Commentary

SCISET
www.sciset.com

Journal of Geology, Earth and Marine Sciences

2023
Vol. 1 No. 1: 104

Factors Affecting Oil Recovery in Hydrocarbon Reservoirs: Numerical Modeling of Water Alternating Gas Injections (WAG)

Zhengming Yang, Meng Du, Zhongkun Niu*

Research Institute of Petroleum Exploration & Development, PetroChina Company Limited, Beijing 100083, China.

Corresponding author:
Zhongkun Niu, Research Institute of Petroleum Exploration & Development, PetroChina Company Limited, Beijing 100083, China. E-mail: zhongkun niu@126.com

Citation: Yang Z, Du M, Niu Z. (2023) Factors Affecting Oil Recovery in Hydrocarbon Reservoirs: Numerical Modeling of Water Alternating Gas Injections (WAG). J Geol Earth Mar Sci. Vol 1(1): 104.

Received: May 02, 2023; **Accepted:** May 19, 2023; **Published:** May 26, 2023

Abstract

As oil production rates diminish in hydrocarbon fields and energy demands rise, Enhanced Oil Recovery (EOR) techniques are deployed to extract remaining oil post primary and secondary recovery methods like water flooding and gas injection. Additionally, reservoir process numerical modeling is an integral component of any field development project. This research delves into the factors influencing oil recovery during the simulation of Water Alternating Gas (WAG) injection into a hydrocarbon reservoir. The findings indicate a correlation between oil recovery and horizontal permeability, with diminishing effects of WAG injection beyond a permeability threshold of 50 md. Moreover, the study identifies a 1:1 water-to-gas ratio as the optimal injection value, maximizing oil recovery.

Keywords: Numerical simulation; Water Alternating Gas; Oil recovery factor; Enhanced Oil Recovery; Formation permeability.

Introduction

Globally, the average oil recovery factor stands at 35% [1-4], leaving approximately one and a half times the extracted amount still within reservoirs. Enhancing the Recovery Factor (RF) by just 10% could potentially yield an additional 2 billion tons of oil in the current scenario.

Among Enhanced Oil Recovery (EOR) technologies, the alternate injection of water and gas (WAG) has gained substantial attention worldwide in recent years [5-8]. Notably, this method offers the advantage of utilizing gas produced within the field as a displacing agent.

The application of alternate injection of water and gas in oil fields has demonstrated an increase in the oil recovery factor, ranging from 5% to 10% when compared to conventional water or gas injection [9-12]. However, its widespread adoption faces challenges due to the intricate nature of the intermittent injection process and the difficulty in predicting performance without resource-intensive and costly technical studies [13-16].

This study aims to analyze the impact of reservoir parameters, reservoir fluid properties, and the injection process on the oil recovery factor. Utilizing numerical reservoir modeling, the research will consider both constant and variable parameters influencing the oil displacement process. Variable parameters include lateral permeability, vertical permeability anisotropy, oil and gas density, water viscosity, water-to-gas injection ratio, and the duration of the alternate injection cycle.

Materials and Methods

Recovery Factor and Mechanism of Water Alternating Gas Injection (WAG)

The comprehensive oil Recovery Factor (RF) in any secondary or tertiary oil recovery method is determined by three distinct efficiency factors [17-19].

The overall oil recovery factor is influenced by various factors, including fluid mobility, injection patterns, areal and vertical heterogeneities, gravity segregation, and the volume of injected pore fluid. The implementation of Water Alternating Gas injection (WAG) yields an additional oil recovery factor due to enhanced lateral and vertical sweep efficiency and a reduction in residual oil saturation [20-23].

The mobility ratio plays a crucial role in controlling the volumetric displacement efficiency during gas injection, with favorable mobility being less than one [24-27]. Adjusting the mobility coefficient involves increasing the viscosity of the gas or reducing the relative permeability of the liquid. The alternation of water and gas injection serves to reduce the mobility of the gas phase, requiring careful adjustment of the water and gas amounts to optimize displacement efficiency. Excessive water may lead to poor microscopic displacement, while excessive gas may result in suboptimal vertical and potentially horizontal displacement coverage [28-31].

