PROCEEDINGS
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Well Testing Operation and Analysis in the Subsea Horizontal Well In Offshore Bali - Indonesia

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Abstract

SB gas field is located at a water depth of about 400 to 750 ft in the Kangean PSC area, +/- 120 km off North coast of Bali. Development drilling campaign was conducted in 2018 with target reservoir is Paciran carbonate. Follow Drill & Complete Philosophy, 3 Horizontal wells and 1 slanted well were drilled using floater – semisubmersible rig and completion phase were ran in 2 stages of Lower completion & upper completion. As part of the field development process well cleaning flow and flow after flow test had been successfully conducted after completion jobs to assist in evaluating reservoir characteristic.

There is one well namely well C whose trajectory is unique because the well must follow the actual geometry of the reservoir, so the trajectory is not perfectly straight at 90 degree.
At the heel position penetrated +/- 400 ft. good permeability carbonate, after that +/- 300 ft. penetrated low to medium permeability and the remaining +/- 900 ft. penetrated good permeability carbonate.

This paper presents the testing design, data acquisition and analysis of well C. Testing design was conducted to meet the testing objectives and operation can be run smoothly. During well testing 3 gauges are used to measured pressure in surface, seabed and bottom hole. Well testing and data acquisition successfully performed with a good result. QA and QC had been done before the analysis; it shows all 3 gauges data are in a good agreement. Initially analytical model has been used to interpret the pressure transient data, however the model result of cannot fitted the derivative pressure in the early and late time period. It's suspected due to response of different permeability of the carbonate reservoir affected pressure behavior. A numerical analysis with 3D simulation model was conducted to take into account the effect of well trajectory which penetrating multiple type of carbonate from the heel until the toe. A Local Grid Refinement (LGR) model is used to model reservoir behavior precisely. In addition well deliverability analysis was performed using flow after flow data.

The preparation including testing design and a good team work during operation is the key for this flawlessly well testing operation. The results of the analysis have helped us better understanding the reservoir characteristic and will be used to update current static and dynamic reservoir simulation model.

Introduction

SB gas Field is located at a water depth of about 400-750ft in the kangean PSC area, +/- 120 km off North coast of Bali (Figure 1). SB Field has been developed with 3 horizontal subsea wells which are placed on the top of structure. Reservoir within the SB field are pliocene age paciran lime stone. The gas is Biogenic contains 99% Methane with no H2S and CO2 the average porosity 45%, perm average varies significantly from 2-300 mD.

Figure 1. SB Field location

Well Testing Objectives

Well C is subsea horizontal well big-bore well with 7'' production tubing as a upper completion and 5.5" screen open hole gravel pack along the horizontal section. Figure 2 gives the schematic Well C completion diagram. The objectives of this well testing is to clean up the well, well deliverability analysis, reservoir pressure measurement, and estimate skin and permeability around the well.

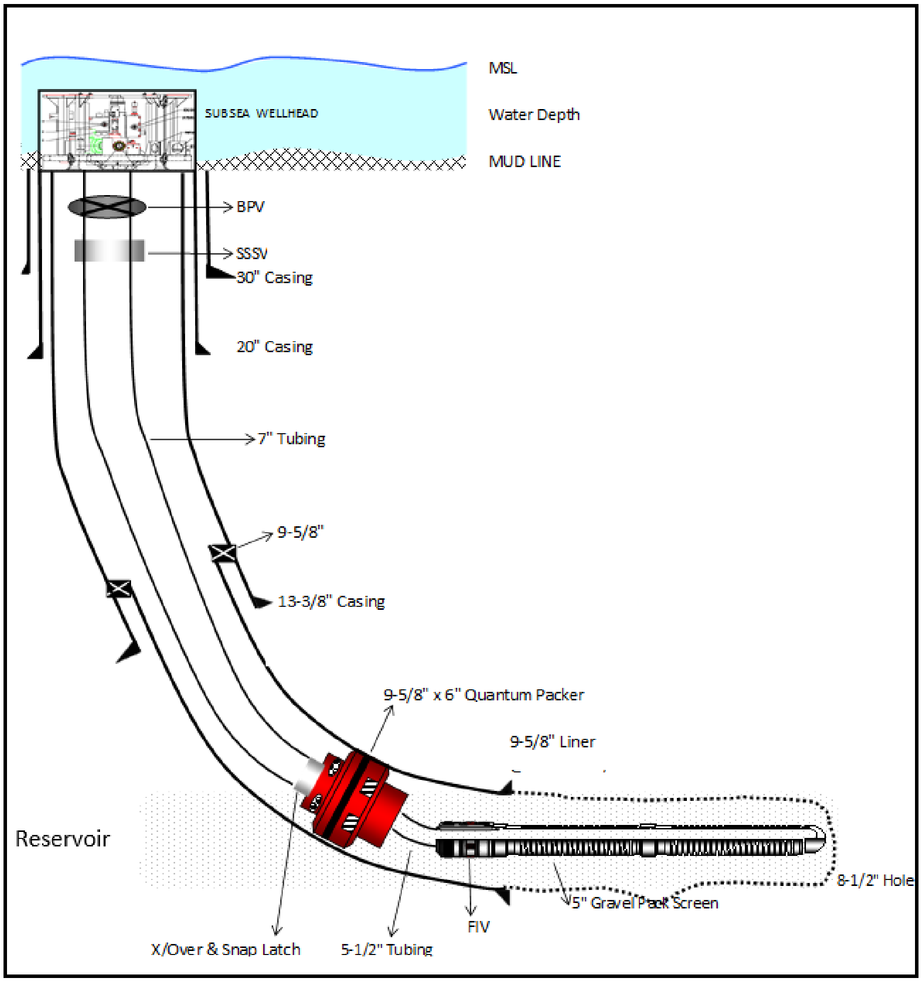

Figure 2. Well C schematic completion diagram

Horizontal Well Testing Theory

In the Log-Log plot of horizontal well model there are three important period to be consider (see figure 3 below) ; 1) Early radial flow where indicated by radial flow around the horizontal section, in this period skin and permeability around the horizontal well can be estimated, 2) Linear flow indicates by ½ slopes where in this period we can estimate the effective length of horizontal section, 3) Second radial flow indicates second stabilization or zero slope where in this period average reservoir permeability can be estimated.

