Performance Analysis of Advanced Wells in Reservoirs Using CO2 Enhanced Oil Recovery

Prakash Bhattarai, Soheila Taghavi and Britt M.E. Moldestad

November 13, 2024

Performance Analysis of Advanced Wells in Reservoirs Using CO_2 Enhanced Oil Recovery

Prakash Bhattarai*, Soheila Taghavi Hosnaroudi *, Britt M. E. Moldestad*

**Department of Process, Energy and Environmental Technology, University of South-Eastern Norway, Norway*

E-mail corresponding author: soheila.t.hosnaroudi@usn.no

Abstract: Oil and gas will remain an important source of energy for years and it is crucial to improve oil recovery with less carbon footprint to meet the future energy demands. Carbon capture utilization and storage offers a potential solution to mitigate the effects of anthropogenic CO_2 and to reduce the direct CO_2 emissions from stationary sources into the atmosphere. The captured CO_2 can be utilized to enhanced oil recovery (EOR) and is injected into the depleted oil fields or saline aquifers, or into the oil fields for storage and/or EOR. However, the injected CO_2 can be reproduced without contributing to EOR. This is due to the breakthrough of CO_2 into the well. Also, the corrosive mixture of CO_2 and water can be produced from the production well. This may cause damages to the pipeline and process equipment on the platform. Autonomous inflow control valves (AICVs) can mitigate these problems. They may reduce or stop the reproduction of CO_2 from the zones with CO_2 breakthrough and reduce the production of mixture of CO_2 and water. The main objective of this study is modelling and simulation of oil production in a heterogenous reservoir using CO_2-EOR in combination with AICVs. The simulation models are developed using an industry standard software. The outcome of numerical simulations is analyzed to study the effect of various parameters on oil recovery. In addition, the impact of AICVs on EOR is assessed against perforated casing completion (without AICV). The results demonstrate that oil recovery factor, water cut, and cumulative gas production are better in the wells completed with AICVs than perforated casing completion. This will result into both increased oil production and a better CO_2 storage potential.

Keywords: CO_2-EOR, Carbon capture utilization and storage, Autonomous inflow control valve, Advanced wells, Miscible injection, WAG

1. INTRODUCTION

The global energy crisis has led to a movement towards the development of clean energy technologies to ensure energy security. The oil and gas industry accounts for more than 50% of the global energy supply with oil holding approximately one-third of the global energy supply (*Supply – Key World Energy Statistics 2021 – Analysis*, n.d.) According to the World Energy Outlook 2023 (*World Energy Outlook 2023 – Analysis*, n.d.) published by the International Energy Agency (IEA), the demand for oil is estimated to reach its peak in near future. In conjunction with growing energy demand, the carbon dioxide (CO_2) emission from oil production is escalating. Thus, it is essential to improve the production of oil, simultaneously reducing the carbon footprint. In this prospect, CO_2 Enhanced Oil Recovery (EOR) has emerged as the prospective solution to support Carbon Capture, Utilization, and Storage (CCUS) by ensuring permanent storage of CO_2 in geological formation while offering commercial opportunities to oil industries.

CO_2 EOR is the process of injecting CO_2 into the depleted oil reservoirs to improve oil recovery. It is a proven method and has been in commercial practice for several decades. Based on the miscibility of injected CO_2 with oil at reservoir conditions, the process is divided into miscible and immiscible. In miscible flooding, the CO_2 is injected at operating pressure above Minimum Miscibility Pressure (MMP). MMP is the minimum pressure necessary for CO_2 to be miscible in the oil at reservoir conditions. The injection of CO_2 is carried out at operating pressure below MMP in immiscible flooding. Miscible flooding has higher efficiency than immiscible flooding due to greater sweep efficiencies. The CO_2 flooding process often faces the challenges of viscous fingering, channeling, and gravity override; therefore, the water is injected alternating with gas referred to as the Water Alternating Gas (WAG) process. The injection of water reduces the problem associated with gas flooding and assists in maintaining reservoir pressure above MMP (A. Khan et al., 2021). Even though the miscible CO_2 WAG process is very effective in recovering residual oil, the injected CO_2 can break through into the production well without affecting in EOR process, and the corrosive mixture of CO_2 and water can damage the production facility. Often these problems lead to the permanent shutting down of the reservoir.

By utilizing advanced wells in combination with Flow Control Devices (FCDs), the performance of CO_2 EOR processes can significantly be improved. The FCDs like Autonomous Inflow Control Valves (AICVs) have the potential to solve the issues of early breakthroughs, production of unwanted fluids, gas and water conning, and non-uniform pressure distribution in horizontal wells. Therefore, the implementation of AICVs in

CO_2 WAG EOR, can enhance the oil recovery, and reduce the cost associated with handling unwanted fluids.

The objective of this paper is to study the performance of AICVs integrated in the reservoir subjected to the miscible WAG EOR utilizing CO_2. This aim is realized by implementing and analyzing the benefits and constraints of AICVs against the standard well perforations through numerical simulations for various WAG operating parameters. The experimental data presented by (Taghavi et al., 2022) is utilized to numerically simulate the functional behavior of AICVs in CMG STARS simulator.