Additionally, the expansion and evaporation of oil in the presence of both oil and gas phases contribute to additional recovery in WAG. Gas injection enhances oil recovery by swelling oil, reducing gas-oil surface tension, decreasing oil viscosity, and recovering light and intermediate hydrocarbons through immiscible displacement towards fully miscible displacement [32-35].

Results and Discussion

Sensitivity to Reservoir Properties

In response to declining production rates in petroleum reservoirs and escalating energy demands, petroleum engineers are increasingly exploring Enhanced Oil Recovery (EOR) technologies. These techniques aim to recover additional oil through post-primary and secondary recovery methods, such as waterflooding, gas injections, and Water Alternating Gas (WAG) processes. EOR has proven effective in enhancing field recovery factors and maintaining production plateaus. Notably, the WAG process, leveraging injection water to stabilize the displacing front and achieve a favorable mobility ratio, outperforms gas injection or water flooding. It efficiently sweeps the bottom part of the reservoir due to the higher density of water, while injected gas enhances sweep efficiency by reaching previously un-swept zones.

Reservoir permeability emerges as a pivotal factor influencing WAG performance, as evidenced by numerous studies [36]. Variations in reservoir permeability significantly impact WAG effectiveness, with vertical inhomogeneity playing a crucial role. Studies have revealed an inverse relationship between permeability coefficients and the degree of oil recovery. Given the inherent heterogeneity in depositional environments, most reservoirs exhibit random permeability variations, markedly influencing vertical sweeps in WAG displacement. Laboratory investigations emphasize that lower values generally lead to higher oil recovery in heterogeneous reservoirs, attributing this to dominant vertical permeability. Lateral permeability and vertical anisotropy of the formation are considered variable parameters in this study.

Sensitivity to Reservoir Properties

The immiscible displacement modeling of oil by gas and water revealed a correlation between horizontal permeability and the final oil recovery factor, demonstrating an increase with higher permeability (Figure 1). However, beyond a permeability threshold of 50 md, no significant additional oil production was observed under the same conditions.

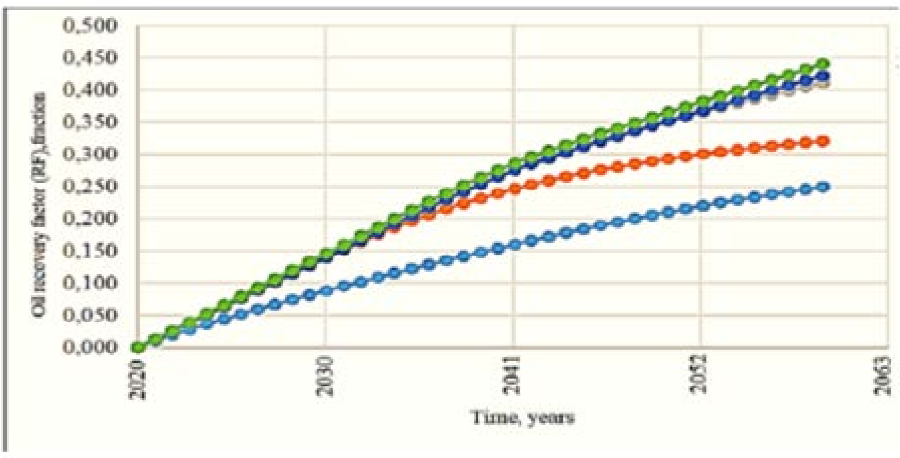

Figure 1: Influence of horizontal permeability on oil recovery factor during immiscible displacement.

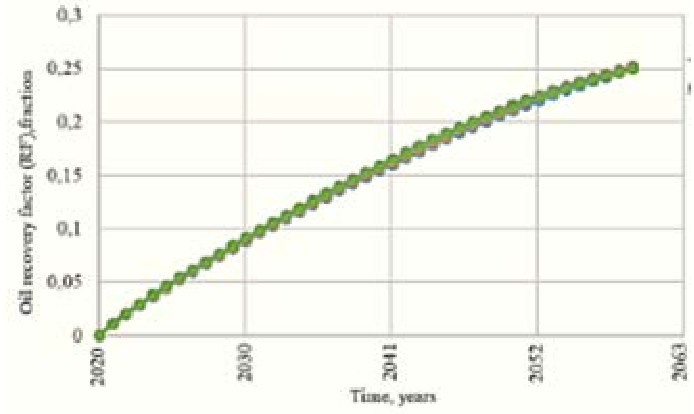

Figure 2: Effect of vertical permeability anisotropy on oil recovery factor under immiscible displacement.

