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Petrophysical Analysis of Well Log Data for Hydrocarbon Reservoir Ranking in "Essy" Field, Niger Delta, Nigeria

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Abstract: Petrophysical analysis of well logs for hydrocarbon reservoir ranking was carried out in "Essy" field, Niger Delta, Nigeria. The study is aimed at identifying and ranking the production potential of hydrocarbon bearing sand units using derived petrophysical parameters. Hydrocarbon bearing reservoirs were identified as sands with corresponding high resistivity values from resistivity logs. The fluid types in each identified sand unit were distinguished using a combination of neutron and density logs. Petrophysical parameters such as volume of shale, porosity, permeability and hydrocarbon saturation were determined for each sand unit. The saturating fluids were observed to be both oil and gas. Each of the identified sand units were ranked according to their hydrocarbon production potential by assigning weighted average values to the petrophysical parameters determined. Four (4) hydrocarbon-bearing reservoirs (Sand 01, Sand 02, Sand 03 and Sand 04) were identified in the study area. Permeability values range between 1050 – 6620 mD, volume of shale 2 – 30%, hydrocarbon saturation 28 – 67% and effective porosity 11 – 27%. Sand 04 has total average ranking value of 46.9% while Sands 01, 02 and 03 have total average ranking values of 25.2%, 21.3% and 24.0% respectively. The study concluded that Sand 04 with average values of permeability, hydrocarbon saturation, volume of shale, porosity and thickness of 4240 mD, 63.5%, 4.5%, 22.5% and 97 m respectively, ranked highest among all the hydrocarbon sands delineated in the study area with a total average ranking value of 46.9%.

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Keywords: Petrophysical Analysis, Reservoir Ranking, Hydrocarbon Saturation, Porosity, Permeability.

1. Introduction:

Well logging is the study of acquiring information on physical properties of rocks that become exposed while drilling a well (Adel *et al.,* 2014). A reservoir is a subsurface formation that has effective permeability and porosity which usually contains commercially exploitable quantity of hydrocarbon. Reservoir characterization is undertaken to determine a reservoir's capability to both store and transmit fluid. Hence, characterization deals with determination of reservoir parameters such as, permeability (K), porosity (φ), volume of shale (V_{sh}), etc, from well log data (Ologe, 2016). It is well recognized that improvements in reservoir characterization will increase the amount of exploitable hydrocarbon. Thus, well logging techniques gives maximum information at a very minimal cost. In this study, the identified sand units were ranked according to their hydrocarbon production potential by assigning weighted averages to petrophysical parameters of the reservoirs based on their perceived relevance which is a reflection of their significance in the overall rating of the reservoirs relative to hydrocarbon potential.

2. Geological Overview:

"Essy" Field is located Offshore Niger Delta, Southwestern Nigeria within Chevron Nigeria Limited acreage. The Niger Delta is one of the world's largest deltas which covers an area in excess of 105,000 km^2 (Figure 1) and extends beyond 300 km from apex to mouth (Avbovbo, 1978). The regressive wedge of clastic sediments, which it comprises, is thought to reach a maximum thickness of about 12 km. At the mouth of the Benue and Cross River system, the Niger Delta has been built out into the central Atlantic with the Niger-Benue River Complex being its main supplier of sediments but with minor input from the Cross River in the east (Doust and Omatsola, 1990). The interplay between rates of sediment supply and subsidence of the delta has controlled its structure and stratigraphy throughout its geologic history (Alao and Oludare, 2015).

The onshore portion of the Niger Delta Province is delineated by the geology of Southern Nigeria and Southwestern Cameroon. Stratigraphically, the established tertiary sequence in the Niger Delta consists of the Akata, Agbada and Benin Formations (Figure 2).

