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ANALYSIS OF THE PERFORMANCE OF THE TSHIENDE OIL FIELD DURING WATER INJECTION

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ABSTRACT

We analysed the efficiency of the production technique used by Perenco in the Tshiende oil field in the Democratic Republic of Congo. Initially, this field produced oil by natural drainage, based on the mechanisms of fluid expansion and rock compressibility. However, in 1986, a drop in reservoir pressure led to a reduction in production, making it necessary to adopt water injection to compensate for this loss and optimize hydrocarbon recovery.

This research responds to the imperative of satisfying growing energy demand while preventing the early abandonment of fields. We used a data storage unit, a computer system and specialized software to process and analyses the data collected.

The results show that water injection has considerably improved field performance. Oil production increased and the average reservoir pressure remained above the bubble pressure (927). In addition, the volume of water produced (128907050 m^3) gradually exceeded the volume of water injected (107348149 m^3), demonstrating the effectiveness of the reservoir sweep. However, variations in the injection rate created imbalances between injection and withdrawal. In 2014, the Voidage Replacement Ratio (VRR) was equal to 1, indicating a temporary equilibrium. The relationship between oil production and VRR confirms that the production rate is directly dependent on the amount of water injected, signalling inactivity in the aquifer.

Between 1986 and 1991, the production of oil and water was almost equivalent, but currently, the production of water exceeds that of oil, indicating that the water produced is greater than the water injected. Thanks to the injection of water, the recovery rate for the Tshiende field has increased significantly, from 2.6% to 39.8%, due to the improved efficiency with which the oil is displaced. A volume of water corresponding to that of the pores occupied by the hydrocarbons exceeds 0.90, showing that water saturation is greater than that of the oil.

In conclusion, water injection has proved to be an effective solution for extending the productive life of the Tshiende field and improving its recovery rate. We recommend that the company continue to investigate the existence of an aquifer in the field and explore other development campaigns, particularly in the Pinda reservoir, where the results promise new production opportunities.

Keywords: Injection, Performance, Recovery, Production, Enhancement

INTRODUCTION

The oil industry, a pillar of the global economy, is facing a major challenge: maintaining sustained production in fields characterized by falling pressure while optimizing hydrocarbon recovery. The Tshiende field, located in the Democratic Republic of Congo, is a perfect illustration of this problem, as its natural production has gradually declined. To extend the field's productive life and improve the ultimate recovery factor, a water injection technique was used [25, 17].

The recoverable part of the oil present in the ground is referred to as the 'reserve' when it is technically and economically exploitable, taking into account the accessibility of deposits as a function of geopolitics and other variables. This makes it possible to assess the constraints associated with hydrocarbon recovery, bearing in mind that a significant proportion of the oil will not be extracted from the ground [23].

Primary oil recovery refers to the production of hydrocarbons by the natural entrainment mechanisms present in the reservoir, without the aid of injected fluids such as gas or water. In most cases, this mechanism is relatively inefficient, resulting in low overall oil recovery [25,21]. The lack of natural drainage in many reservoirs has led to the adoption of artificial drainage methods, the most basic being gas or water injection.

Often, problems such as loss of pressure or the types of drainage encountered lead to fields being abandoned because production has become uneconomic. So water injection as a hydrocarbon recovery technique remains a major concern for researchers and a key component of operating costs. Studying the effectiveness of this technique will make it possible to assess the quantity of hydrocarbons that can be displaced and to monitor production, which we will attempt to highlight in this article [6, 17, 15].

Our study analyses the performance efficiency of the Tshiende field based on parameters such as historical production data and numerical simulations. This analysis, carried out using specialized software, will make it possible to assess the impact of water injection on reservoir pressure, production rate and the composition of the fluids produced. This will help not only to optimize management of the Tshiende field, but also to improve understanding of hydrocarbon recovery mechanisms in depleted reservoirs [16, 5, 24].

This research is justified by the need to produce more to meet growing demand for hydrocarbons and to combat early field abandonment, while other processes are available to recover as much of the oil contained in our reservoirs as possible. The aim of this study is to analyse the performance of the Tshiende field by injecting water to increase hydrocarbon recovery, which will help to improve overall production in the coastal basin of the Democratic Republic of Congo, which is currently stagnating at 25,000 barrels per day. We will try to answer these two questions:

- How effective is water injection in increasing the recovery rate of hydrocarbons in the Tshiende field?
- How does water injection affect reservoir pressure and production rate?

PRESENTATION OF THE STUDY AREA

The Tshiende field is one of PERENCO's oil fields located in the Coastal Basin of the Democratic Republic of Congo, in the Province of Central Kongo, 4 km from the border between the Democratic Republic of Congo and the Angolan province of Cabinda, 20 km north-west of the town of Moanda and 600 m from the coast. The Tshiende field was first discovered in 1977 when the Mibale-Est 1(EM-01) well was drilled, leading to the discovery of oil between 1,700 and 2,000 metres below sea level in the Pinda and Vermelha formations within a multi-layered sandstone and carbonate reservoir [1].

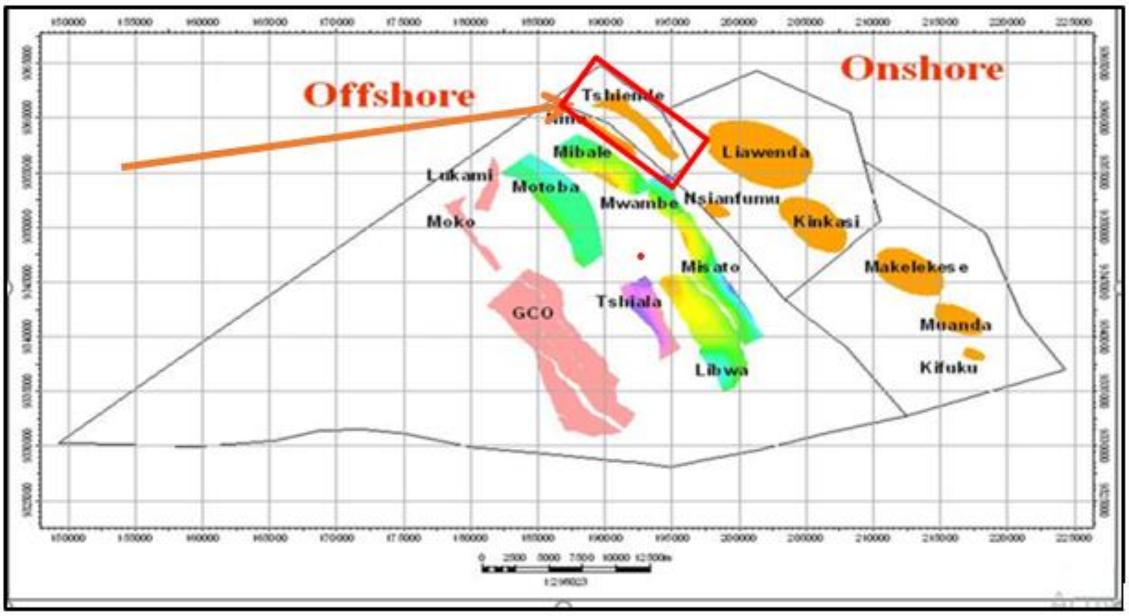

Figure 1*. Location of the study area* [22]