2. CO_2 ENHANCED OIL RECOVERY

Enhanced oil recovery with the injection of CO_2 has played significant role in the tertiary recovery of residual oil since its first pilot project at Mead Strawn Field in 1964 (Holm & O'Brien, 1971). The idea was patented by Whorton Brownscombe in 1952 (Whorton et al., 1952) and the method was successfully implemented in commercial project at the Kelly-Snyder Field in 1972.

The CO_2 EOR is classified primarily into two types of miscible and immiscible, based on the solubility of injected CO_2 in the reservoir oil. The reservoir conditions, composition of injected gas, and interaction of CO_2 with reservoir fluid are the parameters that determine whether the CO_2 EOR is miscible or immiscible. The miscible and immiscible processes differ in the mechanism and subsequently, in the recovery factor (Haynes & Alston, 1990).

2.1 Miscible CO_2 EOR

The miscibility criterion is attained at the reservoir pressure higher than MMP. The MMP is determined based on the temperature and composition of the oil in the reservoir (Haynes & Alston, 1990). At supercritical condition, CO_2 possesses the density close to liquid phase ($0.6 – 0.8$ g/cm^3) while viscosity remains low close to gas viscosity. The supercritical CO_2 dissolves into oil causing oil to swell and a reduction in the viscosity thereby improving the mobility of oil (Mansour et al., 2019).

Miscibility in the reservoir is achieved through two processes of First Contact Miscibility (FCM) and Multiple Contact Miscibility (MCM). In FCM, the injected CO_2 mixes with oil in reservoir in different proportions on first contact to generate a homogeneous (single-phase) solution (Clark et al., 2013). In MCM process, miscibility is attained through the vaporization of hydrocarbons into CO_2, and diffusion of CO_2 into reservoir oil. The former MCM process is termed as vaporizing gas drive while later is called condensing gas drive (Green & Willhite, 1998). In theory, the miscible CO_2 EOR can have recovery factor up to 90%.

Oil swelling, viscosity reduction, mobility ratio reduction, interfacial tension reduction, vaporization of light oil, and wettability change are the mechanisms contributing towards the improvement of oil recovery in miscible CO_2 EOR.

2.2 Miscible CO_2 WAG EOR

Water Alternating Gas (WAG) is an EOR technique that involves injection of water and gas in a cyclic manner. The aim of WAG technique is to improve oil production utilizing microscopic displacement of the oil with injection of gas and macroscopic sweep with injection of water simultaneously (J. Wang et al., 2008).

The WAG process is affected by several factors. WAG ratio is the volumetric ratio of the injected water to the injected gas at reservoir condition (M. Y. Khan & Mandal, 2022). The WAG ratio strongly affects the oil recovery. At low WAG ratios the system works like a gas flood as the volume of injected water is low. This results in a poor vertical sweep associated with gas fingering, channeling, and early breakthrough. At high WAG ratios, the waterfront travels faster and blocks the gas from contacting the oil, consequently reducing the microscopic displacement (Belazreg et al., 2019). Designing the WAG ratio to its optimum value is important as it ensures a higher economic oil recovery by controlling the water cut, mobility ratio, and gas production (S. Chen et al., 2010). The optimum WAG ratio depends on the impacts of gravity overrides, reservoir heterogeneity, capacity of injection wells, economic constraints, etc. (Rogers & Grigg, 2000).
The WAG cycle time refers to the total duration of gas or water injection during an injection cycle in the WAG process. The cycle time directly affects the economy of EOR projects. Zhang et al., (2010) showed that shorter cycle time i.e., higher number of cycles, increases the oil production. According to (B. Chen & Reynolds, 2016) and (Abdullah & Hasan, 2021), decreasing cycle time increases the oil recovery. Araujo Cavalcante Filho et al., (2020) assumed that the shorter cycle time discourages the gravity segregation thus improving the oil recovery. The WAG process can be started at the beginning (initial WAG) and at the later phase (post WAG) of reservoir development. Initial WAG provides better incremental oil recovery than post WAG. However, the overall economics of the project will be affected. Initial WAG accelerates the oil production in both heterogeneous and homogeneous reservoirs (M. Y. Khan & Mandal, 2022).

The distance between injector and producer wells is termed as well spacing. According to (Christensen et al., 2001), well spacing directly affects the sweep efficiency and average reservoir pressure in the WAG process. The gravity segregation dominates if the well spacing is high causing a reduction in oil recovery. While, lower well spacing enhances the response time of WAG process. However, due to the short circuiting of injected gas, the oil recovery reduces.

The heterogeneity and stratification strongly affect the sweep patterns. Highly porous and permeable rocks provide better sweep efficiency resulting in improved oil recovery (Li et al., 2015).

The CO_2 WAG EOR involves the process of injecting CO_2 and water alternately. In the miscible CO_2 WAG EOR, CO_2 is injected in the reservoir when the pressure is above MMP (Dai et al., 2014) as depicted in Figure 1.