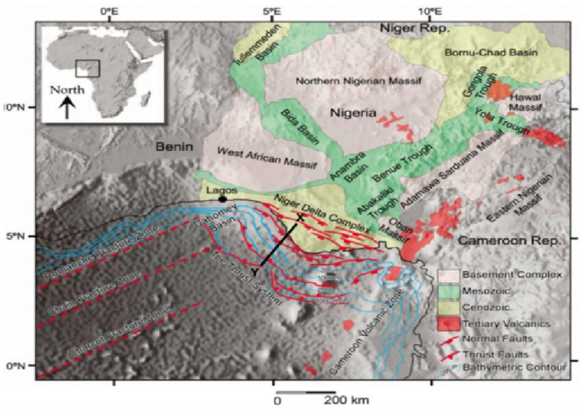

Figure 1. Map of Nigeria indicating the location of the Niger Delta Basin (Corredor et al., 2005)

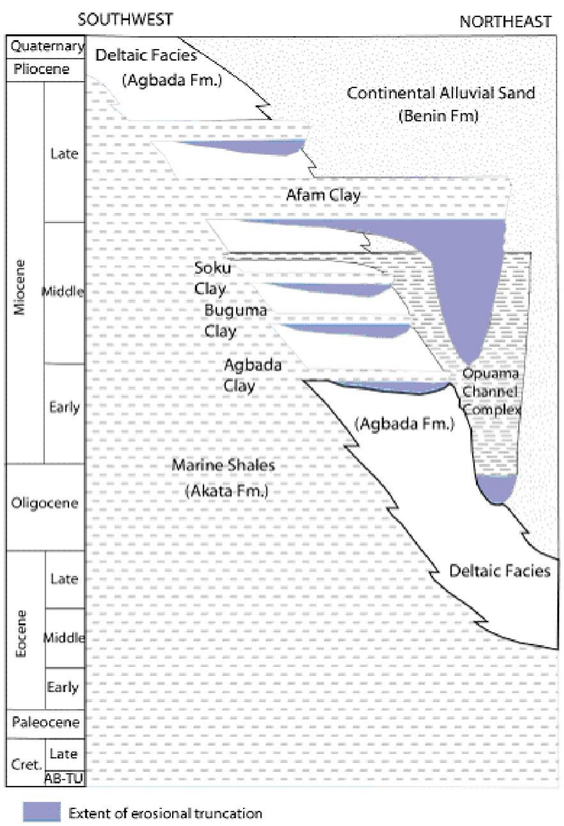

Figure 2. Stratigraphic Column showing the Three Formations of the Niger Delta and their Respective Ages (Modified from Shannon and Navlor, 1989 and Doust and Omatsola, 1990)

3. Materials and Method

A suite of well logs consisting of Gamma ray, Resistivity, Density, Neutron and Sonic logs from two wells in "Essy" Field, Niger Delta, were obtained from the databank of the Department of Geology, Obafemi Awolowo University. A 70 API (American Petroleum Institute) cut-off value enabled the identification of lithologies using the Gamma Ray (GR) log.

Hydrocarbon sand units were inferred from high resistivity values from resistivity log, corresponding to low gamma ray readings from gamma ray log. The fluid types in each of the identified sand units were established using a combination of the neutron and density logs in the same track. Petrophysical parameters such as permeability, water saturation, volume of shale and porosity, were computed employing the following empirical relations;

Volume of Shale (V_{sh}) = $0.083\left(2^{3.7 \times I_{GR}} - 1\right)$ (1)

[Larionov (1969) Tertiary rocks method]

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \qquad (2)$$

Where;
I_{GR} = Gamma-ray index
GR_{log} = Gamma ray reading of formation
GR_{min} = minimum Gamma ray reading (clean sand or carbonate)
GR_{max} = maximum Gamma ray reading (shale)

$$\text{Total Porosity } (\emptyset_d) = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (3)$$

Where;
ρ_{ma} = Density of matrix material (2.648 gm/cc for sandstone)
ρ_b = Bulk density (read from the density log)
ρ_f = Density of the drilling fluid (0.85 gm/cc for oil-based mud)

Effective Porosity ($\emptyset_{eff}$) = $\emptyset_{total} \times (1 - V_{sh})$ (4)

Where;
V_{sh} = Volume of Shale
$\emptyset_{total}$ = Total Porosity
$\emptyset_{eff}$ = Effective Porosity

$$\text{Water Saturation } (S_w) = \left(\frac{R_w \times a}{R_t \times \emptyset^m}\right)^{1/n} \qquad (5)$$

(Archie, 1942)

Where;
S_w = Water saturation of the uninvaded zone
a = Tortuosity factor (2.81g/cc for sandstone)
m = Cementation exponent (usually 2)

n = Saturation exponent (usually 2)
R_w = Resistivity of formation water at formation temperature
R_t = True resistivity of formation
$\emptyset$ = Porosity

The identified sand units were ranked according to their hydrocarbon production potential by assigning weighted averages to petrophysical parameters of the reservoirs based on their perceived relevance. Table 1 is a reflection of their significance in the overall rating of the reservoirs relative to hydrocarbon potential.

