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Flow Dynamics during the Hydrocarbon Exploitation for Prevention and Management of Water Venues in Oil Field: A Study Case of Crystal Field in Badila/Chad

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Abstract

The southern part of the Lake Chad basin is under the gas and oil petroleum industry due to its hydrocarbon potential for about twenty years. This project stands out as the main challenges of the hydrocarbon production and the management of fluxes particularly the groundwater venues. A comprehensive study is thus conducted to develop a dynamic and analytic model for diagnosing the production performances with a particular view on the management of groundwater venues. The three main concerned reservoirs subdivided on subunits evidence their proper characteristics. The porous media, their densities, the internal flows and the water injection techniques such as water flooding were thus adopted. The oil viscosity variability within the reservoirs creates different levels of mobility between water and oil, highlighting the challenges of water management. The material balance model and the behavior of the well analysis were taken in consideration within the identified aquifer, emphasizing the importance of keeping the pressure through injection. The control of water productions, the management of the reservoir, the well strategical position and the specific completions lead to the model functioning. In addition, the CO log and the Pulsed Neutron indicate their limitations as a result of the water salinity and the porosity of the aquifer. The management of groundwater venues at Badila requires various approaches throughout the lifetime of the Crystal field such as the data acquisition and remediation actions and prevention, under a permanent monitoring of the dynamic fluxes in the reservoirs.

Keywords

Groundwater Venues, Analytic and Dynamic Model, Water Flooding, Optimization of Production

1. Introduction

The worldwide hydrocarbons demand is increasing every year whereas there are fewer and fewer new oil fields discovered through exploration drilling as mentioned by [1]. In one hand, the oil industry needs to produce more oil from the existing and known reservoirs, in a more efficient and more economical way. At the beginning of the year 2000, oil companies in the world were already producing 3 barrels of water for each barrel of oil [2]. In the other hand, many reservoirs are linked to aquifers and then are exploited by a secondary recovery through water injection. These reservoirs enable a high oil recovery due either to the supplementary energy naturally provided by the aquifer, or artificially through the water injection. However, the main issue during the exploitation of hydrocarbons is water venues and a water management strategy could better deal with that. The produced water is defined as the one of the geological formations and is extracted from gas and oil production once on the surface. However, that water could come from an active aquifer connected to the producing oil field as a natural flow (water flood) or from the injection well during the sweep oil processes. The issue is to achieve an efficient pressure support through water injection without flooding the oil producer. The water could also come either from any other chemical product during the production treatment processes. Another source could be external origins such as geological layers not normally connected to the oil producing layers but produced through wells with integrity issues caused by damaged cement or casing corrosion and leaks or perforation completion work. Water is thus produced by conventional production of oil and gas besides of non-conventional production sources such as coalbed methane, tight sands and shale gas component. In addition, the water produced differs considerably according to the type and the oil location [3] [4] [5] [6]. It represents waste fluid volume associated to the oil and gas production and the most continuous fluid flow during exploration and production of hydrocarbons. Over 40 billion of dollars each year are spent for the treatment of groundwater venues [7] [8].

Numerous issues occur during the oil production like environmental effects, oil reduction production and increasing rate of corrosion which are direct consequences of unwanted water through oil field. Due to the notable water quantities produced during the oil exploitation, many specialists consider that oil industries can be compared to water industries that produce oil secondary, so much it produces water [9] [10]. It is a complex matter and evidences economic and environmental impacts when the ratio of water/oil namely WOR exceeds the economical limit of the well. Water associated to oil production is by far the most important waste material created by the oil industry. For the US at the beginning of the year 2000, water production was 21 billion of barrel per year, versus 1.9 billion of barrels of oil per year and 23.9 TCF of gas [11] [12] [13]. This water often carries harmful components and if not managed properly, those huge amount could create an environmental disaster. From the early days of oil exploitation, water management has thus been a serial issue. However, the industry now is facing volumes which always increase, whereas environmental legislation becoming always tougher. In several cases, the new water control technologies enable to reduce significantly the costs and improve the oil production. It is thus expedient [14] [15]. Furthermore, it is important to know the different mechanism studies which cause the water production like pipeline and coning whose evidence the major issues of excessive water production in the oil industry [16] [17] [18]. In addition, the geology, the dynamic of the reservoirs and the well behaviour enable a good understanding of the production chain. Several steps occur and are required to understand reservoir and well behavior, and to characterize the interactions between the fluid displacement mechanisms and the well behaviors. This requires permanent surveillance, data collection and analysis such as PLT, Cement bond log, saturation behind casing, and interference tests.

Chad in central Africa has produced oil and gas since the 2000s. After the petroleum contract, the exploration phase started with seismic surveys, exploration boreholes and core analysis. The development stage included the rentability and the lifetime evaluation of the whole field. Oil and gas have thus produced since then and salt. As in many other oil fields, the production of gas and oil is under the water venues. The study area in Badila is constituted by the crystal reservoirs A from the Upper Cretaceous and reservoirs C and D from the Lower Cretaceous including their numerous subdivisions and the 12 wells. The Water Oil Ratio (WOR) is high relative to typical background activities (around 96%). In other words, with the production of 4 barrels of oil, there are 96 barrels of water produced as mentioned by the local oil industry. The challenge is thus to treat the water before re-injected it in the reservoirs using advanced technologies without damaging it and continuously during the production. These reservoirs were thus studied and distinctive examples were chosen to evidence water venues and techniques to manage them in the Crystal field in Badila. However, oil activities declined and hurt deeply the production and the offtake during the covid period from 2019 to 2020. In view of the adequacy between the exploration and the economical aspect in Badila, the aim of this paper is to 1) highlight the reservoir dynamic behaviour, the interactions between the fluid displacement mechanisms and the monitoring system, 2) manage water venues during the oil exploitation and 3) to show succinctly the different technics used by the Operator of the Crystal field in Chad to delay and "soften" the unstoppable water increase of the field.

