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Water production control in the C-lower reservoir, VLE-196 area, block V Lamar, Venezuela

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Abstract: The VLE-196 area, located north of Block V Lamar in Maracaibo, Venezuela, encompasses Eocene reservoirs, especially the C-SUPERIOR and C-INFERIOR sands of the MISOA formation, with a particular focus on the C-4/C-5 sands of C-INFERIOR. In recent years, water production in the 32 active wells has experienced a gradual increase, generating technical-economic problems that threaten oil recovery. The study was divided into four phases. The first consisted of the static and dynamic characterization of the reservoir. Subsequently, a well review was performed for a comprehensive analysis, which provided a diagnosis based on well characteristics and similarities/differences with neighboring wells. The final proposal included actions aimed at minimizing water production, improving sweep efficiency, extending well life, and reducing water treatment and disposal costs. Two pressure zones were identified, one to the north as a low-pressure zone and one to the south as a high-pressure zone. Wells in the high-pressure zone exhibited coning primarily in C-5, while those in the low-pressure zone exhibited adedimentation in C-4 flow units. Differences in fluid behavior between C-4 and C-5 sands suggest considering these reservoirs as separate entities in future studies. The research seeks to address the current challenges through a comprehensive approach, offering solutions tailored to individual well characteristics to optimize production and mitigate water-related problems.

Keywords: Control, sweep efficiency, recovery factor, drainage, pressure zones.

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1. Introduction

The effective management of water in oil wells is a critical imperative for optimizing production and safeguarding operational integrity in the oil and gas industry. Throughout key research in this field, various strategies and technologies have been identified to address the intrinsic challenges of water production in these highly specialized environments.

Smith and Pirson (1963) emphasizes the urgent need for efficient water management to avoid operational and environmental setbacks. Niknam et al. (2020) delves into the intricate relationship between water production and emulsion formation, underscoring the imperative need for specific strategies to enhance separation efficiency.

Seifi et al. (2017) examines significant advances in water control technologies, focusing on the application of polymers and surfactants to improve selectivity in water control in oil wells. De Sousa et al. (2010) address the corrosion risks associated with water production, emphasizing the importance of preventive approaches in this context.

In the realm of offshore wells, Chen (2018) analyze intrinsic challenges, proposing specific strategies to address water production in these maritime environments. White and Johnson (2015) explores advanced methods of chemical injection for water control, particularly emphasizing the need for precise dosing to achieve optimal results.

Chen et al. (2021) advocate for the implementation of real-time monitoring technologies as a cornerstone for effective water management, enabling agile responses to variations in water production. Smith and Taylor (2017) shift their focus to the environmental dimension of water control in oil wells, proposing sustainable practices to mitigate adverse consequences.

Yang (2019) highlight the importance of integrated approaches that consider not only hydrocarbon production but also the efficient and sustainable management of associated water. Looking towards the future, Li et al. (2023) explore emerging perspectives and challenges in water control in oil wells, identifying critical areas that demand increased attention and development.

The VLE-196 area, located in Block V Lamar in Lake Maracaibo, hosts Eocene reservoirs, focusing on the C-4 and C-5 sands of the MISOA formation. The first well, VLE-196, reveals a 32.6° API light oil and a structural reservoir with trapping due to the VLE-400 fault. With a predominant lateral aquifer maintaining pressure, the reservoir produces at an average rate of 11.3 MBND, presenting an increase in water production in recent years as we can see in figure 1 (Choi, 2006; Linares & Richard, 2011; Soto et al., 2014; Watkins et al., 2004). The proposed methodology seeks an integral analysis of the reservoir-well system (Soto & Holditch, 1999), applying methods to identify the origin of water production and propose solutions that preserve oil recovery, crucial to mitigate technical-economic risks (Sukubo et al., 2017).

Structural traps are geological configurations that can retain oil and gas, allowing for their accumulation and extraction. However, these traps can also be associated with the unwanted production of water in oil wells. Here are some types of structural traps and how they may be related to water production:

Anticlines:

Description: These are geological structures in the shape of a dome or arch, where rock layers are folded upward.

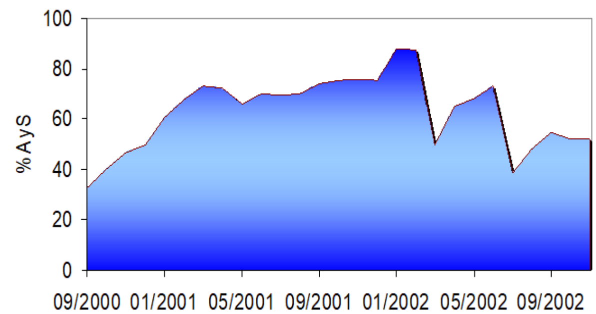

Figure 1. Water cut vs. time. Well VLE-0096. Source: PDVSA 2020.