Table 1. Weighted Average for Ranking of Hydrocarbon Reservoirs

Petrophysical Parameters	Weighted Average
Permeability	40
Hydrocarbon saturation	15
Volume of shale	20
Porosity	15
Thickness	10
Total	100%

4. Results and Discussion

Two wells namely Essy 05 and Essy 06 were analyzed. Figure 3 is the base map of the study area showing the locations of the wells. Segments of the gamma ray logs with low API value relative to the shale baseline were interpreted as sand units. Based on this, four (4) sand units labeled Sand 01, Sand 02, Sand 03 and Sand 04 were identified between the 9,528 m and 11,186 m across the two wells and presented in Tables 2a and 2b. The tables show the summary of the range of thicknesses of the identified reservoirs. Sand units with relatively high resistivity readings were interpreted as hydrocarbon bearing units, while sand units corresponding to relatively low resistivity readings were interpreted as water bearing units. A combination of the resistivity and gamma ray logs revealed four (4) hydrocarbon bearing sand units (Sand 01 – Sand 04) across the wells (Figure 4).

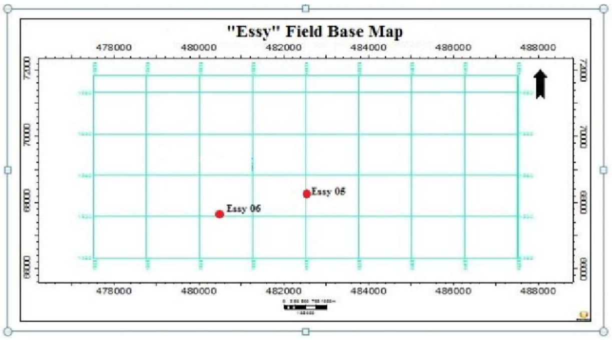

Figure 3. Base Map indicating Wells in the Study Area

Table 2a. Hydrocarbon Sand Thicknesses in Essy 05

Reservoir	Range (m)	Gross Thickness (m)
Sand 01	9,528 – 9,531	3
Sand 02	10,516 – 10,539	23
Sand 03	10, 935 – 10,950	15
Sand 04	11,084 – 11,186	102

Table 2b. Hydrocarbon Sand Thicknesses in Essy 06

Reservoir	Range (m)	Gross Thickness (m)
Sand 01	9,643 – 9,660	17
Sand 02	10,638 – 10,653	15
Sand 03	10,868 – 10,883	15
Sand 04	10,971 – 11,063	92

Petrophysical parameters were computed to characterize the four (4) reservoir sand units (Sand 01 – Sand 04). Volume of shale, water saturation, irreducible water saturation, porosity, permeability and hydrocarbon saturation were computed for the four (4) reservoir sand units.

Sand 01 occurs between a depth interval of 9,528 m and 9,660 m with thicknesses of 3 m and 17 m in Essy 05 and Essy 06 respectively. Values of volume of shale, water saturation, irreducible water saturation and effective porosity computed for these sands are summarized in tables 3a and 3b. It was observed that Sand 01 in Essy 06 has relatively high volume of shale, water saturation, irreducible water saturation and low effective porosity compared to the values obtained in Essy 05. Sand 02 occurs across both wells between a depth interval of 10,516 m and 10,653 m with thicknesses of 23 m and 15 m in Essy 05 and Essy 06 respectively. Values of volume of shale, water saturation, irreducible water saturation and effective porosity computed for Sand 02 are summarized in tables 3a and 3b. The volume of shale in Sand 02 in both wells are the same, the water saturation and irreducible water saturation are relatively higher in Essy 06 while the effective porosity is lower.

The neutron and density logs combination revealed no crossover in both wells (Figures 5a and 5b), thus, indicating the presence of oil.