2. Study Area

2.1. Location, Geomorphology and Climate

The study area is located in the city of Doba which is the Chief town of the Logone Oriental; one of the twenty-three Regions of Chad (Figure 1(a)) and of the Pende's District. The population is around 25,650 inhabitants according to the

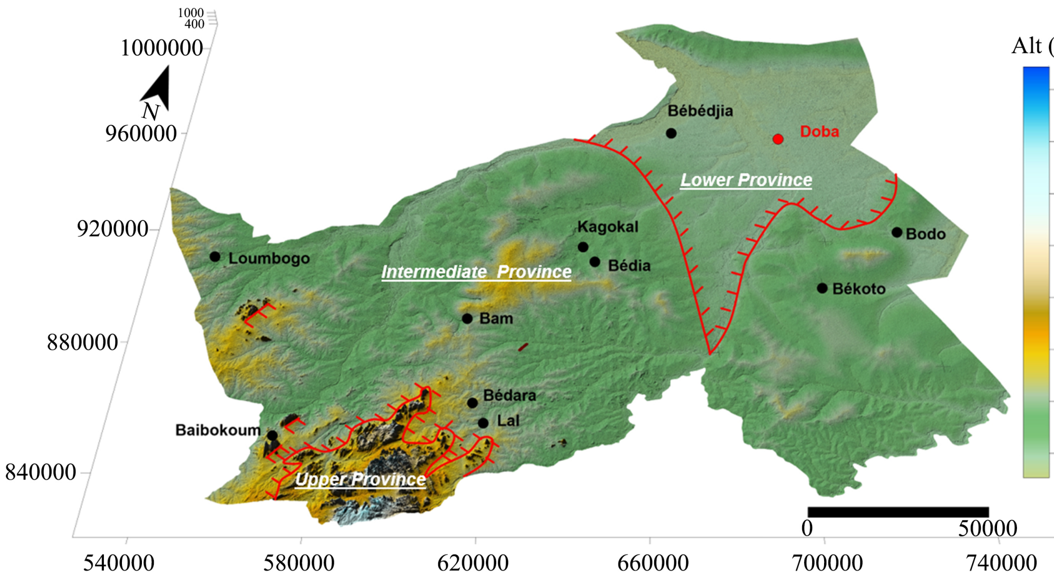


Figure 1. The study area (a) Location of the study area, (b) Geomorphology of the Pende's District.

population census of 2008 [19]. The main activities are agriculture, farming, livestock and gas industry. Doba belongs to the soudano-sahelian climate characterized by one rainy season namely wintering. The annual mean of rainfall is around 800 mm for fourth months (June to September) and the dry period is hot and cold depending of the periods of the year. The Pende's District is a peneplain (**Figure 1(b)**) with the Upper Province indicating altitudes from 700 to up to 1000 m. The Intermediate Province evidences mountain peaks at 500 to 700 m and Doba in the basin precisely in the Lower Province shows altitudes around 300 to 500 m. The main permanent river is locally called Pende supplies the whole District.

2.2. Geological and Hydrogeological Settings of the Study Area

The Lower Province of Doba is a result of an extension phase of the semi-grabens of the Chad basin with a divergent filling of sandstones sediments from the Lower to the Upper Cretaceous period [20] [21]. Structurally, Doba basin is a part of the Central African Rift System (CARS), which was filled with sediments (Lower to Upper Cretaceous) over time. The depositional environment was fluvio-lacustrine throughout the basin history (no marine incursion). Multiple "Micro-Systems" exist with fluvial input when proximal to the surrounding crest, and deltaic (channelized) on more distal/flatter areas in such way that [19] [20]: 1) The Lower Cretaceous formations mainly contain lacustrine sediments, the sandstone and mudstone interbeds are major reservoir strata, and especially a large set of thick shales are developed at top of formation, acting as the good regional caprocks. The Lower Cretaceous reservoirs are weaker, as sands are thinner and less continuous away from the field. 2) The Upper Cretaceous is dominated by abundant fluvial sandstones, with alluvial plain mudstones at the top. Cenozoic formations contain fluvial coarse grained clastic sediments. Badila reservoirs have a strong edge aquifer with good pressure support.

The hydrogeological settings of the study area match with that of the whole Chad basin. Previous studies have defined the main aquifer systems [21] [22] [23]. The upper unconfined Quaternary aquifer is made of less thick fluviatile sands and numerous clayey intrusions of Lower Pleistocene and the sands of Upper Pleistocene. The thickness of these sands increases gradually in the North of the Lake Chad as a consequence of the subsidence movements. The middle-confined aquifer of the Lower Pliocene composed of the sand formations and separated from the upper aquifer by thick clay deposits of the Middle-Upper Pliocene with the Lower Pliocene aquifer as artesian in the whole of the central area around Lake Chad [24] [25]. The thickness of the middle-confined system is around 300 m. the confined aquifer of the Late Continental is a sandy aquifer of about 100 to 600 m in the sunken rifts, like the one in Doba. The confined aquifer of the Intermediary Continental of Aptian and Albian evidences a depth up to 1000 m. A sandy zone at Doba has been identified as Cenomanian/Albian and has a thickness of 500 m starting at a depth of 458 m. Badila in Doba represents thus a depression where the general groundwater flow converges [26] [27] [28].

