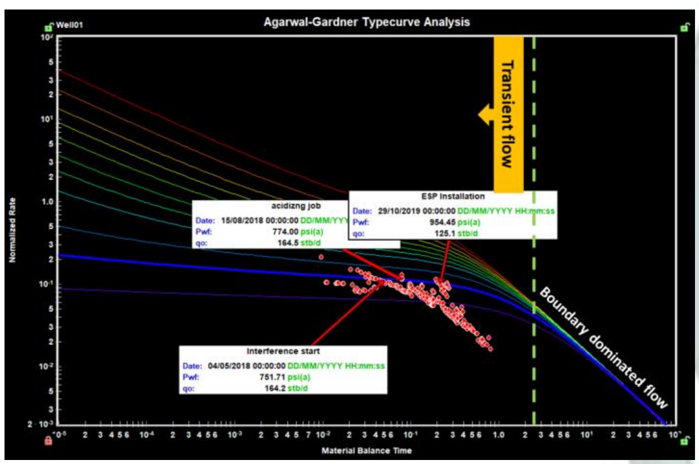

Figure 5. Flow regime Identification from Typecurve Analysis (Well-1)

The unique behavior from this typecurve is although it has 3 trends but it always back to the transient trend. The trend of this plot like going towards to BDF line, but there is an interruption caused by changing well condition that make it transient again. When the plot comeback to transient flow it always followed by declining trend. Declining trend should be the focused here because it told us that there's decreasing energy inside that might come from interference effect

3.1.2 FMB and Typecurve analysis Well-2

Well-2 FMB result was plotted in figure 6. The Oil FMB plot shows there are 3 trends figure out in this FMB confirming with changing Productivity Index (PI) plot as well. Plotting FMB at Well-2 can help to justify the connectivity between Well-1 and Well-2, because there's interference indication from Well-1 FMB and typecurve plot.

From the sequence of well history, there's acidizing job at Sept-2018 and ESP installation at Jan-2019. The trend that created from the result of Well-2 has a similar behavior with Well-1. The changing of well condition that makes changing PI and FMB trend 1 and trend 2 (Figure 6).

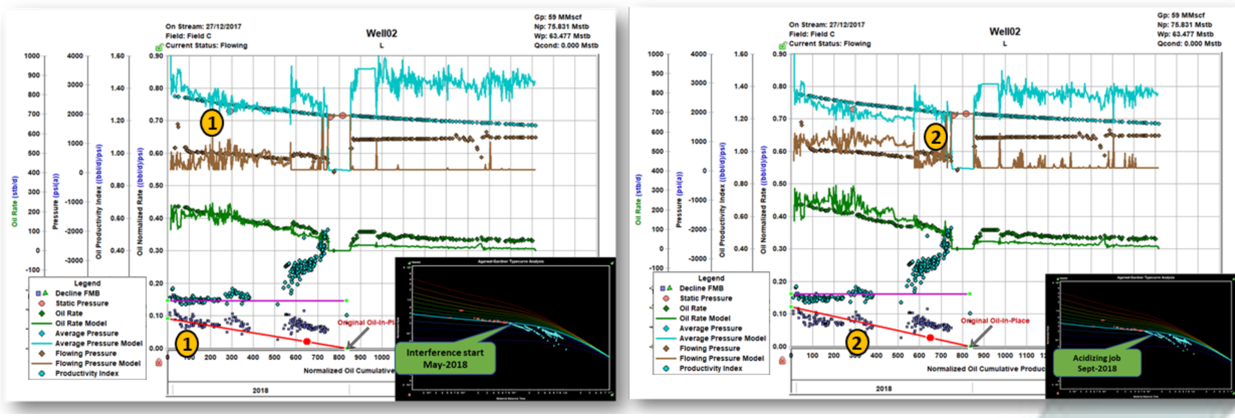

Figure 6. FMB and Typecurve Analysis Well-2 (Trend 1 and Trend 2)

The unique behavior of well-2 is shown in Figure 7, in the trend 3 show an upward trend of PI that indicate pressure support that followed with significant increase of water cut, from 30% increase to 58%. The suspicion to well-2, a water breakthrough did happen shows by significant increase of water rate followed with decreasing of gas rate. This pressure support could be explained that Well-2 felt an extra energy from aquifer as from Figure 1, Well-2 is structurally located near OWC.