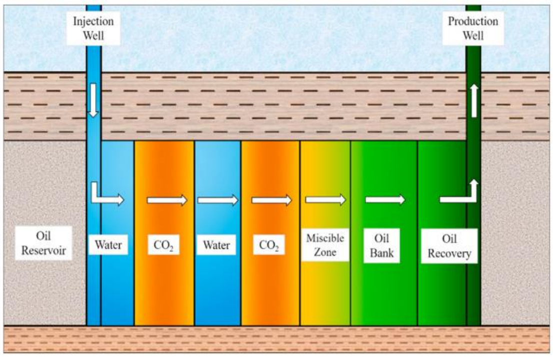

Figure 1. Schematic of miscible CO_2 WAG EOR.

According to (Han & Gu, 2014), the miscibility of CO_2 with light oil is obtained at low MMP, at the same time, the injected water maintains the pressure above MMP, therefore CO_2 WAG has technical benefits. Skauge & Stensen (2003), in their review of 72 fields using WAG with hydrocarbon or non-hydrocarbon gases, reported that the miscible CO_2 WAG had highest average improved oil recovery of 10% of original oil in place (OOIP).
In the experiment conducted by (Yan et al., 2017), supercritical CO_2 played an important role and the authors found that the miscible CO_2 WAG injection should improve the oil production better than either CO_2 or water flooding. Lei et al., (2016) reported improvement in oil recovery factor between 12 -17%, and Q. Wang et al., (2020) found that the ultimate oil recovery reached to 73% from 52% due to the implementation of CO_2 WAG EOR process.

Miscible CO_2 WAG EOR is associated with problems of gravity overrides, early breakthrough, and gas channeling. In addition, Wang et al., (2020) reported a reduction in the permeability of the core due to asphaltene deposition and reaction between CO_2, rock, and brine (see Figure 2). The formation of weak acid takes place when CO_2 and water react with each other. The corrosive weak acid is damaging to production wells and the process equipment (Halland et al., 2013).

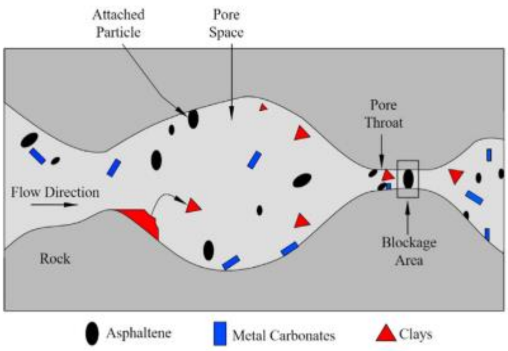

Figure 2. Blockage of pore throat due to asphaltene deposition.

3. ADVANCED WELLS WITH AICV

Horizontal wells are a significant development to maximize the reservoir contact with oil in the reservoir. Increased interaction with the reservoir rock enables more effective fluid injection and drainage. The introduction of horizontal wells greatly raised the recovery factor (Behnoud et al., 2023).

Long horizontal wells allow exposure to a lager reservoir area. However, this may result in a substantial pressure difference between the toe and the heel section of the production well. This is due to the reduction in pressure caused by friction between the fluid travelling through the pipe and the inner pipe surface. As a result, there is a higher pressure drop between the wellbore and the reservoir at the heel than at the toe. Thus, the heel of the well receives more reservoir fluid flow than other regions. This phenomenon is called heel to toe effect (Mahmood et al., 2016). The difference of drawdown between the heel and the toe results in early breakthrough at the heel of the reservoir. The breakthrough is also affected by the heterogeneity of the reservoir. The considerable pressure differences along the wellbore increases the likelihood of early gas and water breakthrough, lowering the recovery efficiency. Innovative solutions, such as the Autonomous Inflow Control Valve (AICV) technology, are required to address the challenges caused by early gas and /or water breakthrough.

3.1 Role of AICVs in advanced wells

AICVs are the flow control devices that work autonomously to restrict the flow of gas and water to the production wells. The valve distinguishes between fluids based on their viscosity and density. An AICV is shown in Figure 3 (Ismail et al., 2021).

Figure 3. View of an AICV.

AICVs are devices capable of preventing flow of unwanted fluids like gas and water, through annulus into the production wells. When gas or water flows into the production well, AICVs automatically shut off in the breakthrough zones, avoiding unwanted fluids from entering the production well. Furthermore, using AICVs eliminates the risks, costs, and logistical issues associated with removing, transporting, and handling the unwanted fluids (Aakre et al., 2014).

4. MODELING OF RESERVOIR AND WELLBORE

The reservoir simulation software CMG 2022.10 general release by Computer Modelling Group Ltd. is used for the modeling and simulation of CO_2 WAG EOR. STARS, a reservoir simulator application included in CMG software, has been selected to simulate the recovery process. The wellbore model in STARS contains a Flexible Wellbore Model (FlexWell). FlexWell allows the integration of advanced well completions including AICVs and concentric wellbores. Even though, Flexwell is solved independently in the CMG software, it is coupled with the STARS simulator. The dataset for the STARS simulator is created in the Builder module. The data of the reservoir model including porosity, permeability, grid distribution, properties of fluid components, rock fluid properties, and well model are obtained from (Taghavi et al., 2023). The detailed descriptions of the reservoir and well models are presented in the following subsections.

