Analysis of Infill Well Location Determination to Increase Oil Production in the DMS Field

Dedy Kristanto[1*], Dyah Rini Ratnaningsih[2], Dimas Suryo Wicaksono[3*]
[1-3] Petroleum Engineering Department, Universitas Pembangunan Nasional "Veteran" Yogyakarta
Jl. Padjajaran 104 (Lingkar Utara) Condongcatur, D.I. Yogyakarta 55283, Indonesia
[*] Correspondences e-mail: dedykris.upn@gmail.com and dimassuryowicaksono@gmail.com

Abstract*— DMS field is produced on five sand units of Duri Formation since 1972. According to the production and reservoir integration analysis, the addition of production infill wells is a quick effort to increase production in the DMS Field significantly. This integration analysis is carried out with the initial step of determining the rock type that applies to the target reservoir, then spreading the Sw and HCPV values in each sand unit based on rock type from the distribution map of the HCPV (Hydrocarbon Pore Volume) value, determining the location of infill in zones that have good HCPV values, then the production forecasting is carried out using a decline curve analysis which aims to determine the increase in production from 2019 to 2041. This result is carried out to economic analysis to determine the success rate of adding infill wells to increase profits in the DMS Field. Finally, this paper discusses the steps taken to add production infill wells to increase old field production by integrating production and reservoir data. Based on the analysis results, 17 infill wells were found, providing additional production and resulting in additional NPV in the DMS Field.

***Keywords*—HCPV; Infill Well; Oil Production; Recovery Factor**

I. INTRODUCTION

The "DMS" field has been in production since 1972 with a production target of the Duri Formation. In the Duri Formation, there are 313 wells with 192 active oil production wells, 49 LTC (Long Term Closed) oil wells, 41 convert to injection wells, 16 water injection wells, 8 LTC (Long Term Closed) observation wells, 3 P&A oil wells, 3 water source wells, and 1 P&A water injection well. The Duri Formation was produced at the sand units of D1600, D1680, D1710, D1740, and D1800 with the original oil in place (OOIP) of 2112.32 MMbbl, production cumulative (Np) of 645.99 MMbbl, and recovery factor of 30.58%.

This paper discusses a comprehensive and integrated analysis by evaluation of production and reservoir data which aims to increase oil production in mature fields by adding production infill wells. One of the methods that can be utilized to determine of infill well location in the mature field is by using production and reservoir data [1].

II. LITERATURE REVIEW

The development of science in oil and gas exploration and exploitation plays a vital role in the development of the times. Oil and gas fields in Indonesia, especially the western part of Indonesia, are dominated by old fields discovered since 1905. With the increasing demand for oil and gas, several studies and technologies have emerged to obtain the optimal recovery factor possible. One method that can be used is to determine the exact location of the infill in the mature field by using production data and reservoir data. The characteristics of a mature field are as follows [1]:

- Has a current recovery factor (RF) value greater than 30%.
- It has been in production for quite a long time, which is more than 30 years.
- Has a field water cut (WC) value higher than 90%.

Furtermore, relate to [1] also state that determining the condition of a field, whether it is mature or not, can also be seen from the results of the decline curve analysis.

A. Hydraulic Flow Unit Analysis

The concept of hydraulic flow unit, or can be shortened as Hydraulic Unit (HU), is defined as the volume that represents the total volume of reservoir rocks which include its geological characteristic. These characteristics control the internal fluid flow, and its difference can be estimated with other rocks physical characteristics. In short, the flow unit can be classified based on its petrophysics characteristic and specific geology parameter. The hydraulic unit is related to the geological facies distribution [1], [2].

The rocks classification based on the geological principle of flow attribute is the underlining concept of this Hydraulic Unit classification. The main parameter affecting the fluid flow is the pores' geometrical attribute. Pores geometry is affected by its mineralogy (type and location N) and the rock texture itself (grain size, grain type, sorting, and packing). The mean hydraulic radius (RMH) concept approach becomes a model to correlate the porosity, permeability, and capillary pressure. The main parameter affecting the fluid flow is pores geometrical attributes [2].

The steps used in determining rock type using the Hydraulic Flow Unit (HFU) method are determining the value of Reservoir Quality Index (RQI), Normalized Porosity (Øz), Flow Zone Indicator (FZI), then grouping rockt ypes based on trend data.

$$\mathrm{RQI} = 0.0314\sqrt{\frac{k}{\text{Ø}_e}} \quad (1)$$

$$\text{Ø}_z = \left(\frac{\text{Ø}_e}{1-\text{Ø}_e}\right) \quad (2)$$

$$\mathrm{HU} = \mathrm{Round}\,[2\ln(\mathrm{FZI}) + 10.6] \quad (3)$$

B. Potenstial Zone Analysis

In determining the location of the infill, the first step that needs to be done is to select the zone that still has the potential to be developed, which is characterized by good reservoir property values such as high porosity, high permeability, and low water saturation [3], [4]. The step that needs to be done is to spread the reservoir property values overlaid with the re bubble map and the Np bubble map. The zones that are still producing can be identified, marked by groups of existing production wells in the zone. Potential zone boundaries are based on the Sw value of the existing production wells and the status of the well that has LTC (Long Term Closed) due to the uneconomical operation of the well and low reservoir property values (porosity, permeability, Sw). An example of the distribution of reservoir property values can be seen in Fig. 1, and for an example of an illustration of the distribution of HCPV values can be seen in Fig. 2.

Potential zone validation is also required by performing sand correlation, followed by recording production (Np, Wp, Gp) and reservoir rock property values (porosity, permeability, thickness). Correlation is carried out in the direction of the unproductive zone then passes through the productive zone to find out the boundaries of the zone that still has potential [5], [6].

