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EVALUATION OF THE CONTRIBUTION OF HYDRAULIC FRACTURING OF THE CENOMANIAN RESERVOIR TO THE PRODUCTIVITY OF WELLS IN THE MAKELEKESE FIELD, DEMOCRATIC REPUBLIC OF CONGO

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ABSTRACT

The Democratic Republic of Congo, with its Coastal Basin, represents a major source of liquid and gaseous hydrocarbons. This study explores the use of hydraulic fracturing as a method to enhance production in the Makelekese-08 (MS-08) and Makelekese-10 (MS-10) wells within the Makelekese field. As many oil fields in the region mature, it becomes essential to adopt advanced techniques to maximize the extraction of remaining reserves.

The primary objective of this research is to assess the impact of hydraulic fracturing by analyzing fracture propagation and its influence on reservoir productivity. Specific objectives include characterizing the lithological and petrophysical properties of the Cenomanian reservoir, including porosity and permeability. Providing a detailed description of the fracturing treatment, including the fluids, additives, and injection parameters. Analyzing production variations before and after fracturing, demonstrating increases of up to three times the initial production.

This study aims to fill a gap in quantitative assessments and local geological data regarding hydraulic fracturing in the Coastal Basin. By integrating geological, petrophysical, and operational analyses, it offers significant insights into reservoir stimulation and its effectiveness in enhancing hydrocarbon recovery.

Keywords: fracturing, productivity, petrophysical, Makelekese field, permeability.

INTRODUCTION

Since the discovery of hydrocarbon deposits in the western part of the DRC, several production and/or development wells have been drilled with a view to optimizing the economic value of the estimated reserves. During the development periods of the oil fields that make up the onshore part of the DR Congo's coastal basin, and even during most of the life of their deposits, several wells were stimulated by hydraulic fracturing in order to optimize their production [2, 22, 24]. Almost all the fields in the coastal basin have declined, in other words, they are mature fields, and the recovery of hydrocarbons in place requires more advanced techniques. The best techniques that can be considered are those that are part of tertiary production methods such as hydraulic fracturing, which was the

subject of this study [1, 3, 8, 24]. The coastal basin of the D.R. Congo, which covers an area of 4,980 sqkm, is bordered to the Congo Basin, which covers an area of 4,980 sqkm, is bordered to the north by Cabinda, to the south by Angola, to the west by the Atlantic Ocean, and to the east by the Mayombe crystalline basement. It is located between meridians 110 and 130 east and parallels 40 and 60 south. The Makelekese field, located at the foothill at the Kitona base (Figure 1), is part of six consecutive onshore oil reserves belonging to the Perenco-Rep company. It is bordered to the east by the city of Muanda, to the west by the Kitona base, to the south by the Muanda field, and to the north by the Kinkasi field [9, 13].

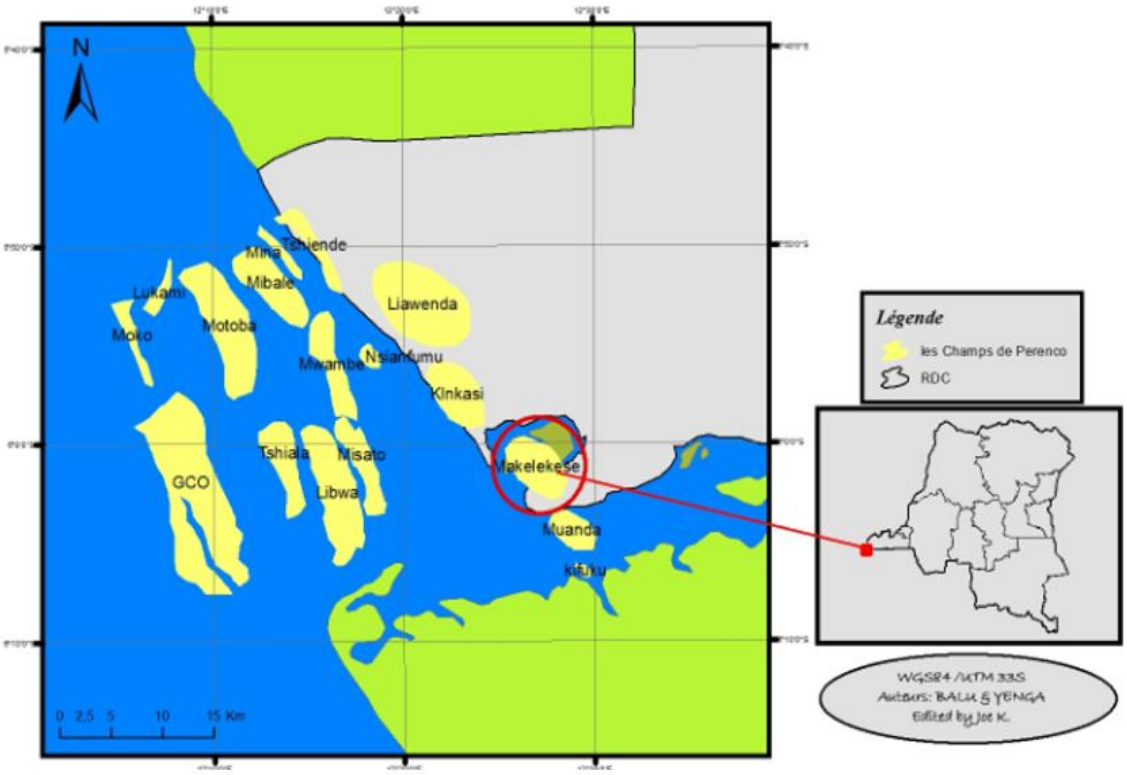

Figure 1. *Main fields in the coastal basin and location of the study field (Makelekese).*

The main objective of this work is to evaluate the applicability of hydraulic fracturing in wells MS-08 and MS-10 of the Makelekese field to increase the productivity of these wells [5]. The study evaluates the effectiveness of hydraulic fracturing in improving the productivity of oil wells in the Cenomanian reservoir of the Makelekese field (MS-08 and MS-10 wells), located in the coastal basin of the DRC. The study it highlights (Figure 2):

- The lithological and petrophysical characterization of the reservoir (porosity, permeability, facies) [16, 12, 17].
- The technical description of the fracturing treatment (fluids, additives, proppants, injection pressures and flow rates) [6, 21].
- The measured evolution of production rates before and after fracturing (2 to 3 times increase in initial production) [11, 23, 24].