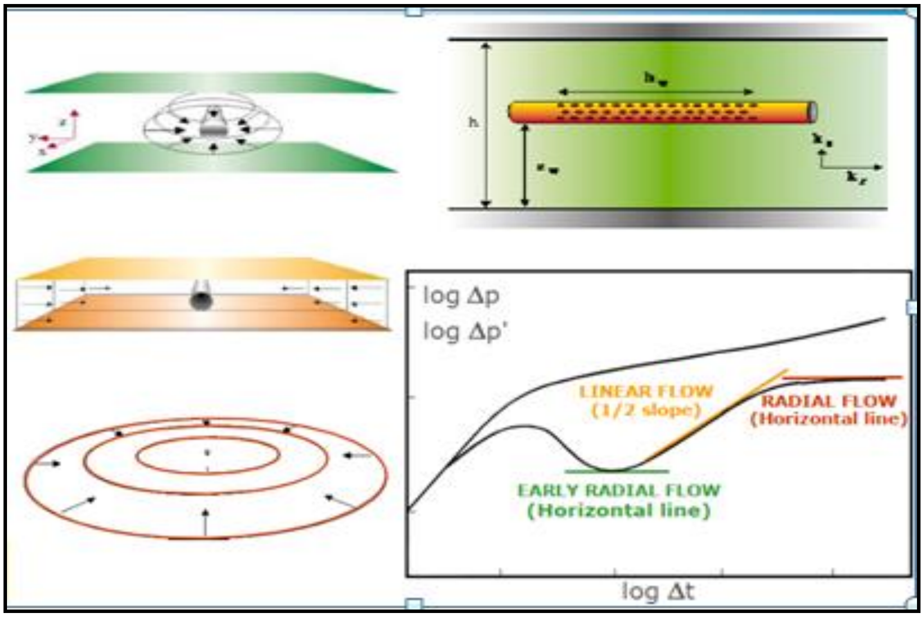

Figure 3. Log-Log plot of horizontal well showing three types of flow [1].

Well Testing Design

The Well C was drilled using a semisubmersible rig with a very expensive daily spread rig cost, well testing is conducted directly after lower and upper completion job done. So the optimum well testing design is needed to meet the testing objectives and operation can be run flawlessly. In this section will be discuss how we made the testing design.

Based on the integrated reservoir study conducted pre-drilling campaign resulted the best horizontal section placed at the sweet spot grainstone area as seen in figure 4 below. As seen on the resistivity log (Figure 4 left) the target are far enough from the gas water contact and has good permeability.

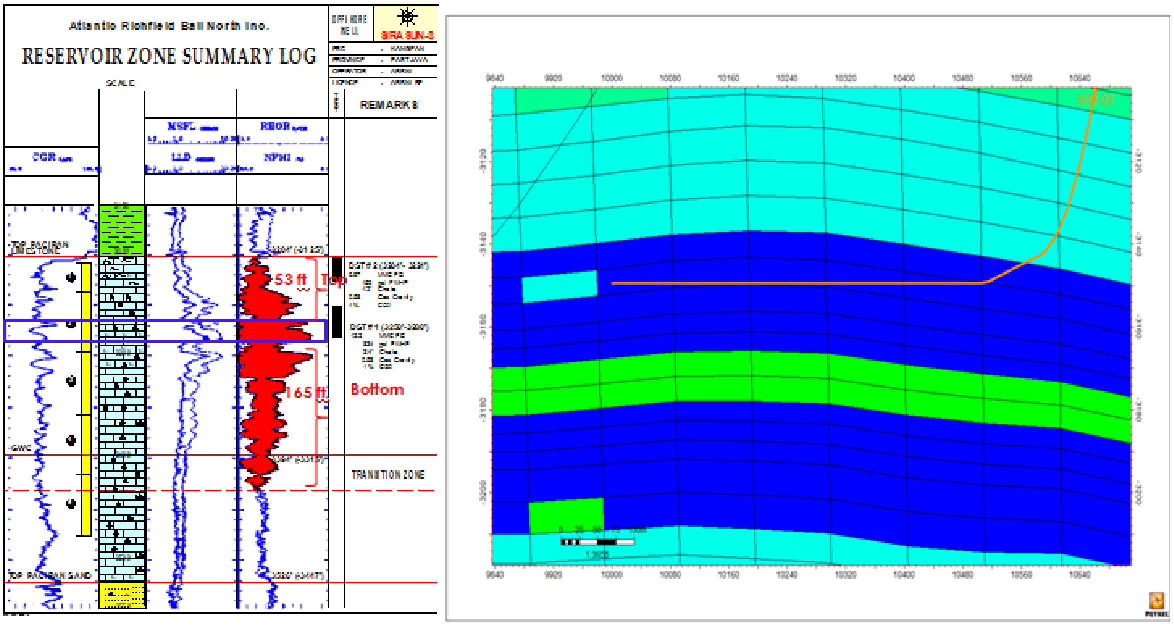

Figure 4. Well C target place the horizontal section on sweet spot area on the Upper Grainstone.