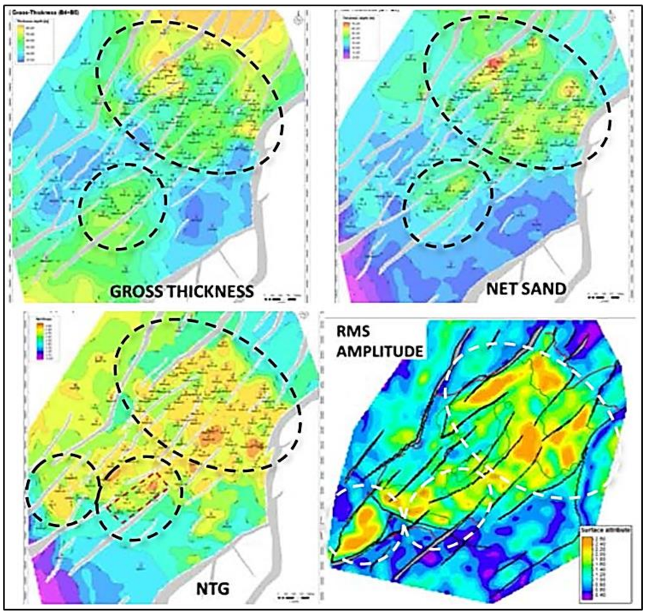

Fig.1. *Reservoir properties map [3]*

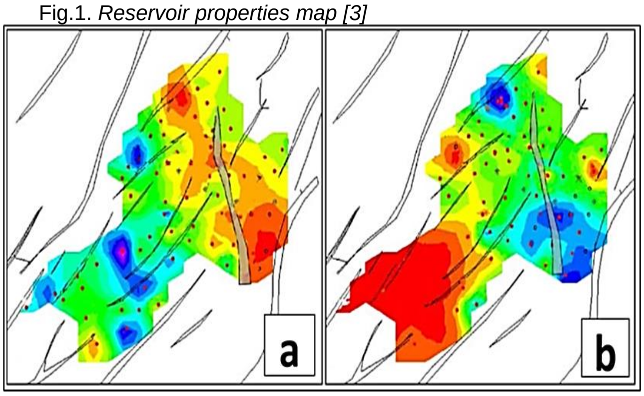

Fig.2. *Hydrocarbon pore volume (HCPV) map [3]*

C. Infill Well Location Analysis

The infill drilling method is the method that can increase and maintain the rate of field production. This method is implemented by adding wells to an actively operating oil field to shorten the radius between wells. In its implementation, an exact design is required [7], [8]. Infill drilling design needs to consider existing wells and evaluate the potential drilling point to eliminate the interference on the well's drainage [9], [10]. Infill drilling design is based on a few factors, including oil reserve, formation productivity, well's drainage radius, and well distribution pattern. the advantage of this method is the ability to produce more oil for short-term treatment. Besides, this infill drilling could reach the oil in a more isolated area and is a proven method. The weakness of this method lies on its relatively higher cost compared to the workover activities such as pump installation or workover [11], [12].

D. Porduction Forecasting with Decline Curve Analysis

Production forecasting plays a vital role in the decision-making of the oil field productivity level determination. One of the forecasting methods is the Decline Curve Analysis as the fastest way to get an early picture. As known, reservoir simulation could take quite some times to get the result [13]. The forecast using this method produce a trend that close to its actual condition, however, needs to be supported with the actual production data and pressure data [14]. In other words, the methodology only applicable when there is no skin or formation damage, no change in lifting method, and there's no equipment or production facilities failure.

Decline curve analysis is one of methods to describe the production behavior and to estimate the oil reserve based on production data in a certain period [15]. Decline curve analysis can be conducted in a certain period with constraints [16], [17], [1], [14]:

- The mechanical condition and the reservoir drainage area is constant (boundary-dominated flow condition);
- Each well is being produced at each capacity;
- Each well is being produced at constant bottom-hole pressure;

Table 1, shows decline curve analysis equation where D is the decline rate (fraction), q is the production rate at time t (bbl/days), qi is the initial production rate (bbl/days), Np is the cumulative oil production (bbl), and b is the decline exponent factor.

TABLE 1. DECLINE CURVE ANALYSIS EQUATIONS [1], [17]

Parameters	Decline Type		
	Exponential	Hyperbolic	Harmonic
Characteristics	Decline is constant	Decline varies with instantaneous rate raised to power "b"	Decline is directly proportional to the instantaneous rate.
Exponent	b = 0	b ≠ 0, b ≠ 1	b =1
Rate time relationship	$q = q_i.e^{-D_i.t}$	$q = q_i(1+bD_it)^{\frac{1}{-b}}$	$q = q_i(1+D_it)^{-1}$
Rate cumulative Relationship	$N_p = \frac{(q_i - q)}{D_i}$	$N_p = \frac{q_i^b}{(1-b)D_i}(q_i^{1-b} - q^{1-b})$	$N_p = \frac{q_i}{D_i}\ln\left(\frac{q_i}{q}\right)$
Dimensionless Time, t_D	$D_it = \ln\left(\frac{q_i}{q}\right)$	$D_it = \frac{\left(\frac{q_i}{q}\right)-1}{b}$	$D_it = \left(\frac{q_i}{q}\right)-1$
Dimensionless Production, q_D	$\frac{N_p}{q_it} = \frac{1-\left(\frac{q_i}{q}\right)^{-1}}{\ln\left(\frac{q_i}{q}\right)}$	$\frac{N_p}{q_it} = \frac{1-\left(\frac{q_i}{q}\right)^{b-1}}{\left(\frac{q_i}{q}\right)^{b}-1}\left(\frac{b}{1-b}\right)$	$\frac{N_p}{q_it} = \frac{\ln\left(\frac{q_i}{q}\right)}{\left(\frac{q_i}{q}\right)-1}$

E. Economic Analysis

Economic calculation on oil and gas exploration and exploitation is mandatory due to its high risk and high return potential. Precise and thorough financial analysis based on actual field conditions must be carried out as the underlining judgment over the field development. The economic calculation of oil and gas resources is based on its produced hydrocarbon, expenses that have been (or will be) incurred, oil price per volume unit, and the calculation system [18], [19].