3. Methodology and Data Acquisition

The Crystal field of Badila is composed of three main units namely the reservoir A of the Upper Cretaceous (Upper K) which is subdivided in several units dynamically independent to each other namely A2.0, A2.1, A2.2, A2.3, A2.4; the reservoirs C and D of Lower Cretaceous (Lower K) as surrounded. The 3 reservoirs A, C and D have good rock properties. However, each main unit is characterized by their own rock properties, own fluid and contacts, and all produce groundwaters.

3.1. Qualitative Methods

Different methodologies have been used particularly concerning the reservoir A such as 1) the analytical approach to understand field/reservoir dynamic and interaction between the wells at different levels, 2) the construction and analyses of Material Balance models, 3) the generation of several "simple" numerical models to address uncertainties before and during the field life (multi-realizations), 4) the generation and update of a robust dynamic model integrating all available data. The summary of the qualitative method is represented in Figure 2.

3.2. Quantitative Methods

The main reservoir is characterized by petrophysical intrinsic properties such as petrophysic, flow dynamic and different Water Oil Contact (WOC) and Gas Oil Contact (GOC). These latters namely the bubble point (psi), Rs (scf/stb), Bo (v/v), the resistivity (cP) and the oil API; are recorded Table 1.

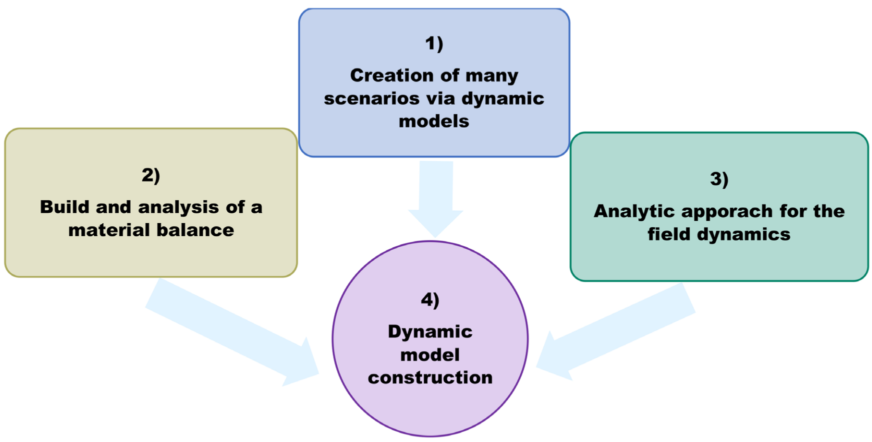


Figure 2. Flow-chart of the qualitative approach using in the Crystal field.

Table 1. Intrinsic properties of crystal reservoir of Badila.

Reservoirs	Bubble point (psi)	Rs (scf/stb)	Bo (v/v)	Visocosity (cP)	Oil API
CRY-A	1068	110.4	1.07	55	21.5
CRY-C	638	71.8	1.06	6.5	30.5
CRY-D	2000	270.8	1.16	3.2	34.5

3.3. Treatment Methods

There are many treatment methods to control and to threat water associated to oil during the exploitation. They are chemical methods that use to increase the viscosity of the water through polymers or gels. The dual completion technic can also be associated by isolating the water layer to avoid water venues. In addition, mechanical methods enable to control water venues through the straddle packers or the ciment portland coming from a treatment of very resistant clays and limestone. However, the noticeable point is the large oil viscosity difference between reservoirs and the important viscosity of the oil of reservoir CRY-A. Typically, with such important oil viscosity, water production can be very high at the field scale. Reservoirs CRY-C and CRY-D have been developed with vertical wells whereas reservoir CRY-A is being produced mainly with horizontal wells. Furthermore, the well completion diagrams are used to inject tracers in the reservoirs.

4. Results and Discussion

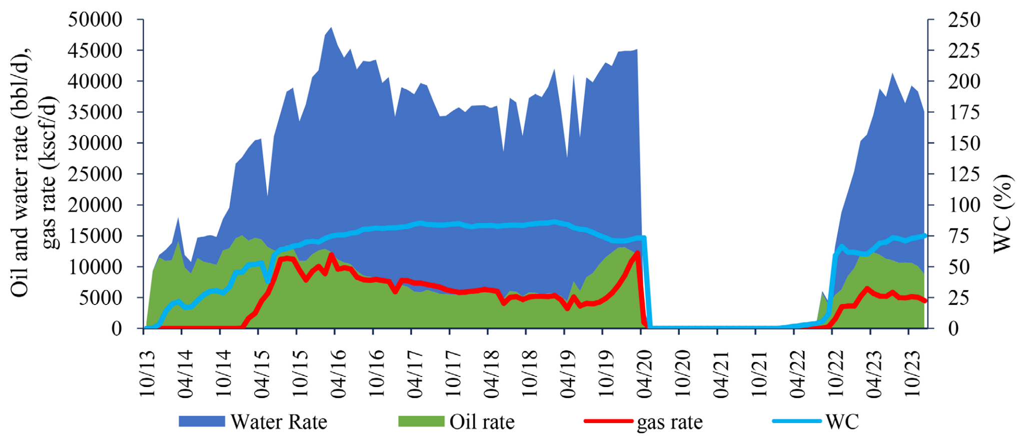
4.1. Water Management Strategy on Crystal A Reservoir

