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New Perspective to Unlock the Potential of Lenses Gas Reservoir in Indonesia Using Integrated Reservoir-Production System

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ABSTRACT

The potential of lenses gas reservoirs has become an interesting target in meeting energy needs in Indonesia. As the next energy backbone in Indonesia, the most suitable strategy needs to be developed for maintaining productivity and maximizing gas recovery. Developing gas reservoir can be challenging due to several reservoir and fluid characteristics. The development strategy must use a special production scenario and an optimized completion design. This paper discusses the process of development strategy determination for lenses gas reservoir by using commercial software. The lenses gas reservoir consists of four interest zones which penetrated by one offshore well. Each interest zone has different reserve and deliverability. The available data used are PVT, petrophysics, tubing diameter, and production parameters. By inputting these data into the software, the well recovery can be estimated. Various production scenarios are tested until a scenario is selected as the suitable production method. The production method selected is commingled using scenario 1, which to produce all lenses together with considering plateau rate 15 MMSCFD for 10 years production. Referring to the suitable production method, optimized completion designs are also selected (wellhead pressure and tubing diameter). The wellhead pressure selected is 150 psig, while the tubing diameter selected is 4.5-inch.

Keywords: potential of lenses gas reservoir, development strategy, production method, optimize completion

I. INTRODUCTION

The gas reservoir potential in Indonesia has been intensely developed to meet the domestic demand for fossil fuel. Gas reservoir development has become an interesting solution to overcome the decline in petroleum production and will be the next energy backbone for Indonesia. However, there are several challenges found in developing gas reservoirs such as high CO_2 content, high H_2S content, deep reservoir, etc. One of the gas reservoirs that is targeted to be developed is the lenses gas reservoir. The potential of lenses gas reservoirs is proved to be great in Mahakam Field. Lenses gas reservoir has a small elliptical shape, containing low reserve gas pockets with a typically short production life. To maintain productivity and maximize gas recovery, a more complex completion design and special production scenario are necessary.

This paper discusses the determination of the development strategy of a lenses gas reservoir consisting of four zones of interest, using commercial software. The project's main objective is to create a development strategy that allows us to obtain a great value of recovery while keeping the production rate as stable as possible. Other than that, due to the characteristic differences of each interest zone (reserve and deliverability), then an optimized completion design is also determined in this project.

BASIC THEORY

Material balance is one of the methods to determine the initial hydrocarbon in place, calculating water influx, and predicting reservoir pressure (Craft, et.al., 1991). The basic concept that is used in material balance is the same as volume balance which stated that the cumulative production, expressed as an underground withdrawal, is equal to the volume expansion of the fluid when the reservoir pressure is decreasing (Permadi, 2016). The general expression of material balance can be seen below:

$$N_p\left[B_o + \left(R_p - R_{so}\right)B_g\right] = N\left[\left(B_o - B_{oi}\right) + \left(R_{soi} - R_{so}\right)B_g\right] + mNB_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) + (1+m)NB_{oi}\left(\frac{S_{wc}c_w + c_f}{1 - S_{wc}}\right)\Delta p + \left(W_e - W_pB_w\right) \dots\dots [1]$$

For gas reservoir, the equation above can be reduced as follow:

$$G = \frac{G_p B_g}{B_g - B_{gi}} \dots\dots [2]$$

By considering the reservoir temperature is remain constant, the gas material balance then can be simplified to:

$$\frac{p}{z} = -\frac{p}{z_i G} G_p + \frac{p_i}{z_i} \dots\dots [3]$$

Inflow performance relationship (IPR) is a relationship between flowing bottom hole pressure and production rate as the fluids move from reservoir into the wellbore, which can be used to describe the well productivity (Guo, et.al., 2007). This relationship usually presented in curve form. The correlation to model the IPR can be derived empirically and analytically. To show the production performance of gas well, the empirical Rawlins and Schellhardt backpressure equation is often used (Ikoku, 1992). The equation proposed by Rawlins and Schellhardt is define as follow:

$$q_g = C\left(\overline{p_R}^2 - p_{wf}^2\right)^n \dots\dots [4]$$

Where C is the flow coefficient and n is the deliverability exponent. The deliverability exponent is defined as the inverse of the curve slope, with the n values ranging from 0.5 to 1.0. In terms of pseudo pressure, Rawlins and Shellhard's equation can be written as follow:

$$q_g = C\left[p_p(\overline{p_R}) - p_p(p_{wf})\right]^n \dots\dots [5]$$

Tubing performance relationship (TPR) is a relationship between flowing bottom hole pressure and production rate as the fluids move from wellbore to the surface through tubing. TPR depends on many variables such as tubing diameter, wellhead pressure (WHP), gas-liquid ratio (GLR), etc (Guo, et.al., 2007). TPR curve is usually overlayed with IPR. Several TPR models have been developed to analyze multiphase flow inside tubing such as Fancher & Brown, Duns & Ros, Hagedorn & Brown, Beggs & Brill, etc. The intersection between IPR and TPR curve is called the operating point at which a well can produce at a given pressure and rate.