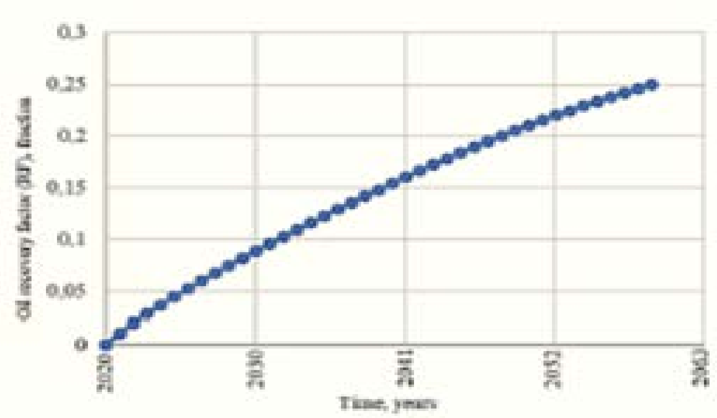

Figure 3: Influence of oil density on oil recovery factor during immiscible displacement.

In contrast, changes in vertical permeability (Figure 2) did not lead to alterations in incremental oil production during the simulation of alternating water and gas injection, highlighting the minor role played by the Kv/Kh ratio.

Sensitivity to Fluid Properties

Various factors, including reservoir petrophysical properties, fluid properties, and field scale considerations, influence the success of Water Alternating Gas (WAG) injection. Literature studies emphasize the significant impact of reservoir heterogeneity, relative permeability, hysteresis, and wettability on WAG performance.

Simulation results indicated no substantial influence from altering formation fluid properties (Figure 3), except for a slight increase in the oil recovery factor with a decrease in the viscosity of formation water.

Sensitivity to WAG Parameters

The WAG process, generating a mixture of gas and water, experiences gravity separation due to density contrasts, mobility ratios, and permeability variations. Slug size, a crucial design parameter, strongly influences the displacement mechanism. Comparing WAG injection results with different slug sizes revealed that shorter gas and water slugs outperformed large cycle injections in terms of efficiency and recovery performance [36].

The duration of the alternate injection cycle and the Cycle Length (CL) of the WAG flooding process also impact the overall waterflooding process. In numerical simulations, the water-to-gas injection ratio was the sole parameter with an effect. Remarkably, a 1:1 ratio proved most effective for maximum oil recovery, as further increases in the proportion of injected gas did not lead to additional oil recovery (Figures 4 and 5).

Conclusion

In tertiary oil recovery, Water Alternating Gas injection (WAG) enhances displaced oil recovery from residual oil left unrecovered during primary and secondary recovery. Numerical modeling highlighted the significance of horizontal permeability, with increased oil recovery up to a permeability of 50 md. Fluid

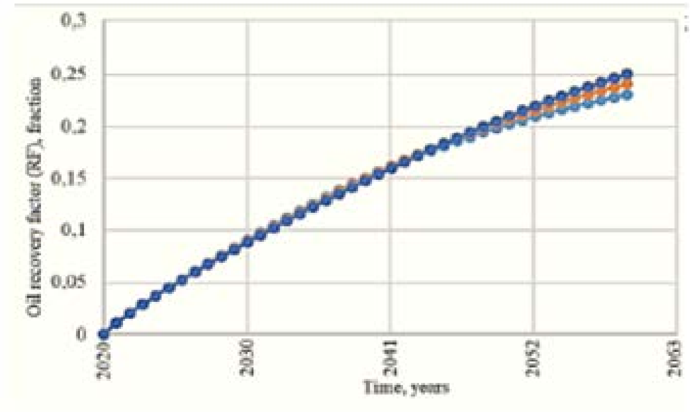

Figure 4: Influence of the ratio of water to gas injection on oil recovery factor with immiscible displacement.