4.1.1. Reservoir Map and Producer-Injector Wells Communication

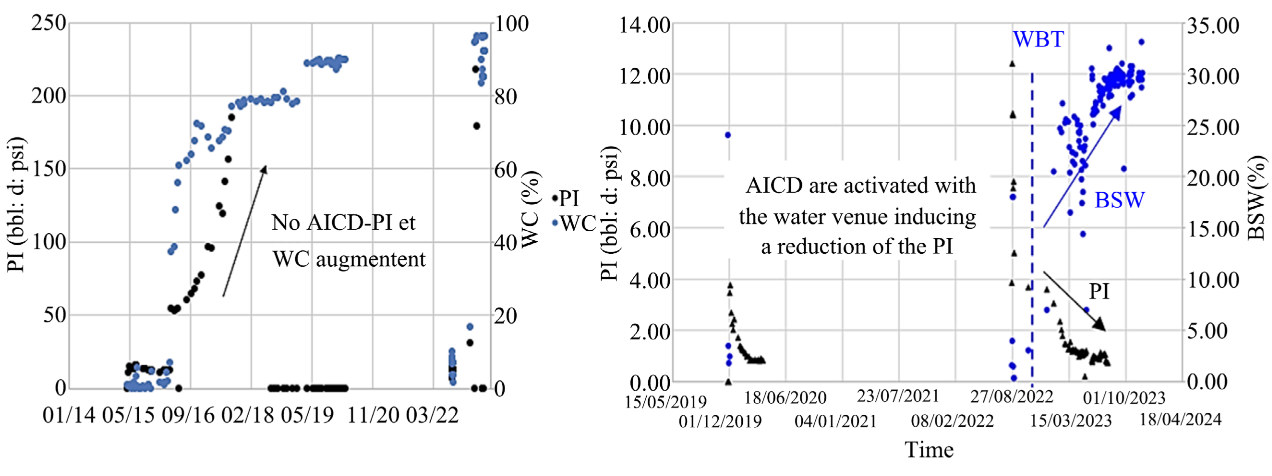
The top of the Crystal A reservoir evidences depths from −830 to −530 m with wells located at depths from −600 to −530 m. The three water point injections spatially represented around −620 to −610 m of depths delineate an area of twelve wells where the water flow direction is towards the depression (**Figure 3(a)**). Reservoir Cry A evidences high values of the psi (1068), the Rs (110.4), the Bo (1.07), the viscosity (55) and the oil API (21.5) in **Table 1**. The horizontally drilling method used for Cry A could explain these values. The production in Crystal A is important because the contact area with the reservoir increases. The water coning effect is reduced and difficult zones are deviated. In the other hand, high coast equipment is required with a special technic to reach the concerned parts horizontally. The recorded withdraw of oil, gas and water is from October 2013 to October 2023. The production of oil, WC and water increase gradually from October 2013 to April 2020 probably due to the high productivity; with water as the most important one. However, gas production starts to increase more latter than the others. During the lack of data from April 2020 to April 2022, only the WC was produced but at very lows quantities. The Crystal A reservoir resumes its operations from June 2022 to December 2023. This fluctuating growth pattern could come from the communication between the wells and highlight a preferential path from INJ-01 to CRY-02 and then to CRY-05, CRY-06 producers. During this activity, high zones producing water are observed.

4.1.2. Well Interventions

The well interventions enable to cross-checked hydrocarbon results. However, some tools and acquired data define better water zone productions [29] [30] [31] such as 1) The tracer injection which allow to define communication between wells, on specific zones depending how the test is designed. This latter is the most used technology in Chad. 2) The RESMAN technology where the tracer installed in the completion well and defined from which area the water comes from. It has been installed in the CRY-01 well. 3) The smart completion can be installed in the well and modifies the contribution of a zone depending on water arrival. This kind of completion has been installed on most of the wells of the CRY-A reservoir and is using the AICD Technology (Figure 3(b)). It reduces the well PI when water comes as well as a lower WC trend increase in comparison with wells without AICD. The Crystal A reservoir evidences an increasing PI with water break due to the high difference in viscosity between oil and water. The PI of CRY-02 well increases while the water increases. The PI of the CRY-10 well which has an AICD completion decreases while the WC increases. 4) The production Logging Tool is commonly used worldwide and allows to identify the contribution of the different layers/zones and identify fluids in presence. This approach is used in Crystal field and has driven some work-over to isolate some zones. 5) The evaluation tools like the "saturation behind casing tool" which compares the CO and Pulsed Neutron feasibility. But Crystal reservoirs are at the limit of these technologies due to the low water salinity and porosity.



(a)



(b)

Figure 3. (a) Communication between injectors and producers; (b) AICD completion effect.

4.2. Water Management Strategy on Crystal C Reservoir

4.2.1. Reservoir C Description and Main Characteristics

The Crystal C reservoir map (Figure 4) shows depths going from −1151 to −970 m with wells mainly located at −1000 to −970 m. Three other wells are found at −1040 to 1030 m at the North and East of the top of the reservoir. The sub units where the producer wells completed from reservoir C to D evidence the difficulty of knowing which layer has produced how much oil and water, and which layer is bringing water. According to Table 1, reservoir D indicates high values with respect to reservoir C. The petrophysical parameters are controlled (pressure, volume, temperature), even the walls of the well so that the production is stabilized. However, water venues increase quickly so that the well can be left and the production is not so important.

The reservoir C principally is a multi-layered one with five separated layers that are dynamically independent (Table 2). The production is expressed in Millions of oil barrels per day (Bopd). The global evaluation is done since the original stock (STOIIP) to the present day (Np). The sub-layer C5 is the one identified that produces mostly water (WCUT) and enable to estimate the percentage of water in the fluid production. The global Recovery Factor (RF) shows a low value (RF = 16.5%), indicating that the wells produce too much water very difficult to manage on surface; while the WCUT shows a value of 91% already.