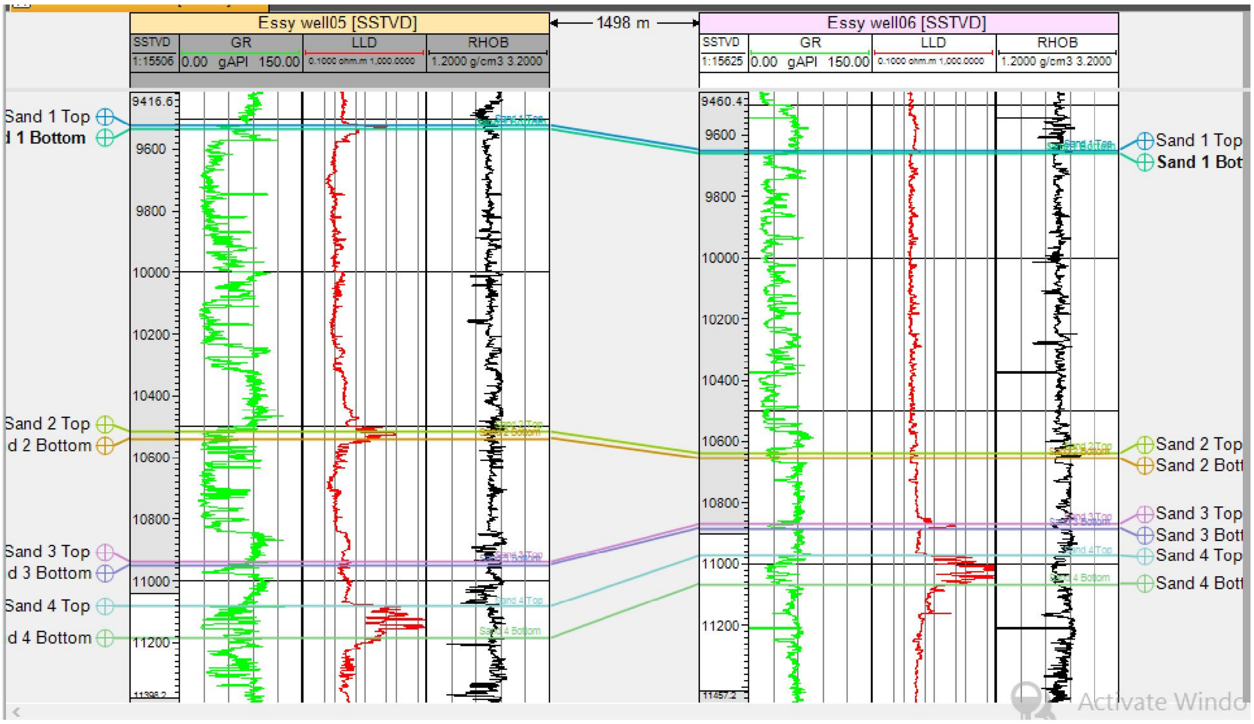

Figure 4. Sand Correlation across the Studied Wells

Sand 03 was identified across Essy 05 and Essy 06 between a depth interval of 10,868 m and 10,950 m with a thickness of 15 m across both wells. The values of volume of shale, water saturation, irreducible water saturation and effective porosity are summarized in tables 3a and 3b.

Table 3a. Petrophysical Parameters Computed for Essy 05

	V_{sh}(%)	S_w (%)	S_{wirr} (%)	$\emptyset_{eff}$ (%)	K(mD)	
					Oil	Gas
Sand 01	6	62	7	27	4,939	-
Sand 02	2	63	8	24	1,866	-
Sand 03	13	61	16	13	1,200	-
Sand 04	4	33	9	21	6,620	-

Table 3b. Petrophysical Parameters Computed for Essy 06

	V_{sh}(%)	S_w (%)	S_{wirr} (%)	$\emptyset_{eff}$ (%)	K(mD)	
					Oil	Gas
Sand 01	30	71	19	11	3,000	-
Sand 02	2	72	12	17	1,050	-
Sand 03	6	72	7	26	-	3,930
Sand 04	5	40	8	24	-	1,860

A relatively higher volume of shale and irreducible water saturation were observed in Essy 05 with a lower effective porosity while Essy 06 maintains higher water saturation with a higher effective porosity. A combination of neutron and density logs in the same track revealed no crossover (Figure 5a) in Essy 05 indicating the presence of oil. In Essy 06, a crossover was observed (Figure 5b) indicating the presence of gas. Sand 04 occurs across Essy 05 and Essy 06 between a depth interval of 10,971 m and 11,186 m. Its thickness in Essy 05 and Essy 06 are 102 m and 92 m respectively. Sand 04 exhibits low volume of shale, water saturation, irreducible water saturation and a high effective porosity in both wells.