Completion system is an important component after the well is drilled. Its purpose is to connect the reservoir to the surface or prepare the well for production (Bellarby, 2009). The basis considerations in designing well completion system are the lithology, fluid properties, and fluid characteristics. Well completion process involves preparing the bottom hole to the required specification, running in the production tubing, perforating and stimulating the well, producing single separate zone or commingle multizone, and installing artificial lift.

II. METHODOLOGY

The workflow of study carried out in this project can be seen in Figure 1. All the field data are input to the commercial software. This action aims to define the reservoir characteristic by assuming that all the field data available already represent the actual reservoir condition. After all data assigned to the commercial software. Then we construct IPR for each reservoir lenses. Based on the data availability and reservoir characterization, the production model that is suitable for all the four lenses reservoir is C and n method. The IPR curve can be seen in Figure 2, Figure 3, Figure 4, Figure 5.

The next step is to construct the tubing performance relationship (TPR). This carried out by input several data such as measured depth, true vertical depth, and the diameter of casing and tubing. The most suitable correlation for each of the lenses gas reservoir is selected based on the standard deviation value. Beggs and Brill's correlation gives the lowest value of standard deviation, therefore Beggs and Brill correlation is selected as the most suitable correlation for each of the lenses gas reservoir. Figure 6, Figure 7, Figure 8, Figure 9 show the IPR/TPR curve. Run prediction is done by integrating all the results obtained from the previous step into another commercial software. The well design to run the production prediction can be seen in Figure 10. This production prediction is run for 10 years with time step per year. Several production methods/scenarios were made to find the best production method that gives the biggest gas recovery (Table 5). After the best production method is obtained, we do sensitivity on the wellhead pressure and tubing diameter to increase the gas recovery more.

CASE STUDY

The well investigated in this paper is located offshore in Indonesia. The development strategy targets four lenses with the same type of fluid. All the four lenses are gas reservoir and produced through 4.5-inch tubing. The well is produced with plateau rate 15 MMSCFD for 10 years. Some of the assumptions used in this project study are:

- Constant CGR and WGR in prediction
- No sand problems and water coning

Lenses 1
Lenses 1 is a gas reservoir with 1121 psi reservoir pressure. The initial gas in place value of this lenses is 19.3 BSCF and produced at 2500 – 2515 ft depth. Other reservoir properties of this lenses can be seen in **Table 1**.

Lenses 2
Lenses 2 is a gas reservoir with 1176 psi reservoir pressure. The initial gas in place value of this lenses is 20.7 BSCF and produced at 2623 – 2638 ft depth. Other reservoir properties of this lenses can be seen in **Table 2.**

Lenses 3
Lenses 3 is a gas reservoir with 1209 psi reservoir pressure. The initial gas in place value of this lenses is 11.05 BSCF and produced at 2721 – 2737 ft depth. Other reservoir properties of this lenses can be seen in **Table 3.**

Lenses 4
Lenses 4 is a gas reservoir with 1242 psi reservoir pressure. The initial gas in place value of this lenses is 22.1 BSCF and produced at 3115 – 3133 ft depth. Other reservoir properties of this lenses can be seen in **Table 4.**

III. RESULT AND DISCUSSION

3.1. Production Method Selection

As mentioned before several production methods/scenarios are made (Table 5) to estimate which production method that gives the best recovery. The production period prediction starts in 2021 until 2031. Figure 11 is the production prediction result for base scenario. The result shows that by opening the choke fully without considering any constraint, the well cannot maintain a stable production rate for 10 years or the production rate drops quite fast.

The result of scenario 1 production prediction can be seen in Figure 12. From the result, we may know that this type of scenario can maintain the well production rate of 15 MMSCFD for almost 10 years. The production rate by the end of the production period (2031) has decreased up to 31% from the initial rate. But it is still considered acceptable because the decrease does not exceed 40%. The decrease limit of 40% is an assumption value given. This value is used because it is relatively small. For scenario 2 and scenario 3 the production prediction as shown in Figure 13 and Figure 14. By looking at the production prediction result, the well cannot maintain the production rate of 15 MMSCFD for 10 years. As for scenario 2, the production rate has decreased up to 58% from the initial rate by the end of production period (2031). While for scenario 3, by the year 2026 the production rate has decreased up to 72% from the initial rate. The last production prediction is for scenario 4 (Figure 15). From the result, the well production rate goes up and down really fast throughout the production period.

In the production prediction result of base scenario, scenario 1, scenario 2, and scenario 3 it is evident that the lenses 3 production rate drops more significantly than other lenses. This indicates the occurrence of cross flow. The solution can be done to overcome this problem is to produce the well with intermittent method or produce the fluid through two production tubing consisting of short string and long string.

The most suitable production method chosen is one that can maintain a stable production rate preferably during the whole production period, with a production rate decrease allowed below 40%. It is important to be able to keep the production rate stable during the production period to prevent an over-design of surface facility specification and can decide an optimum surface facility. Aside from the production rate, the well recovery (Table 6) is also considered as the basis of production method selection. Therefore, the production method chosen is scenario 1 which is to produce all four lenses together (commingled) with constraint 15 MMSCFD production rate for 10 years. There are several advantages and disadvantages of commingled production method. The advantages are accelerating production, relatively more economical, and allow reservoir with low liquid rate to be produced. While the disadvantages are the occurrence of cross flow (if the pressure between reservoirs significantly differs) and interactions between fluids and rock (if the fluid type and geological formation between reservoirs different).