4.1 Construction of reservoir model in CMG

A heterogeneous reservoir with a depth of 181 ft in k-direction (vertical) is considered for the simulation. The reservoir is divided into 9375 grid blocks with 25*25*15 grid blocks in i, j, and k-directions respectively. The size of each grid block in i and j-directions is 130 ft while the grid blocks along the k-direction have variable thicknesses ranging from 4 to 33 ft. The porosity variation in the reservoir is between 0.234 and 0.317. The horizontal permeability along i and j-directions, ranges from 0 to 2588 mD, while permeability in the vertical (k) direction is half of the horizontal permeability varies from 0 to 1294 mD. The distribution of permeability along the horizontal and vertical directions are shown in Figure 4 and Figure 5, respectively. The initial pressure and temperature of the reservoir are 4200 psi and 186 ^{0}F, respectively.

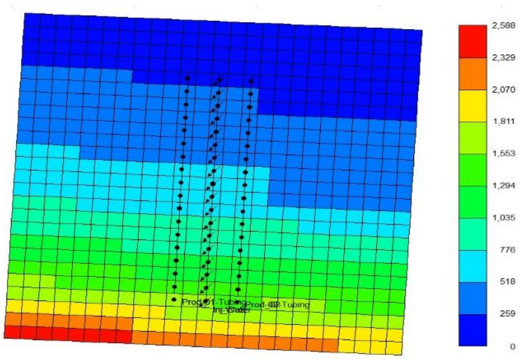

Figure 4. Variation of horizontal permeability along the wells (i-j plane).

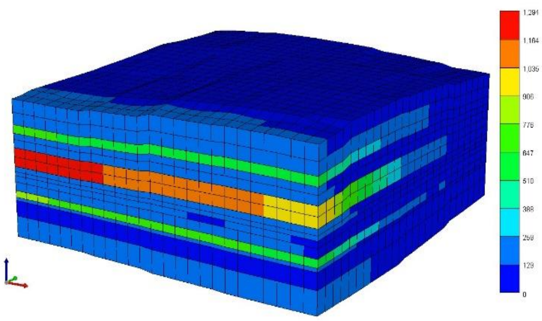
Figure 5. 3D view of the reservoir with distribution of vertical permeability.

4.2 Description of well model

The well model consists of approximately 2210 ft long three horizontal wells placed along j-direction. Two producer wells are placed on either side of central injector well as shown in Figure 6. The producers and injector wells are placed at the same height in the region with higher permeabilities. The distance between the producer wells and injector well is 260 ft.

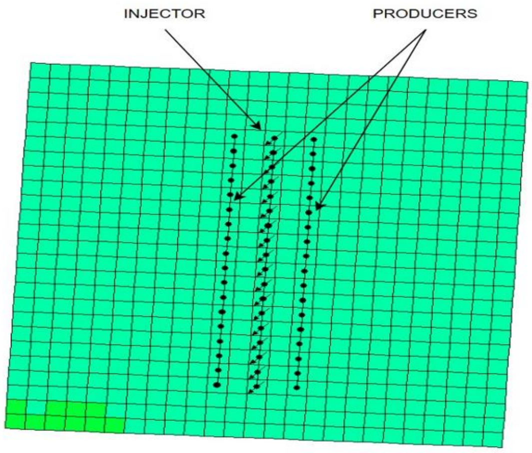

Figure 6. Placement of wells in the reservoir.

The well constraints applied to all producer and injector wells are listed in Table 1.

Table 1. Well constraints

Wells	Function	Constraints
Inj_CO_2	CO_2 Injector	MAX BHP 5000 psi
		Variable based on WAG ratio
Inj_Water	Water Injector	MAX BHP 5000 psi
		Variable based on WAG ratio
Prod-01	Producer	MIN BHP 700 psi
		MAX STL 2500 bbl/day
Prod-01-Tubing	Producer	MIN BHP 500 psi
		MAX STL 2500 bbl/day
Prod-02-Tubing	Producer	MIN BHP 500 psi
		MAX STL 2500 bbl/day
Prod-02	Producer	MIN BHP 700PSI
		MAX STL 2500 bbl/day

To analyse the performance of AICVs, the producer wells are completed with two different settings. In the first completion setting, both producer wells have standard perforations i.e., without any flow control devices. In the second setting, the producer wells are completed with AICVs. In both cases, the production takes place from 18 zones and each production zone is isolated with packers. Each isolated production zone is completed with 12 AICVs in the second completion scenario. FlexWells are coupled with FCD tables developed by (Taghavi et al., 2023) to simulate the behaviour of AICVs so that, the flow of water and pure CO_2 gas or supercritical CO_2 can be restricted.

The simulations are carried out for eight years starting from 1st of January 2023 to 1st of January 2031. The well events for injection of CO_2 and water are setup to ensure that the injection of water and CO_2 takes places in the cycle of three months, while production wells are operational throughout the simulation period. The timeline view of the CO_2 WAG process is shown in Figure 7.