III. RESEARCH METHODOLOGY

The flow methodology in this research is intended to solve problems that occur in the Duri Formation "DMS" Field, including data collection and preparation, data analysis, and validation of analysis results. Flowchart of the methodology is shown in Fig. 3.

IV. RESULTS AND DISCUSSION

A. Rock Type Analysis with Hydraulic Flow Unit (HFU) Method

Following the available method, HFU analysis is performed for all samples to determine of Duri Formation's rock type. After that, the rock types are classified according to their reservoir quality index (RQI) value and flow zone indicator (FZI) value based on the data distribution. The result can be seen in Fig. 4 and Table 2.

The rock type is classified based on the Log FZI value because the difference between rock types flow units is more visible. The distribution of rock type by considering the Log FZI value is used because the change in the FZI trend shows a change in the flow unit (8 rock types). Based on the rock type division that has been done, it can be seen that the relationship between the porosity and permeability values for each rock type can be seen in Fig. 5 and for the distribution of water saturation (Sw) values based on the capillary pressure value for each rock type, it can be seen in Fig. 6.

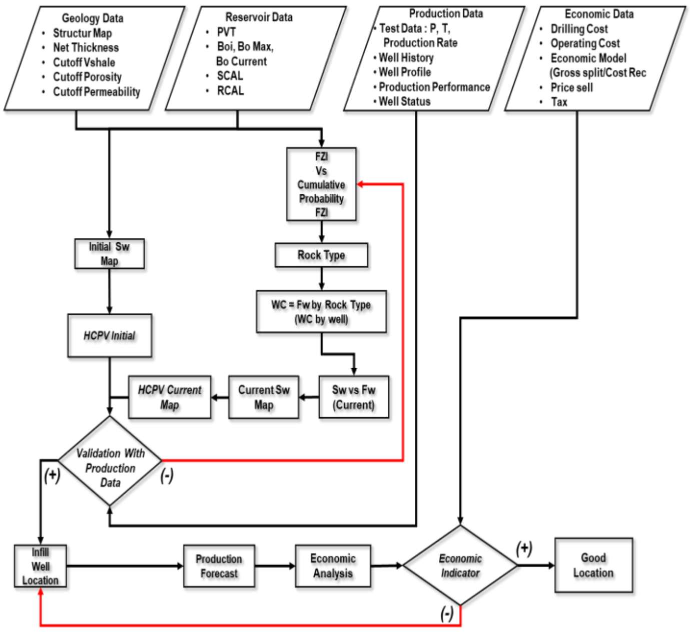

Fig. 3. *Research Methodology*

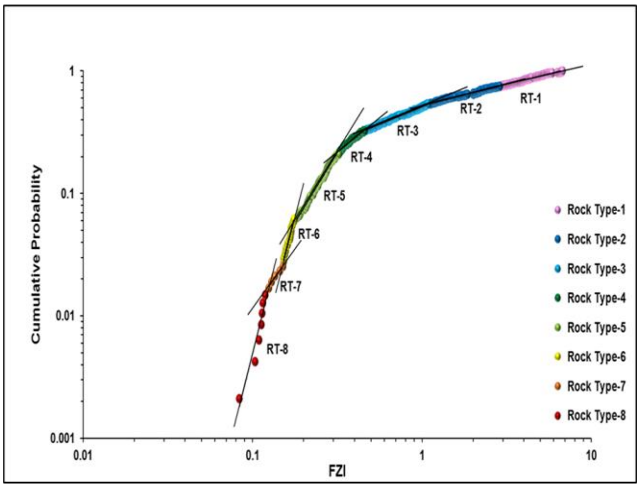

Fig. 4. *Rock Types of Duri formation*

TABLE 2. ROCK TYPES OF DURI FORMATION

Rock Types	Flow Zone Indicator (FZI)
Rock Type-1	> 3.39
Rock Type-2	1.14 - 3.39
Rock Type-3	0.44 - 1.14
Rock Type-4	0.32 - 0.44
Rock Type-5	0.17 - 0.32
Rock Type-6	0.15 - 0.17
Rock Type-7	0.13 - 0.15
Rock Type-8	≤ 0.13