Water production: If water is present at the bottom of the anticline, it can migrate towards the well as oil is extracted, especially if the oil-water contact is close to the production well.

Fault Traps:

Description: Fault traps form when rock layers are displaced by faults, creating a seal for hydrocarbons.

Water Production: Faults can act as conduits for water, allowing water to move up from adjacent aquifer formations and mix with the produced oil.

Salt Dome Traps:

Description: Salt domes form when a mass of salt rises due to its low density, deforming the overlying rock layers.

Water production: Dissolution of salt by water can create preferential pathways for water to reach the production well. Additionally, if the oil is located in the upper parts of the dome, water can accumulate in the lower parts and migrate to the well as oil is extracted.

Combination traps (stratigraphic and structural):

Description: These traps form when changes in rock lithology and geological structures like folds or faults combine to create a trap.

Water production: The presence of permeable layers in contact with aquifers can facilitate water migration to the well. Additionally, discontinuities in the rock can act as preferential pathways for water flow.

Unconformity traps:

Description: These traps form when an erosion surface is overlain by an impermeable layer, trapping hydrocarbons in the underlying formation.

Water production: Eroded zones may be in contact with aquifers, allowing water to enter the producing well along with the oil.

To minimize water production in oil wells associated with these structural traps, it is crucial to conduct detailed geological and geophysical studies, implement appropriate sealing techniques, and continuously monitor water production to take corrective actions as necessary.

1.2. General objective

To propose a methodology for the control of water production in the C-Lower Reservoir Area VLE-196 Block V Lamar in order to preserve the energy of the reservoir.

1.3. Specific objectives:

- Identify the origin of water production in the wells, depending on its origin: filtration, channeling, dynamic contacts, fractures or faults.

- To analyze the origin of water production in the wells, based on the patterns of water samples through the study of different methods diagnostic graphs as we can see in figure 2.

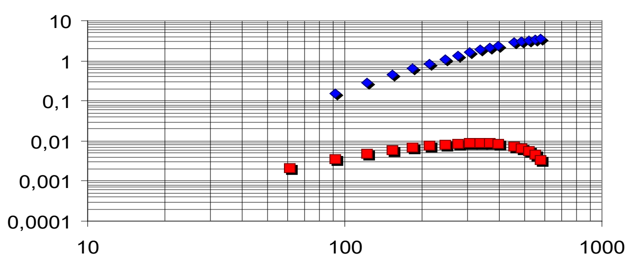

Figure 2. RAP and derived RAP vs. cumulative days. Well VLE-0096. Chan graph-conification. Source: PDVSA (2020).

2. Materials and methods

The figure 4 refers to the study area of this research, located in the Maracaibo Basin, representing one of the crude oil extraction areas. Geologically, it is associated with productive Miocene formations, with sands containing high-viscosity hydrocarbons. This block has been exploited for decades, with significant production that has declined due to the lack of reinvestment in infrastructure. Its proximity to other fields in the lake facilitates integration into oil transportation and processing networks. Despite operational challenges, the field remains crucial to the country's energy economy.

The methodology for water production control in the C-INFERIOR reservoir, VLE-196 AREA of Block V LAMAR, is structured in four crucial stages. Static characterization focuses on geological, petrophysical aspects and isoproperty maps to understand the reservoir structure. Figure 3 and figure 5 shows us this Dynamic characterization addresses fluid properties, production behavior and pressures, incorporating PVT analysis and production data (Soto & Holditch, 1999). The methodology seeks to mitigate significant water production, affecting barrel cost and reserve recovery, proposing solutions in areas such as reservoir history, well review, diagnostics and proposals (Ayeni et al., 2018; Mahgoup & Khair, 2015; SPE, 2016; Sukubo et al., 2017). Focused on maximizing added value and mitigating risks, the methodology seeks efficient and sustainable management of reservoir resources, considering challenges such as mechanical isolation, channeling, and inefficient water patterns.