This scope is therefore both academic (modeling and analysis of fracture propagation) and operational (concrete improvement of oil recovery from the reservoir). Prior to this study, there were few documented studies on the actual effectiveness of hydraulic

fracturing applied to reservoirs in the DRC coastal basin, particularly in the Makelekese field. The gaps were:

- The absence of a quantitative assessment of the impact of this technique on the productivity of wells in the basin.
- The lack of local data incorporating geological parameters (alternating carbonate, silty, and clayey facies) and operational parameters (nature of fluids, pressure, fracture conductivity).
- The study therefore fills this gap by providing an integrated geological-petrophysical-operational analysis, validated by actual production results.

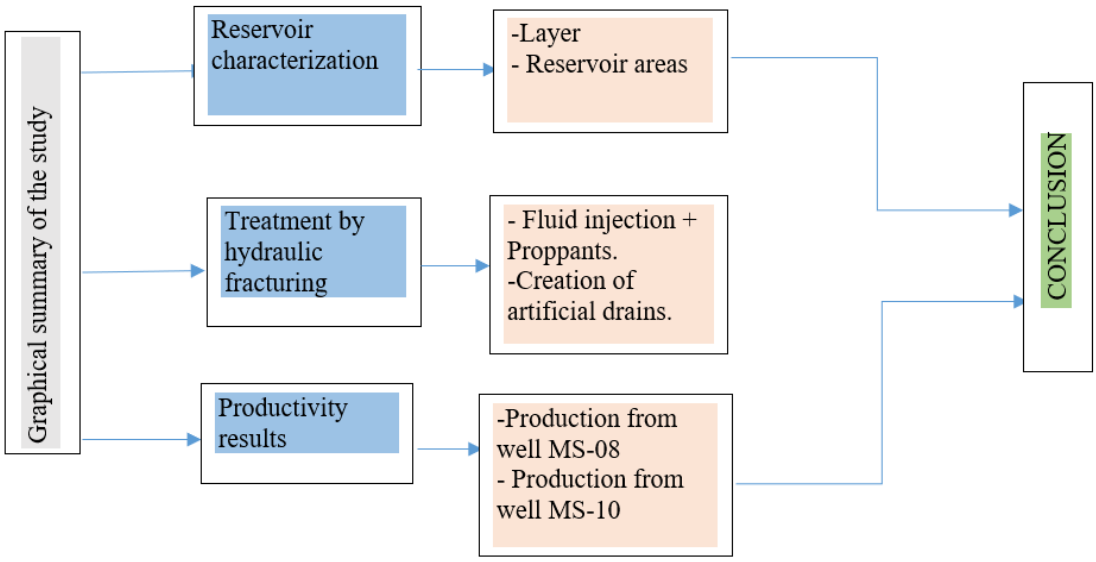

Figure 2. *Graphical summary of the study*

This study is innovative in several ways:

- Systematic evaluation of hydraulic fracturing applied to the Cenomanian reservoir at the Makelekese field.
- Joint use of sedimentological, petrophysical, and operational monitoring data to measure treatment effectiveness.

Measuring treatment effectiveness involves several key metrics:

1. Production Rates: We assess the oil and gas production rates before and after the treatment. A significant increase in these rates can indicate successful fracturing.
2. Fracture Geometry and Extension: By analyzing sedimentological data, we can determine the geometry and extent of fractures created during the treatment. This information helps us understand how well the fractures are propagating through the reservoir.
3. Petrophysical Properties: Evaluating changes in the rock's petrophysical properties—such as permeability and porosity can reveal how the treatment has impacted the reservoir's ability to store and transmit hydrocarbons.
4. Highlighting the differentiated role of reservoir zones (thick but low-permeability zone G, more porous and permeable zone K) in stimulation.

MATERIALS AND METHODS

This work was made possible by using the following research methods and materials:

- Geographic Information System (GIS) software, specifically ArcGIS 10.2, to develop various maps related to the study area;
- Excel 2010 software: for statistical calculations of production data and their graphical representation;
- GPS (geographic information system) for recording the geographic coordinates of wells and other points of interest [14, 18, 20].

The information and data covered in this study come from two producing wells that have crossed the Cenomanian reservoir in the Makelekese field. These are:

- Production data from these wells three months before hydraulic fracturing and three months after hydraulic fracturing [10,15,25];
- Petrophysical data from the Cenomanian reservoir in the Makelekese field, in particular porosity and permeability;
- Sequential analysis data to identify the different facies of the Cenomanian reservoir [4,7,26].

RESULTS AND DISCUSSION

Sedimentology study and sequence analysis

The sediments were deposited in a lagoonal environment. The lithology is complex and consists mainly of limestone, vacuolar limestone, siltstone, and claystone. The Cenomanian reservoir in the Makelekese field is a multi-layer reservoir consisting of 11 sequences of varying thickness and lithology, ranging from zone A to K (Figure 3).

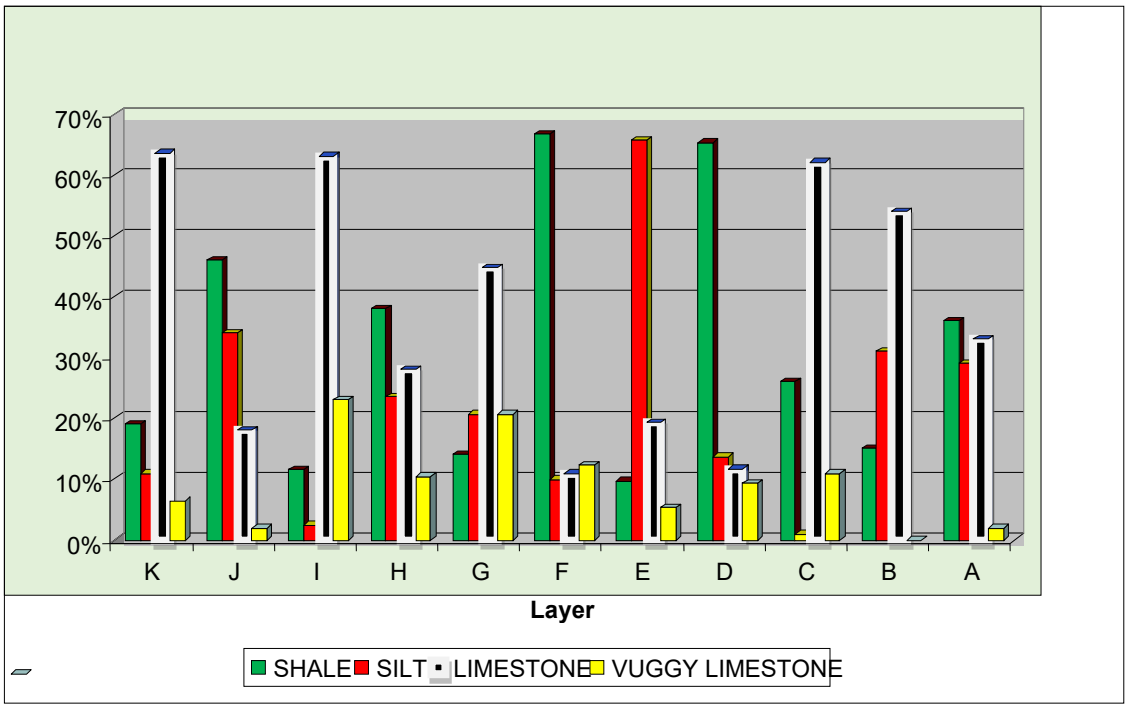

Figure 3. *Alternating facies of the Cenomanian reservoir in relation with 11 layers (A to K).*