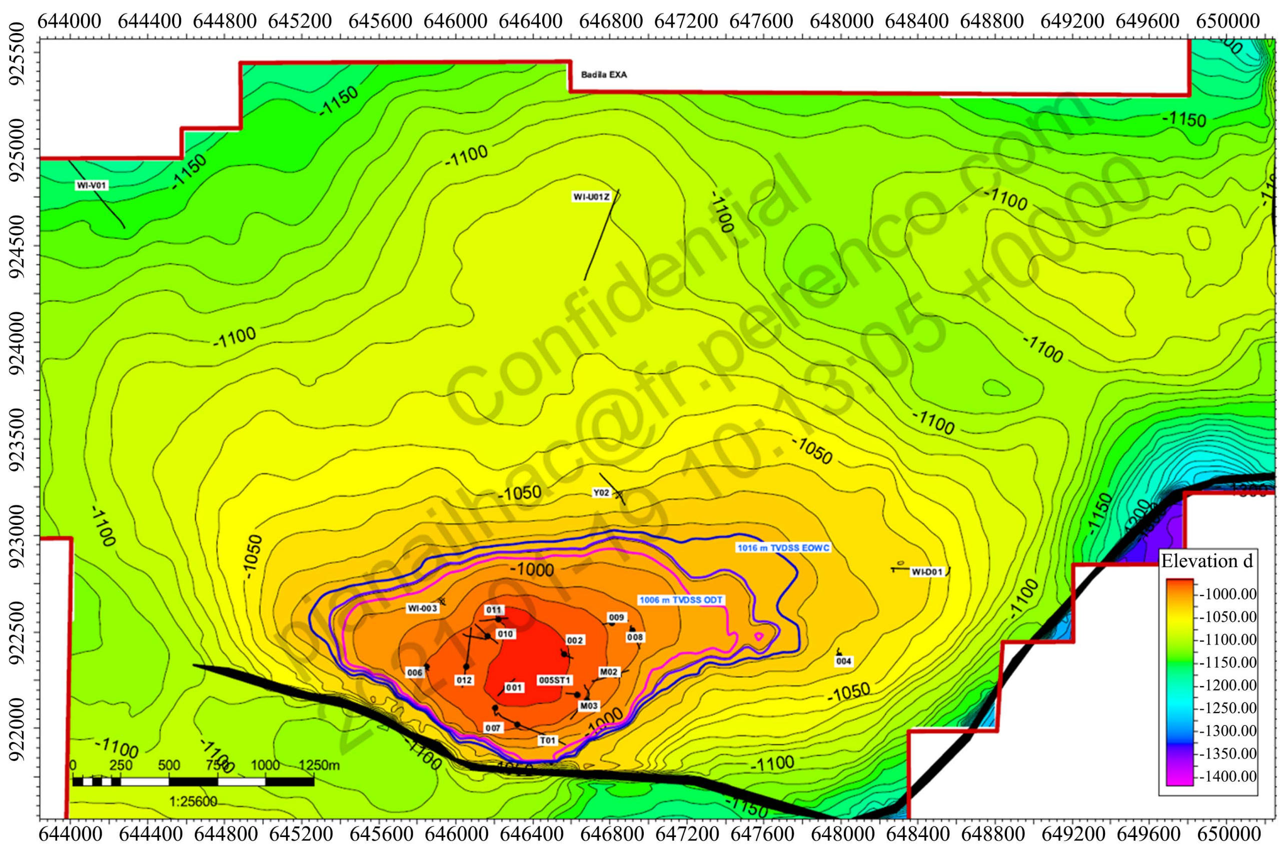


Figure 4. Crystal C reservoir map.

Table 2. Reservoir C STOIIP and RF.

Age	Key Layer	Top (Sub-Layer)	Hydrocarbon	Tank #	STOIIP (MMstb)	Cum STOIIP (MMstb)	GIIP (Bscf)	Np (MMstb)	RF	# Prod	Oil (bopd)	WCUT
Lowercretacous C Sands	C1	C1a	Oil	2	10	**40**	0	6,649	17%	6	1080	91.3%
		C1b	Oil	3	5		0					
	C2	C2	Oil	4	8		0					
	C3	C3	Oil	5	17		0					
	C4	C4	Oil	6	NA	NA	0	NA	NA	NA	NA	NA
	C5	**C5**	**Oil**	**Wet**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

4.2.2. Reservoir C Results and Dynamic Analysis

The data collection requires effective tools that can follow oil and water production per layer. The Production Logging Tool (PLT) has a spinner to measure the total flow and can measure the water and oil percentage. The tool is run through the Y tool while the ESP is producing. This tubing is perforated at the different locations of the reservoirs to produce the oil and isolate the other layers containing undesirable fluids and is slowly moved up across the entire perforated interval, favouring the collection of raw data. These latters can then be interpreted in a more usable way as shown in Table 3.

The first analytical method has been to plot WOR (Water Oil Ratio) of the reservoir C in Y axis in logaritmic scale *versus* the Cumulated oil in MMbbl. It shows the water content and its percentage in the tank and it often takes techniques or models to evaluate the content, quantify and solve them. A WOR of 50 corresponding to a Water Cut of 98% is considered as being the economic limit for oil reservoirs. However, the production tends often to follow a linear trend. For Crystal C reservoir without well intervention, the ultimate recovery is around 7.5 Mmstb; corresponding to 18.7% of the Ultimate Recovry Factor (URF). According to this low recovery factor, there is some interests to recover more oil from the reservoir C by doing wells interventions.