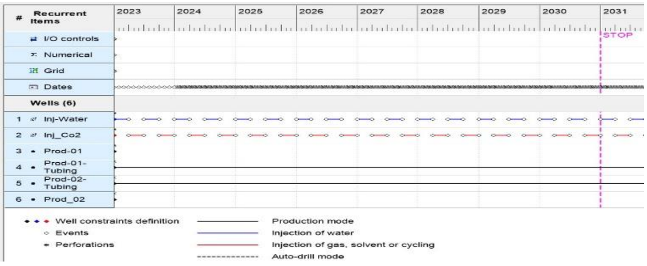

Figure 7. Timeline view of the well events.

5. RESULTS AND DISCUSSION

The performance of the WAG process is influenced by various parameters. The operational parameters of WAG ratio, well spacing, and permeability are selected for performance analysis of AICVs against standard well perforations.

5.1 WAG ratio

The total volume of water or gas injected in one cycle at a WAG ratio of 1:1 is approximately 0.45 hydrocarbon pore volume (HCPV). The injection rates of water and CO_2 at different WAG ratios at standard conditions are presented in Table 2.

Table 2. Injection rates at different WAG ratios

WAG ratio	Water injection rate (bbl/day)	CO_2 injection rate (ft^3/day)
1:1	1000	2650000
2:1	2000	2650000
3:1	3000	2650000
4:1	4000	2650000
1:1.5	1000	3980000
1:2	1000	5310000
1:3	1000	7950000

Figure 8 to Figure 10 shows the difference in oil recovery factor, cumulative GOR, and water cut at different WAG ratios between wells completed with AICVs and perforated casing. The wells completed with AICVs recovered on average 0.2% more oil than the perforated casing. The simulation case with AICVs has 25 ft^3/bbl less cumulative GOR than the case with perforated casing at WAG ratio of 1:3.

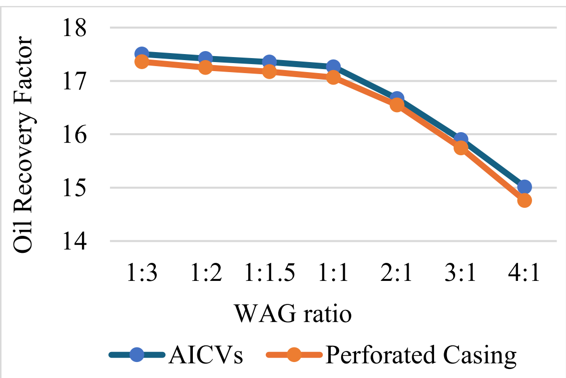

Figure 8. Comparison of oil recovery factor between AICVs and perforated casing.

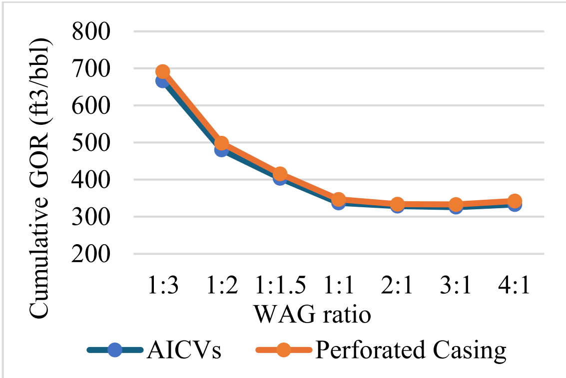

Figure 9. Comparison of cumulative GOR between AICVs and perforated casing.

At the WAG ratio of 4:1, the water cut is 1.5% lower in the case of AICVs than perforated casing completion.

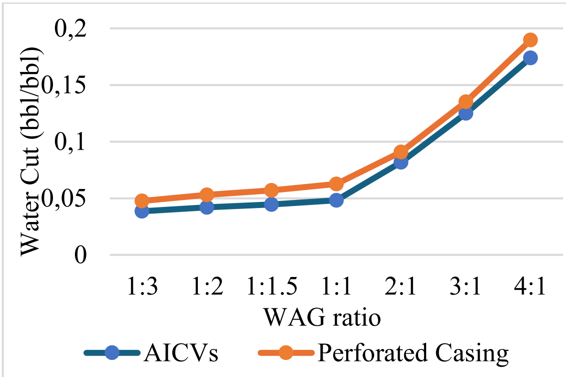

Figure 10. Comparison of water cut between AICVs and perforated casing.

The GOR profile of AICVs and perforated casing along the well shown in Figure 11 demonstrates that the GOR values at the heel section of the production well completed with perforated casing peaking at approximately 3000 ft^3/bbl at the third production zone however, the GOR values are evenly distributed along the well completed with AICVs.