Stratigraphy

Drilling in this deposit traversed various stratigraphic sections from the Pleistocene period to the Precambrian basement. The main formation of petroleum interest is the Pinda/Vermelha formation, which is considered to be the main reservoir of the deposit, producing oil between 1700 and 2200 m.ss. The Pinda is essentially calcareous in nature, and overlying this formation are sediments from the Cretaceous and Tertiary periods, comprising sands and clays that predominate with good correlation between wells, as confirmed by seismic data [1,11].

The Vermelha formation is considerably faulted and correlation in some places is made difficult by missing sections in some wells [18]. Beneath the salt, the older Cretaceous sediments form complex faulted massifs showing rapid variations in the preserved section.

Reservoir zonation and correlation

The Pinda and Vermelha formations consist of alternating and interbedded layers of clays, sandstones, limestones and dolomites. The distinct separate zones that exist have been confirmed by the different levels of oil-water contacts and by the non-uniform reservoir pressures within identical layers. These facts are observed and confirmed by the detailed correlation carried out in this deposit [29]. However, in other areas, layer correlation is made difficult by the missing sections associated with the faults that gully the deposit [10,11,18].

Vermelha Formation

The most important oil reservoirs in the Tshiende field are located in the Vermelha, which is made up of alternating layers of sandstone, silt, clay, dolomite and anhydrite [10, 18]. The sandstone and dolomite layers form the main oil reservoirs. However, the Vermelha Formation was stratigraphically subdivided by Zairep into 13 main zones identified as A to M, with A as the top. These subdivisions of the Vermelha Formation lean strongly to the north-east. It should be noted that these 13 subdivisions are classified into two main parts, namely the Upper Vermelha, which extends from the A horizon to the D horizon, and the Lower Vermelha, which extends from the E horizon to the M horizon. This differentiation was made possible by variations in the mineralogical nature of the layers traversed by the various boreholes drilled in this field. The various subdivisions are as follows (Figure 2):

- Zone A: The Vermelha summit formation, comprising silty dolomites, this zone initially produced in wells TS-02, TS-03 and in TS-04;
- Zone B: Dolomites are interbedded with silty sands, it produced in wells TS-02, TS-03 and 4;
- Zone C: Dolomitic silts and fine sands are generally found, this zone initially produced in wells TS-02 and 3;
- D Zone: Dolomites with occasional sandstones, this zone produced in wells TS-02 and 5. It is partially faulted in TS-03 and aquifer-bearing in TS-4.

The four zones above make up the upper part of the Vermelha. The zones making up the Lower Vermelha are listed below.

- Zone E: This is made up of clayey sands with a basal dolomitic layer. This zone initially produced in the TS-05 well.
- F zone: Silts alternating with dolomites and silts. Like the E zone, it only produced in the TS-05 well.
- G zone: As above, but the only difference is that it contains a basal dolomitic layer and only produced in the TS-05 well when the deposit was discovered.
- H zone: This zone consists mainly of silts and some dolomites. Initially, it only produced in the TS-05 shaft.
- Zone I: Alternating layers of silty silts and dolomites. It only produced in the EM-01 well.
- Zone J: Made up of clays, clayey limestones and sandstones, all of which alternate. When this zone was discovered, it only produced in the EM-01 well.

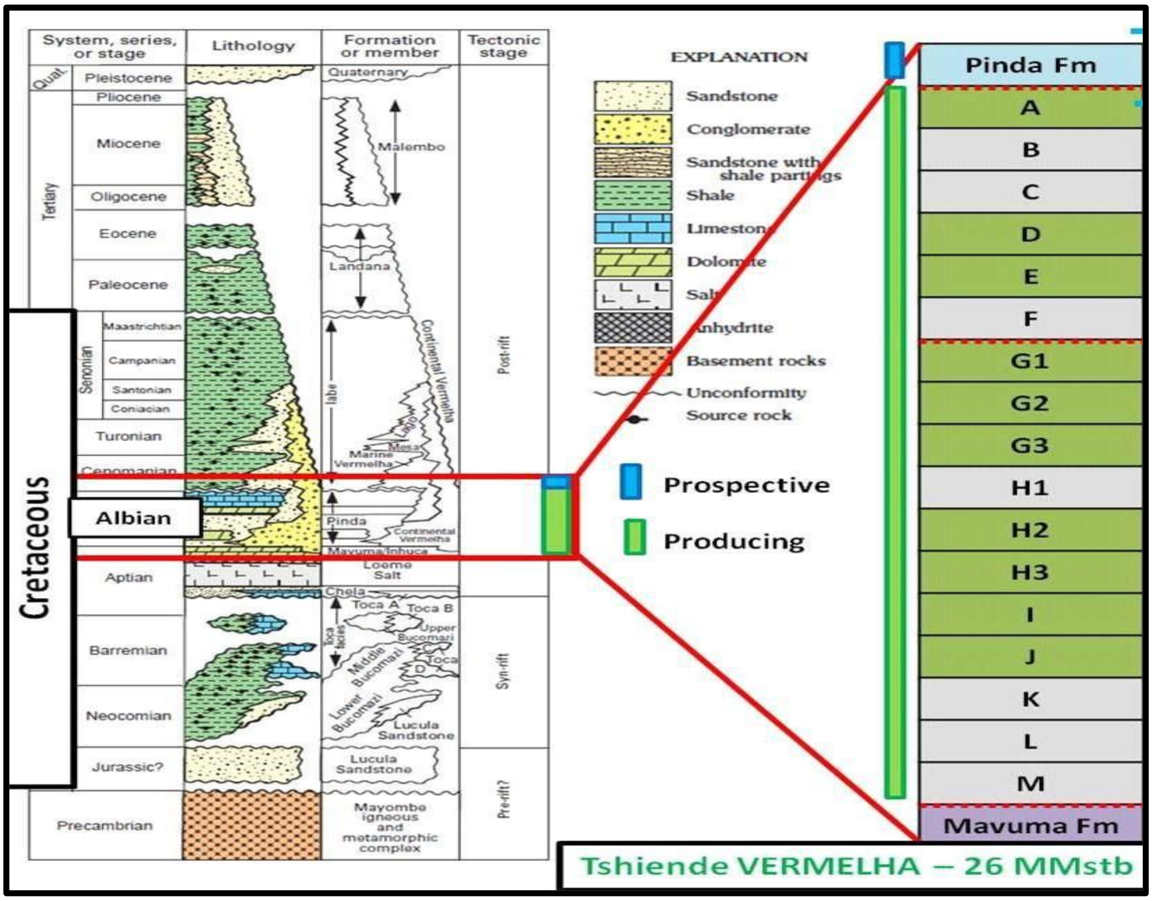

Figure 2. *Stratigraphy of the Vermelha formation* [22]