3.2 WHP and Tubing Diameter Sensitivity

Wellhead pressure and tubing diameter sensitivity are done by using scenario 1 as the production method. The initial wellhead pressure setup for scenario 1 is 285.3 psig, then the wellhead pressure is reduced from 285.3 psig to 150 psig. Lowering/reducing the wellhead pressure consequently increases the production rate or in this case can maintain the well production rate of 15 MMSCFD longer (Figure 16). More than that, the reduction of wellhead pressure shows an increase in the well recovery. The well recovery results are tabulated in Table 7. From the result, we know that using 150 psig wellhead pressure improved the well recovery to 74% from the initial setup wellhead pressure.

As for tubing diameter sensitivity, the initial tubing diameter setup for scenario 1 is 4.5-inch. Then the sensitivity carried out by reducing the tubing diameter from 4.5-inch to 2.5-inch. The main purpose of reducing the tubing diameter is to increase the production rate, so then the well can maintain the production rate of 15 MMSCFD longer. Figure 17 shows the production prediction result for various tubing size. It is noted that reducing the tubing diameter cannot keep the 15 MMSCFD of production rate longer. This happens probably due to the volume of tubing that is too small so the tubing incapable to deliver a great amount of produced gas. The well recovery result from tubing diameter sensitivity is in Table 8. Therefore, the most optimum size of tubing diameter is the same as initial setup which is 4.5-inch.

IV. CONCLUSION

The conclusions of study carried out in this project are:

1. The development strategy determination technique carried out in this paper able to yield the most suitable production method for the lenses gas reservoir, after the production prediction is obtained.
2. The suitable production method obtained is commingled by using scenario 1, which is all lenses produce together with considering plateau rate 15 MMSCFD for 10 years.
3. The cross-flow problem is overcome by producing the well with an intermittent method or producing the fluid through two production tubing.
4. The wellhead pressure that gives the greatest well recovery is 150 psig.
5. The tubing diameter that gives the greatest well recovery is 4.5 inch.

RECOMMENDATION

The development strategy determination technique still needs further improvement. In this project due to lack of data, many assumptions are being used. Aside from that, the software's inability to consider more complex constraint limits the production method that can be predicted. In future work, complete data such as well completion data and DST data will give more reliable development strategy. A surface facility design also can be added to give more comprehensive development strategy.

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NOMENCLATURE

WHP = Wellhead Pressure (psig)

C = Flow coefficient (MSCFD/psi^{2n})

n = Deliverability exponent

CGR = Condensate Gas Ratio (STB/MMSCF)

WGR = Water Gas Ratio (STB/MMSCF)

AOF = Absolute Open Flow (MMSCF/Day)

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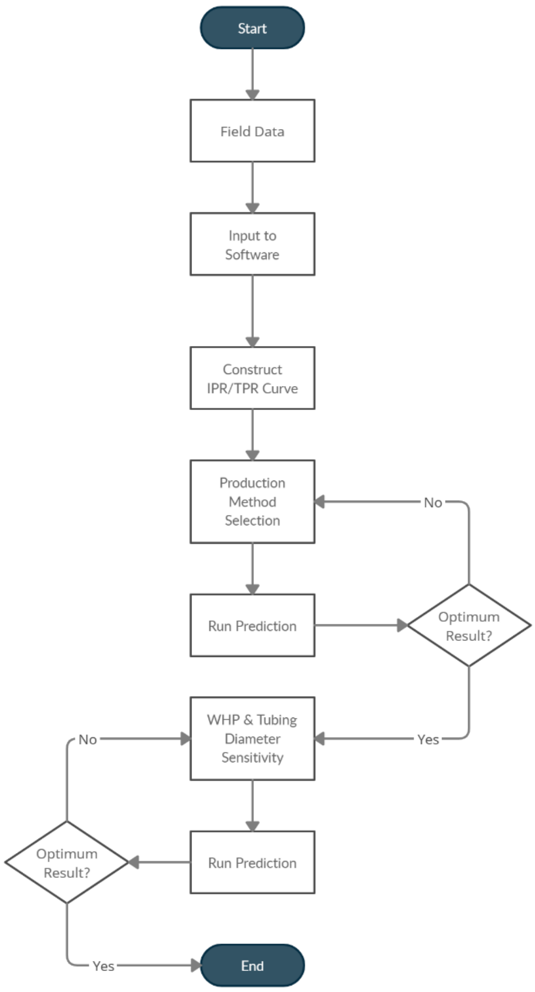