Consequently, the average thicknesses of the layers listed below are those obtained from wells MS-8 and MS-10. The distribution of facies within each sequence can be seen in Table 1. To determine the thicknesses of the reservoir, we added the thicknesses of each zone per well and then calculated the average thickness in each well. This allows us to determine the thickness of the reservoir. The average thicknesses of the zones are as follows: Layer K: 16.50 m thick; Layer J: 14 m thick; Layer I: 17.70 m thick; Layer H: 15.50 m thick; Layer F: 20 m thick; Layer G: 50.70 m thick.

Table 1. *Data on the distribution of thicknesses of the Cenomanian reservoir zones of the Makelekese field in wells MS-08 and MS-10.*

Well	**Areas**					
Layers	K	J	I	H	G	F
MS-08	10	12	18.50	12	29.50	20
MS-10	23	16	17	19	72	21

Across the entire field, zone G has a large thickness averaging 50.70 m, which is why it contributes more to the field's production. It is followed by zone F, which has an average thickness of around 20 m. The lithostratigraphy of the Cenomanian reservoir, which includes the Makelekese field, is determined by alternating silts, carbonates, and clays. The structure of the reservoir shows variations in layer thickness for each zone.

PETROPHYSICAL ANALYSIS

Porosity

In the Table 2 are presented the average porosities of different sequences taken in relation to the different zones making up the Cenomanian reservoir in the Makelekese field.

Table 2. *Average porosity of different areas and their assessments*

Areas	**Average porosity (%)**	**Appraisals**
K	17.20	Good
J	10.40	Average
I	14.60	Average
H	15.40	Good
G	14.50	Average
F	10.40	Average

Permeability

The average permeabilities of different sequences taken from the various zones that make up the Cenomanian reservoir in the Makelekese field are shown in table 3. In Table 3, we can see that zone K has an average permeability of around 30 mD and consists mainly of a much more calcareous than silty facies; it is a more porous and permeable zone, followed by zone H, which has an average permeability of around 17 mD. We also observe that zone G is porous (14.50%) but less permeable (7 mD), despite its great thickness. The same is true for zone I. These porous layers retain a large amount of hydrocarbons stored in the pores, but do not drain fluids. This shows that there are

quantities of hydrocarbons in several sequences or zones that are more porous but less permeable, thus preventing good drainage of hydrocarbons.

Table 3. *Average permeabilities of different zones and their assessments*

Areas	Average permeabilities (mD)	Appraisals
K	29.90	Good
J	1.98	Average
I	8.80	Average
H	16.80	Good
G	7.00	Average
F	1.30	Average

HYDRAULIC FRACTURING TREATMENT

Fluids used and their additives

The two wells examined in this study were drilled vertically. To facilitate the hydraulic fracturing treatment, a series of perforations were made in each well. This operation is conducted in multiple stages or phases for each well. The stages involved are as follows:

I. Injection of a fluid without proppants (pad volume), specifically YF130ST and YF125ST. This mixture consists of a water-based fracturing fluid combined with a friction-reducing agent. It is designed to fill the entire volume of the borehole and the fractures created by the perforation. This fluid will establish a network of fractures around the wellbore, thereby enhancing fluid circulation under high pressure.

II. Injection of proppants using "PPA/YF130ST and PPA/YF125ST": these fluids are infused with proppants. The proppants consist of finely graded particles known as Jordain Unimin 12/20 (PPA). Their purpose is to maintain the fractures created by hydraulic fracturing open, preventing them from closing once the injection pressure subsides.

III. Evacuation of fracturing fluid without proppants (WF120, WF125): this is an unloaded fluid used to flush out the fracturing fluid and gradually increase the size of the proppants by forcing them into the fracture. Table 4 summarizes the different fluids used in each well.

Table 4. *The different fluids used in this study*

Well	*Fluid name*
MS-08	YF130ST, WF120
MS-10	YF125ST, WF125

The main additives in YF130ST and YF125ST fluids are as follows:

- Biocide: bactericide;
- Gelling agent: used to increase viscosity;
- Breaker: breaking agents used to break the polymer chain created by the gelling agent;

- Surfactant;
- Gloystabilizer: clay controller to prevent clay particles from swelling;
- Non-emulsifying agent;
- Crosslinker: receded polymers used to assemble polymers to create three-dimensional structures;
- Activator.

Properties of proppants are as follows:

- Mesh size: 12/20;
- Density: 2.65;
- Laminar friction coefficient: 1.00;
- Turbulent friction coefficient: 0.70.

Table 5 summarizes the different types of additives used in each well and their pumped quantities.

Table 5. *Types of additives used in each well and their pumped quantities.*

Additives	***Quantities used in each well***	
	Well MS-08	Well MS-10
M290, Bactericide	17 gal	15 gal
L064, Claystabilizer	23 gal	19 gal
F103, EZEFLO, Surfactant	23 gal	17 gal
J532A,Borate crosslinker	170 gal	16 gal
J218,life Breaker	55 gal	52 gal
J564FB,green slurry	96 gal	89 gal

Hydraulic fracturing operation in wells MS-08 and MS-10

Hydraulic fracturing in MS-08 well was performed with the following values (Figure 4):

- Average treatment pressure of 1572 psi;
- Maximum treatment pressure of 1824 psi;
- Minimum treatment pressure of 0 psi;
- Immediate post-shut-in pressure (ISIP) of 1100 psi;
- Average injection flow rate of 16.30 bbl/min;
- Maximum injection flow rate of 20.0 bbl/min;
- Maximum fluid concentration of 6.0 PPA.

Following hydraulic fracturing in MS-08 well, monitoring and control tests carried out on the reservoir yielded the following results (Figure 5):

- Length of the open fracture: 38.70 m;
- Average height of open fracture: 33 m;
- Efficiency: 0.554 or 55.4%;
- Effective conductivity: 1746 md.ft;
- Average gel concentration: 434.4 lb/mgal;
- Estimated closure time: 47.80 min.

