ISSN: 3029-0732

Review Article

Journal of Cardiovascular and Cardiology

Modeling of Water Flooding Effects During Enhanced Oil Recovery

Merzouk Zatout

Institute of Architecture and Earth Sciences, Ferhat Abbas University Sétif Algeria, Algeria

Corresponding author
Merzouk Zatout, Institute of Architecture and Earth Sciences, Ferhat Abbas University Sétif Algeria, Algeria.

Received: February 20, 2026; **Accepted:** April 09, 2026; **Published:** April 20, 2026

ABSTRACT
Secondary oil recovery using the water injection method was adapted to enhance oil production from the Algerian X-field by maintaining reservoir pressure. The Albian aquifer was used for this purpose. This operation caused many problems with the production facilities. Indeed, several solids, including halite, gypsum (rarely anhydrite), calcite, dolomite, barite, and iron oxides, were deposited in the reservoir, on the downhole completion equipment, along the tubing, and in the surface equipment. On the other hand, the diagenetic sequence of the reservoir sandstones is marked by late cements such as anhydrite, dolomite, barite, and pyrite. To understand the formation of late diagenetic cements and solids observed after water flooding, and the factors involved, a geochemical simulation of the individual and the combined effects of Cambrian oil brine and Albian injection water was carried out. The PHREEQC software was used with two different thermodynamic databases, Pitzer.dat and llnl.dat. The Pitzer database is suitable for highly concentrated waters (brines) and tested for high pressure and temperature brines. The llnl.dat database is suitable for high pressure and high temperature. It gave good results, especially for speciation determination. Thus, a combination and comparison of these two databases was used.

The results obtained by the PHREEQC simulation perfectly reproduced the observations made. Indeed, the late diagenetic iron cement crystallized because of the supersaturation of the oil brine in hematite and goethite during its installation in the Cambrian HMD trap after the oil secondary migration. This favored the crystallization of the late anhydrite and dolomitic cement. In addition, interactions between sulfate-rich Albian water and Cambrian oil brine containing barium, iron, calcium and strontium explain the precipitation of anhydrite, calcite, barite, and iron oxides. The high concentrations of sodium and chlorine in the oil brine, and the progressive decrease of temperature along the hydrocarbon production pathway explain the precipitation of halite throughout.

This study shows that it is useful to simulate the water flooding operation with the starting water flooding and reservoir brine ionic compositions to ovoid salts precipitation by pretreating the injection water or including specific chemical inhibitors of insoluble salts.

Keywords: Secondary Oil Recovery, Water Flooding, Late Diagenetic, Salt, Inhibitor, Phreeqc, Geochemical Modeling

Introduction

Discovered in 1956, the Algerian oil X-field is a very thick sandstone reservoir of Cambro-Ordovician age covering an area of 2000 km2. It is located between 5°30 6°00 and the parallels 31°00 and 32°00N. It is one of the largest oil deposits in the world. It is a multi-billion barrel oil field in the Oued Mya Basin [1,2].

The initial reservoir pressure was 6,825 psi, and the bubble point of the crude varies from 2,880 psi to 2,130 psi. The gas oil ration varies from 1,390 to 1,030 cu ft/bbl depending on the geographical location in the field [3].

At the late stage of digenesis, barite, anhydrite, dolomite, and pyrite are observed [1]. After water flooding, a systematic barite in the sandstone reservoir, the tubing, wellhead, and surface installations were clearly identified. The deposition of gypsum, calcite, dolomite and halite along the production column is regularly reported [3].

To understand the phenomenon of these solids' formation, a thermodynamic simulation was conducted using PHREEQC software with two thermodynamic databases, the Pitzer indicated to highly concentrated water, and the llnl.dat database, which is suitable for high thermodynamic conditions [5-6].

The effects of low salinity water injection are well known from a petrophysical point of view but not from the chemical and thermodynamic effects on field facilities. The main objective of this article is to simulate under real thermodynamic conditions and with the same water involved the water injection process to predict its possible effects on the reservoir sandstones and the production installations [7,8].

Citation: Merzouk Zatout. Modeling of Water Flooding Effects During Enhanced Oil Recovery. J Cardiovas Cardiol. 2026. 4(2): 1-3.
DOI: doi.org/10.61440/JCC.2026.v4.57

Materials and Methods

The Cambrian brine samples were taken from the separators of the wells without Albian reinjection and the Albian injection water from the wellheads of the Albian wells. Given the long history of water injections in the field, all production parameters are regularly monitored: temperatures, pressures, chemical compositions of all effluents (oil, gas, water) and solids deposited on production infrastructure, from the bottom of the hole to the processing center. Dolomite and calcite are located at the bottom of the well equipment; halite and gypsum (rarely anhydrite) have often been encountered near the surface; and finally, barite is encountered all along the oil production trajectory. Iron oxides are also reported, and according to the company's internal reports, their origin is attributed to corrosion phenomena. There are several technical reports on the operations that ensure this monitoring, but they are not published and remain internal documents of the national oil company. The data presented here (Table-1) are the mean 50 representative data for both brine and injection water, sampled in 2017 [9].