Evolution of oil activities undertaken in the field

The wells in the Tshiende field were mainly aimed at the Vermelha, which for a long time was the only producing area, as studies had revealed significant hydrocarbon accumulations in this zone. However, following the drop in production observed in this area, a recent drilling campaign aimed at developing the Pinda formation was carried out with a view to increasing production from the field. The Tshiende field has a total of 28 wells, 15 of which are perforated in the Vermelha section and 13 in the Pinda. These wells include 20 producing wells, 6 injector wells and 2 abandoned wells.

Hydrocarbon properties

The PVT analyses carried out on the EM-01 and TS-02 wells show that the Vermelha reservoir contains highly undersaturated oil. Although some zones have not been subjected to PVT analyses (Table 1), the production history in terms of gas-oil ratios measured using the GOR parameter is very similar to those of the zones that have undergone this analysis. This would suggest that the content of these different zones is similar [10,18]. This similarity suggests that the Tshiende field does not have a gas cap.

***Table 1**. PVT properties of the Tshiende field* [11].

Initial tank pressure (psi)	2845
Tank temperature (°F)	178
Pressure at bull point (psi)	927
Oil FVF (bbl/stb) @ pi/pb	1,155/1,173
GOR (scf/stb) @ pb	213
Oil viscosity (cp) @ pi/pb	2,2/1,8
Oil density (g/cm^3) @ pi/pb	0,798/0,784
Oil density (°API)	33,1
Gas specific gravity	0,95
Water salinity (ppm)	300000
Formation compressibility (psi^{-1})	$4.3*10^{-6}$
Oil viscosity (cp)	2.5
Water viscosity B(cp)	3.5

MATERIALS AND METHODS

To carry out this research, we used documentation techniques and collected production data from the Tshiende field. We then used a laptop computer containing: Word, Excel, Prosper/Mbal. A workflow diagram is presented in the Figure 3.

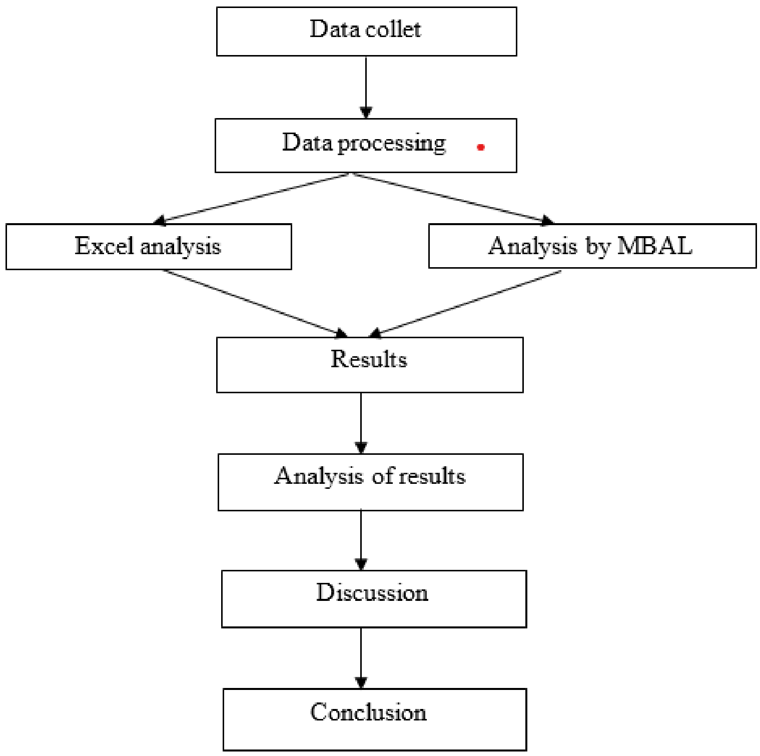

***Figure 3**. Workflow diagram of the methodology*

RESULTS AND DISCUSSIONS

After calculating and processing the data using the software, Table 2 shows the results [26, 5, 8, 14].

***Table 2**. Data processing*

DATE	Pressure (psia)	NP	Winj	fws	WP	NP/N	VRR	HCPVi
1980	2845	0	0	0	0	0	0	0
1981	1775	146000	0	0	0	0,002	0	0
1982	1500	228125	0	0	0	0,003	0	0
1983	1290	282875	0	0	0	0,004	0	0
1984	1000	319375	0	0	0	0,004	0	0
1985	750	927830	0	0,47	547500	0,012	0	0
1986	1700	2114080	0	0,43	1460000	0,026	0	0
1987	1650	3939080	1140625	0,50	3285000	0,049	0,29	0,012
1988	1600	6220330	3878125	0,58	6478750	0,078	0,47	0,042
1989	2021	8197170	6798125	0,62	9672500	0,102	0,53	0,073
1990	2120	9565920	10904375	0,63	11953750	0,119	1,06	0,118
1991	1640	11573420	15010625	0,63	15375625	0,144	0,71	0,162
1992	1690	12942170	17976250	0,70	18569375	0,161	0,62	0,194
1993	1660	14006875	20941875	0,73	21489375	0,175	0,71	0,226
1994	1560	14919375	22995000	0,78	24683125	0,186	0,48	0,248
1995	1805	16069125	25960625	0,78	28789375	0,200	0,54	0,280
1996	1725	17437875	28698125	0,79	34036250	0,217	0,40	0,310
1997	1600	18066081	30751250	0,88	38598750	0,225	0,39	0,332
1998	1505	18849581	34173125	0,84	42686750	0,235	0,68	0,369
1999	1460	19604300	37823125	0,85	47066750	0,244	0,69	0,408
2000	1300	20253674	40816125	0,87	51264250	0,253	0,60	0,441
2001	1270	21155450,3	44703375	0,83	55644250	0,264	0,72	0,483
2002	1360	21648364,5	47440875	0,90	60206750	0,270	0,53	0,512
2003	1270	22033381,1	50406500	0,92	64586750	0,275	0,61	0,544
2004	1250	22464092,1	53372125	0,90	68601750	0,280	0,66	0,576
2005	1310	22810199,7	56794000	0,91	72251750	0,284	0,84	0,613
2006	1350	23133856,1	60215875	0,92	75901750	0,289	0,85	0,650
2007	1385	23432156	63637750	0,93	79779875	0,292	0,81	0,687
2008	1305	24105865,7	67059625	0,89	85492125	0,301	0,53	0,724
2009	1370	24581873,2	70612900	0,93	91660625	0,307	0,53	0,762
2010	1400	25085146,1	74719150	0,93	98048125	0,313	0,59	0,807