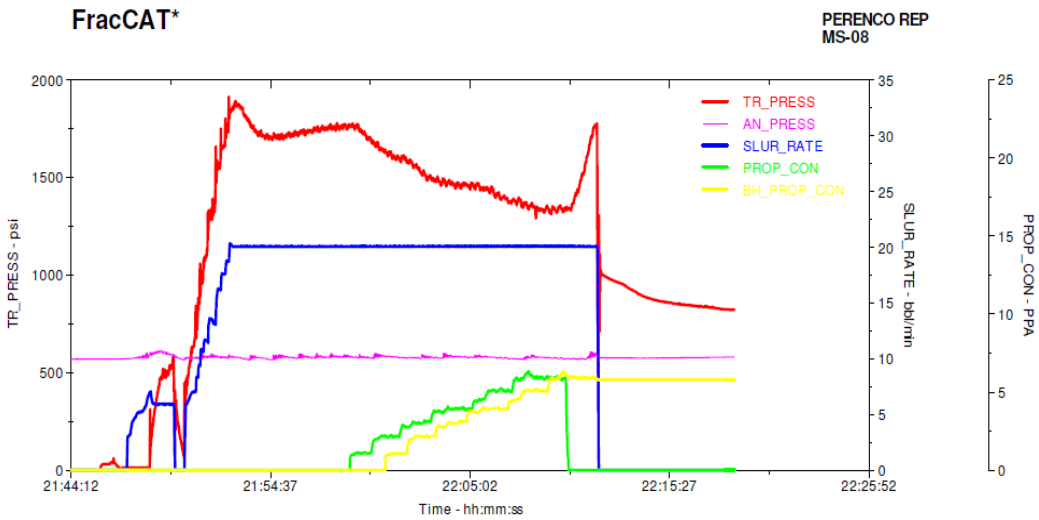

Figure 4. *Hydraulic fracturing being performed in well MS-08*

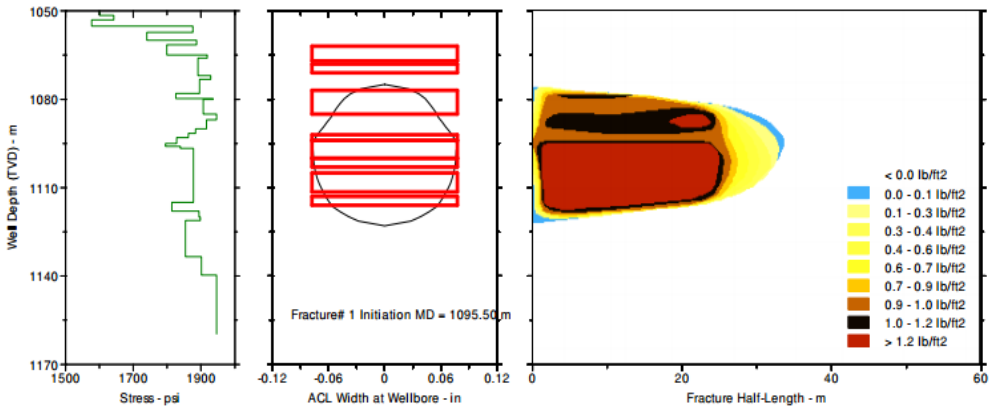

Figure 5. *Propagation and orientation of the fracture using the P3D model in the MS-08 well.*

Of all the sequences subjected to hydraulic fracturing, the sequence with the most fractures is sequence G, followed by sequence I and finally the other two sequences. So far, it is assumed that the operation has opened up a large number of permeable drains extending as far as possible, which should provide good conductivity in the rock and even increase the productivity of this well. The evolution of pressures (treatment and annular pressure), fluid pumping rate, and proppant concentration is summarized in the graph from Figure 6.

Hydraulic fracturing in MS-10 well was performed with the following values (Figure 6):

- Minimum treatment pressure: 0 psi;
- Average treatment pressure: 1,500 psi;
- Maximum treatment pressure: 2,000 psi;
- Pressure measured immediately after closure: 925 psi;
- Average injection rate: 13.80 bbl/min;
- Maximum injection flow rate 17 bbl/min;

- Maximum fluid concentration 6.20 PPA.

At the end of the hydraulic fracturing in MS-10 well, monitoring and control tests carried out on the reservoir gave the following results (Figure 7):

- Fracture opening length: 44.0 m;
- Average height of open fractures: 67 m;
- Efficiency: 0.23 or 23%;
- Effective conductivity: 2273 md.ft;
- Average gel concentration: 125.9 lb/mgal;
- Estimated closure time: 121.5 min.

The conductivity of the fracture was calculated using a permeability of 50%.