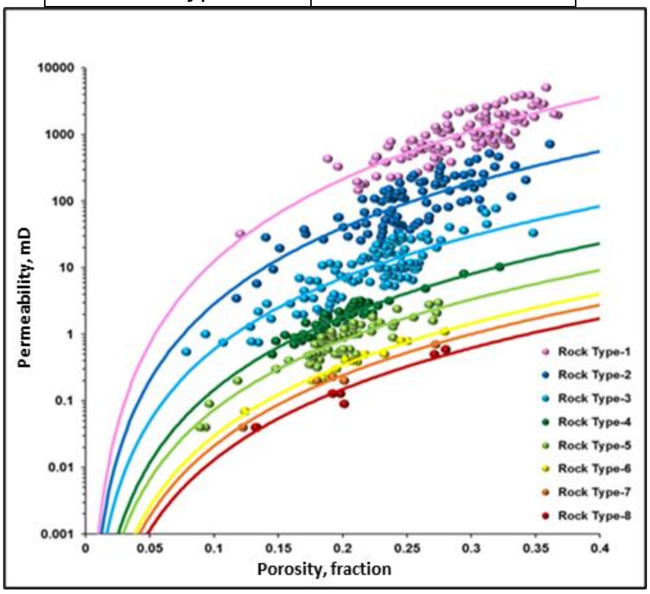

Fig. 5. *Porosity vs permeability curve based on rock types*

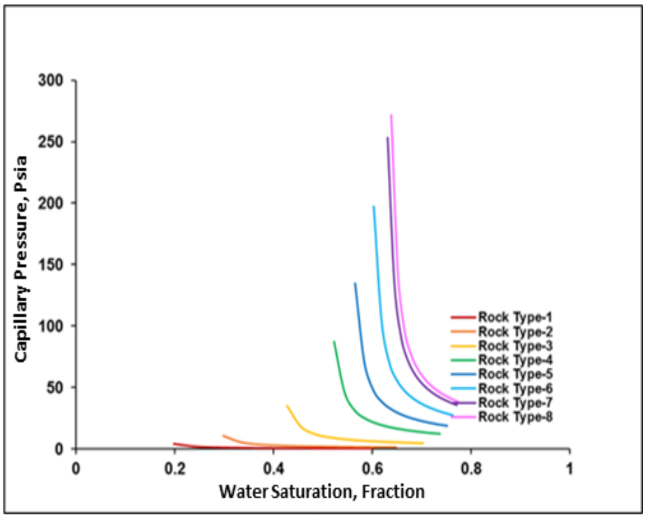

Fig. 6. *Pc vs Sw curve*

B. Potential Zone Analysis

Potential zone analysis aims to map the potential zone or area for future development [20]. The comprehensive analysis using geological maps and production data shows that the higher production is directly correlated to the higher pore volume and permeability value distribution [3]. The enclosed result represents that rocks quality is as crucial as hydrocarbon saturation on its contribution to the field production. The reservoir property maps, fluid contact, and fault modeling significantly support the risk identification over the proposed location.

Drilling in a high-risk area is avoided to save investment value. The process of analyzing geological properties and production data aims to determine the distribution pattern of oil, water, predict the distribution of sand, and select the distribution of hydrocarbon areas, which are then used to develop productive layers. The analysis is divided into two, namely static reservoir analysis and dynamic reservoir analysis [21].

Reservoir static analysis is an analysis carried out on initial conditions only. This analysis is assumed not to be influenced by a function of time, as for geological properties (porosity, permeability, and thickness). Porosity, permeability, and thickness analyses were carried out to determine which area had the minimum value by using a predetermined property cut-off value. The minimum value of porosity, permeability, and thickness is justified as the minimum value of the reservoir's ability to flow fluid obtained from the cut-off value. After mapping the porosity, permeability, and thickness values, the map is overlaid with the fluid contact boundary (LKO) to separate the hydrocarbon zone from the water zone. This is performed to minimize the determination of the potential area outside the fluid contact (LKO). Map of the distribution of porosity, permeability, and thickness values for each sand unit in the Duri Formation can be seen in Fig. 7 through Fig. 9.

Reservoir dynamic analysis is an analysis stage influenced by the function of time, while the properties analyzed are Sw (water saturation) and WC (Water cut). Further calculations were performed from the Sw property, which is Sw and HCPV (Hydrocarbon Pore Volume). The results of these calculations are influenced by the function of time, so initial conditions and current conditions are obtained (cut of date 2019). The existing production data will validate this dynamic analysis to predict areas in the zone that still have the potential to be productive. The results of dynamic reservoir analysis can also serve to validate static reservoir analysis. The results of dynamic analysis for the HCPV map of each sand unit shown in Fig. 10.