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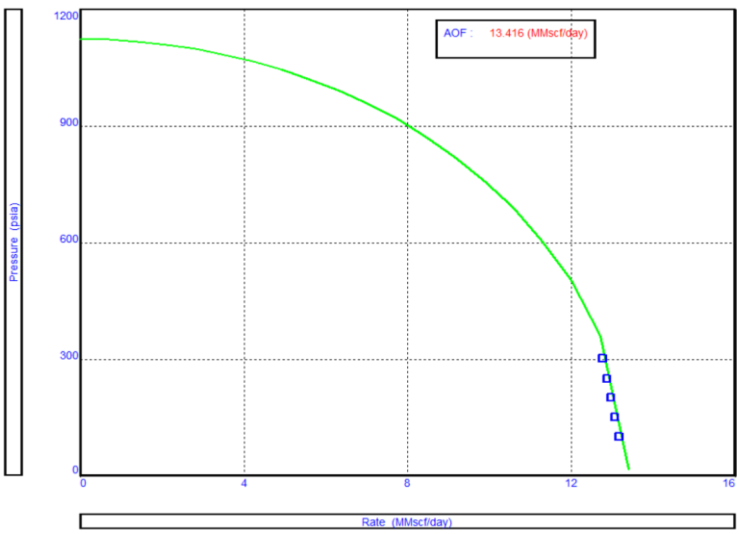

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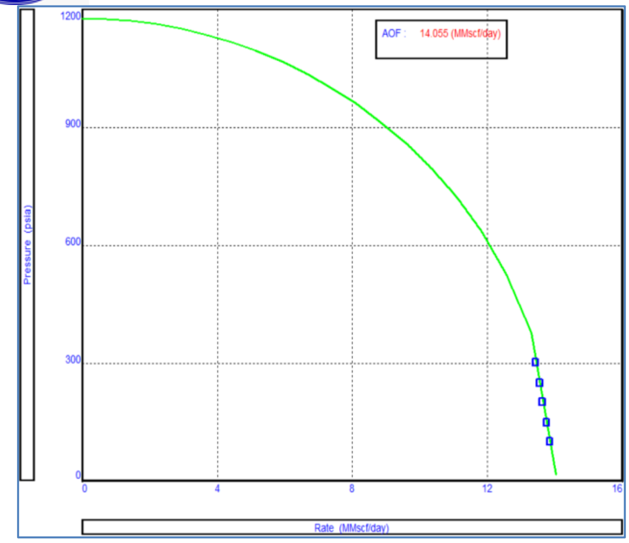

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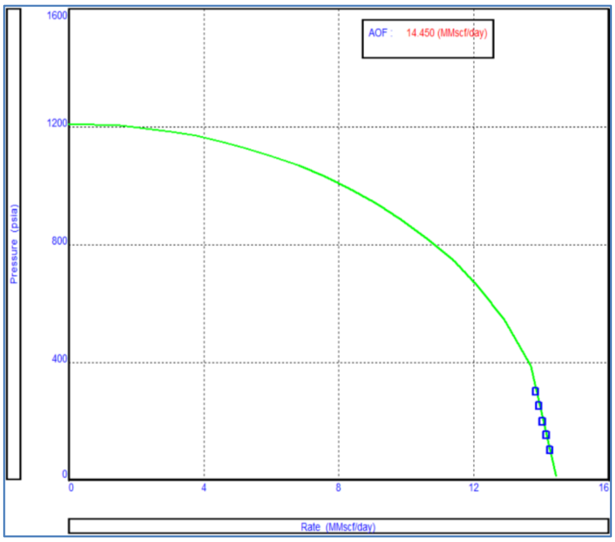

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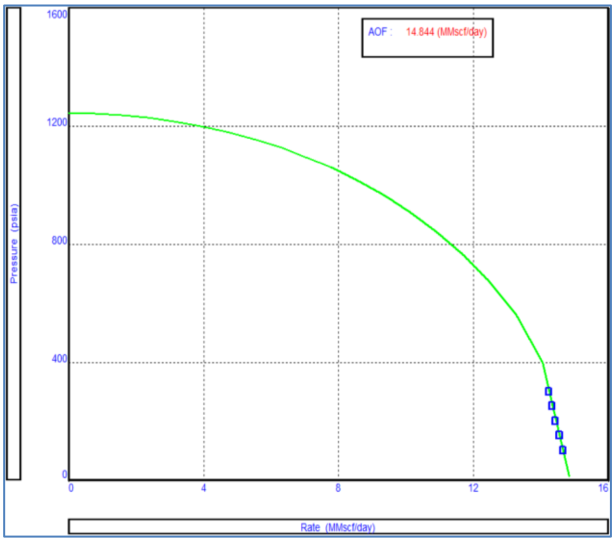

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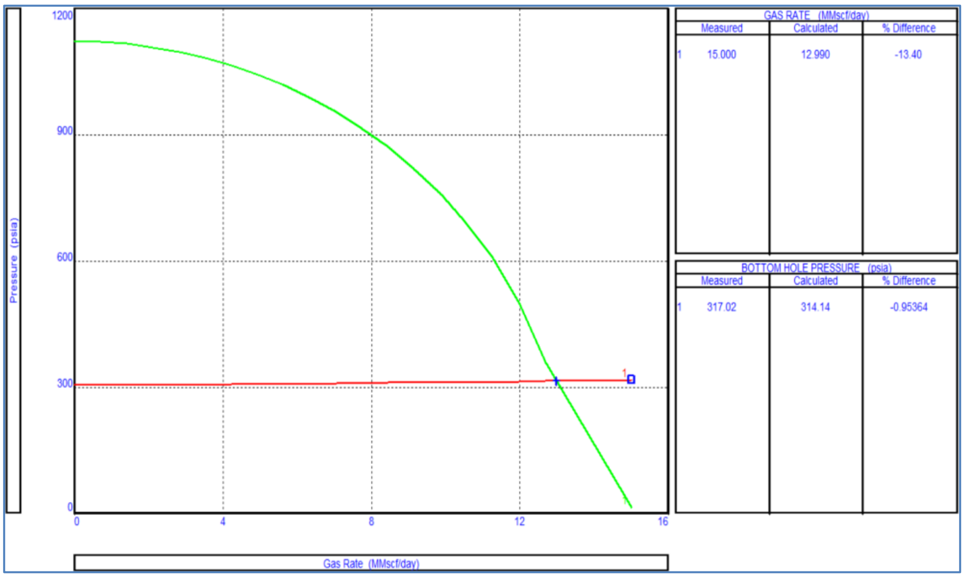