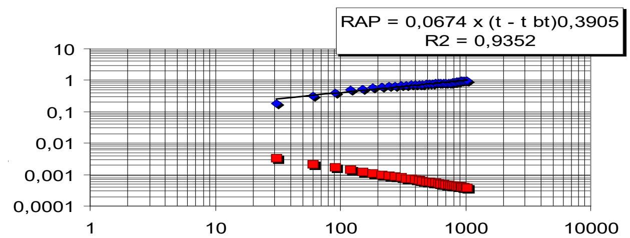

Figure 3. RAP and derived RAP vs. cumulative days. Well VLE-0096. Louisiana State University (LSU) method–conification. Source: PDVSA (2020).

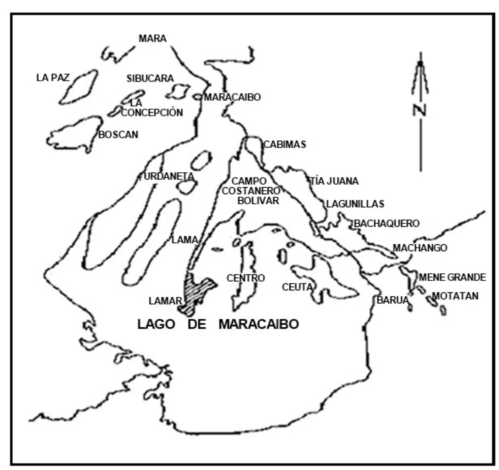

Figure 4. Location map of Lamar Field. Source: PDVSA.

2.1. Well VLE-0096:

The well, completed in 1984 with gas artificial lift, faced persistent high water production challenges. Despite multiple interventions, including workover and recompletion, water cut persisted, reaching 99%. Despite additional efforts, production declined to 620 BPD with 40% water cut.

Once the well review was completed, diagnostic methods (K.S. Chan - LSU) were applied to determine the origin and source of the high water cut for the period under study (Chan, 1995; Prasun, 2020).

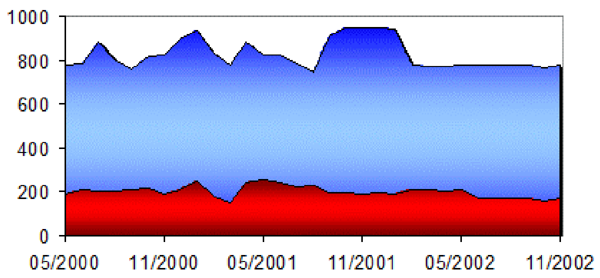

Figure 5. RAP and derived RAP vs. cumulative days. Well VLE-0096. Louisiana State University (LSU) method–conification. Source: PDVSA (2020).

The well in the southern high-pressure zone of the VLE-196 area, completed in the C-4 sand, faces persistent challenges with a 52% water cut. Despite promising petrophysical properties, analysis reveals coning problems associated with high permeability channels, all these petrophysical properties are setting on the table1, table 2, table 3. It is proposed to perform a physicochemical analysis of the water and verify the quality of the cementation. In case of problems in the C-4 Sand, forced cementing is suggested. For leaks in the C-5 sand, a verification and correction is recommended. Once the coning is confirmed, it is proposed to produce at the optimal rate to minimize water production. This approach seeks to prolong well life and mitigate challenges associated with high water cut.

2.2. Well VLE-0196:

Well VLE-0196, drilled in 1958 and completed in the C-5 sands, Figure 6 show us the water cut behavior has faced persistent challenges, such as inter-sand communication and cementing problems. Despite numerous interventions, including workovers, the well has experienced production fluctuations and high water cuts, revealing ongoing operational challenges.

Table 1. Petrophysical properties corresponding to the interval open to production. Well VLE-0096. Source: PDVSA (2020).

INTERVALO (pies)	Unidad de Flujo	ANT (pies)	Porosidad (%)	Permeabilidad (md)	ANP (pies)	Porosidad (%)	Permeabilidad (md)	k x h (md - pies)
11252-11270	C-4-4	35	21,15	433	30	21,95	496	14880

Table 2. Petrophysical properties corresponding to the interval open to production. Well VLE-0196. Source: PDVSA (2020).

INTERVALO (pies)	Unidad de Flujo	ANT (pies)	Porosidad (%)	Permeabilidad (md)	ANT (pies)	Porosidad (%)	Permeabilidad (md)	k x h (md – pies)
11838-11846 11852-11858	C 4-1	39	18,43	137	27	18,72	117	3159
11880-11888	C 5-10	16	17,97	168	12	17,14	100	1200

Table 3. Petrophysical properties corresponding to the interval open to production. Well VLE-0449. Source: PDVSA (2020).