2011	1350	25715880,7	79281650	0,92	105348125	0,321	0,57	0,856
2012	1300	26174061,6	84300400	0,93	111735625	0,326	0,72	0,910
2013	1350	26483169,1	87950400	0,93	116079125	0,330	0,78	0,950
2014	1385	26783925,5	91221894,5	0,91	118999125	0,334	1,00	0,985
2015	1350	27191878,7	94618804,1	0,88	121919125	0,339	1,00	1,022
2016	1370	27736487,9	96721206,5	0,73	123384965	0,346	1,00	1,044
2017	1320	28334602,4	98341848,9	0,61	124306225	0,353	1,00	1,062
2018	1430	29031095,4	99916572,4	0,52	125067250	0,362	1,00	1,079
2019	1470	29790660,4	101581121	0,51	125844700	0,372	1,00	0,000
2020	1450	30583075,4	103379085	0,52	126717050	0,381	1,00	0,000
2021	1520	31274385,4	105226394	0,60	127757300	0,390	1,00	0,000
2022	1515	32106950,4	107348149	0,58	128907050	0,400	1,00	0,000

INTERPRETATION

Drainage indices

In order to highlight the drainage mechanisms involved in production and to estimate quantitatively the contribution of each of them, we have drawn a graph representing the evolution of the indices of the different mechanisms as a function of time [12,20,8]. Figure 4 shows the evolution of the indices of the different drainage mechanisms in our field of study as a function of time from 1980 to 2022. Three periods can be identified:

- From 1980 to 1984: during this period the pressure was above the bubble point pressure, a natural mechanism. The predominant mechanism was oil expansion, with a drainage index of 56%, of which 44% was contributed by water expansion and formation. This confirms the hypothesis that "the entrainment mechanism by volume change of rock and water continue in the reservoir cannot be neglected before the bubble point pressure;
- After 1984; the mechanism by oil expansion reaches 100%, because it is below the bubble point pressure;
- During the water injection (from 1987 to 2022, this artificial mechanism became predominant.

RECOVERY FACTOR

- The RF recovery factor (efficiency) of any secondary or tertiary oil recovery method is the product of a combination of three individual efficiency factors (ED, ES, EV). In this study, we determined the recovery factor in terms of cumulative oil production [8,15,21,25]
- The recovery factor during injection as a function of time is shown in Figure 5.