The summary of the results of the petrophysical parameters for each identified sand units are presented in table 4. These parameters are weighted using the approach described in the methodology. The weighted average of the parameters for each of the sand units is presented in table 5. From this table, it was observed that the total average ranking value of Sands 01, 02 and 03 range between close intervals of 21.3 – 25.2%, Sand 04 was observed to be almost double (46.9%) this range.

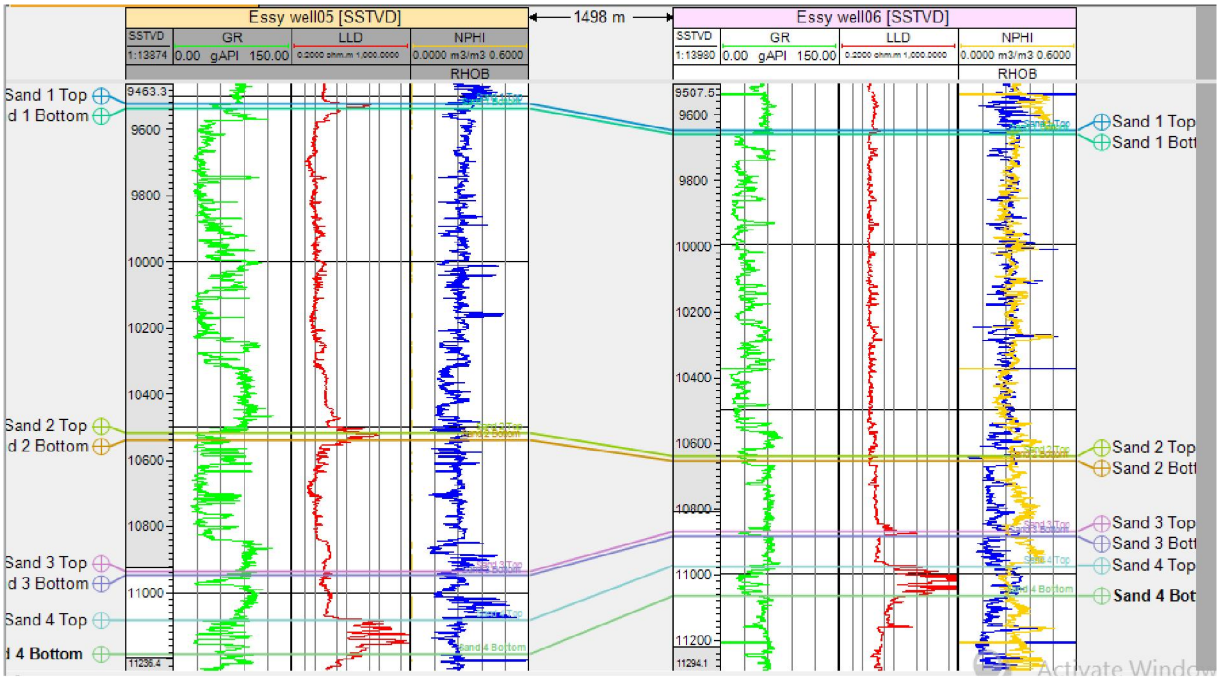

Figure 5a. Neutron and Density Combination Plots in Essy 005 Well for Fluid Type Identification