Based on those horizontal target, we proposed the multi-layer model horizontal for testing design purposes. The reservoir parameter input were based on core data and the result of DST interpretation of exploration well (Table 1)

Well C

Data Source	S3 DST			S3 Core		Reservoir Simulation Model		
Item	Facies	Perm	Skin	Facies	Perm	Facies	Perm	Skin
DST#2	WS	3.5	9.8	WS	3.6	WS+WP	4.11	0
DST#1	WP+GS	79.8	8.3	WP+GS	42.5	WP+GS	40.1	0
Horizontal Target	Tested Comingle in DST#1			GS	42.2	GS	46	0

Table 1. Reservoir parameter from exploration well

To accommodate the testing objectives a cleanup flow following by flow after flow test and ending with Long Pressure Build Up (Figure 5) period was proposed. The gas rate was derived from the DST of exploration well and maximum rate limited by maximum flow capacity of surface well testing equipment 30 MMScfd.

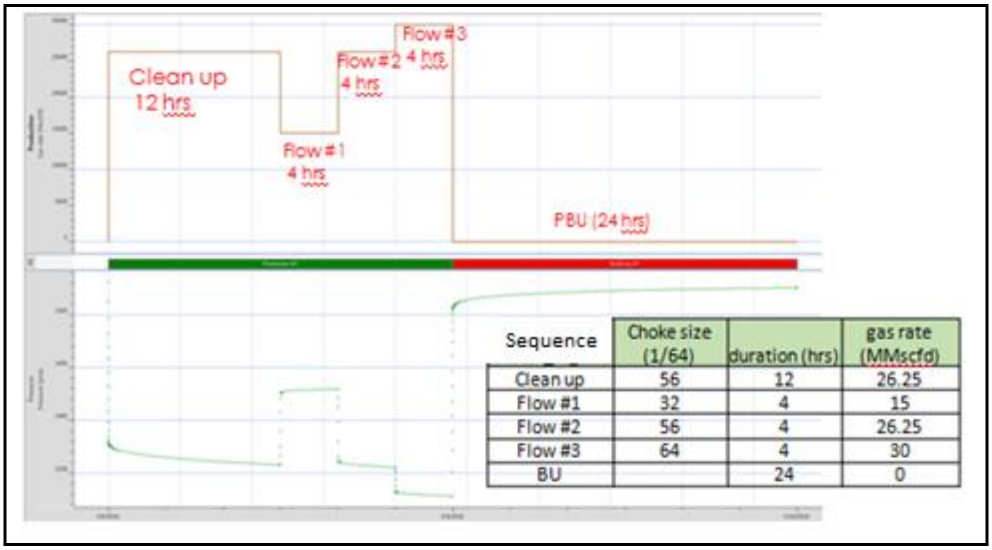

Figure 5. Well C clean up, flow after flow and Pressure Build up duration

The Constanta of wellbore storage was calculated based on available data as shown in figure 6 below.