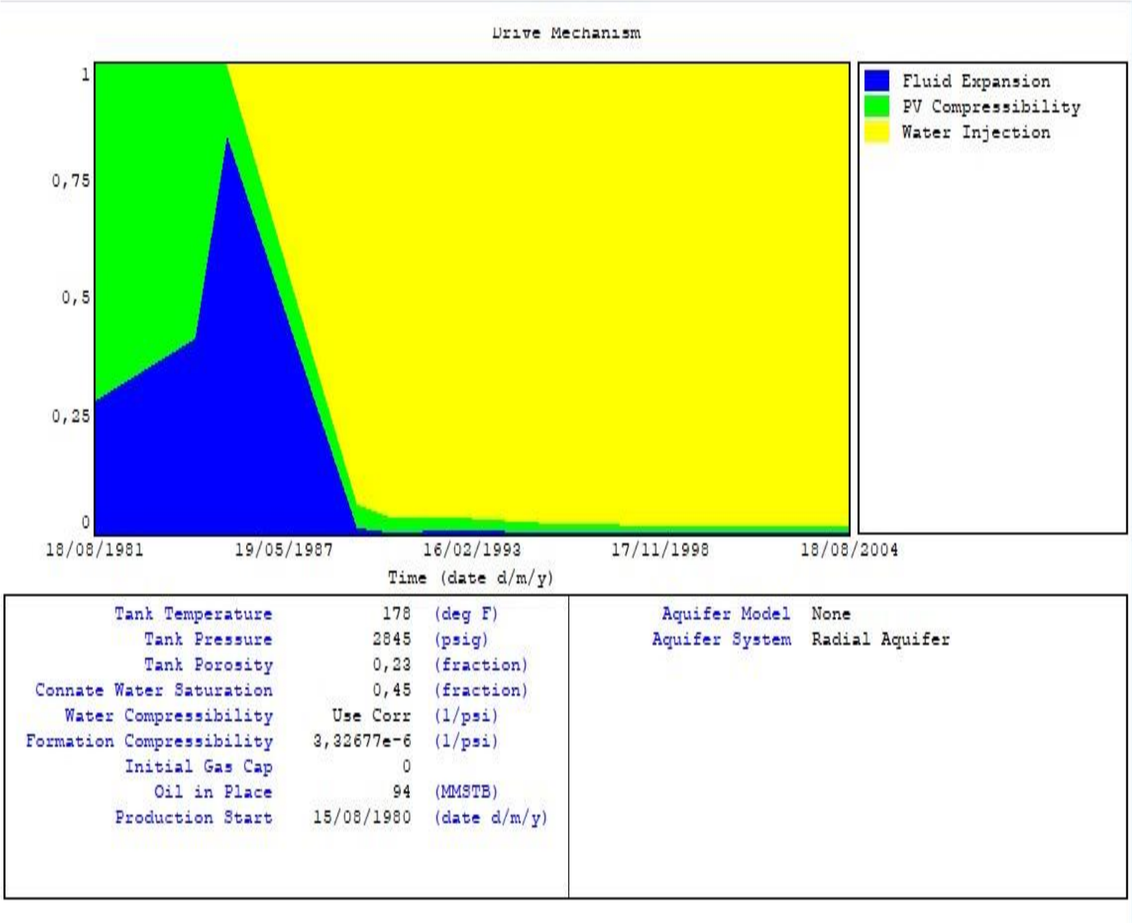

Figure 4*. Evolution of the drainage index in the Tshiende field*

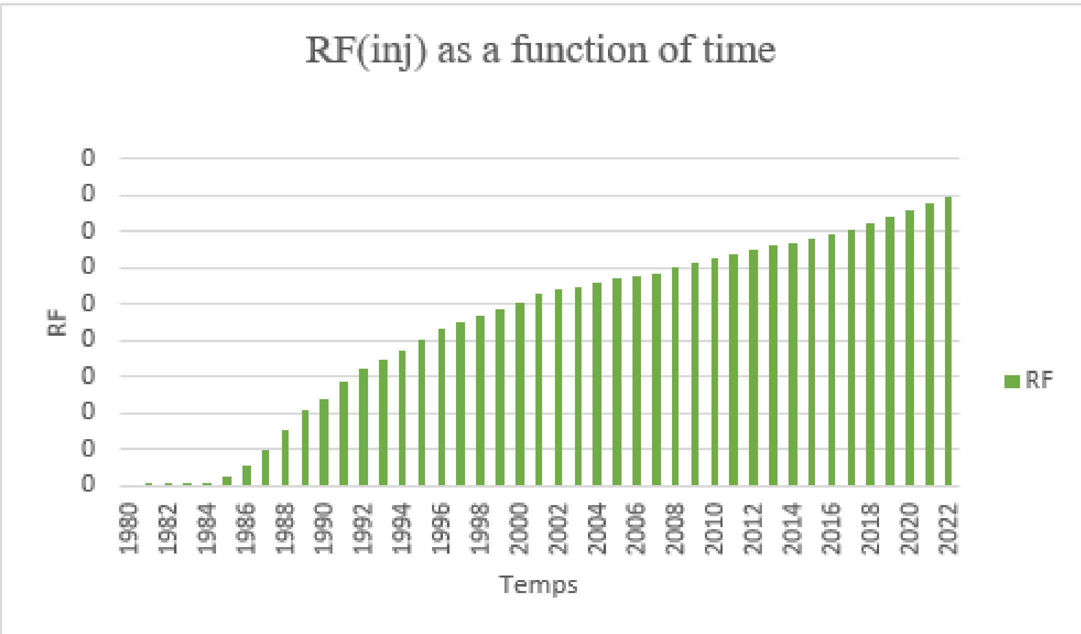

Figure 5*. Evolution of injection RF as a function of time*

- We note that between 1987 and 1995 annual production was high. After 1995, annual production fell.
- In 2022, the recovery rate in the field is 39.8%

The figure 6 shows the impact of injection on the recovery rate.

- Before water injection, the recovery rate was 2.6%, thanks to the natural drainage mechanism of compressibility;
- During injection, recovery reached 39.8% thanks to a volume of water corresponding to an HCPVi greater than 0.90. This value indicates that the water saturation in the reservoir is greater than that of the oil.

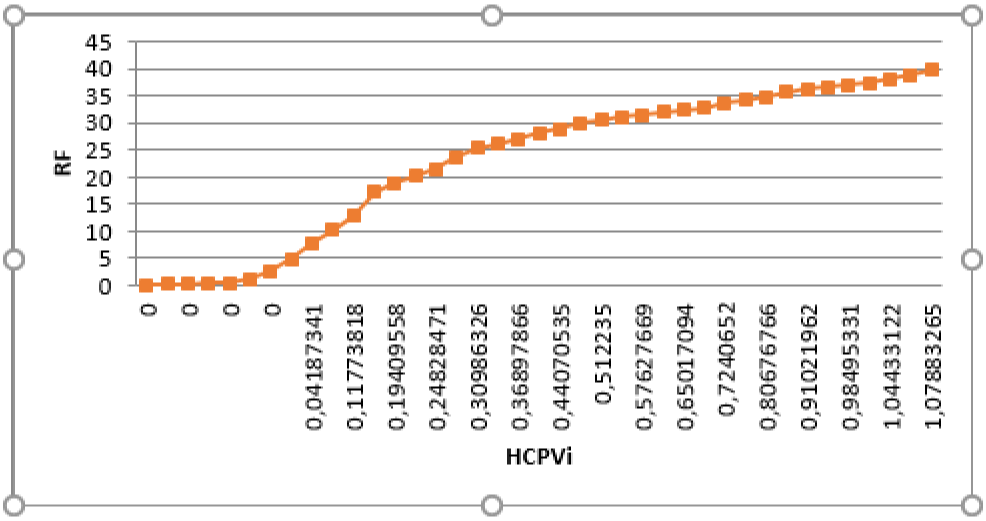

Figure 6. *Impact of water injection on recovery rate*

Analysis of the total VRR (Voidage Replacement Ratio)

The VRR is the essential parameter that defines the injection-draw-off balance and thus makes it possible to determine the effectiveness of such an injection [3,8,28]. Analysis of the total VRR (Voidage Replacement Ratio) enabled us to determine the effectiveness of the injection (Figure 7).

Since the water injection flow rate, the VRR varied greatly and the balance between injection and withdrawal was not ensured because of the variation in the injection flow rate. Around 2014, the VRR is equal to 1, which shows the balance between injection and withdrawal.

The effect of injection can be seen in the improvement in oil production and also in the fact that the average pressure is maintained above the bubble point pressure. Furthermore, the relationship between *Qo* and VRR confirms that the production rate depends on the amount of injection, so the aquifer is inactive. Figure 8 shows the evolution of cumulative water (production and injection) as a function of time.