4.2.3. CRY C-5 Well Intervention History and Production Results

The oil production in barrel of oil per day (bopd), the water production in barrel of water per day (bwpd), and the Percentage of water (BSW) over the production of the well CRY C-5 are the parameters obtained during the process which give the well intervention history and the production results. According to the PLT log with the results the results presented in the previous section, two water shut off operations were conducted in 2015 and in 2023. This operation consisted in isolating the zone suspected of having important water production and minimum oil production. At the first completion in 2013, all reservoirs were open to flow (C1, C2, C3U, C3L). The BSW increased quickly and was above 90% in 2015. The decision was made to isolate the C3U during a workover operation. The reservoirs open to flow were C1, C2, C3L until 2023. The operation did not

Table 3. PLT Results of CRY C-5 well in December 2015 when well was flowing at 7000 bpd (barrels per day).

Contributions at Downhole Conditions Flowing # 4 - 7000 bpd Badila-5 (ST1)								
Layer	Press (psia)	Flowing intervals		Qo (bbl/d)	Qw (bbl/d)	Qg (bbl/d)	Qt (bbl/d)	% Total Rate
		Top	Bottom					
C1	1731.7	1441.0	1451.0	0.0	0.0	0.0	0.0	0.0
C1	1760.4	1462.0	1464.5	0.0	0.0	0.0	0.0	0.0
C1b	1793.2	1486.0	1491.5	0.0	0.0	0.0	0.0	0.0
C1b	1804.2	1494.0	1497.0	0.0	183.1	0.0	183.1	2.5
C2	1896.3	1561.0	1565.5	51.7	33.0	0.0	84.8	1.1
C2	1917.8	1576.5	1579.5	0.0	423.3	0.0	423.3	5.7
C2	1930	1585.5	1587.0	0.0	0.0	0.0	0.0	0.0
C3 Upper	1942	1616.0	1625.5	578.3	2822.4	0.0	3400.7	45.8
C3 Lower	1989	1631.0	1638.0	1172.8	1909.7	0.0	3082.5	41.6
C3 Lower Base	2004	1639.5	1651.5	243.6	0.1	0.0	243.7	3.3

manage to significantly lower the BSW which reached 96% in 2020. In 2023, it was the C3L that was isolated during a workover operation. Only C1 and C2 were then open to flow, the BSW decreased noticeably and is now at 88%, with a downward trend. By that, the CRY C-5 well indicates that a simple way to control the water production of a well is to shut off the zones producing water.

4.2.4. CRY C-5 Well Interference with Parasite Water Injector Well CRY C-2

In view of the high pressure in the system, the water injection is commonly the best way to maintain the pressure in the reservoir constant, limit depletion and optimize the reserves. Since the valves open from the 1st December 2013 to the 1st December 2023, different phases in production were observed namely oil peaks, decrease of the WOR, reservoirs pressures and production shutdown. However, the simultaneous and antagonist action of the water injection and the water production which maintain the equilibrium pressure for the production, with the voidage ration (VRR) around 1.2%. This latter is an important parameter to monitor the water injection and corresponds to an over-injection during the period 2014 and 2020. Its value is much lower about 0.2 from the period 2022 to 2023. However, the excessive water injection can result in parasite water recycling, and has a negative impact on the producer wells in some cases. All the different wells tend to have the same pressure, showing that the reservoir is homogenous. Despite the reduction of injection during the period 2022-2023, the reservoir pressure has stayed relatively stable, showing that there is an active aquifer. In addition, It should be noted that contrary to the previous well (CRY C-005), there was no workover operation on this well. Nevertheless, the Water

Cut (WC) went down also, showing the importance of water injection management.

4.3. Models and Simulations

Models and simulations are used in oil activities to correct and to improve the production and are applied to completion during production. According to the drilling method (vertical or horizontal method), the treatment and the productivity fluctuate [32] [33] [34] [35] [36]. The material balance models were adopted in Badila to show the presence of aquifer. The production history and the simulations of the tanks with the aquifer and without the aquifer were thus made. They evidence a good calibration in the reservoirs when the water and gas are injected. This process enables to maintain the reservoir pressure and to reduce liquid rate decline because there is a need of an extra energy to limit depletion and even more when the offtake increases. However, an equilibrium must be found due to the high difference in mobility of fluids because the drop in pressure of the tank leads to the drop in oil production.

Due to high environmental constraints particularly the high-water density, all produced water is re-injected in a producing reservoir and disposal reservoirs which have some constraints. This causes some water movements in aquifers and in the reservoirs as the production progresses. The high difference between oil and water mobility hurts production in Crystal A reservoir if the water is injected at a high rate. A dynamic model is thus extensively used to define future well behaviour and help on tuning production/injection ratio. Furthermore, the model helps defining the main contributing zones, the main by-passed areas which plan further infill wells to reduce water production and increase oil production.

4.4. Monitoring and Diagnosis

During the production phase of a field, a good monitoring of the wells is requested as continuous data acquisition to allow good analysis. The two important steps of the monitoring and the diagnosis are: 1) The well integrity as the key of a drilled and completed well. It is necessary to check the cement quality to avoid channeling behind casing or put any water reservoir in communication with the production zone. For this reason, running a Cement Bond Log (CBL) is highly recommended. 2) The occurrence of water breakthrough with different techniques to define the water venue such as “Chan plot model”. However, it is important to work both in the whole reservoir and in the concerned well, as a water breakthrough or increase in rate can be linked as well to other wells (producers and/or injectors); to know the flow direction of fluids in the reservoir [2] [8]. It is also important to understand the limitations and uncertainties of each used analysis and as well to the data quality and their uncertainties. This includes the dynamic behavior which can be a multilayer system like reservoir A. The Dietz model was used, due to the high difference viscosity between water and oil. The monitoring and diagnosis of production is thus characterized in one hand by the integrity of the well during drilling (well-cemented, well-placed casing) to insulate the well and prevent any ingress of undesirable fluids; and in the other hand enable to avoid water ingress into the production column using control techniques.