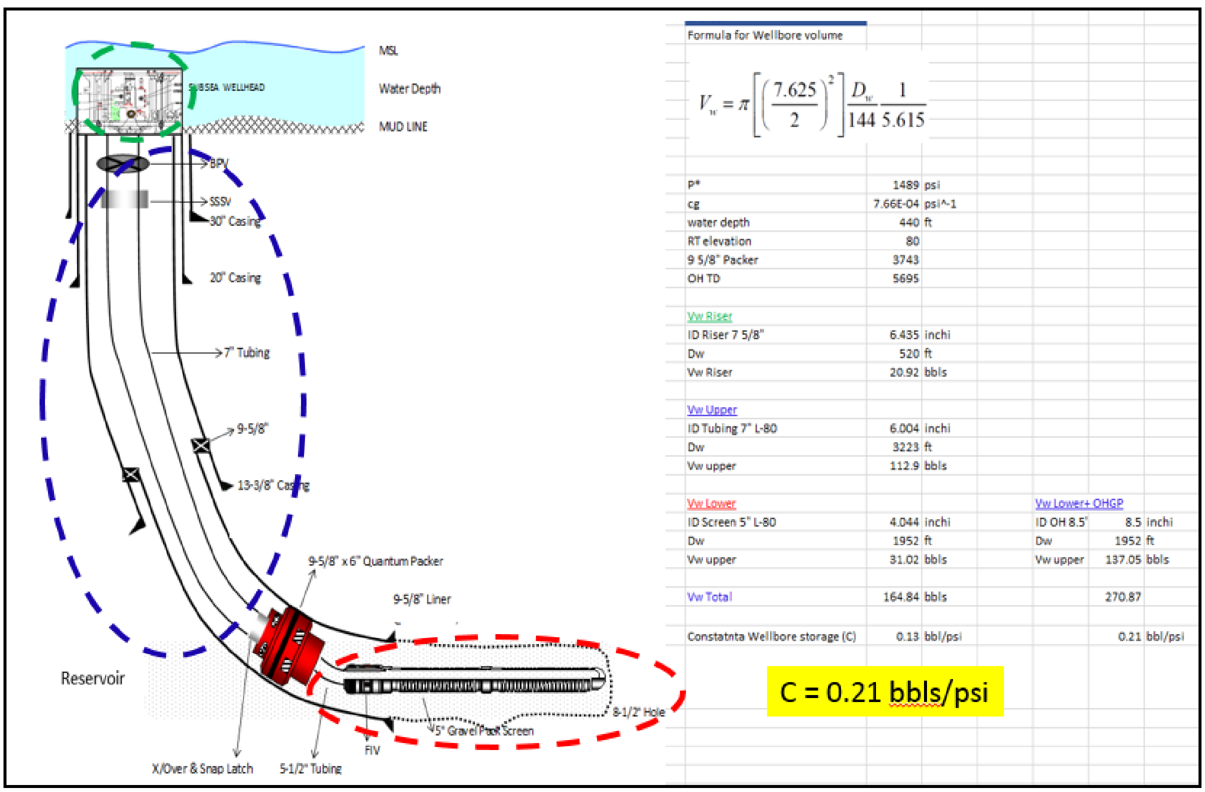

Figure 6. The Constanta of wellbore storage estimation

Firstly we make a base model with input C 0.21 Bbls/psi, permeability 250 mD based on core data in GS facies in S1 exploration well and skin factor 0 to see how the response in pressure and derivative plot. The result can be seen in figure 7, with this kind of input we can see first radial flow can be achieved lower than 1 hrs shut in period, then after 1 hr we can see linear flow until end of Shut in period.

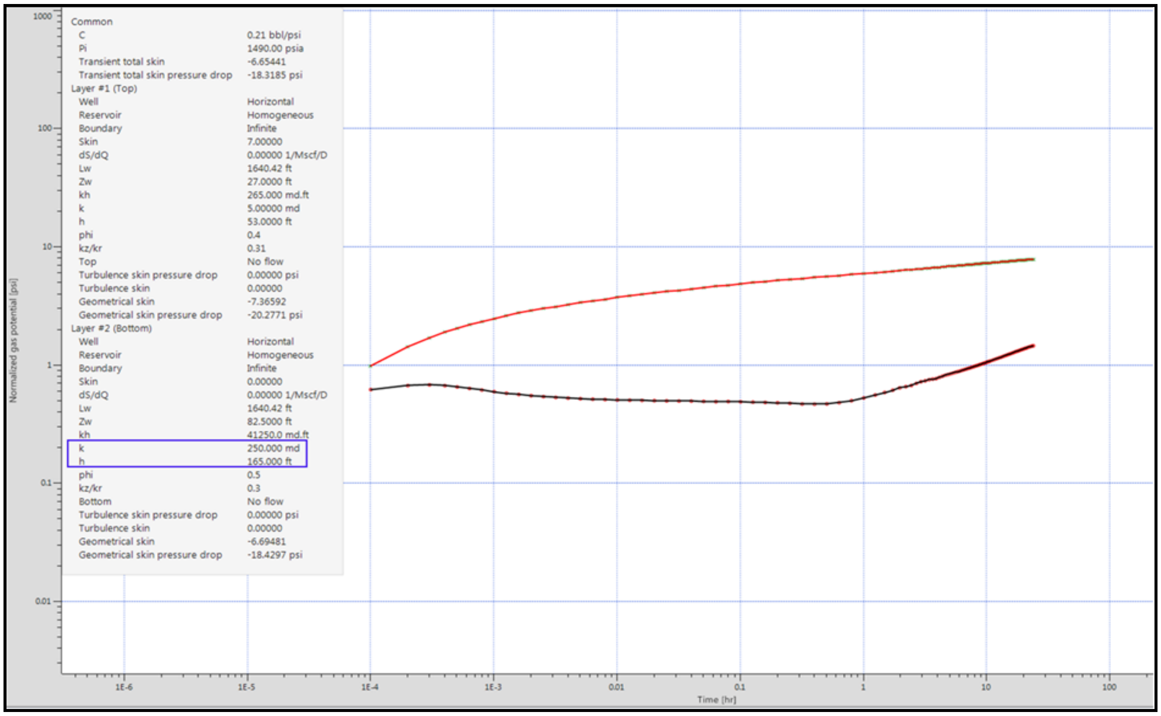

Figure 7. Log-Log plot of Base Model

Sensitivity analysis was conducted to see whether the propose time duration Well testing is enough or not to investigate early radial flow and linear flow. Table 2 shows the parameter use for sensitivity analysis.

No	Length [m]	k [mD]	s	C Bbls/psi
1	500	5	0	0.21
2		15	7	
3		50	20	
4		250		

Table 2. Reservoir parameter use for sensitivity analysis

Based on the sensitivity analysis it can be seen that 24 hrs BU was enough to investigate first Radial flow and linear flow for cases with permeability ranging from 15 to 250 mD and skin factor 0 and 7 (Figure 8 Top). Figure 8 bottom shows that the case with combination high skin value 20 and low permeability value 5 to 15 mD could not be able to investigate linear flow regime.