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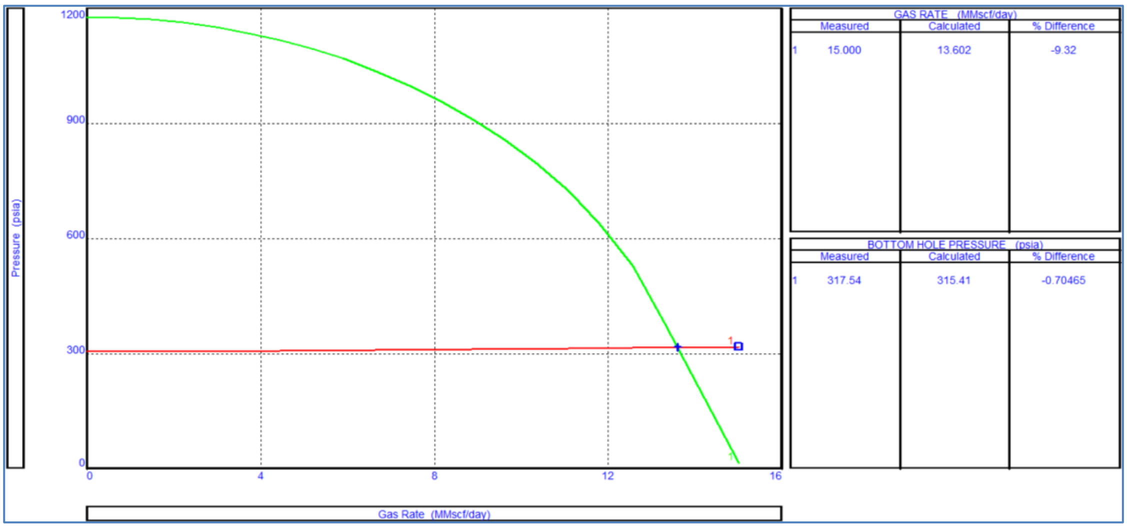

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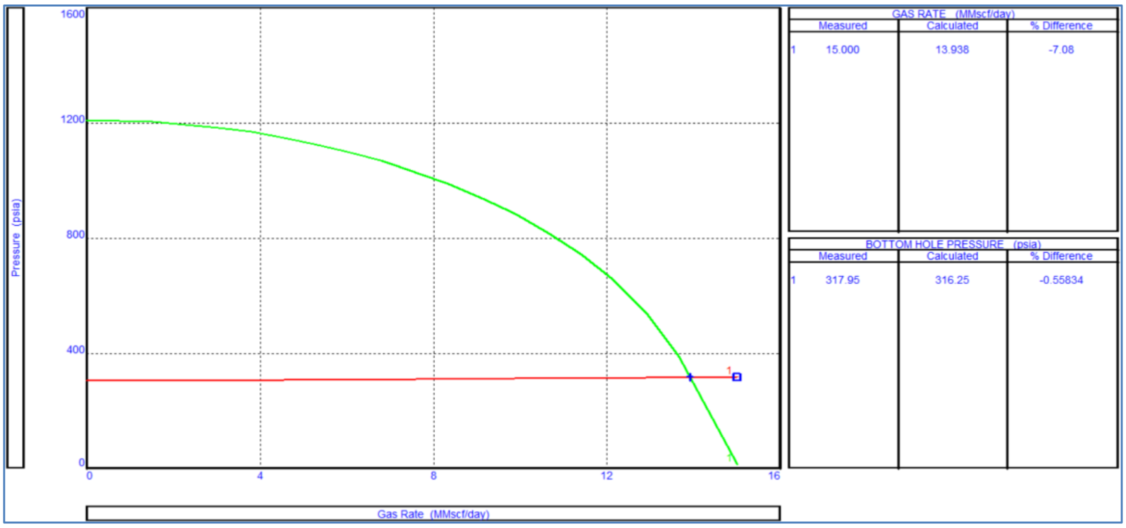