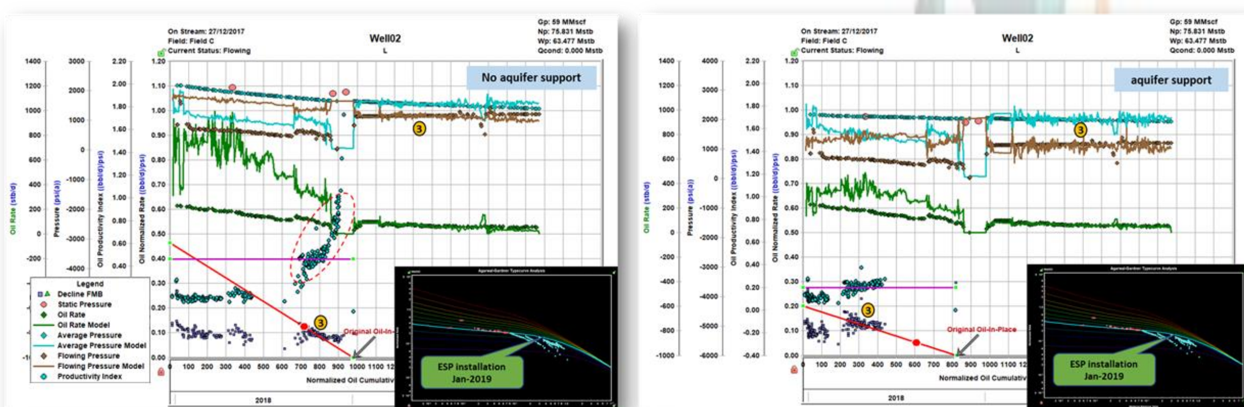

Figure 7. FMB and Typecurve Well-2 (Trend 3 – considering aquifer support)

In figure 7 shows the comparison of matching quality if considering aquifer and no aquifer. To improve the match at the trend, the FMB plot require an aquifer model for the better match. PSS water drive model has been applied in the plot by estimating OWIP around 100 MMbbl and PI_{aq} around 7 bbl/d/psi. However, this estimation requires further validation in the history matching of multi-well model. The estimated connected volume come up from intersection of FMB line around ±826.5 Mstb. To make sure if interference did happen, it should be clearly seen from typecurve analysis.

Typecurve of Well-2 in details shown in Figure 8. Well-2 typecurve result shows the declining plot which has not continue to BDF line yet. There are 3 sequences of declining trend that shows from this typecurve plot. The interpretation referring to previous FMB, there's acidizing job and ESP installation, it also confirmed changing trend from typecurve at the date of those activity was done. The trend is also similar with Well-1 behavior, it means both well has connectivity. There's also a declining trend at around May-2018 clearly seen in this plot, there's no activity was done at that time based on well history data. Referring to Well-1 typecurve result, Well-2 felt the same declining trend at May-2018. These well was start producing almost simultaneously, Well-1 at Nov-2017 and Well-2 at Dec 2017. So that interference might happen between them, justified with the same result of RTA interpretation

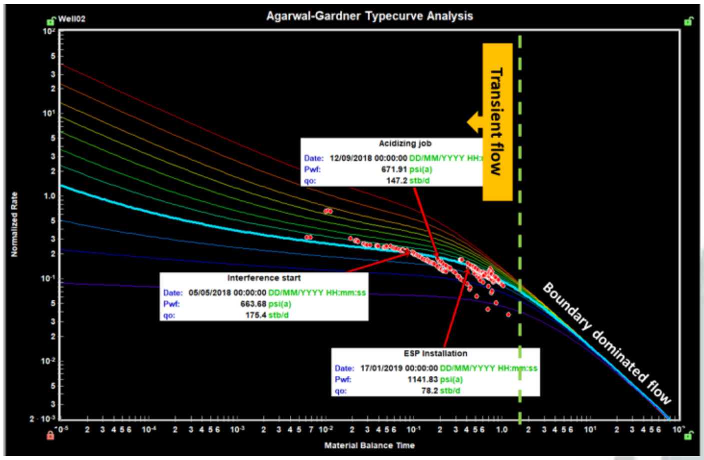

Figure 8. Flow regime Identification from Typecurve Analysis (Well-2)

The dynamic reservoir properties result from typecurve estimation give permeability 5.82 md with skin 5.5. However, this result should be validated in the history matching.