The modeling of the water injection enhanced recovery method, the PHREEQC software was used to simulate it under the real conditions and with the same types of the involved waters. PHREEQC It is a computer code capable of performing geochemical calculations on water using several databases. Its capabilities include the mixing of different aqueous solutions, the calculation of aqueous speciation and the minerals' saturation indices. Two thermodynamic databases are used. The first is an improved Pitzer database for calculating hydrogeochemical reactions of minerals and gases, at high pressures and temperatures, in saline waters. In addition, all interaction coefficients for the Na-K-Mg-Ca-Ba-Cl-CO2-HCO3-SO4-H4SiO4 system have been adjusted. Moreover, the pressure-dependent equilibrium constants are calculated based on the apparent molar volume of the solutes deduced from density measurements [4,5,10]. A number of works successfully used the Pitzer database for brines. The second database is llnl.dat, which is more accurate and reliable for aqueous speciation at high pressures and temperatures [8,11-13].

Table 1: Ionic Composition, Ph and Density of the Studied Waters

Property	HCO^{3-}	Cl^-	$SO4^{2-}$	Ca^{2+}	Mg^{2+}	Ba^{2+}	Sr^{2+}	Na^+	K^+	Fe^{2+}	pH	Density
Albian water (g/L)	0.17	0.42	0.6	0.21	0.7	0	0	0.25	0.4	0	7	1
Cambrian brine (g/L)	0	210	0	36	6.5	0.8	0.97	80	6	5.5	3.5	1.23

The mineral saturation index (SI) is used to determine the crystallized and the dissolved salts in the simulation conditions, with positive value indicating crystallization and the negative value indicating non-saturation. Increases in the saturation index reflect mineral precipitation and decreases reflect dissolution, thus allowing the determination of precipitated and under-saturated or dissolved phases [5]. Less than 0.05, SI translates the equilibrium of the solution with respect to the mineral [14].

The density, the ionic compositions and the pH of both the Cambrian oil brine and the Albian water flooding were used as input data (Table 1) of the PHREEQC software.

To follow the saturation state of the brine with the hydrocarbons from the reservoir rock to the surface, temperatures of 140°C, 50°C, and 25°C corresponding respectively to the bottom hole, the medium of tubing, and the surface equipment, were used.

Results

Saturation State of the Mixed Cambrian Brine and Albian Water Injection

Figure. 1 represents the plotted results of the water flooding modeling obtained with the Pitzer.dat and Llnl.dat, respectively. They reveal that with the Pitzer database, anhydrite and iron minerals did not crystallize before and after the flooding; barite and halite crystallized only after the flooding at the surface and the bottom wells, respectively; and finally, calcite and dolomite occurred before and after the flooding operation. On the other hand, the Llnl database shows the occurrence of calcite, dolomite, and iron oxides (hematite, goethite, and magnetite) before flooding. After flooding, the obtained solids are calcite, dolomite, anhydrite, and iron oxides, but not halite.

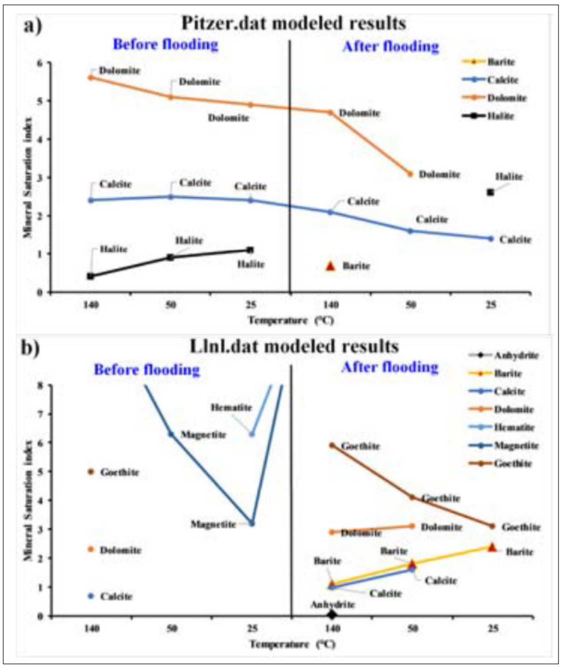

Figure 1: Modeled saturation indices Vs Temperature: a) Pitzer.dat, b) Llnl.dat

Discussion

The thermodynamic simulation of the flooding operation with the two databases reveals that calcite, dolomite, and iron oxides crystallized before the water flooding operation Fig. 1. These minerals effectively present in the late diagenetic sequence of the sandstones forming the reservoir rock. Therefore, barite, anhydrite, and pyrite observed on the thin section, are not obtained by the thermodynamic modeling. This deviation indicates that the physicochemical environment of late diagenesis was different.