By this simple approach, a "tongue surface" is expected and even some fingering implying a non-homogeneous waterfront and sweep and early breakthrough. This phenomenon is explained by the difference in viscosity between the oil and the water. By computing the mobility ratio, the water is 15 - 20 higher than the oil. This range is required to maximize reserves thus, to be able to handle a lot of water. Furthermore, the maximum liquid rate should be lower than 5 bbl/d to avoid any unstable waterfront which will cancel any economic development of the crystal field. On the Chan curves, the water and oil ratio (WOR) were adjusted at different times to stand out the impact in the production particularly the oil production variation. This evidences the mobility parameters and the production performances. For this reason, some special completions will be used and facilities will be designed to handle "some water" such as mechanical technics like a mix of very resistant limestones and clays to them, always in the effort to plan and prevent early water arrivals, fractional flow analysis was performed by using SCAL and production data.

In addition, interference and crossover tests were realized in crystal field to define the performance between the injectors and the productors (wells). This enables to characterize the relationship between them. The observation was that the productors (wells) are mostly dependent of injectors. All these analyses show that perforations/drains shall be far from the WOC. At 40% Sw, the WC is about 90% and the crystal A reservoir producers were placed at the top of the structure to maximize their reserves. The water is thus injected in the reservoir (reservoir A) to maintain its pressure. Several interference tests were performed between the injectors and the producers to define interactions [30] [31] [32] [36]. When INJ-01 was shut, quick and strong changes were observed on several producers and the parameters are obtained using a sample from the bottom of the well at the reservoir during drilling. This latter, this sample is called "core" with controlled parameters. The PVT are adjusted according to its petrophysical parameters to have a good production.

Previous highlighted techniques allow to define zones with water contribution and by this, allow to take water remedial actions, the WOR is to isolate these zones and Water Shut Off which have already been realized on the Crystal Field. In addition, another possibility to handle water is to debottleneck the surface facilities to be able to handle more water. On Crystal field, an upsize of the water treatment capacity is planned such as for the well 01 by using an injector well which plays an essential role in maintaining production and pressure for a good efficiency.

5. Conclusion

Water production and management is a major constraint in the Oil and Gas industry. They are a huge issue in the development of any hydrocarbon field and require to be planned, anticipated, and followed. Water must be addressed from the early stage of any field development. This must be done through a good understanding at different levels from the reservoirs to the wells and then to surface facilities. A good monitoring and good data acquisition plan allow to reduce uncertainties and drive to the right action plan and decisions. In the Crystal field, several approaches were used along the field span to optimize its production. Studies highlighted the high-water production trend and some technologies were used to reduce this trend. The well location was studied to maximize reserves per individual well by looking at the oil/water mobility ratio (theoretical Fw (fractional flow) *vs* observed Fw). The specific technologies were then used like AICD completion to maximize oil production and reduce water production. At first, the data analysis and tools were used to define the point of water entrance in the wellbore, starting from well integrity (through Cement Bond log) or tracers, or Production logging tool, once water was observed at the wells. These data acquisition and analysis allowed to plan and execute proper Water Shut Off jobs. Secondly, when the water production increases continuously, a debottleneck of the facilities depending on economics was planned. However, if several actions can be taken at well level, surface facilities should not be neglected in the water management process including a full economic overview.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Al-Mutairi, S.M. and Al-Harbi, M.H. (2006) Water Production Management Strategy in North Uthmaniyah Area, Saudi Arabia. *SPE Europec/EAGE Annual Conference and Exhibition*, Vienna, June 2006, SPE-98847-MS. https://doi.org/10.2523/98847-MS

[2] Chan, K.S. (1995) Water Control Diagnostic Plots. *SPE Annual Technical Conference and Exhibition*, Dallas, October 1995, SPE-30775-MS. https://doi.org/10.2118/30775-MS

[3] Dake, L.P. (1978) Fundamentals of Reservoir Engineering. Elsevier, Amsterdam, 345-348.

[4] Economides, M.J. (1994) Petroleum Production Systems. Prentice Hall, Englewood Cliffs.

[5] Satter, A. and Thakur, G.C. (1994) Integrated Petroleum Reservoir Management: A Team Approach. PennWell Publishing Company, Tulsa. https://doi.org/10.1190/1.1822876

[6] Guo, B., Liu, X. and Tan, X. (2017) Petroleum Production Engineering.

[7] Naemeka, E. (2010) Petroleum Reservoir Engineering Practice. Prentice Hall Publishing Company, Englewood Cliffs, 728-734.

[8] Reynolds, R.R. (2003) Produced Water and Associated Issue. Petroleum Technology Transfer Council.

[9] Ershaghi, I. and Omoregie, O. (1978) A Method for Extrapolation of Cut vs Recovery Curves. *Journal of Petroleum Technology*, **30**, 203-204. https://doi.org/10.2118/6977-PA

[10] Chou, S.I., Bae, J.H., Friedman, F. and Dolan, J.D. (1994) Development of Optimal Water Control Strategies. *SPE 69th Annual Technical Conference and Exhibition*, New Orleans, September 1994, SPE-28571-MS. https://doi.org/10.2118/28571-MS

[11] Seright, R.S. (1997) Improved Methods for Water Shutoff. Annual Technical Progress Report (U.S. DOE Report DOE/PC/91008-4), U.S. DOE Contract DE-AC22-94PC91008, BDM-Oklahoma Subcontract G4S60330.