Because the interference did happen between them, the connected volume of each well become uncertain because there's interruption performance from the neighbor's well. Connected volume from well-2 is bigger than well-1 in interference condition, it may indicate that well-2 is more dominant than Well-1. To confirm the connected volume and drainage area as the reflection of material balance respond from the particular well, RTA should be performed in the tank basis using multi-well analysis.

3.2 Connected Volume Estimation, Drainage Area, and Future Prediction of Layer L Potential

Continuing analysis of connectivity between Well-1 and Well-2, tank basis analysis was done to make sure the connected volume. Tank basis RTA will do history matching and lead to future prediction of reservoir potential. Workflow to analyze RTA in tank basis is same as well basis. Starting from FMB, typecurve, and history matching.

3.2.1 FMB and Typecurve Analysis Tank Basis

Total field production data with the well flowing bottom hole pressure is used to perform RTA in the tank basis which will result some estimation such as total connected volume of reservoir, drainage area, and reservoir performance. Tank basis FMB result are plotted in figure 9 using well-1 and well-2 as reference well in the plot. The Oil FMB plot with well-1 as reference shows there's a declining trend that indicate lack of energy felt by reservoir beside FMB with well-2 as reference not shown the declining trend. This interpretation needs to confirm by looking at typecurve. Multiphase FMB is implemented to be able doing history matching with pressure and rate in the FMB plot. Some data of static pressure data is used here as matching point for average reservoir pressure trend to lock the connected volume estimation. The connected volume of tank basis from intersection of FMB lines with x-axis come up with ±1892 Mstb and drainage area ±104 acres. This value comparable with volumetric estimation that the OOIP 1800 Mstb.