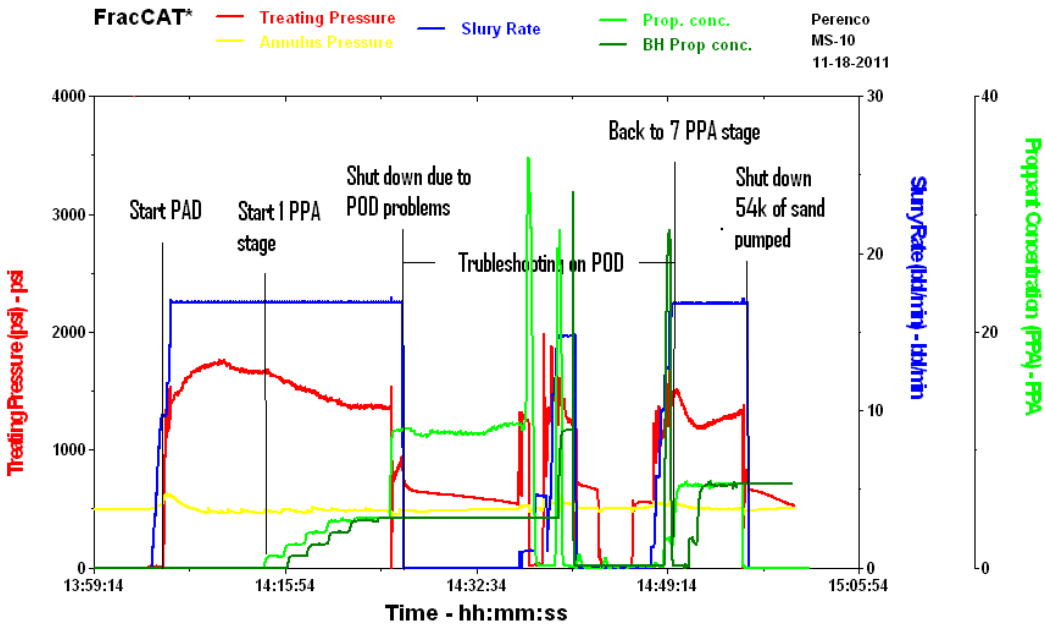

Figure 6. *Hydraulic fracturing treatment being performed in well MS-10*

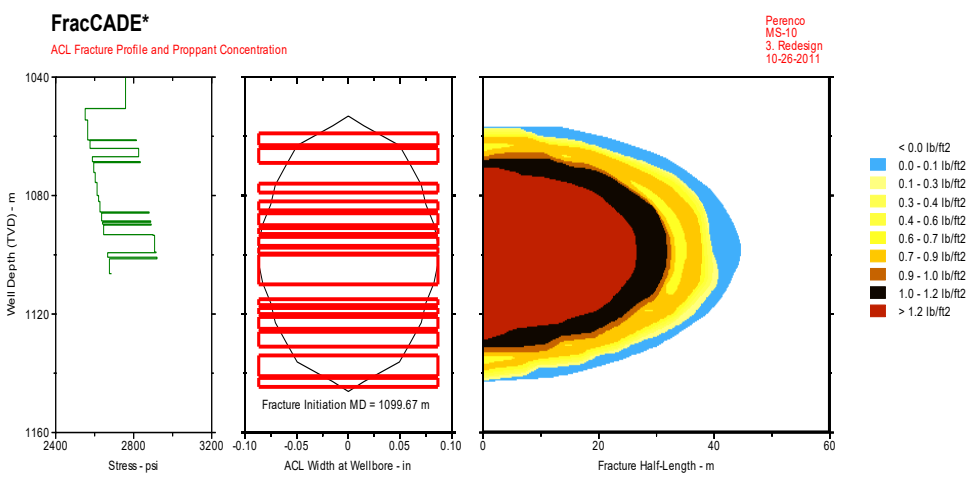

Figure 7. *Propagation and orientation of the fracture using the P3D model in the MS-10 well.*

Evaluation of production data three months prior to hydraulic fracturing in the MS-08 well

Production data for the MS-08 well prior to hydraulic fracturing are presented in Table 6 and in the graph in Figure 8.

Table 6. *Production evolution of the MS-08 well before hydraulic fracturing*

Dates	Productive areas	Activation mode	BOPD	BFPD	BWPD	GOR (scf/bbl)
05/12/2012	GHI	PCP	24	25	1	717
12/12/2012	GHI	PCP	26	29	3	574
23/12/2012	GHI	PCP	18	22	4	384
28/12/2012	GHI	PCP	19	24	5	619
06/01/2013	GHI	PCP	20	25	5	508
14/01/2013	GHI	PCP	19	22	3	695
21/01/2013	GHI	PCP	18	21	3	811
29/01/2013	GHI	PCP	19	22	3	687
09/02/2013	GHI	PCP	22	24	2	324
15/02/2013	GHI	PCP	23	24	1	342
21/02/2013	GHI	PCP	19	22	3	752
01/03/2013	GHI	PCP	16	19	3	507
07/03/2013	GHI	PCP	22	28	6	653

Table 6 shows the fluid production from the MS-08 well, with an average of 23.6 barrels of fluid per day (BFPD) containing an average of approximately 20.3 barrels of oil per day (BOPD) and an average of approximately 3.2 barrels of water per day (BWPD), but with a GOR of 582.5 scf/bbl.

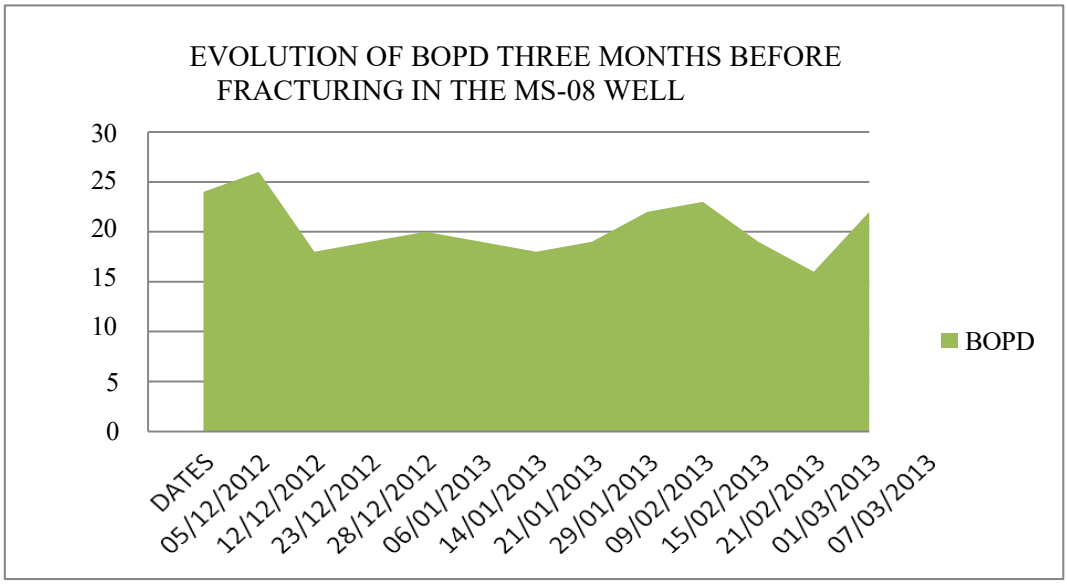

Figure 8. *Graph showing production data in barrels of oil per day (BOPD) three months prior to hydraulic fracturing in the MS-08 well.*

Evaluation of production data three months prior to hydraulic fracturing in the MS-10 well

Production data for the MS-10 well prior to hydraulic fracturing are presented in Table 7 and in the graph in Figure 9.