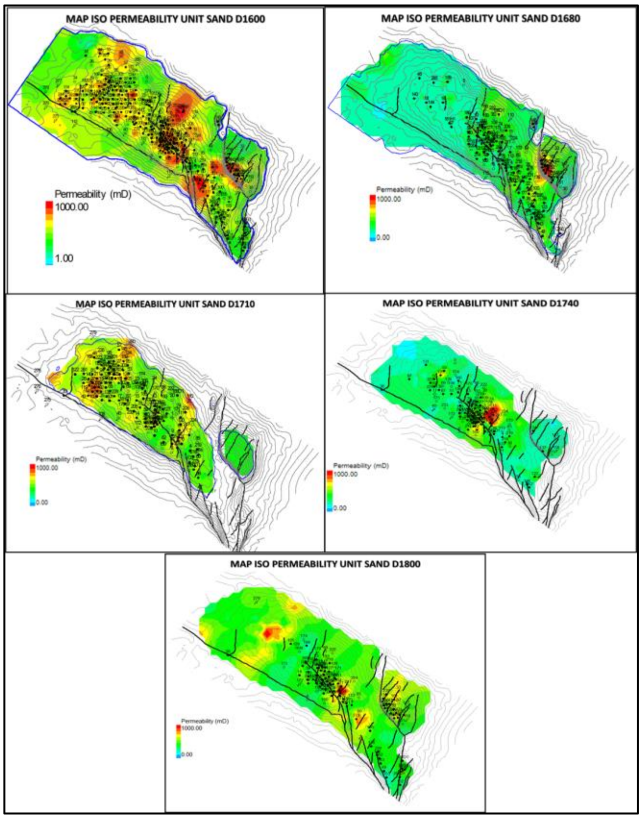

Fig. 7. *Permeability map*

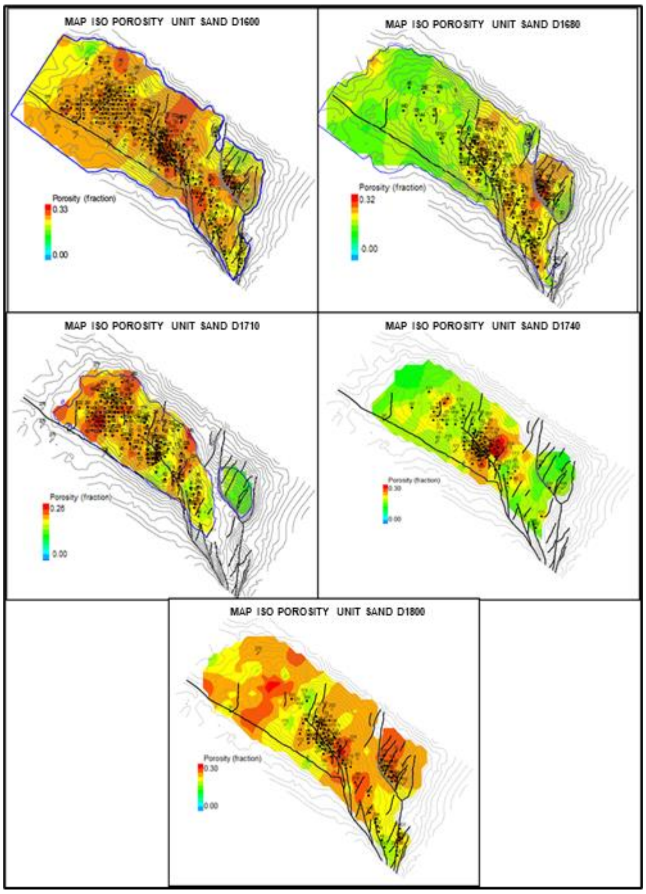

Fig. 8. *Porosity map*

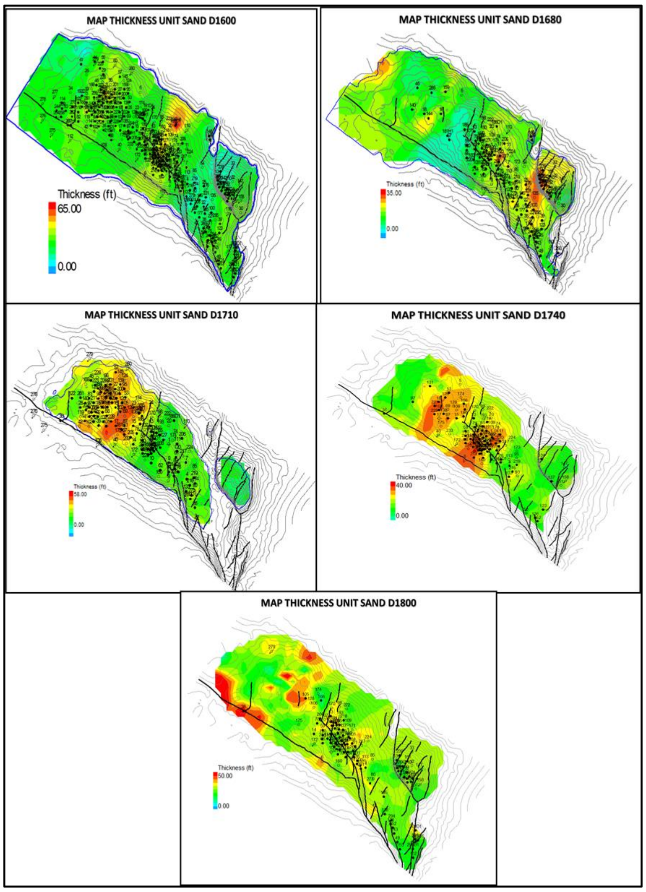

Fig. 9. *Thickness map*

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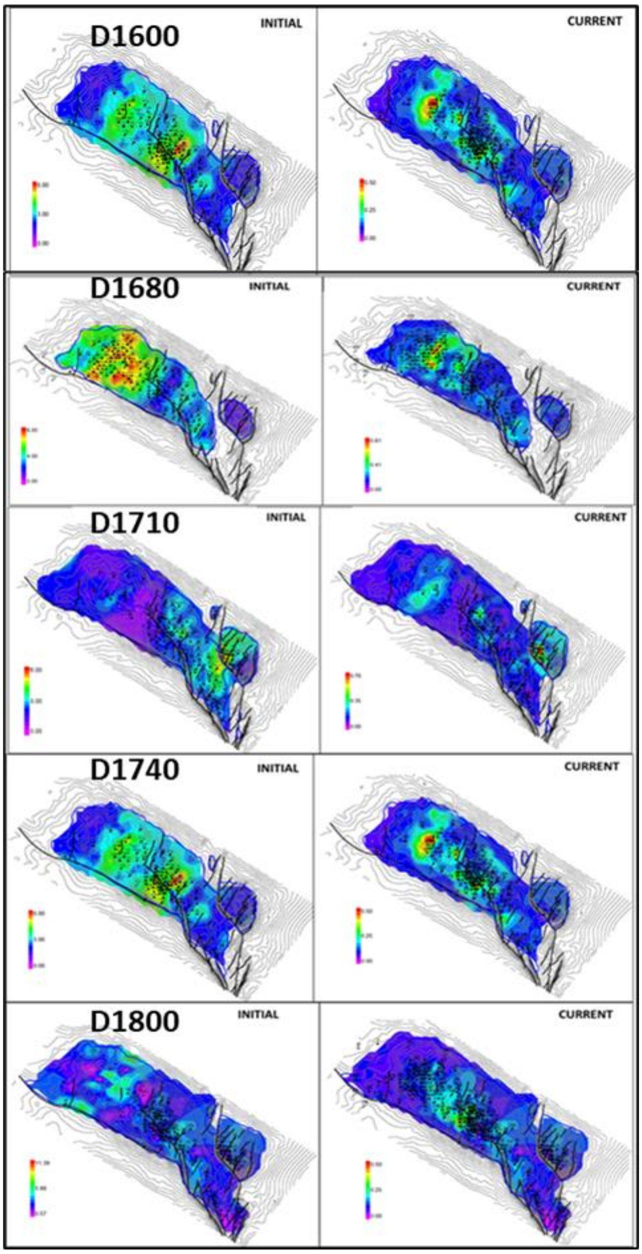