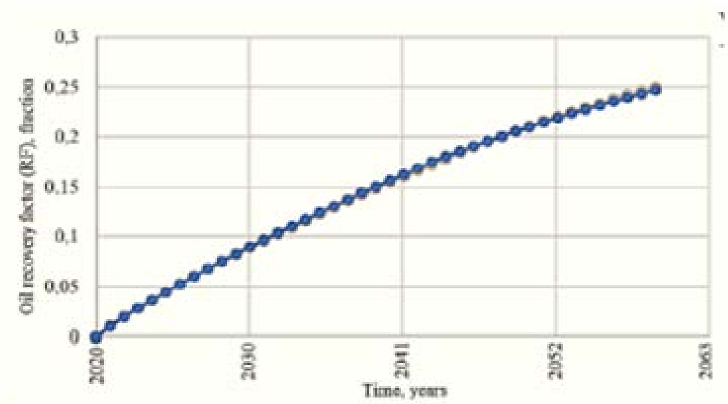

Figure 5: Effect of WAG cycle duration on oil recovery factor during immiscible displacement.

properties minimally affected oil production, except for a slight increase in oil recovery with decreased formation water viscosity. The optimal injection ratio for maximizing oil recovery was determined to be a water-to-gas WAG ratio of 1:1.

References

1. Muggeridge A, Cockin A, Webb K, Frampton H, Collins I, Moulds T, et al. Recovery rates, enhanced oil recovery and technological limits. Philos Trans Royal Soc A. 2014;372(2006):20120320.
2. Al-Obaidi SH, Khalaf FH. Development of traditional water flooding to increase oil recovery. Int J Sci Technol Res. 2019; 8(1):177-181.
3. Smirnov VI, Al-Obaidi Sudad H. Innovative methods of enhanced oil recovery. Oil Gas Res. 2008;1:101.
4. Al-Obaidi SH. Analysis of hydrodynamic methods for enhancing oil recovery. J Petrol Eng Tech. 2021; 6:20-26.
5. Li X, Cheng Y, Tao W, Sarulicaoketi S, Ji X, Yin C. Experimental study on enhanced oil recovery by nitrogen-water alternative injection in reservoir with natural fractures. Geofluids. 2021;2021:1-9.
6. Al-Obaidi SH, Hofmann M, Khalaf FH. Enhanced oil recovery in terrigenous oil fields using low-salt water. Nat Sci Adv Technol Edu. 2023;32(2).
7. Patkin A, Al-Obaidi S. Influence of temperature and pressure of incoming oil-containing liquid from field wells on the gas separation process. J Petrol Eng Emerg Technol. 2001;3(4):20-24.
8. AL-Obaidi SH, Wj C, Hofmann M. Modelling the development of oil rim using water and gas injection. Nat Sci Adv Technol Edu. 2022;31(3).
9. Li X, Li A, Guo W, Liu S, Cui S. Experimental study on mechanism of water-alternating-gas injection in thick sandstone reservoir. In E3S Web of Conferences. 2022;338:01001.
10. Al-Obaidi SH. Improve the efficiency of the study of complex reservoirs and hydrocarbon deposits-East Baghdad Field. Int J Sci Technol Res. 2016; 5(8),129-131.
11. Hofmann M, Al-Obaidi SH, Chang WJ. Evaluation of quantitative criteria for triassic reservoirs in the South Mangyshlak basin. Nat Sci Adv Technol Educ. 2023;32(1):7-24.
12. Al-Obaidi SH, Khalaf FH. A new approach for enhancing oil and gas recovery of the hydrocarbon fields with low permeability reservoirs. Pet Petro Chem Eng J. 2023;7(2):000343.

13. Xiao K, Li X, Li X. Physical simulation of gas injection mechanism for high dip reservoir. Processes. 2023;11(7):2111.

14. Al-Obaidi SH, Khalaf FH, Smirnov VI. New technologies to improve the performance of high water cut wells equipped with ESP. Technium. 2020;3(1)104-113.

15. Al-Obaidi SH, Khalaf FH. The Effect of anisotropy in formation permeability on the efficiency of cyclic water flooding. Int J Sci Technol Res. 2017;6(11):223-226.

16. Al-Obaidi SH. High oil recovery using traditional water-flooding under compliance of the planned development mode. J Petrol Eng Technol. 2016;6(2),:48-53.