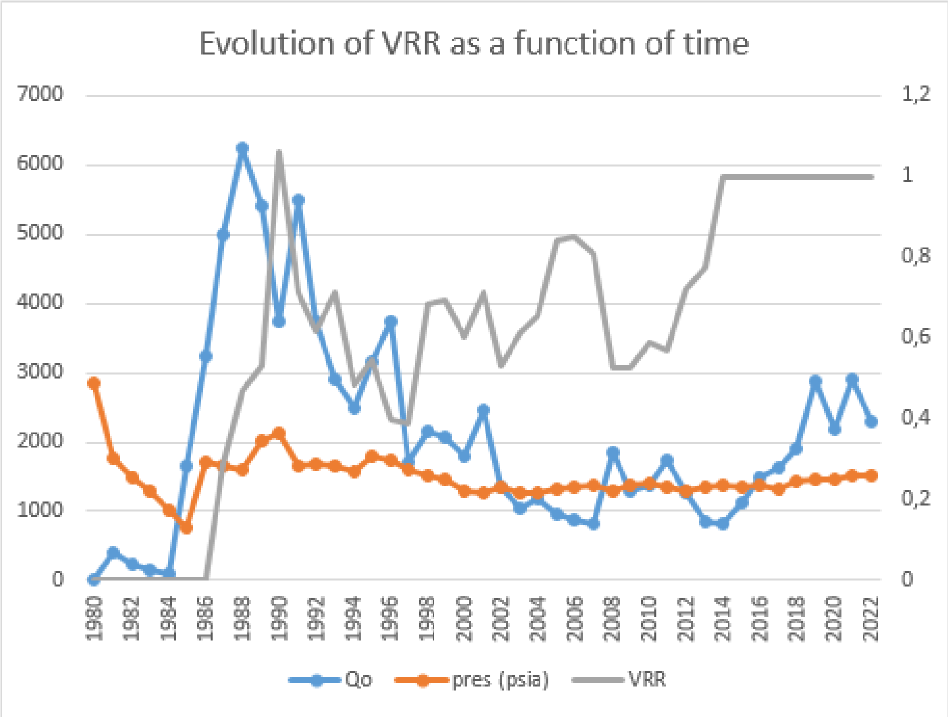

***Figure 7**. Evolution of VRR as a function of time*

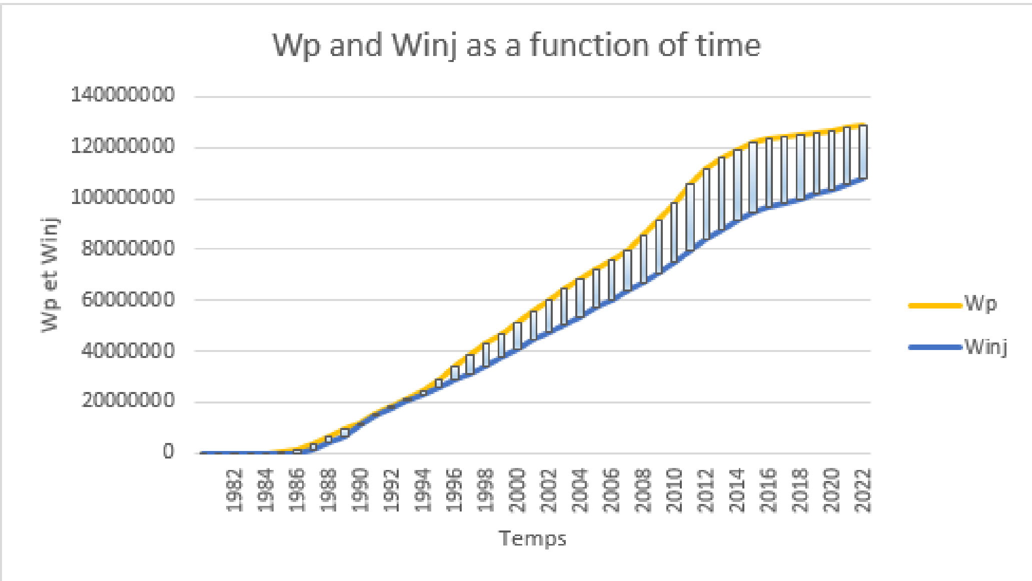

***Figure 8**. Cumulative water evolution (production and injection) as a function of time.*

We can see that the amount of water produced is greater than the amount of water injected, which contributes to the complexity of our field. This gives us an idea of the significant water saturation in certain layers of our field. Figure 9 shows the evolution of *Qo* and *Qw* as a function of time.

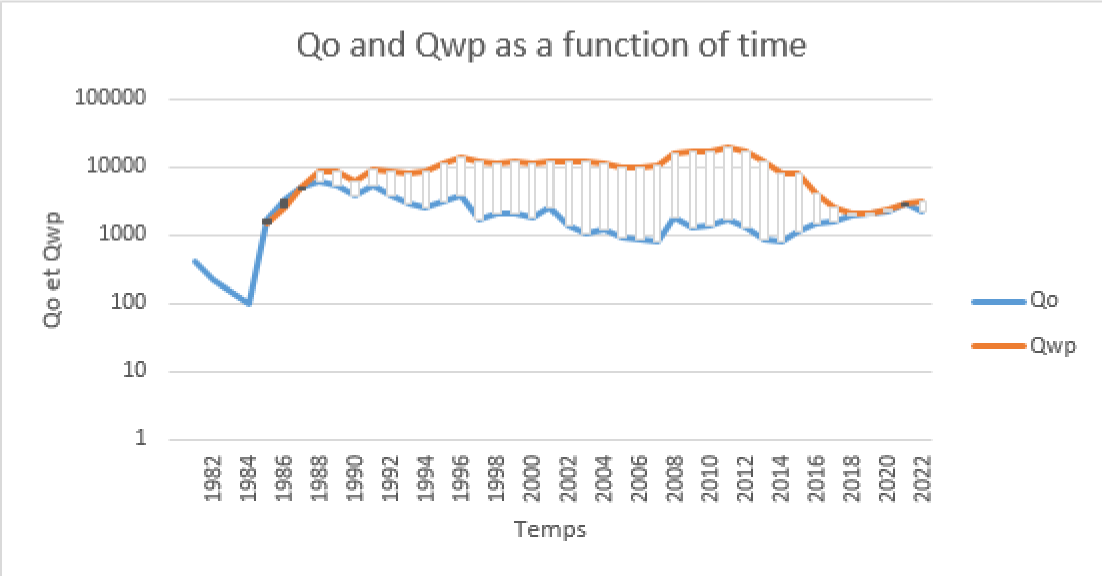

Figure 9. *Evolution of Qo and Qw as a function of time*

The figure 9 shows average oil and water flow rates as a function of time in a logarithmic scale.

- Our field started producing oil only until 1985;
- From 1985 to 1991, water and oil production were almost similar;
- From 1992 to 2014, water production was far higher than oil production;
- From 2015 to 2018 water production starts to decrease and oil production increases thanks to VRR stability and the start of production from new wells drilled in the Pinda.

CALCULATION OF THE OVERALL EFFICIENCY OF THE TSHIENDE FIELD

a) In-place reserve calculation at injection rate [4, 17, 22, 27]

$$N_S = \frac{V_p * S_o}{B_o} \quad (1)$$

Vp = pore volume,

So = oil saturation,

Bo = volumetric oil formation factor,

We know that:

$$NB_{oi} = V_P \times S_{oi} \quad (2)$$

$$VP = \frac{80186537.33 * 1.155}{1 - 0.48} \quad (3)$$

$VP = 178106636\ bbl$ and

$$S_O = (1 - S_{wi})\left(1 - \frac{NP}{N}\right)\left(\frac{B_O}{B_{oi}}\right) \quad (4)$$

$$S_O = (1 - 0.48) * (1 - 0.026)\left(\frac{1.155}{1.1656}\right) = 50$$

Hence $N_S = 178106636 * 0.50/1.1657 = 76394713 \ stb$

b) Displacement efficiency

To calculate displacement efficiency, it is essential to know how the relative permeability of oil and water vary with water saturation [27, 2, 9, 13, 24, 7]. For the purposes of this work, Table 3 shows the displacement efficiency.