Fig. 10. *Hydrocarbon Pore Volume (HCPV) map of Duri formation*

From the HCPV map result, both maps are combined to become the Duri formation's HCPV map. Based on this map, the infill location is determined and the production used as the initial forecasting of a decline curve is P50 or the base category.

C. Production Forecasting using Decline Curve Analysis

The analysis carried out before forecasting is to determine the Qoi of the reference infill wells for the first production and last oil production for surrounding wells. Then the value of P10 as the initial production of the low category infill well, P50 as the initial production of the base category, and P90 as the initial production of the high category are calculated. The Initial Production value used as the initial production forecasting using a decline curve is P50 or the base category. The initial production value of each well can be seen in Table 3.

TABLE 3. INITIAL PRODUCTION OF INFILL WELLS

Forecast	Low	Base	High	Ev
X-1	44.40	115.50	160.70	106.87
X-2	31.20	93.50	160.70	95.13
X-3	54.40	84.50	111.80	83.57
X-4	66.80	127	179.50	124.43
X-5	55.80	78	197.80	110.53
X-6	55.80	78	197.80	110.53
X-7	56	99.50	195.00	116.83
X-8	34	50	85.00	56.33
X-9	68.60	151	267.80	162.47
X-10	46.40	82.50	129.80	86.23
X-11	42.40	109	156.40	102.60
X-12	80.50	112	185.50	126
X-13	80.50	112	185.50	126
X-14	80.50	112	185.50	126
X-15	41.20	90	127.40	86.20
X-16	41.20	90	127.40	86.20
X-17	34	50	85.00	56.33

After knowing the initial production value of each infill well, production forecasting can be carried out based on the forecasted equations from the surrounding wells, as shown in Table 4.

TABLE 4. FORECASTING EQUATIONS

Wells Name	Equations Forecast
X-1	$q = 116 * \exp(-0.0145294 * t)$
X-2	$q = 94 * \exp(-0.0145294 * t)$
X-3	$q = 85 * \exp(-0.0217804 * t)$
X-4	$q = 127 * \exp(-0.0145294 * t)$
X-5	$q = 78 * \exp(-0.0145294 * t)$
X-6	$q = 78 * \exp(-0.0145294 * t)$
X-7	$q = 99 * \exp(-0.0145294 * t)$
X-8	$q = 48 * \exp(-0.0145294 * t)$
X-9	$q = 151 * \exp(-0.0145294 * t)$
X-10	$q = 83 * \exp(-0.0155275 * t)$
X-11	$q = 109 * \exp(-0.0165376 * t)$
X-12	$q = 109 * \exp(-0.0165376 * t)$
X-13	$q = 109 * \exp(-0.0165376 * t)$
X-14	$q = 112 * \exp(-0.0165376 * t)$
X-15	$q = 90 * \exp(-0.0185953 * t)$
X-16	$q = 90 * \exp(-0.0185953 * t)$
X-17	$q = 48 * \exp(-0.0145294 * t)$

Production forecasting is carried out using the decline curve analysis method. The forecast equation for each well to the cumulative annual production of each infill well can be seen in Table 5. The graph of the forecasting production results can be seen in Fig. 11.