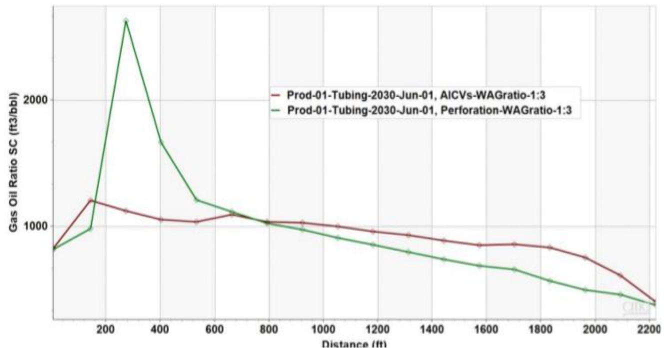

Figure 11. Comparison of GOR profile along the well between AICVs and perforated casing

The water flow rate along the well shown in Figure 12 illustrates that water production rate is significantly high in the heel section of the well in perforated casing scenario while the AICVs have balanced the water rate along the well.

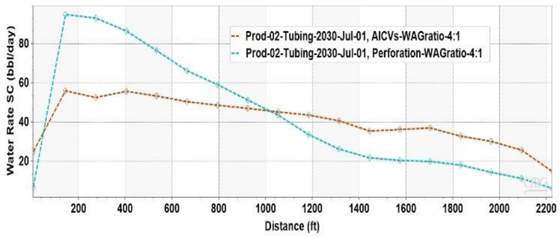

Figure 12. Comparison of water rate along the well between AICVs and perforated casing.

5.2 Well spacing

Apart from the original well spacing of 260 ft between producer and injector wells, the simulations are conducted for all the WAG ratios and both completion settings at well spacing of 130 ft and 390 ft. The well distance is changed by shifting the producer wells while keeping the injector well at the same position. However, the simulation period for these cases is reduced to 5 years.

The plots displaying a comparison of the oil recovery factor and water cut of the AICVs and perforated casing completion scenarios at different WAG ratios for both well spacing of 130 ft and 390 ft are presented in Figure 13 to Figure 16. The differences in the results of AICVs and perforated casing in both well spacings are very marginal as in the previous case.

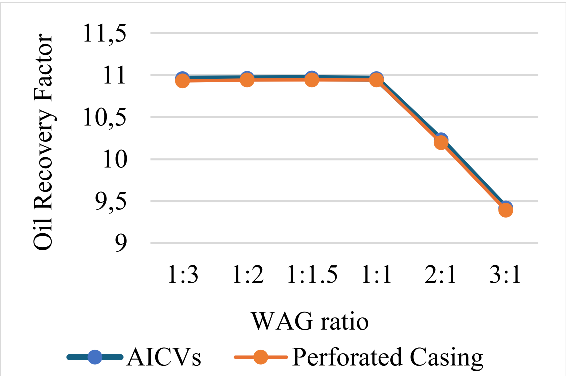

Figure 13. Oil recovery factor at well spacing of 130 ft.

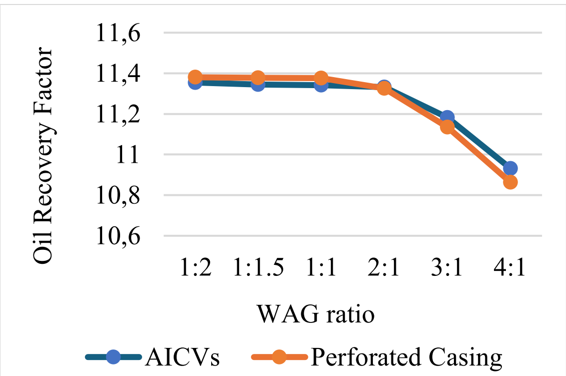

Figure 14. Oil recovery factor at well spacing of 390 ft.

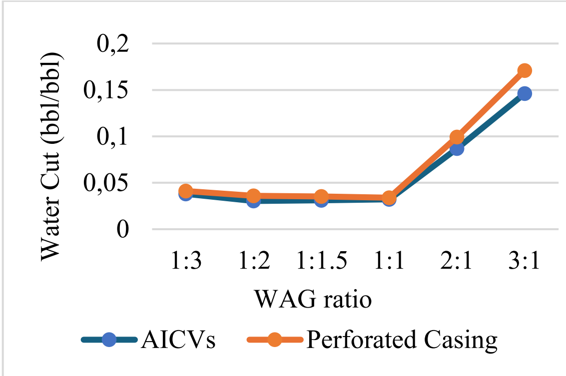

Figure 15. Water cut at well spacing of 130 ft.

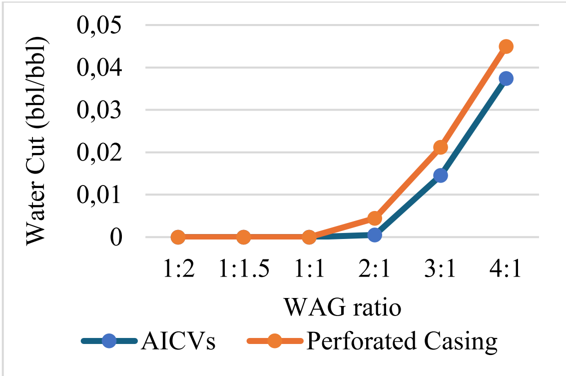

Figure 16. Water cut at well spacing of 390 ft.