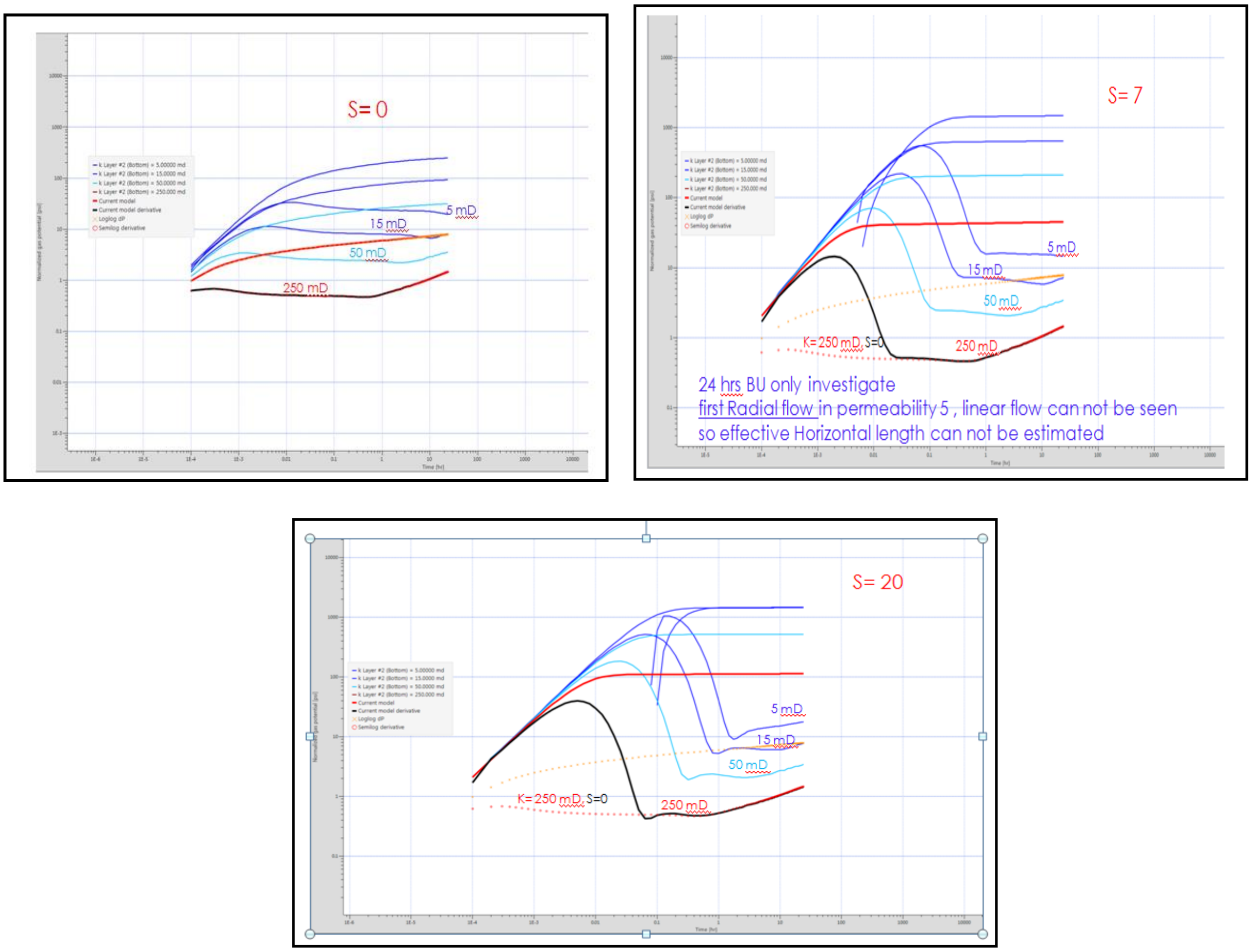

Figure 8. Log-Log plot of all sensitivity cases

Data Acquisition and Analysis

Well C actual trajectory clearly shows the well was not perfectly straight at 90 degree, but follows good facies quality in this structure as shown in Figure 9 below.

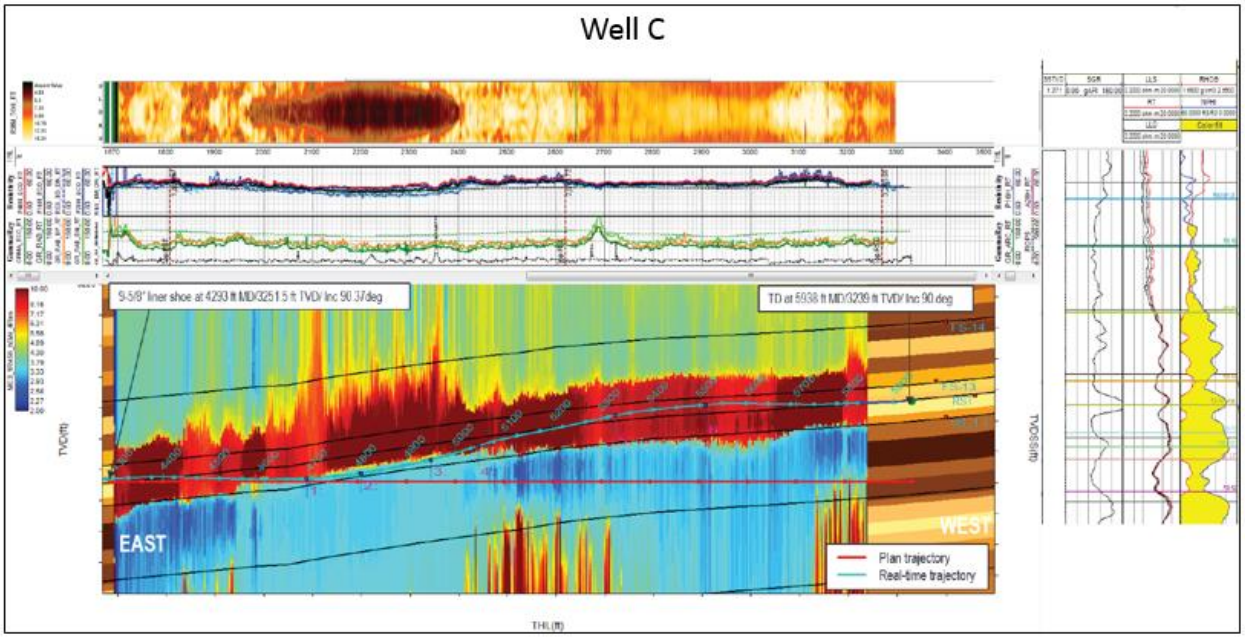

Figure 9. Well C proposed trajectory (red line) vs actual trajectory which follow the good facies quality or good resistivity (light blue line) overlaid with resistivity log.