The brine was probably more sulfate rich. Halite, detected only by the Pitzer.dat before flooding, crystallized principally near the surface, after flooding. Moreover, barite did not precipitate before water flooding, but precipitates after flooding along all trajectory of the hydrocarbon. Similarly, anhydrite did not obtain by both the two databases, before and after flooding. Indeed, the small value (0.03) given by Llnl.dat (Fig. 1b) in the bottom conditions indicates the equilibrium state of this mineral, which can ever been in dissolution or crystallization. Calcite precipitated essentially in the bottom hole, in the tubing, and decreased up to the surface. This corroborates well except for calcite solubility, which decreases with the increase of temperature [14].

The simulation with the Llnl.dat database reproduces some of the types of cement observed in the late stage of sandstone diagenesis and supports that the solids obtained for higher depths and pressures after flooding are barite and iron oxides. Ferrous minerals are iron oxides, and it is clear now that their presence is due not only to corrosion phenomena but also to the iron in the Cambrian brine and thermodynamic changes.

The results of the Llnl.dat database are consistent with the field observations at high depth and pressure. Moreover, the results of the Pitzer.dat database agree with the real crystallized salts near the surface at low pressure. Thus, their combination better contributes to understanding the behavior of the mixing waters since they forgive different and complementary information.

Conclusions

The modeling of the mixing of those involved in Algerian oil X-field, with Phreeqc code version 3, and using the Pitzer and Llnl.dat thermodynamic databases concluded the following results. The late diagenetic cements observed occurred in a different diagenetic environment, characterized probably mainly by more sulfate-rich brines. The solids are regularly observed in production facilities after the water flooding perfectly reproduced by combining the two selected databases. Iron oxides originate from the iron contained in Cambrian oil brines, not just from corrosion.

This study shows that simulating water injection operations using ionic compositions of water injection and reservoir brine can help predict and avoid solids precipitation on production facilities. This can be achieved by demineralizing the injected water or injecting chemical inhibitors.

References

1. Bessa F. Reservoir characterization and reservoir modeling in the northwestern part of Hassi Messaoud field, Algeria, University of Hamburg. 2004.
2. Sonatrach and Schlumberger. Well Evaluation Conference. Schlumberger. Houston, TX, USA. 2007.
3. Haskett CE, Tartera M. A Practical Solution to the Problem of Asphaltene Deposits-Hassi Messaoud Field, Algeria. J. Pet. Technol. 1965. 387-391.
4. Parkhurst DL, Appelo CAJ. Description of Input and Examples for PHREEQC Version 3—A, U.S. Geological Survey, Denver, Colorado. 2013.
5. Appelo CAJ. Principles, caveats and improvements in databases for calculating hydrogeochemical reactions in saline waters from 0 to 200°C and 1 to 1000atm, Appl. Geochemistry. 2015. 55: 62-71.
6. Lu P, Zhang G, Zhu C. Comparison of thermodynamic data files for PHREEQC. J. Apps. Earth Science Rev. 225. 2022.
7. Thomas S. Enhanced Oil Recovery – An Overview. Oil Gas Sci. Technol. 2008. 63: 9-19.
8. Li Y. Oil Recovery by Low Salinity Water Injection into a Reservoir: A New Study of Tertiary Oil Recovery Mechanism. Transp. Porous Media. 2011. 90: 333-362.
9. Ahmed MH, Mohammed MA. Oil brine effects on the hydrocarbon production - Hassi Messaoud field. Kasdi Merbah Ouargla University. Algeria 2017.
10. Appelo CAJ, Parkhurst DL, Post VEA. Equations for calculating hydrogeochemical reactions of minerals and gases such as CO2 at high pressures and temperatures. Geochim. Cosmochim. Acta. 2014: 125.
11. Plummer LN, Parkhurst DL, Fleming GW, Dunkle SA. A Computer Program Incorporating Pitzer's Equations. U.S. Geological 1988.
12. Zermeno MIM, Nieto-Delgado C, Cannon FS, Cash CC, Wunz CC. Chemical modeling for precipitation from hypersaline hydrofracturing brines. Water Research. 2016. 103: 233-244.
13. Wolery TJ, Sutton M. Evaluation of Thermodynamic Data. Lawrence Livermore National Lab (LLNL). United States. 2013.
14. Mahmoud SMAEA, El-Sayed MI, M'nif A, Sillanpää M. Crystallization sequence during evaporation of a high concentrated brine involving the system Na-K-Mg-Cl-SO4-H2O. Desalination. 2015: 355: 11-21.