INTERVALO (pies)	Unidad de Flujo	ANT (pies)	Porosidad (%)	Permeabilidad (md)	ANP (pies)	Porosidad (%)	Permeabilidad (md)	k x h (md - pies)
11150-11170	C-4-3a	71	22,20	269	71	22,20	269	19099
11346-11366	C-5-9	42	16,07	35	42	16,07	35	1470
11512-11530	C-5-7	52	16,32	63	52	16,32	63	3276

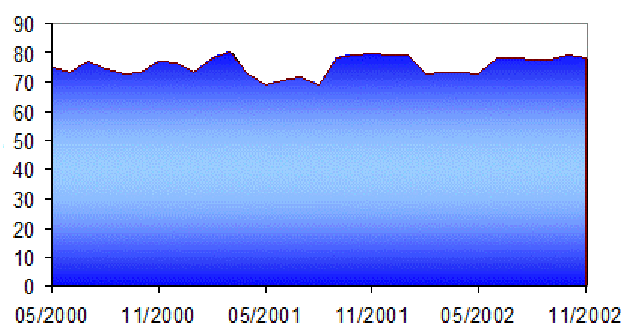

Figure 6. Water cut vs. time. Period 2020-2022. Well VLE-0196. Source: PDVSA 2020.

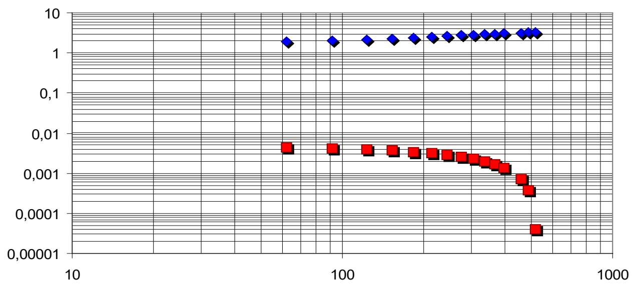

Figure 7. RAP and derived RAP vs. cumulative days. Well VLE-0196. Chan graph-conification. Source: PDVSA (2020).

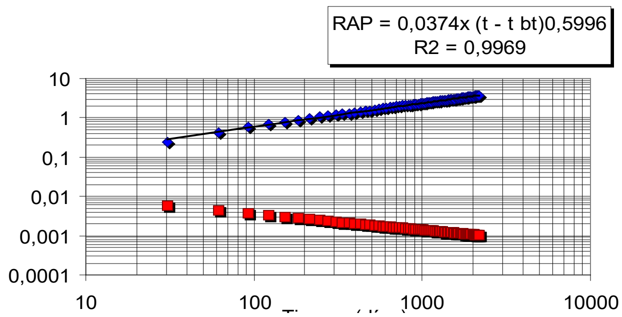

Figure 8. RAP and derived RAP vs. cumulative days. Well VLE-0196. Louisiana State University (LSU) method–conification. Source: PDVSA (2020).

Figure 7 and Figure 8 shows the RAP vs cumulative days behavior with different methods. The well, completed in the C-4 and C-5 sands, shows moderately prospective petrophysical properties. Although it has maintained relatively stable production, water cut has been significant (79%). The analysis reveals behavior associated with a coning in the well, indicating a phenomenon linked to aquifer advancement due to the historical drainage of the reservoir. The diagnosis suggests that water production comes from the advance of the aquifer, manifesting itself as a conification. Actions proposed include taking a water sample for analysis, running a PLT to determine oil and water rates for each sand, and considering forced cementing if coning is more pronounced in the C-5 sand. It is suggested to study additional flow units and the C-SUPERIOR reservoir for future work.

2.3. Well VLE-0449:

Well VLE-0449, drilled in 1964, has been producing from the C-2/3 and C-4/5 sands by short and long strings, respectively. The short string, plugged with sand, showed stable production until 1989. The long string, initially high, experienced increasing water cut, reaching 900-1000 BNPD in 1995. An intervention in 1999 reduced the water cut to 60%, but the well has high gas consumption.

Currently the well is producing 472 BNPD with a water cut of 71%.the production behavior of well VLE-0449 for the period under study 1999-2002 is shown graphically in the figure 9 and figure 10.

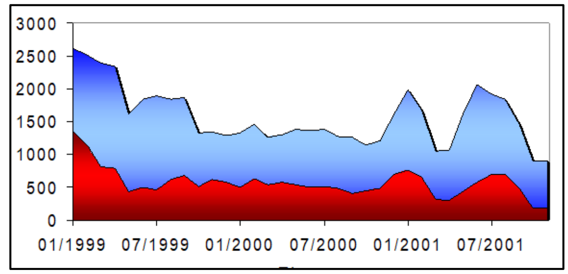

Figure 9. Real oil rate and real water rate vs. time. Period: 1999-2002. Well VLE-0449. Source: PDVSA (2020).