During well testing data acquisition there were 3 gauges deploy in the well C. Of three gauges only one located on surface (deck area), the others are located on the sea bed and bottom hole close to reservoir (Figure 10). The gauges which located near the sea bed and the surface are real time basis so very helpful to monitor the pressure during well testing. The bottom hole gauge was deploy using Coiled Tubing. Coiled Tubing also be used to unload the completion fluid using Nitrogen and open the formation isolation valve (FIV). To optimize CT tripping time we combine the BHA which able to do all jobs using the same BHA. After sufficient completion fluids unloaded then the well able to flow and continue to clean up flow for 12 hours. The Main flow which consist of three different gas rate with 4 hours duration each then continue by 24 hours Pressure Build Up.

The reading from all the gauges is very important in quality check the data. Figure 11 shows a comparison between three gauges during well testing, all pressure data are in a good agreement hence we are confident use this data for the interpretation and analysis. The operation of well testing was successfully performed. The preparation including testing design and a good team work during operation is the key for this flawlessly operation.

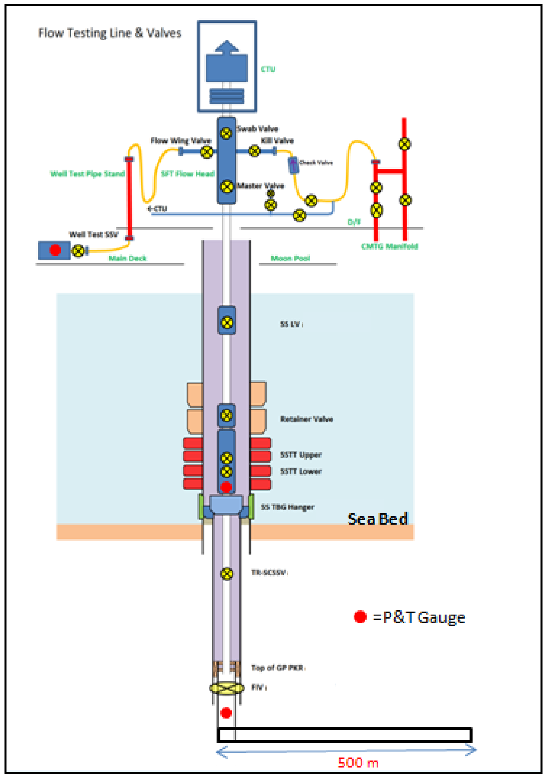

Figure 10. Well C Pressure gauges location

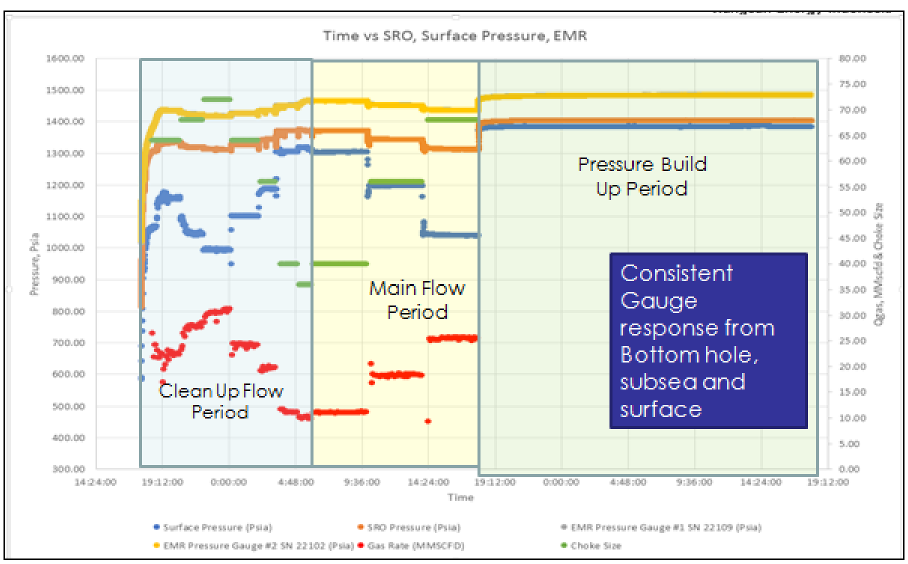

Figure 10. The comparison between three gauges during well testing, all pressure data are in a good agreement.

After QC and prepare the data done then load the input data into commercial well testing analysis software. The Analytical model was used in this interpretation; the result can be seen in figure 11-12 below. Historical pressure is good matched with the model, from Log-Log plot derivative curve cannot be fitted in the early and late period. Its suspected cause by heterogenic facies penetrated in this horizontal section. Moreover from the derivative curve indicated early radial flow felt on 0.01 hours then follow by linear flow. Hence it can be conclude that the testing design duration was enough to meet all testing objectives.
At the end of testing shows pressure derivative curve cannot be matched properly its might be analytical solution unable to model the effect of heterogenic facies on the pressure response properly.