***Table 3**. Displacement efficiency*

Sw	So	Sw*	So*	kro	Krw	kro/krw	kro+krw	uw/uo	fw
0,21	0,79	0	1	0,80	0		0,80	1,4	0
0,26	0,74	0,0625	0,9375	0,63822091	8,82E-05	7238,47707	0,63830908	1,4	9,8669E-05
0,31	0,69	0,125	0,875	0,49664845	0,000931	533,609159	0,49757918	1,4	0,0013368
0,36	0,64	0,1875	0,8125	0,37466886	0,003694	101,417177	0,3783632	1,4	0,00699379
0,41	0,59	0,25	0,75	0,2716144	0,009825	27,6455347	0,28143929	1,4	0,02518654
0,46	0,54	0,3125	0,6875	0,1867503	0,020981	8,90101389	0,20773109	1,4	0,07428637
0,51	0,49	0,375	0,625	0,11925606	0,038998	3,05803461	0,15825368	1,4	0,18934917
0,56	0,44	0,4375	0,5625	0,06819654	0,065865	1,03539284	0,13406191	1,4	0,40823825
0,61	0,39	0,5	0,5	0,03247371	0,103712	0,3131137	0,13618589	1,4	0,69523664
0,66	0,34	0,5625	0,4375	0,01073461	0,154792	0,06934862	0,16552655	1,4	0,91150385
0,67	0,33	0,4075	0,5925	0,00791707	0,166802	0,04746376	0,17471952	1,4	0,93769112
0,68	0,32	0,4175	0,5825	0,00557091	0,179456	0,03104326	0,18502713	1,4	0,95834959
0,69	0,31	0,4275	0,5725	0,00367614	0,192773	0,01906982	0,19644906	1,4	0,97399649
0,70	0,3	0,4375	0,5625	0,00221023	0,206772	0,0106892	0,20898259	1,4	0,98525576
0,71	0,29	0,4475	0,5525	0,00114704	0,221475	0,00517909	0,22262158	1,4	0,99280147
0,72	0,28	0,4575	0,5425	0,00045508	0,2369	0,00192099	0,23735472	1,4	0,99731783
0,73	0,27	0,4675	0,5325	9,37E-05	0,253068	0,00037026	0,25316167	1,4	0,99948191
0,74	0,4	0,6625	0,3375	0	0,27	0	0,27	1,4	1

Figure 11 shows the variation in relative permeability of oil and water as a function of water saturation. With low water saturation at the start of production, kro was high, indicating that the oil flows easily. During water injection, water saturation increases progressively, leading to an increase in K_rw, i.e. water flow increases and oil flow decreases.

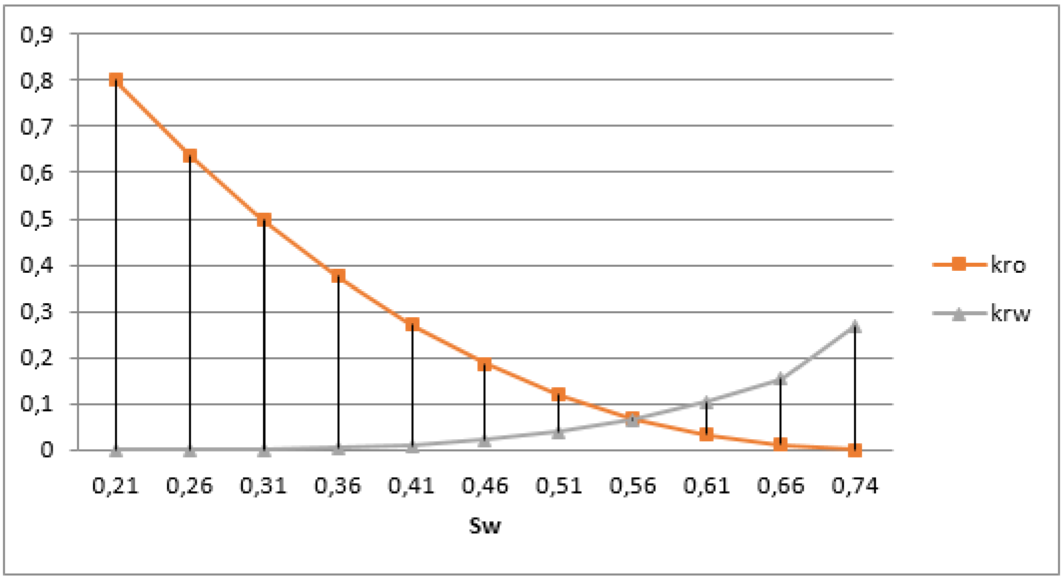

Figure 11. *Variation in relative permeability of oil and water as a function of water saturation*

Figure 12 shows the water fraction (fw) as a function of water saturation (Sw). This curve is also very important in the analysis of water injection into oil reservoirs. In the first period, the water fraction was zero, as shown by the fw curve, because the field was only producing oil, which means there was only oil displacement in the reservoir.

In the second period, we have the variation of the fw curve as a function of saturation, and this rapid variation provides further support for the hypothesis that water injection is the mechanism that causes oil to move in the reservoir, i.e. at a water saturation greater than 0.36, water and oil move in the reservoir.