TABLE 5. FORECASTING PRODUCTION BY WELLS

YEARS	Production Cumulative by Years (MBO)																
	X-1	X-2	X-3	X-4	X-5	X-6	X-7	X-8	X-9	X-10	X-11	X-12	X-13	X-14	X-15	X-16	X-17
2022	38.86	31.49	27.9	27.9	26.13	26.13	30.57	14.82	46.62	25.49	30.73	25.37	26.78	31.57	27.19	27.19	13.48
2023	32.65	26.45	21.03	21.03	21.95	21.95	28.27	13.71	43.13	23.31	60.56	25.23	26.64	31.4	24.01	24.01	13.71
2024	27.49	22.28	16.23	16.23	18.49	18.49	23.81	11.55	36.32	19.4	25.13	20.74	21.9	25.82	19.26	19.26	11.55
2025	23.03	18.66	12.46	12.46	15.49	15.49	19.94	9.67	30.42	16.06	20.54	16.96	17.9	21.11	15.36	15.36	9.67
2026	19.35	15.68	9.6	9.6	13.01	13.01	16.76	8.13	25.56	13.33	16.85	13.91	14.68	17.31	12.29	12.29	8.13
2027	16.25	13.17	7.39	7.39	10.93	10.93	14.08	6.83	21.47	11.07	13.82	11.41	12.04	14.2	9.83	9.83	6.83
2028	13.69	11.09	5.71	5.71	9.21	9.21	11.86	5.75	18.08	9.21	11.36	9.38	9.9	11.67	7.89	7.89	5.75
2029	11.47	9.29	4.38	4.38	7.71	7.71	9.93	4.81	15.15	7.62	9.29	7.67	8.1	9.54	6.29	6.29	4.81
2030	9.63	7.81	3.38	3.38	6.48	6.48	8.34	4.05	12.73	6.33	7.62	6.29	6.64	7.83	5.03	5.03	4.05
2031	8.09	6.56	2.6	2.6	5.44	5.44	7.01	3.4	10.69	5.25	6.25	5.16	5.45	6.42	4.03	4.03	3.4
2032	6.82	2.52	2.44	2.44	4.58	4.58	5.91	2.86	9	4.37	5.14	4.24	4.48	5.28	3.23	3.23	2.86
2033	5.71	4.63	6.25	6.25	3.84	3.84	4.94	2.4	7.54	3.62	4.2	3.47	3.66	4.31	2.58	2.58	2.4
2034	4.8	3.89	5.25	5.25	3.23	3.23	4.15	2.02	6.34	3	3.45	2.84	3	3.54	2.06	2.06	2.02
2035	4.03	3.26	4.41	4.41	2.71	2.71	3.49	0.16	5.32	2.49	2.83	2.33	2.46	2.9	0.16	0.16	0.16
2036	3.39	2.75	3.71	3.71	2.28	2.28	2.94		4.48	2.07	2.32	2.03	2.03	2.39			
2037	2.84	2.3	3.11	3.11	1.62	1.62	2.46		3.76	0.45	1.46	1.65	1.65	165			
2038	2.39	1.64	2.61	2.61			2.07		3.16								
2039	2.01		2.2	2.2			0.46		2.65								
2040	0.16		1.12	1.12					2.23								
2041									1.28								
Total	232.63	186.46	141.18	255.62	153.07	153.07	196.98	90.13	305.92	153.06	191.52	158.69	167.31	196.95	139.22	139.22	88.79
Grand Total	2949.81																

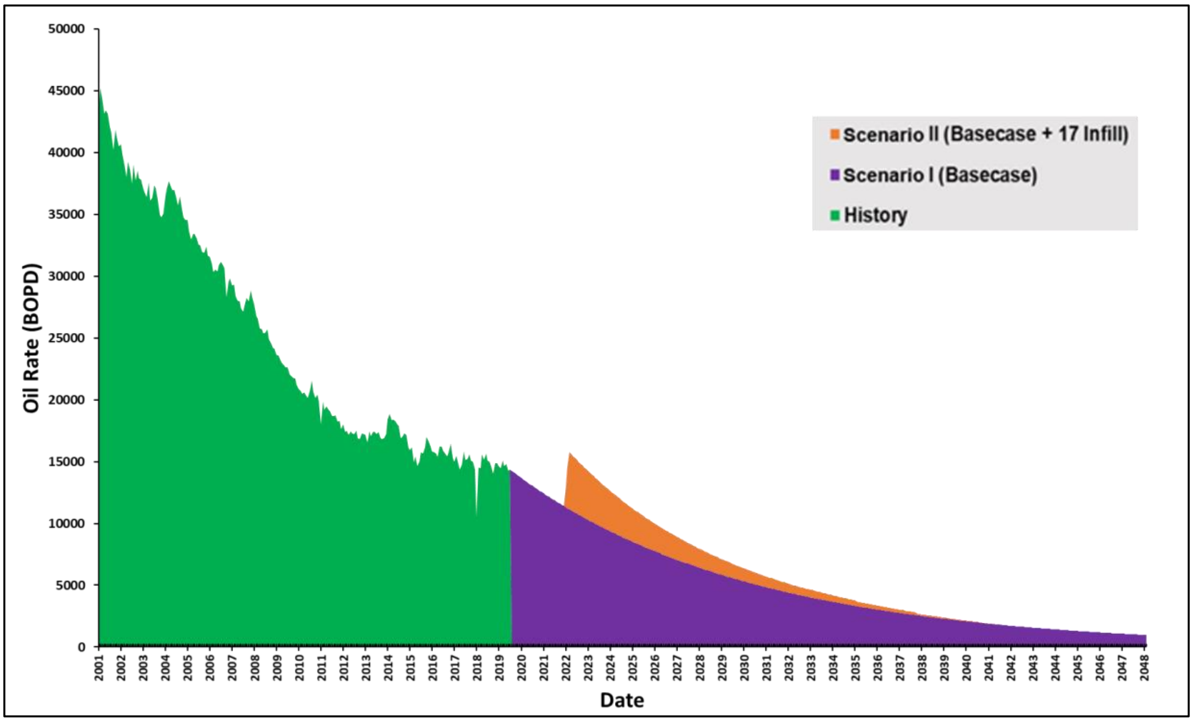

Fig. 11. *Forecast production results*

D. *Infill Well Determination*

The infill location selection is performed using the HCPV formation map. The chosen area has a high HCPV value or near the maximum HCPV value within the maps. Result validation is performed by examining the surrounding wells' production trend. The infill wells' distribution on HCPV maps overlayed to the production wells' map can be seen in Fig. 12, and for the infill wells' coordinate can be seen on Table 6.