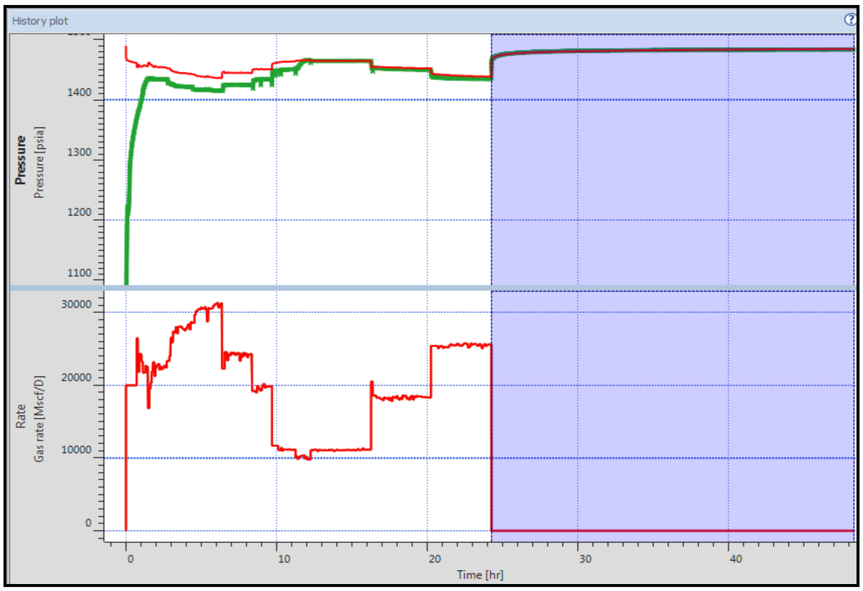

Figure 11. Pressure Historical data (green line) matched with the model (red line)

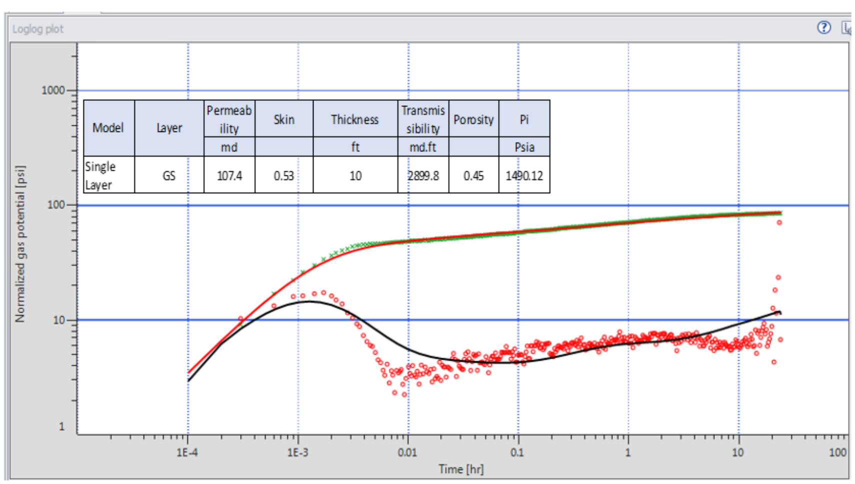

Figure 12. Log Log Plot Well C, model (black line) and actual data (red dot).

In order to solve this matter a numerical model using 3D reservoir simulation was proposed. Local Grid Refinement (LGR) method was then used to model the heterogeneity of limestone on lateral section. The schematic LGR model is shown on figure (13) below.

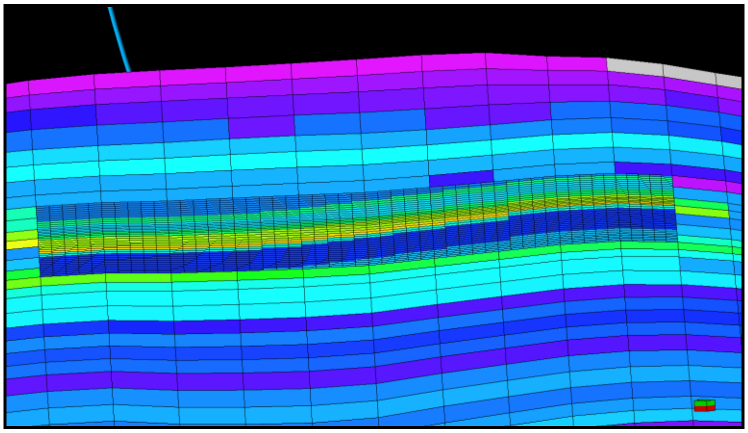

Figure 13. LGR model on well C lateral section

After using LGR Model and run using reservoir simulation, the model can be matched with actual data (Figure 14). With LGR model the heterogeneity effect can be modeled precisely. Figure 15 shows the pressure transient in the LGR and Global grid during well testing well C