Table 7. *Production evolution of the MS-10 well before hydraulic fracturing*

Dates	Productive areas	Activation mode	BOPD	BFPD	BWPD	GOR (scf/bbl)
17/07/2011	HIJ	SRP	28	31	3	459
13/08/2011	HIJ	SRP	24	25	1	423
06/09/2011	HIJ	SRP	27	31	4	527
12/09/2011	HIJ	SRP	25	30	5	320
25/09/2011	HIJ	SRP	24	32	8	494
04/10/2011	HIJ	SRP	24	30	6	536
16/10/2011	HIJ	SRP	24	28	4	424

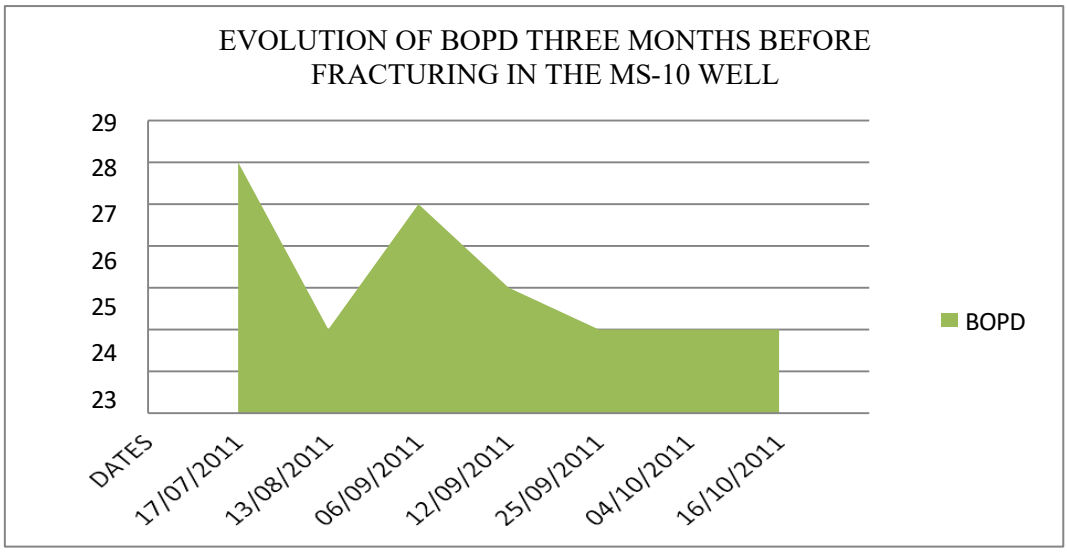

Figure 9. *Graph showing oil production in barrels per day (BOPD) three months prior to hydraulic fracturing in the MS-10 well*

After calculating the production data, we found that production in this well varied around an average of approximately 29.5 barrels of fluid per day (BFPD), with an average of 25.1 barrels of oil per day (BOPD) and an average water volume of approximately 4.4 barrels per day (BWPD), with an average GOR of approximately 454.7 scf/bbl.

Evaluation of production data three months after fracturing

The production data for well MS-08 after the hydraulic fracturing operation are presented in the Table 8 and in the graph in Figure 10. Based on these results, we can agree that the Cenomanian reservoir in well MS-08 has been stimulated, showing that the drains have

been opened as far as possible, reflecting a fracture length of approximately 38.7 m and an effective conductivity of approximately 1746 md.ft. This operation increased the natural permeability of the reservoir by significantly extending the radius of the well. This confirms that permeability was reduced around the well and even inside the well, causing a significant decrease in its productivity. By evaluating production trends, we arrive at a daily production in barrels of fluid per day (BFPD) of an average of approximately 53.5, in which we have an average oil quantity of 48.4 barrels per day (BOPD), an average water output of 5.1 barrels per day (BWPD), and a fairly good GOR 852.9 scf/bbl.

Table 8. *Production results for well MS-08 three months after hydraulic fracturing.*

Dates	Productive areas	Activation mode	BOPD	BFPD	BWPD	GOR (scf/bbl)
06/11/2013	GHI	PCP	99	115	16	597
13/11/2013	GHI	PCP	56	62	6	1130
20/11/2013	GHI	PCP	58	66	8	672
24/11/2013	GHI	PCP	49	56	7	772
02/12/2013	GHI	PCP	59	68	9	726
11/12/2013	GHI	PCP	45	46	1	732
18/12/2013	GHI	PCP	39	41	2	1017
01/01/2014	GHI	PCP	40	44	4	792
03/01/2014	GHI	PCP	32	34	2	1109
10/01/2014	GHI	PCP	37	40	3	914
17/01/2014	GHI	PCP	37	41	4	894
30/01/2014	GHI	PCP	38	40	2	893
06/02/2014	GHI	PCP	40	42	2	840

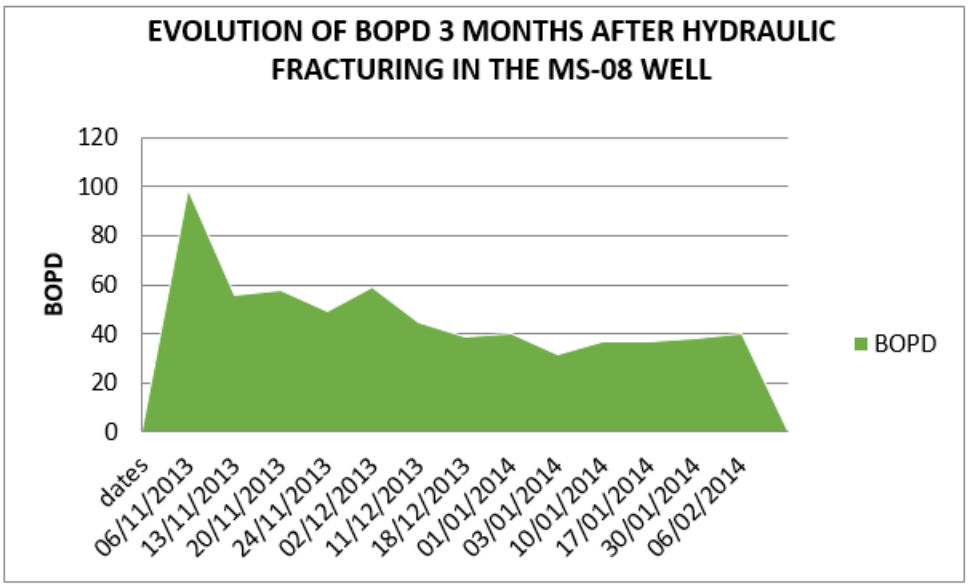

Figure 10. *Graph showing oil production in barrels per day (BOPD) three months after hydraulic fracturing in the MS-08 well.*

Production data from well MS-10 three months after hydraulic fracturing

Production data obtained after fracturing treatment in well MS-10 are listed in the table 9 and are presented in the graph in Figure 11.