TABLE 6. INFILL WELL COORDINATES

Well Name	X Coordinate	Y Coordinate
X-1	708578.78346	190191.21745
X-2	708272.94043	190127.59747
X-3	712555.75142	187146.81843
X-4	708425.86194	189402.32973
X-5	708922.85688	189319.62375
X-6	708865.51131	189103.31583
X-7	709191.84000	189051.29000
X-8	707986.21258	189084.22984
X-9	709363.58000	188398.46000
X-10	712391.98973	187400.38035
X-11	712704.70505	186881.94797
X-12	712734.71401	186765.02309
X-13	712826.09283	187092.41097
X-14	712440.54000	186872.65000
X-15	705836.79000	190995.83000
X-16	706089.31000	190712.74000
X-17	707816.62000	189520.82000

E. *Economic Analysis*

The final decision in carrying out field development is to conduct an economic analysis [22], [18], [19]. The analysis was carried out to determine the level of success in adding production infill wells. Net Present Value (NPV), Rate of Return (ROR), Profit to Investment Ratio (PIR), Discounted Profit to Investment Ratio (DPIR), and Pay Out Time (POT) are values that need to be obtained in economic analysis of oil and gas activities to knowing the economics of a field development activity, whether it is profitable or not. The economic analysis calculation result shows that by adding 17 infill wells in the Duri Formation will give a ROR of 13% and NPV of 2.37 MMUSD, with a POT of 4.65 years.

V. CONCLUDING REMARKS

The division or classification of rock types in the Duri Formation is carried out using the hydraulic flow unit (HFU) method. Based on the HFU method, the reservoir rocks in the Duri Formation are divided into eight rock types used as the basis for the distribution of porosity, permeability, and water saturation values. The analysis of determining the infill location resulted in 17 production infill wells, with the coordinates and targets of each sand unit. The results of the production forecasting with the basecase scenario + 17 infill wells from July 2019 to December 2041 show that the infill wells increase the oil production by 2.94 MMBBL or recover factor value of 0.14%. The results of the field scale economic analysis in the basecase scenario + 17 infill wells using the gross split scheme, it is shown that the scenario of adding infill wells generates profits by providing 13% ROR and 2.37 MMUSD NPV with a POT of 4.65 years.

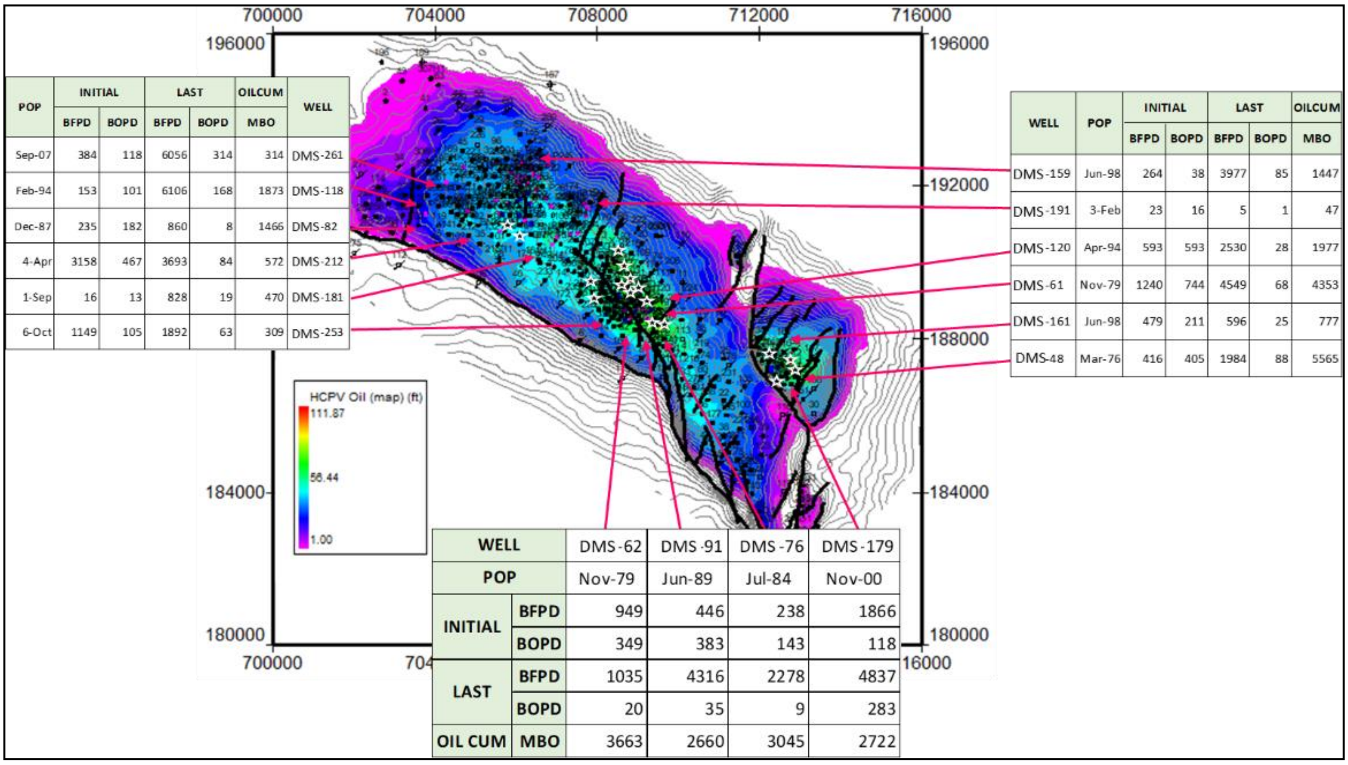

Fig. 12. *Infill well location*

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