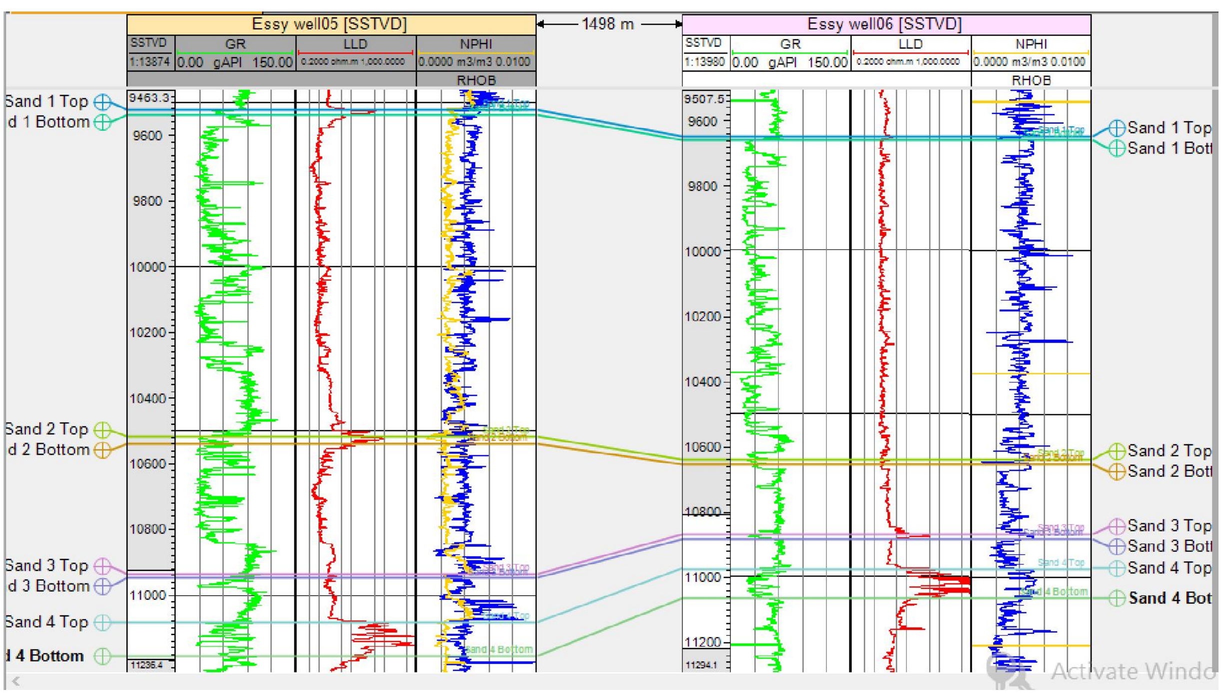

Figure 5b. Neutron and Density Combination Plots in Essy 006 Well for Fluid Type Identification

Table 4. Ranking of Identified Reservoir

	Sand 04	Sand 02	Sand 03	Sand 01
Thickness (m)	92 – 102	15 – 23	15	3 – 17
Depth (m)	10,971 – 11,186	10,516 – 10,653	10,868 – 10,950	9,528 – 9,660
Hydrocarbon saturation (%)	60 – 67	28 – 37	28 – 39	29 – 38
Volume of shale (%)	4 – 5	2	6 – 13	6 – 30
Porosity (%)	21 – 24	17 – 24	13 – 26	11 – 27
Permeability (md)	1,860 – 6,620	1,050 – 1,866	1,200 – 3,930	3,000 – 4,939
Rank	Very Good	Good	Very Fair	Fair

Table 5. Summary of the Total Average Ranking Value of the Identified Reservoir

RESERVOIR	WEIGHTED AVERAGE					
	Thickness (m)	Hydrocarbon Saturation (S_h)	Volume of Shale (V_{sh})	Porosity (Ø)	Permeability (mD)	Total Average
Sand 01	2.0	13.4	2.7	3.8	0.6	25.2
Sand 02	1.9	13.0	0.3	4.1	2.0	21.3
Sand 03	1.5	13.4	1.4	3.9	3.8	24.0
Sand 04	9.7	25.4	0.7	4.5	6.6	46.9

5. Conclusion

A suite of well logs consisting of Gamma ray, Resistivity, Density, Neutron and Sonic logs in two wells from "Essy" Field, Niger Delta, were obtained from the databank of the Department of Geology, Obafemi Awolowo University. Two wells namely Essy 05 and Essy 06 were analysed for petrophysical parameters. Four (4) sands were identified in the two wells within the study area. The sand units were labelled Sand 01, Sand 02, Sand 03 and Sand 04. Sand 01, Sand 02, Sand 03 and Sand 04 in Essy 05 contain oil while in Essy 06, Sand 01 and Sand 02 contain oil, and Sand 03 and Sand 04 contain gas. As shown in Table 5, Sand 04 has total average ranking value of 46.9% while Sand 01, 02 and 03 has total average ranking value of 25.2%, 21.3% and 24% respectively. Sand 04 has the highest total average ranking value, almost double of the other sand units. It is therefore concluded that Sand 04 is the best reservoir compared to the other reservoir which range between close intervals.

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