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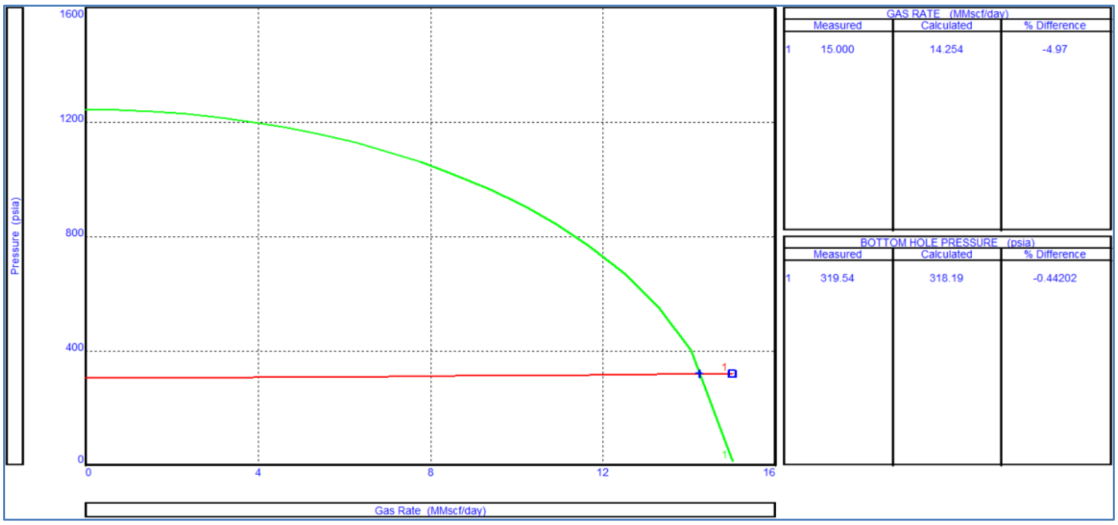

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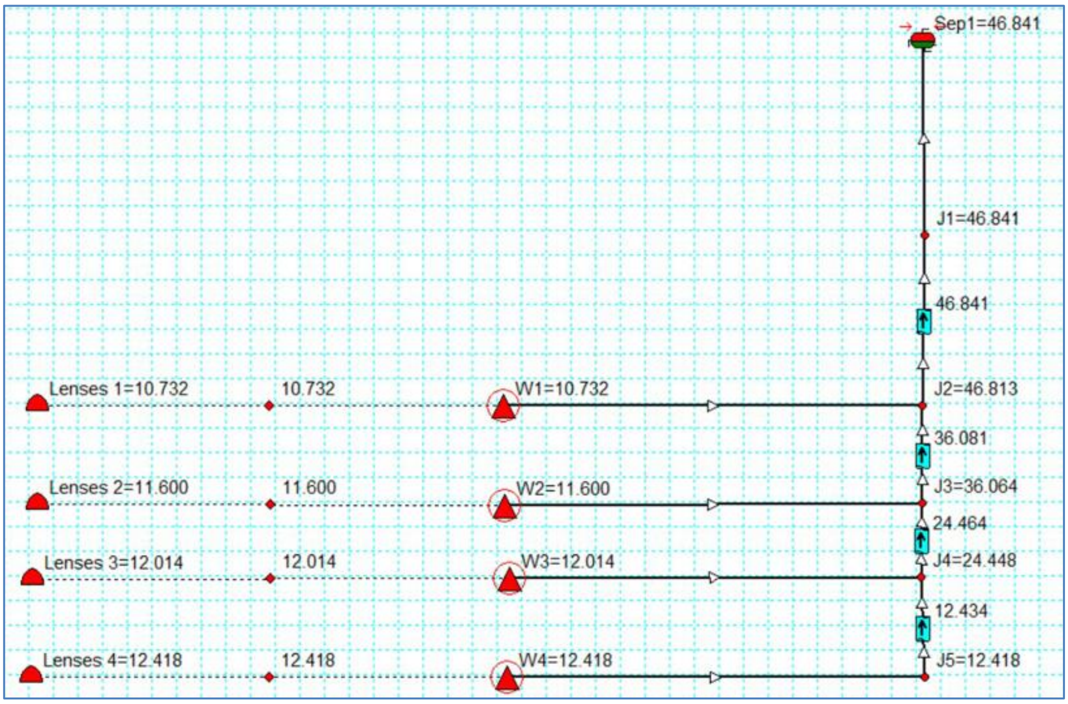

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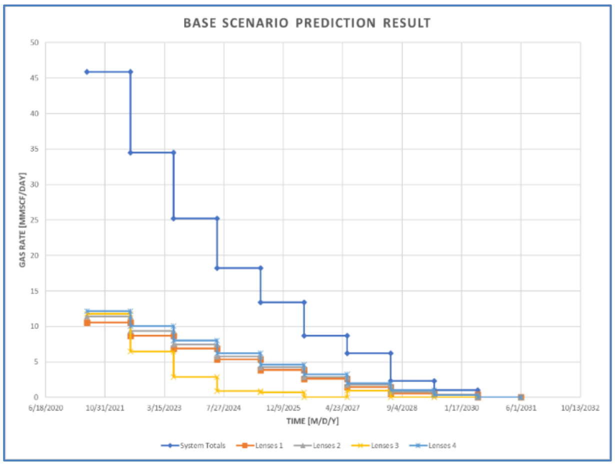