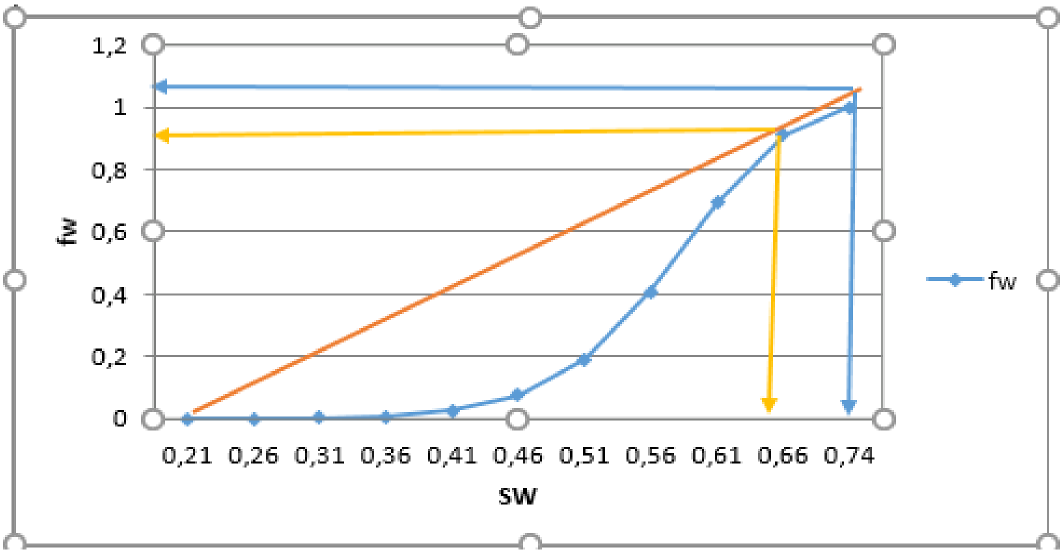

Figure 12. *Variation of fractional flow as a function of saturation*

Displacement efficiency

$$E_D = \frac{0.68 - 0.48}{1 - 0.48} = 0{,}385 \tag{5}$$

Surface efficiency at breakthrough point

$$M = \frac{krw@swBT}{kro@swi} * \frac{\mu o}{\mu w} = 0.8429 \tag{6}$$

$$Es = 0.54602036 + \frac{0.03170817}{0.8429} + \frac{0.30222997}{4.5143} - 0.00509693.(0.8429) = 0.7095 \tag{7}$$

Calculating the pore volume of water injected at the breakthrough point

$$Q_{iBT} = (\overline{S}_{wBT} - S_{wi}) = (0.68\text{-}0.48) = 0.20 \tag{8}$$

Calculation of cumulative water injected at breakthrough point

$$W_{iBT} = (PV) Q_{iBT} * E_{SBT} \tag{9}$$

$$W_{iBT} = 178106636*0.20*0.7095 = 25273331.65\ bbl$$

Vertical efficiency

$$E_V = 1$$

DISCUSSIONS

This study analyzed the effectiveness of water injection in the Tshiende oil field, located in the Democratic Republic of Congo, based on production data and PVT parameters. Initially, oil production in this field relied on natural entrainment mechanisms, such as fluid expansion and rock compressibility. However, from 1986 onwards, a significant drop in pressure led to a reduction in production, making it necessary to integrate water injection to compensate for this loss.

The reservoir's geological composition, mainly carbonate with limited levels of permeability and porosity, posed a challenge to injection efficiency. This configuration makes it crucial to consider other factors that may have contributed to the early drop in production, such as operational decisions made by the company during the early phases of operation. In addition, the presence of numerous faults in the region complicates the analysis of reservoir performance and behavior.

Drilling carried out between 1977 and 1995 targeted the Vermelha formation, which has long been the main source of hydrocarbons in the field. However, given the decline in production observed in this formation, efforts were made to develop the Pinda formation, with the aim of increasing the field's total production.

Results show that, following the initiation of water injection, the recovery rate increased significantly, from 2.6% to 39.8%. Water injection not only increased oil production, but also maintained reservoir pressure above bubble pressure. Examination of the volumes showed that the water produced gradually exceeded the water injected, indicating good scavenging efficiency in the reservoir.

However, challenges remain, notably the variation in injection rate, which has highlighted imbalances between injection and withdrawal, requiring rigorous control of operations.

In 2014, the Voidage Replacement Ratio (VRR), which reached a value of 1, signaled a temporary balance between injected and withdrawn volumes. The analysis shows a direct relationship between production throughput and the quantity of water injected, underlining that production flows are highly dependent on water injection efficiency.

Finally, it is important to note that, in more complex reservoirs, only part of the porosity may offer sufficient permeability to benefit effectively from water injection. This reinforces the need for precise injection management in low-permeability or thin-walled reservoirs. Although water injection has been shown to be an effective technique for extending production in the Tshiende field, it is recommended that further research be carried out into the potential existence of an aquifer and that other development campaigns be explored, particularly in the Pinda formation, which could offer production opportunities without relying exclusively on water injection. This integrated approach contributes not only to optimizing field performance, but also to the sustainability of oil resource development in the region.

CONCLUSIONS

At the end of this study, we have concluded that knowledge of field performance analysis is one of the major problems associated with exploiting the Tshiende field. These concerns are largely addressed by integrated multidisciplinary efforts namely, reservoirs and production to analyze field performance in the geological reservoir taking into account water injection.

The in-depth study of the Tshiende field highlighted several key elements. Firstly, the analysis of pressure and production data revealed a significant evolution of the field over the years, marked by an initial period of natural decline with a recovery rate of 2.6%, followed by a stimulation phase thanks to water injection with a recovery rate of 39.8%.

Analysis of the field's performance highlighted the importance of water injection as the main drainage mechanism. The high recovery factor achieved, thanks to the large volume of water injected, testifies to the effectiveness of this technique. However, the study also highlighted challenges related to injection management, notably the VRR varied widely and the injection-drainage balance was not assured due to the variation in injection rate. In 2014, the VRR was equal to 1, showing the balance between injection and withdrawal.

The effect of injection is felt in improved oil production and also in maintaining the average pressure above the bubble point pressure. In addition, the relationship between *Qo* and VRR confirms that the production rate depends on the amount of injection. While the field produced only oil from 1986 to 1991, the two fluids had almost similar production rates. Today, water production is much higher than oil production, and we have noted that the water injected is lower than the water produced, thanks to a volume of water corresponding to an HCPVi greater than 0.90. This value indicates that the water saturation in the reservoir is greater than that of the oil. The volume of water injected up to 2022 W_inj = 107348149 m^3 is greater than the quantity of oil produced N_P = 128907050 m^3. The Tshiende field also contains wells closed for various reasons, such as for WOR, a medium-performance well. The calculated sweep efficiency shows that injection yields good results, provided that injection and production rates are respected.

Abbreviations

$m.ss$: Depth to sea level	S_O: Oil saturation
VRR: Voidage Replacement Ratio	S_w: Water saturation
NP: Cumulative oil production	ES: Surface efficiency
N: Oil reserves in place	ED: Displacement efficiency
W_P: Cumulative water production	K_{ro}: Relative oil permeability
W_{inj}: Cumulative water injection	K_{rw}: Relative water permeability
RF: Recovery factor	uw: Water viscosity
Fws: Water cut	uo: Oil viscosity
$HCPVI_i$: Pore volume occupied by hydrocarbons	VP: Pore volume
B_O: Oil bottom volumetric factor	EV: Vertical efficiency
M: Mobility	

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