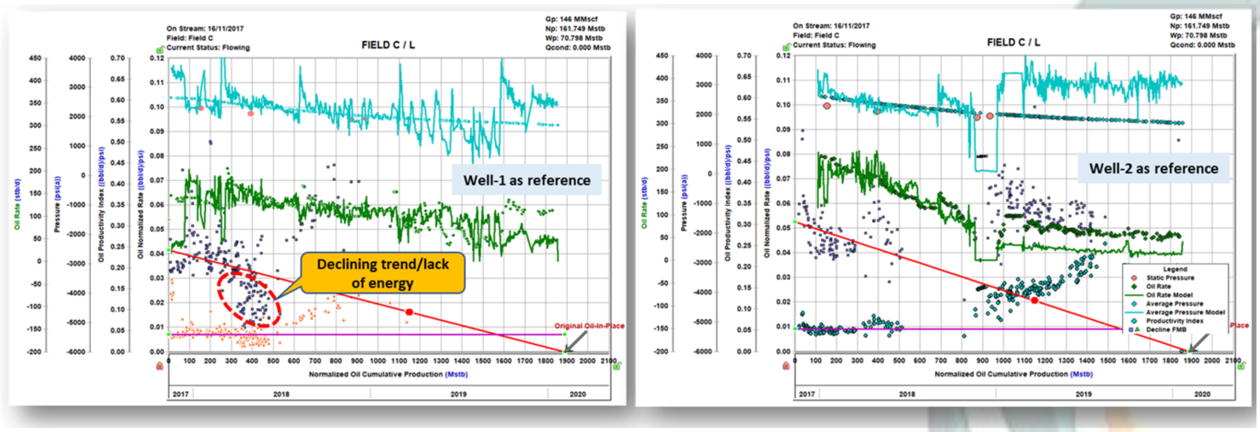

Figure 9. FMB using combined production data of Well-1 and Well-2

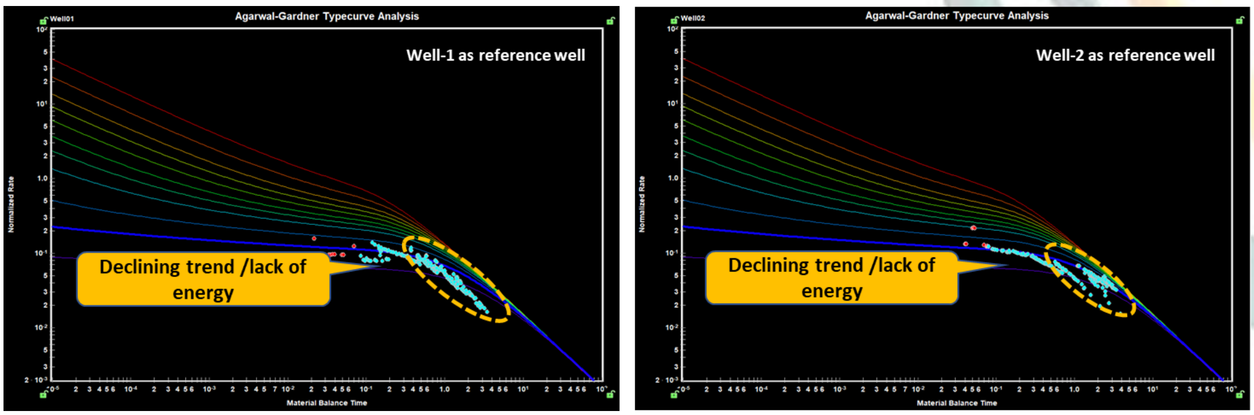

Figure 10. Typecurve Analysis using combined production data of Well-1 and Well-2

Tank basis of Typecurve plot in detail shown in Figure 10 using well-1 and well-2 as reference well in the plot. Both typecurve results shows the same result of the declining plot which has not continue to BDF line yet. The declining trend that doesn't follow the BDF line is the sign of lack of energy that felt by reservoir. Those existing well are connected and interference each other plus the energy already decrease. This plot said the performance is still in transient, so that it helps to validate the result from FMB and bubble map as shown above.

The bubble map also created to describe drainage of existing well as shown in figure 11. From this picture, the interference already exists between Well-1 and Well-2 because from material balance response they're covered each other.

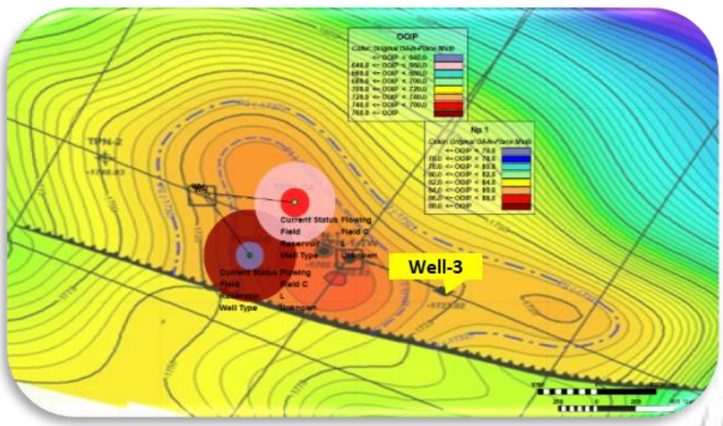

Figure 11. Bubble map of Well-1 and Well-2

3.2.2 Multi-well Model (History Matching)

In order to validate all of those interpretation that was done before, history matching is the last workflow of this study. Figure 12 shows a good match of historical rate and can perform reservoir pressure along production life of reservoir. The estimated connected volume OOIP of reservoir based on average properties and matched actual production history plot is 1926 Mstb which covered area 95 acres that pretty close with FMB tank basis result. With RF 31.79% the EUR value is 612.27 Mstb, so that the remaining reserve based on RTA result is 450.52 Mstb.

Based on volumetric analysis, P1 + P2 OOIP is 1800 Mstb, compare with connected volume result from RTA 1926 Mstb, it means that from this existing wells already covering until P2 area (Figure 1).