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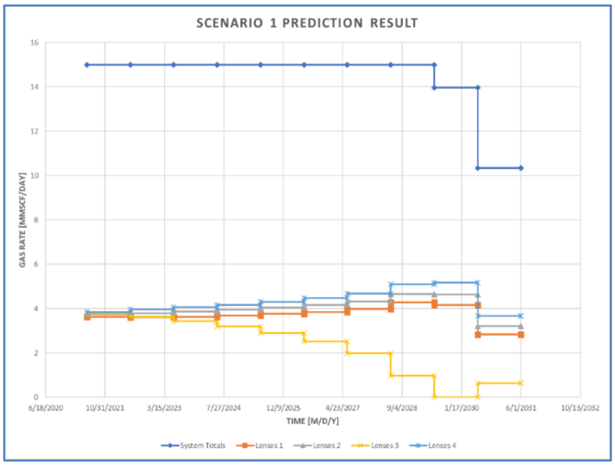

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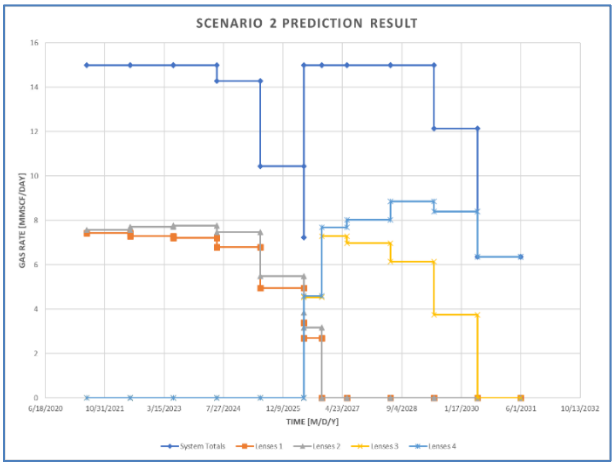

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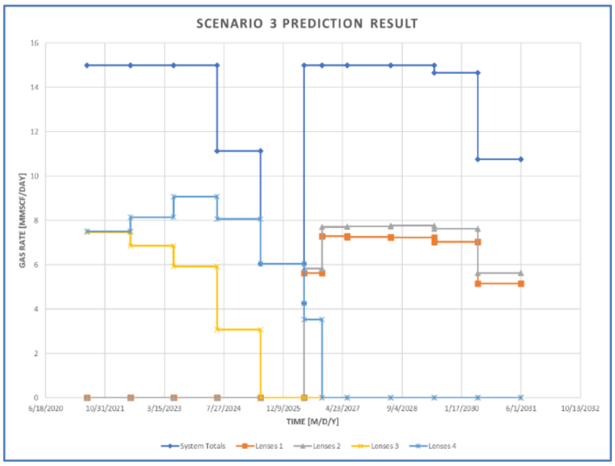

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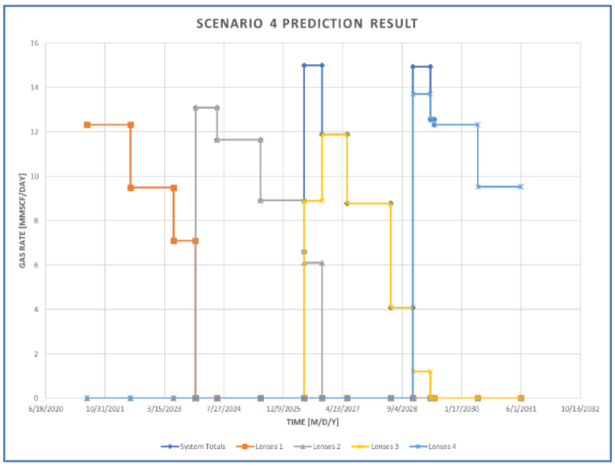

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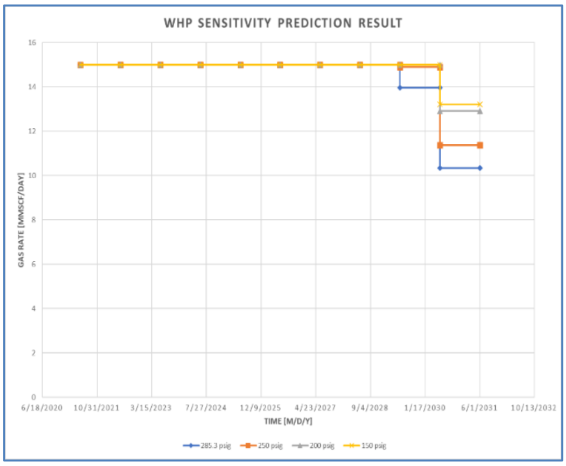

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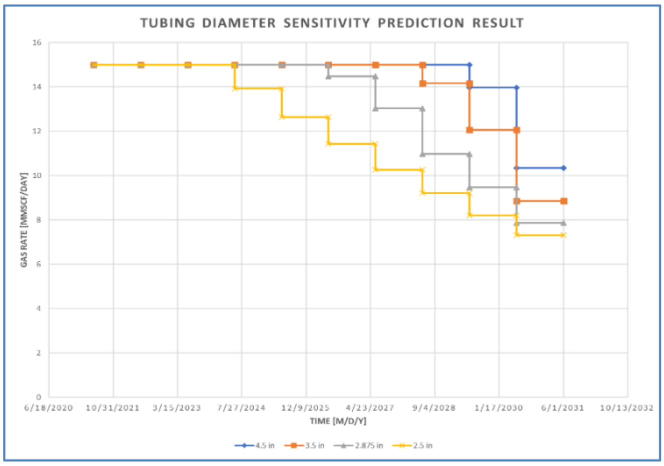