[12] Ershaghi, I. and Abdassah, D.A (1984) A Prediction Technique for Immiscible Processes Using Field Performance Data (Includes Associated Papers 13392, 13793, 15146 and 19506). *Journal of Petroleum Technology*, **36**, 664-670. https://doi.org/10.2118/10068-PA

[13] Arnold, R., Burnett, D.B., Elphick, J., *et al.* (2004) Managing Water-From Waste to Resources. Oilfield Review inTrans. A.I.M.E. (1944), **160**, 228-247.

[14] Chen, E.T. (2012) Produced Water Treatment Technologies. *International Journal of Low-Carbon Technologies*, **9**, 157-177.

[15] Guengant, J.P. and Guealbaye, D.M. (2012) Population et dividende démographique au Tchad. IRD-AFD, Paris.

[16] Lawal, K.A. and Utin, E. (2007) A Didactic Analysis of Water Cut Trend during Exponential Oil Decline. *The 31st Nigeria Annual International Conference*, Abuja, August 2007, SPE-111920-MS. https://doi.org/10.2523/111920-MS

[17] Permana, D. (2013) Selection Criteria for Successful Water Shut-Off Treatment-Brown Field Success Story. *SPE Asia Pacific Oil and Gas Conference and Exhibition*, Jakarta, October 2013, SPE-165753-MS. https://doi.org/10.2118/165753-MS

[18] Eduin, O.M., Ana, T.F., Gaspar, R., Carlos, E. and Denis, J.S. (2010) An Integrated Methodology for Water Management under Operational Restrictions. *The SPE Latin American and Caribbean Petroleum Engineering Conference*, Lima, December 2010, SPE-139336-MS.

[19] Schneider, J.-L. (1966) Relation entre le Lac Tchad et la nappe phréatique (République du Tchad). Publication AIHS N°70, Symposium de Garda. 122-131.

[20] Schneider, J.L. and Wolf, J.P. (1992) Cartes géologique et hydrogéologique à 1/1 500000ème de la République du Tchad. Mémoire explicatif. Documents du BRGM N° 209. Orléans (France), Vol. 2.

[21] PNUD-FAO-CBLT (1973) Etude des ressources en eau du bassin du Lac Tchad en vue d'un programme de développement. Tome I. Hydrogéologie, rapport de synthèse BRGM ined. N°Lam 67 A.

[22] Goni, I.B., Fellman, E. and Edmunds, W.N. (2001) Rainfall Geochemistry in the Sahel Region of Northern Nigeria. *Atmospheric Environment*, **35**, 4331-4339. https://doi.org/10.1016/S1352-2310(01)00099-1

[23] Djoret, D. (2000) Etude de la recharge de la nappe du Chari-Baguirmi par les méthodes chimiques et isotopiques. Thèse de doctorat, Université d'Avignon et des Pays de Vaucluse, Avignon, 161 p.

[24] Schneider, J.-L. (2001) Géologie, Archéologie, Hydrogéologie de la République du Tchad. Mem. 1100 p., 2 vol. Carte de valorisation des eaux souterraines de la République du Tchad, 1/1500000, Direction de l'hydraulique, N'djamena.

[25] BGR-CBLT (2009) A Review of the Groundwater Situation in the Lac Chad. Report, 18 p.

[26] BGR-CBLT (2010) Recherche sur la qualité de l'eau dans la partie Sud-Est du Bassin du Lac Tchad. Rapport N°3, 41 p.

[27] Hamit, A. (2012) Etude du fonctionnement hydrochimique su système aquifère du Chari-Baguirmi (Repubique du Tchad). Thèse de doctorat, Université de Poitier, Poitier, 289.

[28] BGR-CBLT (2013) Etude de la qualité des eaux souterraines dans la plaine d'inondation du Logone inférieur. Rapport N°7, 49 p.

[29] Jarrel, P.M. and Stein, M.H. (1991) Maximizing Injection Rates in Wells Recently Converted to Injection Using Hearn and Hall Plots. *The SPE Petroleum Operations Symposium*, Oklahoma City, April 1991, SPE-21724-MS. https://doi.org/10.2523/21724-MS

[30] Spivey, J.P., Gatens, J.M., Semmelbeck, M.E. and Lee, W.J. (1992) Integral Type Curves for Advanced Decline Curve Analysis. *The SPE Annual Technical Conference*, Mid-Amarillo, April 1992, SPE-24301-MS. https://doi.org/10.2523/24301-MS

[31] Bourdet, D. (2002) Well Test Analysis: The Use of Advanced Interpretation Models.

[32] Peaceman, D.W. (1983) Fundamentals of Numerical Reservoir Simulation (Developments in Petroleum Science).

[33] Horne, R.N. (1995) Modern Well Test Analysis: A Computer-aided Approach.

[34] Höök, M. (2009) Depletion and Decline Curve Analysis in Crude Oil Production.

[35] Guo, B. (2019) Well Productivity Handbook, Vertical, Fractured, Horizontal, Multilateral, Multi-Fractured, and Radial-Fractured Wells. Elsevier, Amsterdam. https://doi.org/10.1016/B978-0-12-818264-2.00008-7

[36] Poston, S. and Poe, B.D. (2020) Analysis of Production Decline Curves.