However, a significant difference for well spacing of 130 ft at a WAG ratio of 1:3 is presented in Figure 17. The peaks in the figure indicate the breakthrough of gas in the wells completed with perforated casing while AICVs restricted the breakthrough of gas.

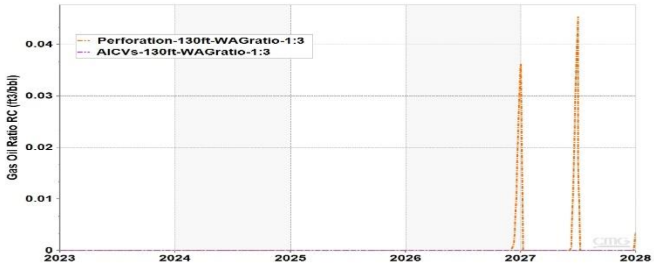

Figure 17. Comparison of GOR at reservoir condition.

5.3 Permeability

The permeability of the reservoir is changed to twice of its original permeability and the simulation cases are developed at this changed permeability distribution for both completion settings of producer wells at all WAG ratios.

Figure 18 shows the water cut for both well completion scenarios in the reservoir with doubled permeability. The plot shows that AICVs are better at resisting inflow of water in comparison to perforated casing completion.

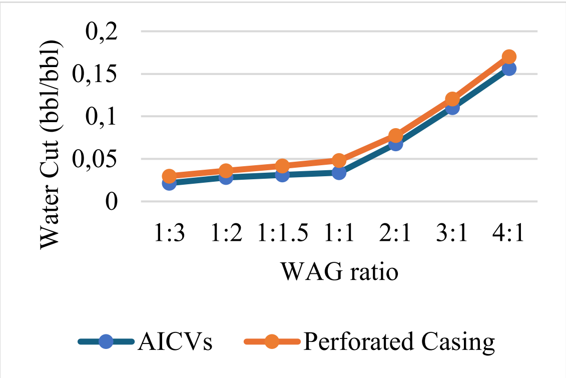

Figure 18. Water cut in the reservoir with doubled permeability.

The profile plots of GOR and water rate as shown in Figure 19 and Figure 20, respectively, indicat that AICVs perform better in regulating inflow along the length of the well by mitigating the effect of reservoir heterogeneity and heel to toe effect associated with horizontal wells. The figures also show that the coning effect in the well with perforated casing completion is prevalent thus, the water rate is maximum at the heel section.

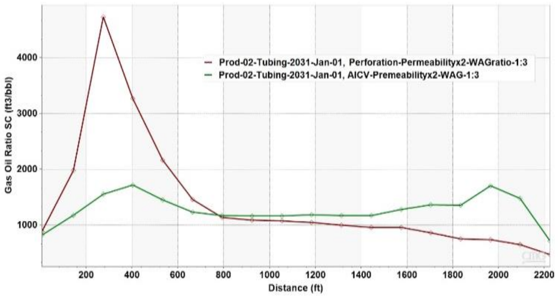

Figure 19. GOR along the well in the reservoir with doubled permeability.

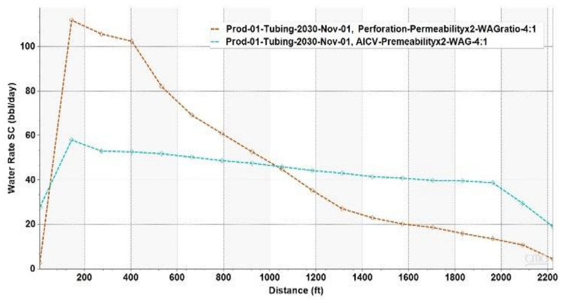

Figure 20. Water rate along the well in the reservoir with doubled permeability.

6. CONCLUSIONS

The performance of AICV in a miscible CO_2 WAG EOR process is investigated through numerical simulations using the reservoir simulator CMG STARS. The outcome of this study demonstrates that the oil recovery of the miscible CO_2 WAG EOR in the horizontal well can be improved by utilizing AICVs. AICVs restricts the production of unwanted fluids. Besides, it is demonstrated that the WAG ratio, well spacing, and permeability of reservoir influence the oil production process. In overall, the miscible CO_2 WAG EOR method has significant potential to address the ever-growing energy demand, at the same time, resolving the problems associated with the increase of atmospheric CO_2. Also, AICVs have potential to contribute substantially to improve the miscible CO_2 EOR processes.