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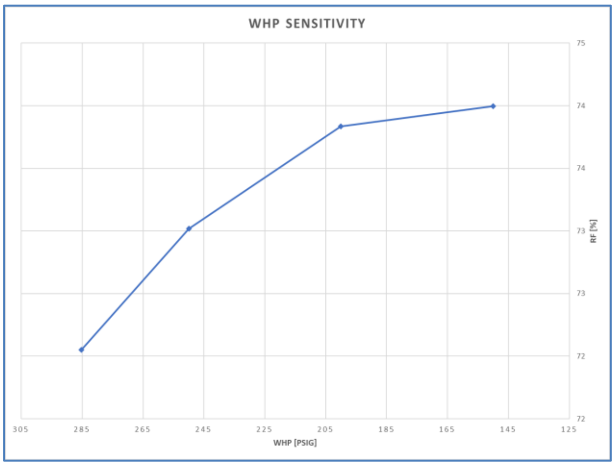

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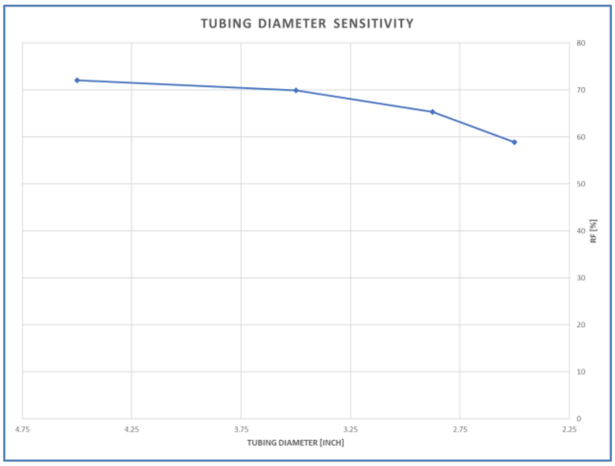

Figure 19. Tubing Diameter Sensitivity Well Recovery Result

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Table 1. Reservoir Properties of Lenses 1

Parameters	Unit	Value
Condensate *API Gravity*	API	93.49
SG Gas	sp. Gravity	0.693
WGR	STB/MMSCF	10
CGR	STB/MMSCF	2.68
Temperature	°F	92
Initial Pressure	psi	1121
Porosity	fraction	0.19
S_{wc}	fraction	0.4
Permeability	md	185

Table 2. Reservoir Properties of Lenses 2

Parameters	Unit	Value
Condensate *API Gravity*	API	93.49
SG Gas	sp. Gravity	0.693
WGR	STB/MMSCF	10
CGR	STB/MMSCF	2.68
Temperature	°F	94
Initial Pressure	psi	1176
Porosity	fraction	0.177
S_{wc}	fraction	0.4
Permeability	md	231

Table 3. Reservoir Properties of Lenses 3

Parameters	Unit	Value
Condensate *API Gravity*	API	93.49
SG Gas	sp. Gravity	0.693
WGR	STB/MMSCF	10
CGR	STB/MMSCF	2.68
Temperature	°F	94.7
Initial Pressure	psi	1209
Porosity	fraction	0.16
S_{wc}	fraction	0.4
Permeability	md	172

Table 4. Reservoir Properties of Lenses 4

Parameters	Unit	Value
Condensate *API Gravity*	API	93.49
SG Gas	sp. Gravity	0.693
WGR	STB/MMSCF	10
CGR	STB/MMSCF	2.68
Temperature	°F	95
Initial Pressure	psi	1242
Porosity	fraction	0.158
S_{wc}	fraction	0.4
Permeability	md	140

Table 5. Production Scenarios

Production Method	Description
Base Scenario	All lenses produce together for 10 years without considering any constraint.
Scenario 1	All lenses produce together with considering plateau rate 15 MMSCFD for 10 years.
Scenario 2	Lenses 1 & 2 produce together, then lenses 3 & 4 produce together with considering plateau rate 15 MMSCFD for 10 years.
Scenario 3	Lenses 3 & 4 produce together, then lenses 1 & 1 produce together with considering plateau rate 15 MMSCFD for 10 years.
Scenario 4	Lenses 1, 2, 3, and 4 produce one by one with considering plateau rate 15 MMSCFD for 10 years.

Table 6. Gas Recovery Calculation Result Each Production Method

	Base Case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Recovery Factor [%]	77.60	72.05	66.51	66.19	52.69

Table 7. WHP Sensitivity Well Recovery Result

WHP	Recovery Factor
[psig]	[%]
285.3	72.052
250	73.019
200	73.836
150	73.996

Table 8. Tubing Diameter Sensitivity Well Recovery Result

Tubing Diameter	Recovery Factor
[inch]	[%]
4.5	72.052
3.5	69.945
2.875	65.330
2.5	58.896