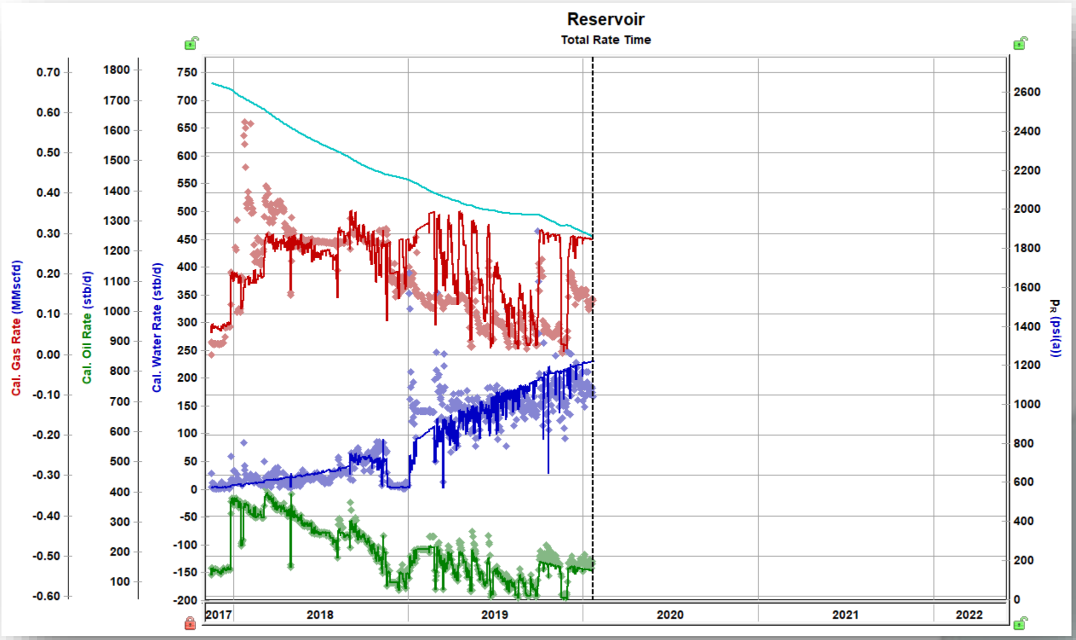

Figure 12. History Matching Reservoir

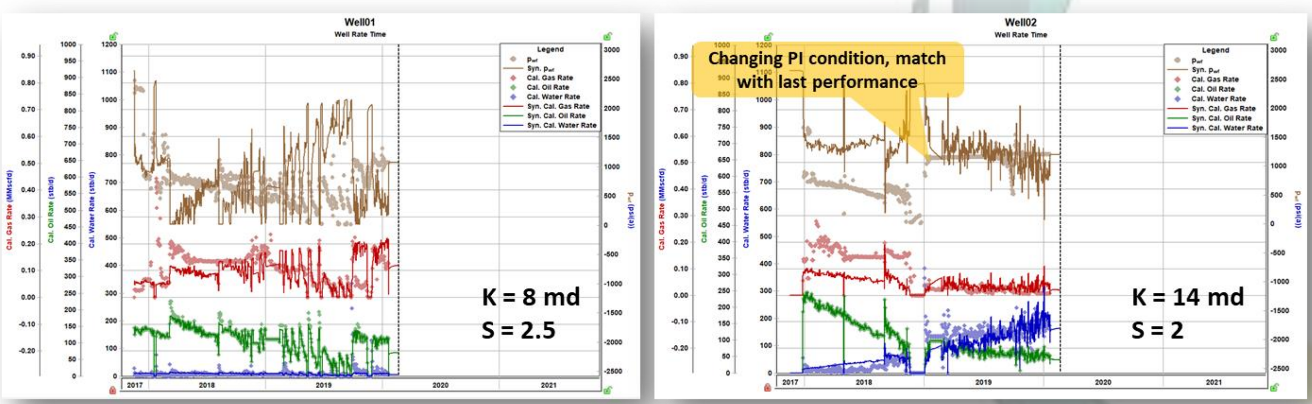

Figure 13. History Matching Well-1 (left) and Well-2 (right)

History matching of each well displayed in figure 13. The reservoir properties result of well-1 and well-2 after history matching bring the permeability value for well-1 is 8 md with skin factor 2.5 and permeability value for well-2 is 14 md with skin factor 2. On the Well-2, history matching is taken at the latest performance because there's significant changing PI due to ESP installation and water encroachment indication.

Well-3 is planned to produce for production optimization but in this paper reservoir surveillance of Layer L is investigated first before executing development plan. The conclusion from this RTA method giving information that the connected volume from material balance response of Well-1 and Well-2 already covering until P2 area. Forecast of existing well performance is conducted to know how much the recovery factor as shown in figure 14. And the resume result shown on Table 1.