Table 9. *Production data from well MS-10 three months after hydraulic fracturing*

Dates	Productive areas	Activation mode	BOPD	BFPD	BWPD	GOR (scf/bbl)
25/12/2011	GIK	SRP	79	88	9	1215
28/12/2011	GIK	SRP	72	103	31	677
31/12/2011	GIK	SRP	62	100	38	1763
04/01/2012	GIK	SRP	79	114	35	1456
16/01/2012	GIK	SRP	78	100	22	1049
30/01/2012	GIK	SRP	58	75	17	1123
02/02/2012	GIK	SRP	65	93	18	944
14/02/2012	GIK	SRP	57	71	14	1074
23/02/2012	GIK	SRP	57	63	6	1093
07/03/2012	GIK	SRP	48	59	11	1347
14/03/2012	GIK	SRP	59	61	2	1029
20/03/2012	GIK	SRP	41	49	8	1347

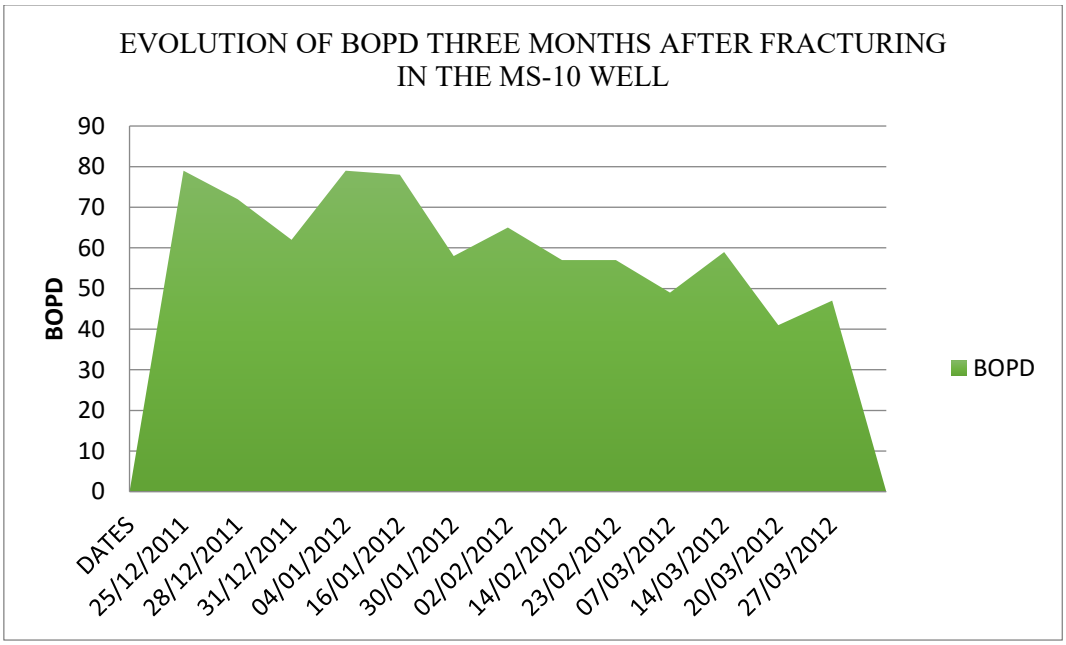

Figure 11. *Graph showing oil production in barrels per day (BOPD) three months after hydraulic fracturing in the MS-10 well.*

After evaluating production trends, we find ourselves with a daily production in barrels of fluid per day (BFPD) averaging 81.3, in which we have an average oil quantity of 62.9 barrels per day (BOPD) and an average water quantity of 17.5 barrels per day (BWPD) and a fairly good GOR 1176.4 (scf/bbl).

Comparative study of production data between different wells three months after hydraulic fracturing

Based on the oil production results obtained after hydraulic fracturing in the various wells in the Makelekese field (wells MS-08 and MS-10), we conducted a comparative study of oil production data over a period of approximately three months.

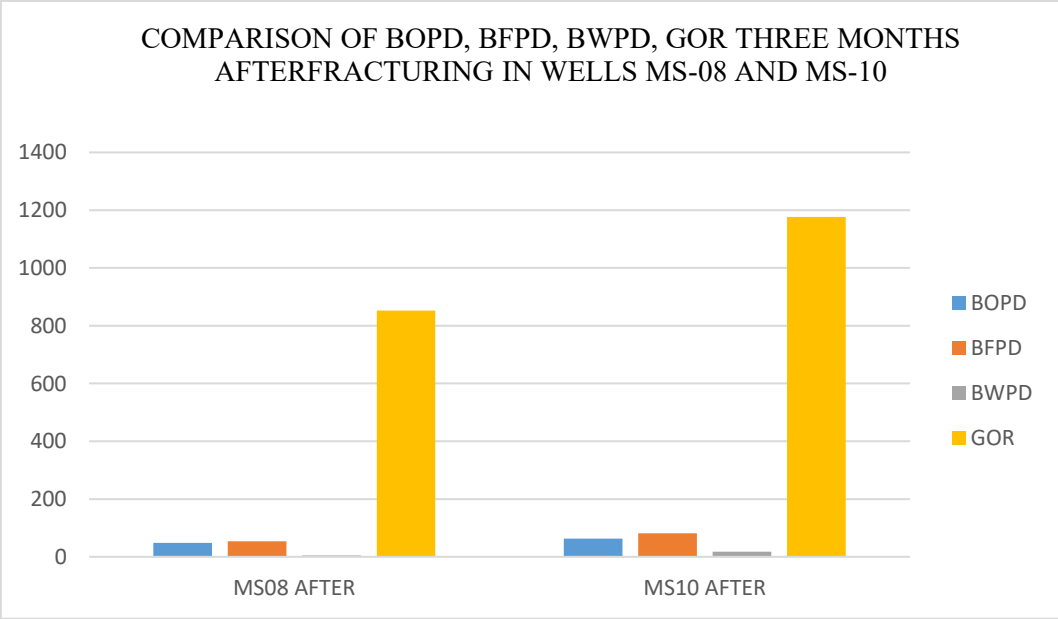

Figure 12. *Graph showing a comparative study of production data between different wells three months after hydraulic fracturing*

Well MS-10 shows a much stronger response to fracturing, with production of 62.9 BOPD and 81.3 BFPD, significantly higher than MS-08. However, water production is also increased, reaching 17.5 BWPD, indicating a higher water content. The GOR of 1,176.4 scf/bbl indicates a potentially richer gas zone or a more efficient reservoir drainage mechanism. This high GOR could contribute to the improved oil mobility and overall production rates seen in MS-10.

Overall, both wells benefited from hydraulic fracturing, however MS-10 shows a greater improvement in performance, possibly due to more efficient fracture spread or more favorable reservoir characteristics. At the same time, MS-08 remains the purest well in terms of water production, indicating a likely more isolated oil zone.

CONCLUSIONS

In this study, we examined the hydraulic fracturing of the Cenomanian reservoir in two wells, evaluating the production of each three months before and after the operation. The production data prior to hydraulic fracturing are presented in the corresponding sections of our report, where we analyzed the performance of the wells.