17. Tunio SQ, Tunio AH, Ghirano NA, El Adawy ZM. Comparison of different enhanced oil recovery techniques for better oil productivity. Int J Appl Sci Technol. 2011;1(5):143–153.

18. Obaidi SH, Khalaf FH. Prospects for improving the efficiency of water insulation works in gas wells. J Geol Geophys. 2020;9(6):483.

19. Kamensky IP, Al-Obaidi SH, Khalaf FH. Scale effect in laboratory determination of the properties of complex carbonate reservoirs. Int Res J Mod Eng Technol Sci. 2020;2(11):1-6.

20. Kumar S, Mandal A. A comprehensive review on Chemically Enhanced Water Alternating Gas/CO2 (CEWAG) injection for enhanced oil recovery. J Petrol Sci Eng. 2017;157:696-715.

21. Al-Obaidi SH. Modified use of microbial technology as an effective enhanced oil recovery. J Petrol Eng Emerg Technol. 2004;4(2):41-44.

22. Chang WJ, Al-Obaidi SH, Patkin AA. Assessment of the condition of the near-wellbore zone of repaired wells by the skin factor. Int Res J Mod Eng Tech Sci. 2021;3:1371-1377.

23. Al-Obaidi SH. A way to increase the efficiency of water isolating works using water repellent. Int Res J Modern Eng Technol Sci. 2020;2(10):393-399.

24. Sheng JJ. Mobility control requirement in EOR processes. Modern Chemical Enhanced Oil Recovery: Theory and Practice, Gulf Professional Publishing, Houston. 2011:79-100.

25. Al-Obaidi SH, Hofmann M, Smirnov VI, Khalaf FH, Alwan HH. A study of compositions relevant to selective water isolation in gas wells. J Geol Geophys. 2021;10(7):1000.

26. Hofmann M, Al-Obaidi SH, Kamensky IP. Calculation method for determining the gas flow rate needed for liquid removal from the bottom of the wellbore. J Geol Geophys. 2021; 10(5):1-5.

27. Al-Obaidi SH, Kamensky IP, Hofmann M, Khalaf FH. An Evaluation of water and gas injections with hydraulic fracturing and horizontal wells in oil-saturated shale formations. Nat Sci Adv Technol Edu. 2022;31(4).

28. Belazreg L, Mahmood SM. Water alternating gas incremental recovery factor prediction and WAG pilot lessons learned. J Petrol Explor Prod Technol. 2020;10(2):249-269.

29. Al-Obaidi SH, Kamensky IP. Express study of rheological properties and group composition of oil and condensate using nuclear magnetic resonance–relaxometry. J Oil Gas Coal Technol. 2022;4(1):102.

30. Hofmann M, Al-Obaidi SH, Patkin AA. Problems of transporting “heavy” gas condensates at negative ambient temperatures and ways to solve these problems. J Petrol Eng Technol. 2013;3(3):31-35.

31. AL-Obaidi SH, Hofmann M, Smirnova V. Improvement of oil recovery in hydrocarbon fields by developing polymeric gel-forming composition. Nat Sci Adv Technol Educ. 2022;3:425-434.

32. Sun Y, Zhang W, Tian J, Meng Y, Zhang L. Research progress on displacement mechanism of supercritical CO2 in low-permeability heavy oil reservoir and improvement mechanism of displacement agents. Molecules. 2023;28(16):6154.

33. Al-Obaidi S. Investigation of rheological properties of heavy oil deposits. In Conference of the Arabian Journal of Geosciences. 2019:399-402.

34. Miel H, Hameed AO, Hussein KF. Modeling and monitoring the development of an oil field under conditions of mass hydraulic fracturing. Trend Sci. 2022;19(8):3436.

35. Al-Obaidi SH, Kamensky IP, Hofmann M. Changes in the physical properties of hydrocarbon reservoir as a result of an increase in the effective pressure during the development of the field. engrXiv. 2010.

36. Liao H, He Y, Xu G, Cui M, Zhang Y, Fang X, et al. Field application and experimental investigation of interfacial characteristics of surfactant and CO2 alternative injection. ACS Omega. 2022;7(38):34222-34229.