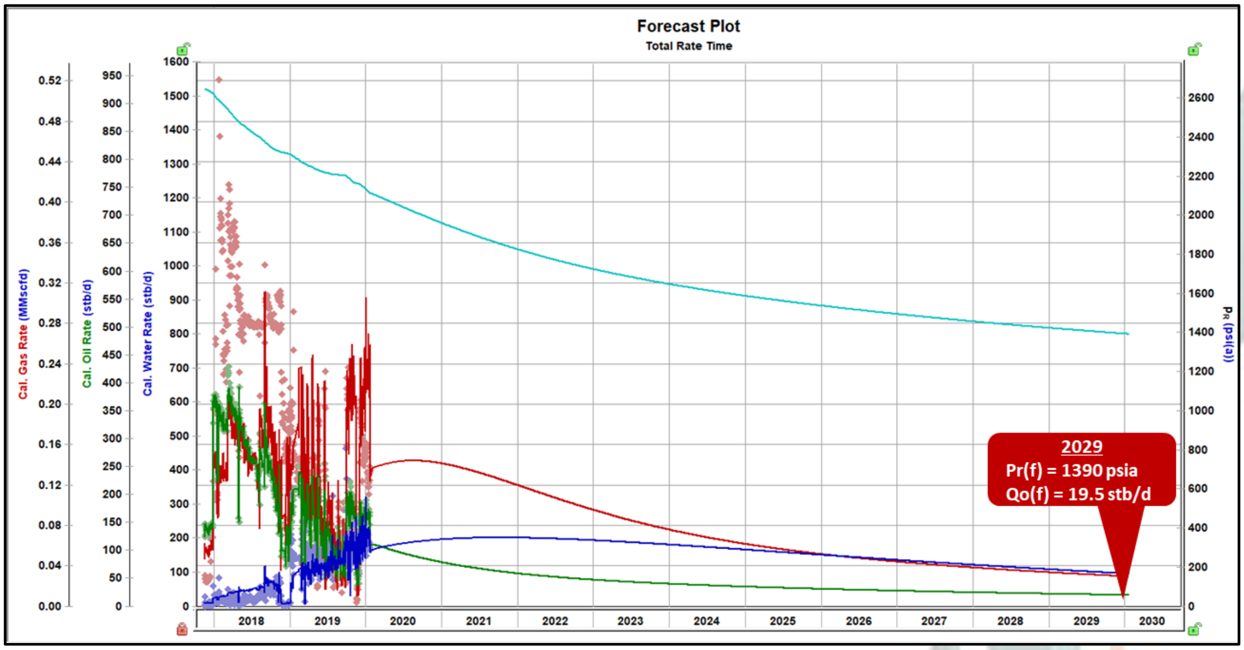

Figure 13. Forecast Result

Table 1. Forecast Summary

	Connected Volume	EUR	RRo	Np		RF
	Mstb	Mstb	Mstb	History (MStb)	Forecast (Mstb)	%
Total	1926	612.2754	450.526	161.749	151.683	16%
Well-1				85.918	124.132	
Well-2				75.831	27.551	

The forecast controlled by bottom hole pressure (Pwf) taken by latest Pwf for each well, Well-1 is 1072 psia and Well-2 is 1200 psia. Assumed that the bottom hole pressure is constant for 10 years of production. Recovery factor result if well-1 and well-2 are producing for 10 years until 2029 only covered 16% from 31.79% estimated RF. Therefore, producing well-3 would help to accelerate the production from Layer L as production optimization. This requires further analysis of updated RTA after Well-3 is produce to keep monitor the performance and identify anomaly early. However, this method could be a good, fast, and simple surveillance tool which could provide investigation and analysis regarding the unusual well and reservoir performance along production life of reservoir.

4 Conclusions

This paper shows the application of maximizing production data analysis to give an informative result of well and reservoir performance. Those analytical comprehensive approach can help reservoir and production engineers to define the boundary, understand dynamic reservoir properties, monitor the performance, and provide an input data before continuing to complex reservoir simulation. Below are the conclusions:

1. From the well basis RTA result, both FMB and typercurve plot of Well-1 and Well-2 still in transient, followed with changing well condition. Transient condition means that those well haven't reached its boundary so based on current data this layer is still potential to be developed.
2. All existing wells are in communication. Well-1 appears to have interference with well-2 starting in May-2018.
3. Total connected volume of Layer L from current RTA result is 1924 Mstb, with RF 31.79% the EUR value is 612.27 Mstb, so that the remaining reserve is 450.52 Mstb.
4. Recovery factor result if well-1 and well-2 produce for 10 years until 2029, assumed with constant Pwf Well-1 is 1072 psia and Well-2 is 1200 psia only covered 16% from 31.79% estimated RF.
5. Well-3 is potential to produce in order to help accelerate production.

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