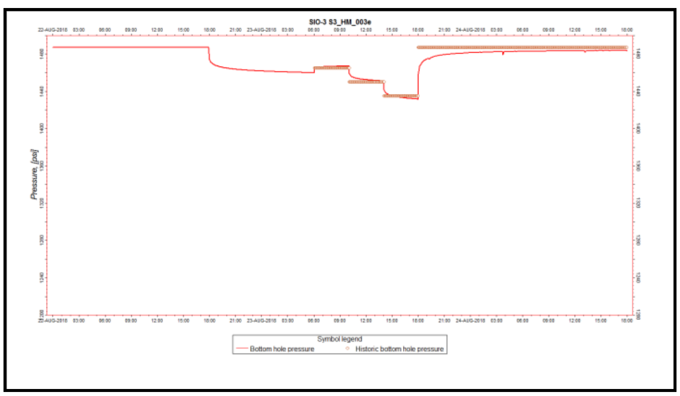

Figure 14. BHP matching with LGR Model

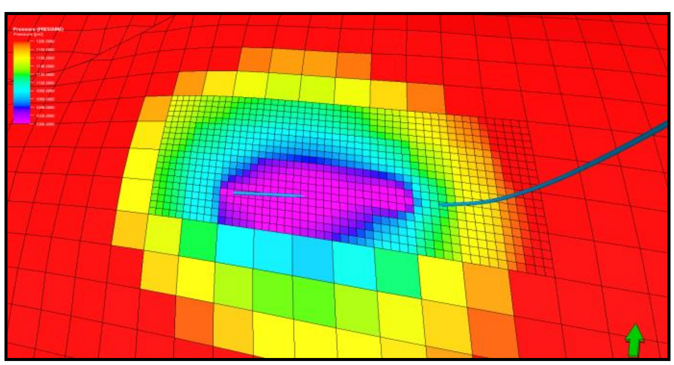

Figure 15. Pressure depletion in the LGR and Global grid during well testing well C.

Well deliverability analysis also be conducted with the input data from Main flow period. Figure 16 shows the IPR (Inflow Performance Relationship) curve of well C matched with Main flow period data (red dot). Before the well put on production, we performed commissioning test to test well deliverability without facility limitation (green triangle). The IPR comparison indicated well testing and commissioning test are in a good agreement. We can conclude that even with limitation data from well testing due to capacity limit on surface well testing, as long as the data are valid well deliverability can be calculated precisely.

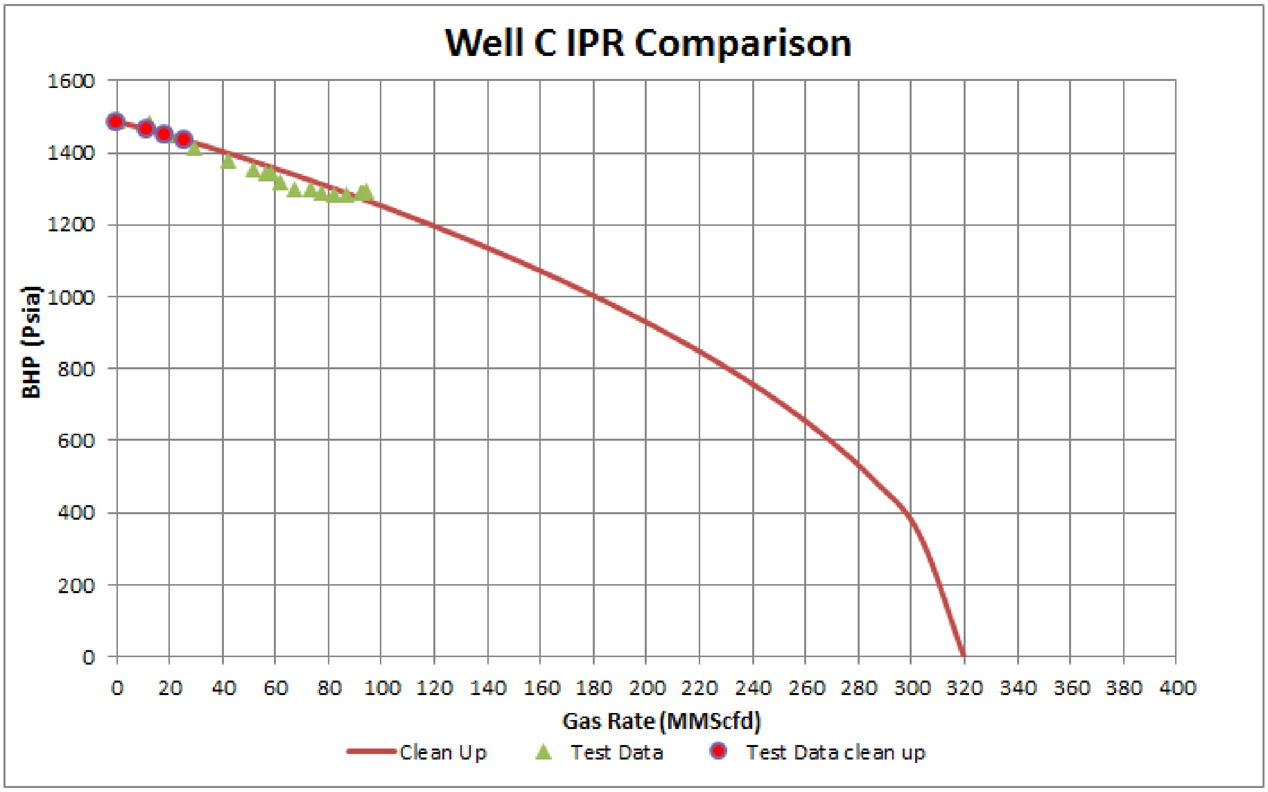

Figure 16. IPR comparison well testing and commissioning test are in a good agreement, red dot is well testing data, and green triangle is commissioning data.

Conclusions

1. The preparation including testing design and a good team work during operation is the key for this flawlessly well testing operation.
2. A Comprehensive testing design give us good well testing result.
3. Quality assurance and check the welltesting data are very important before conduct the analysis.
4. Analytical model well testing analysis has limitation to model reservoir heterogeneity.
5. Local Grid Refinement (LGR) model able to model reservoir heterogeneity along lateral section and model the pressure transient during testing precisely.
6. The results of the analysis have helped us better understanding the reservoir characteristic and will be used to update current static and dynamic reservoir simulation model.

References

1. Lee John., Well testing Fundamental: Elsevier Publishing Company, 1985.

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