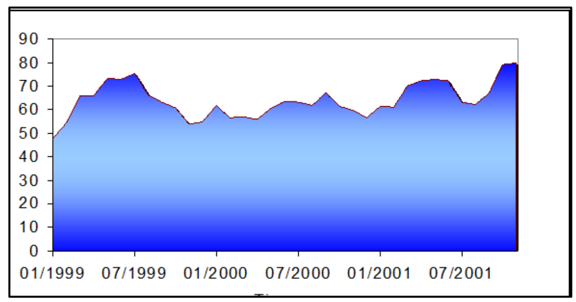

Figure 10. Water cut vs. time. Well VLE-0449. Source: PDVSA (2020).

Well VLE-449, located in the central area of the high-pressure structure, is completed in the C-4 and C-5 sands. It produces from the C-4-3a, C-5-9 and C-5-7 flow units, showing atypical behavior with respect to neighboring wells. The petrophysical properties of the sands vary, with C-4-3a showing permeabilities of 269 md and porosity of 22%, while C-5 has permeabilities between 35-63 md and porosities around 16%. The latest report, in October 2002, indicates an oil rate of 472 NDB with a water cut of 71%.

The Chan analysis suggests a buildup problem, while the LSU Method indicates coning. Given this discrepancy, a study of vertical and horizontal permeabilities is recommended to identify the predominant channels accurately (Bailey et al., 2000; Mahgoup & Khair, 2015; Smith & Pirson, 1963; Yortsos et al., 1999).

To address layered channeling, it is proposed to take a water sample and, if necessary, perform a PLT to assess oil and water rates in each interval. In case the water comes from the C-5 sand or lower intervals of the C-4, it is suggested to abandon it and continue producing from the C-4. If the water comes from middle/upper C-4 intervals, production at optimal rate is proposed and, if negligible, abandonment or coiled tubing forced cementing is suggested to minimize water production and prolong well life (Bailey et al., 2000; Garcia et al., 2019; Hu et al., 2023; James et al., 1999; Kabir et al., 1999;

Quintero et al., 2020; Sinha et al., 2020; SPE, 2016; Taha & Amani, 2019; Zhizhuang et al., 2006).

In summary, the diagnosis points to a complex channeling and coning challenge, and the recommended actions seek optimal management considering reservoir characteristics and petrophysical properties of the sands (Mukhanov et al., 2018; Rabiei, 2011; Salem et al., 2022).

3. Conclusions

- The proposed methodology constitutes a breakthrough for the analysis, diagnosis and proposal of actions to be taken in wells with high water cut problems.
- In the C-INFERIOR reservoir, two pressure zones located to the north and another high-pressure zone in the south of the VLE-196 AREA, Block V LAMAR, were detected.
- The C-INFERIOR reservoir, VLE-196, Block V LAMAR is drained by thirty-two wells, twelve of which were studied due to high water cut problems.
- From the analysis it is observed that the best petrophysical properties (k, φ, k x h) are found towards the northern zone of the reservoir, basically at the level of the C-4 sand flow units, while towards the southern zone they are found at the level of the C-5 sand flow units, which show proximity to the water-oil contact.
- A large part of the wells studied in the reservoir are completed together (commingled) in the flowing units corresponding to the C-4 and C-5 sands.
- There are representative differences in fluid behavior (°API, RGP) for wells completed only in the C-4 or C-5 sands, which evidences the character of each sand as an independent reservoir.
- Based on the available information it was not possible to generate a synthetic PVT representative of the C-4 and C-5 sands.
- Wells: VLE-1063, VLE-1139, located in the north - low pressure zone of the C-INFERIOR reservoir (C-4 and C-5 sands), area VLE-196 Block V Lamar, show adedimentation mechanisms at the level of the C-4 flow units.
- Wells: VLE-0096, VLE-0677 and VLE-1222, located in the south - high pressure zone of the C-INFERIOR reservoir (C-4 and C-5 sands), VLE-196 Block V LAMAR AREA, show coning mechanisms basically at C-5 level; while wells: VLE-1130, VLE-1295 and VLE-1336, show adduction mechanisms at C-4 flow units level.

Conflict of interest

The authors have no conflict of interest to declare.

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