It is evident that hydraulic fracturing has a significant impact on the productivity of the wells. To ensure effective implementation and monitoring of operations, it was crucial to define several parameters. These include the equipment used, the fluids and their additives, as well as the models necessary to supervise the process.

We observed that the extension of fractures is greater in well MS-10 than in well MS-08, due to higher stress that favored superior effective conductivity. Well MS-10 exhibits good conductivity, and the proppant injection was particularly successful. In contrast, well MS-08, being the highest in the structure of the Cenomanian reservoir of the Makelekese field, suffers from lower production. This is due to a very high oil-to-gas ratio (GOR) and thinner fractures, which limits the risk of reaching the gas cap.

Data collected from wells MS-08 and MS-10 indicate the presence of oil in layers G, H, and I for well MS-08, and in zones H, I, and J for well MS-10. It is worth noting that layers H and G are weakly saturated, as they are located in water transition zones.

REFERENCES

[1] Amaefule, J., Altunbay M., Tiab D., Kersey D., Keelan D., Enhanced reservoir description, using core and log data to identify hydraulic (flow) units and predict permeability in uncored intervals/wells, Annual Technical Conference and Exhibition, SPE, Extended Abstracts, SPE 26436, 1993

[2] Austin C.E., Rose R.E., Shuh, F.J., Simultaneous multiple entry hydraulic fracture treatment of horizontally drilled wells, paper SPE 18298. 1988

[3] Barry B., Jack E., Mark M., Hugo M., Cracking rock, progress in fracture treatment design, ed. Bobby Poe, Houston, Texas. p 104. 1992

[4] Boudjema, A., Rahmani A., Belhadj E.M., Hamel M., Bourmouche R., Source rock identification and oil generation related to trap formation: southeast Constantine oil field: Presented at the Annual Convention, AAPG. 1990

[5] Busetti S, Reches Z. Formation of network fractures during hydraulic fracturing of the Barnett shale, a tight gas shale with preexisting fractures. In: AGU Fall Meeting Abstracts; 2007.

[6] Castagna, J.P., Batzle, M.L., Eastwood, R.L., Relationships between compressional wave and shear-wave velocities in clastic silicate rocks. Geophysics, 50, 571-581. 1985.

[7] Cherepanov S.S., Chumakov G.N., Ponomareva I.N., Results of applying acidic hydraulic fracturing with proppant in the Tournaisian-Famennian reserves at the Ozernoe field. Bulletin of PNRPU. Geology. Oil & Gas Engineering & Mining, no. 16, pp. 70-76. 2015, DOI: 10.15593/2224-9923/2015.16.8

[8] King G.E., Hydraulic fracturing: what every representative, environmentalist, regulator, reporter, investor, university researcher, neighbor and engineer should know about estimating frac risk and improving frac performance in unconventional gas and oil wells, SPE Hydraulic Fracturing Technology Conference and Exhibition, The Woodlands, TX, USA, Paper SPE-152596-MS, Feb. 2012.

[9] Ghassal B.I., Littke R., Atfy H.E., Sindern S., Scholtysik G., Source rock potential and depositional environment of Upper Cretaceous sedimentary rocks, Abu Gharadig Basin, Western Desert, Egypt: An integrated palynological, organic and inorganic geochemical study. International Journal of Coal Geology, 186, 14–40. 2018

[10] Goodman, H.E., Connolly P., Reconciling subsurface uncertainty with the appropriate well design using the mechanical Earth model (MEM) approach. TLE, May, 585-588. 2007.

[11] Gregory, A.R., Aspects of rock physics from laboratory and log data are important to seismic interpretation. In Seismic Stratigraphy applications to hydrocarbon exploration. AAPG memoir 26, Ed. C.E.Payton. 1977.

[12] Guo G., Diaz M.A., Paz F.J., Smalley J., Waninger E.A., Rock typing as an effective tool for permeability and water-saturation modeling: A case study in a clastic reservoir in the Oriente Basin. SPE Reservoir Evaluation & Engineering, 10(6), 730–739. 2007

[13] Lucia, F.J., Carbonate reservoir characterization. The University of Austin, Bureau of economic geology, geological circular P 342. 2007

[14] Economides M.J., Nolte K.G., Reservoir stimulation, 1st ed. New York, USA, John Wiley & Sons, 1989.

[15] Economides M.J., Modern Fracturing: Enhancing Natural Gas Production, Publishing-2007. BJ Services Company.

[16] Nguyen, J., Techniques d'exploitation pétrolière. Institut Français du Pétrole – Éditions Technip, Paris, 1993.

[17] Nougaro, J., Cours de forage rotary, Institut Français du Pétrole – Éditions Technip. Paris. 1964.

[18] Perrin, D., Moudrian, P., Information sur l'ingénierie du pétrole. Institut Français du Pétrole Publications. Paris, 2010.

[19] Perrin, M., Canon, G., Gaillot, J., Techniques d'exploitation pétrolière: Production de fond**.** ENSPM – Institut Français du Pétrole Éditions. Paris, 1995.

[20] Perrodon, A., Géodynamique pétrolière: Genèse et répartition des gisements d'hydrocarbures. Paris, Éditions Elf Aquitaine. 1985.

[21] Ross D.J.K., Bustin R.M., The importance of shale composition and pore structure upon gas storage potential of shale gas reservoirs. Marine Petroleum Geology, 26(6): 916-927. 2009

[22] Mbudi S., Balu E. et al., Analyse de l'argilosité d'un réservoir pétrolier par approche géostatistique: Cas du Cénomanien du champ Makelekese (Onshore de la RD Congo), International Journal of Innovation and Applied Studies, Vol. 33, No. 4, pp. 710-725, 2021.

[23] Simm, R.W., Practical Gassmann fluid substitution in sand/shale sequences. First Break, 25, 61-68. 2007.

[24] Opuluku, R., Lohadje, J.E., Dyese, O.K., Manianga, G.K., Lungembo, J.I., Bihivu, D.A., Analysis of fracture geometry in fluid drainage after hydraulic fracturing. Case of wink MS-09 in Makelekese field, DR Congo. Romanian Journal of Petroleum & Gas Technology, 5(2), 23-42, 2024. DOI: 10.51865/JPGT.2024.02.02

[25] White, R.E., Partial coherence matching of synthetic seismograms with seismic traces. Geophysical Prospecting, 28, 333-358. 1980.

[26] Xing, Y., Zhang, G., Luo, T., Jiang, Y., Ning, S., Hydraulic fracturing in high-temperature granite characterized by acoustic emission, Journal of Petroleum Science and Engineering, 178, pp. 475-484. 2019, https://doi.org/10.1016/j.petrol.2019.03.050

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