REFERENCES

Aakre, H., Halvorsen, B., Werswick, B., & Mathiesen, V. (2014, September 24). *Autonomous Inflow Control Valve for Heavy and Extra-Heavy Oil*. SPE Heavy and Extra Heavy Oil Conference: Latin America. https://doi.org/10.2118/171141-MS

Abdullah, N., & Hasan, N. (2021). The implementation of Water Alternating (WAG) injection to obtain optimum recovery in Cornea Field, Australia. *Journal of Petroleum Exploration and Production*, *11*(3), 1475–1485. https://doi.org/10.1007/s13202-021-01103-7

Andrei, M., De Simoni, M., Delbianco, A., Cazzani, P., & Zanibelli, L. (2010). *Enhanced Oil Recovery with CO2 Capture and Sequestration*. https://www.osti.gov/etdeweb/biblio/21403705

Bagci, A. S. (2007). Immiscible CO2 Flooding through Horizontal Wells. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *29*(1), 85–95. https://doi.org/10.1080/009083190934022

Behnoud, P., Khorsand Movaghar, M. R., & Sabooniha, E. (2023). Numerical analysis of pore-scale CO2-EOR at near-miscible flow condition to perceive the displacement mechanism. *Scientific Reports*, *13*(1), Article 1. https://doi.org/10.1038/s41598-023-39706-1

Belazreg, L., Mahmood, S. M., & Aulia, A. (2019). Novel approach for predicting water alternating gas injection recovery factor. *Journal of Petroleum Exploration and Production Technology*, *9*(4), 2893–2910. https://doi.org/10.1007/s13202-019-0673-2

Chen, B., & Reynolds, A. C. (2016). Ensemble-based optimization of the water-alternating-gas-injection process. *SPE Journal*, *21*(3), 786–798. Scopus. https://doi.org/10.2118/173217-pa

Chen, S., Li, H., Yang, D., & Tontiwachwuthikul, P. (2010). Optimal parametric design for water-alternating-gas (WAG) process in a CO2-miscible flooding reservoir. *Journal of Canadian Petroleum Technology*, *49*(10), 75–82. Scopus. https://doi.org/10.2118/141650-PA

Christensen, J. R., Stenby, E. H., & Skauge, A. (2001). Review of WAG Field Experience. *SPE Reservoir Evaluation & Engineering*, *4*(02), 97–106. https://doi.org/10.2118/71203-PA

Clark, N., Shearin, H. M., Schultz, W. P., Garms, K., & Moore, J. L. (2013). Miscible Drive—Its Theory and Application. *Journal of Petroleum Technology*, *10*, 11–20. https://doi.org/10.2118/1036-G

Dai, Z., Middleton, R., Viswanathan, H., Fessenden-Rahn, J., Bauman, J., Pawar, R., Lee, S.-Y., & McPherson, B. (2014). An Integrated Framework for Optimizing CO2 Sequestration and Enhanced Oil Recovery. *Environmental Science & Technology Letters*, *1*(1), 49–54. https://doi.org/10.1021/ez4001033

de Araujo Cavalcante Filho, J. S., Santos Silva, V. L., & de Sant'Anna Pizarro, J. O. (2020, August 30). *Assessment of Miscible*

WAG Injection Performance in a Giant Carbonate Reservoir using Analytical and Numerical Approaches. SPE Improved Oil Recovery Conference. https://doi.org/10.2118/200333-MS

Green, D. W., & Willhite, G. P. (1998). *Enhanced oil recovery*. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers.

Halland, E. K., Riis, F., Magnus, C., Johansen, W. T., Tappel, I. M., Gjeldvik, I., Solbakk, T., & Pham, V. T. H. (2013). CO2 Storage Atlas of the Norwegian Part of the North Sea. *Energy Procedia*, *37*, 4919–4926. https://doi.org/10.1016/j.egypro.2013.06.403

Han, L., & Gu, Y. (2014). Optimization of Miscible CO2 Water-Alternating-Gas Injection in the Bakken Formation. *Energy & Fuels*, *28*(11), 6811–6819. https://doi.org/10.1021/ef501547x

Haynes, S., & Alston, R. B. (1990, April 22). *Study of the Mechanisms of Carbon Dioxide Flooding and Applications to More Efficient EOR Projects*. SPE/DOE Enhanced Oil Recovery Symposium. https://doi.org/10.2118/20190-MS

Holm, L. W., & O'Brien, L. J. (1971). Carbon Dioxide Test at the Mead-Strawn Field. *Journal of Petroleum Technology*, *23*(04), 431–442. https://doi.org/10.2118/3103-PA

Ismail, I., Mathiesen, V., Abraham, A., Ranjbar, E., Zarei, F., & Walter, J. (2021, January 22). *An Innovative Modelling Approach in Characterization of Autonomous Inflow Control Valve Performance to Maximizing Oil Recovery in Heavy Oil-SAGD Application*. https://doi.org/10.2118/203859-MS

Khan, A., Saxena, S., Baloni, S., Sharma, M., & Kodavaty, J. (2021). Overview and methods in Enhanced Oil Recovery. *Journal of Physics: Conference Series*, *2070*(1), 012061. https://doi.org/10.1088/1742-6596/2070/1/012061

Khan, M. Y., & Mandal, A. (2022). Analytical model of incremental oil recovery as a function of WAG ratio and tapered WAG ratio benefits over uniform WAG ratio for heterogeneous reservoir. *Journal of Petroleum Science and Engineering*, *209*, 109955. https://doi.org/10.1016/j.petrol.2021.109955

Lei, H., Yang, S., Zu, L., Wang, Z., & Li, Y. (2016). Oil Recovery Performance and CO2 Storage Potential of CO2 Water-Alternating-Gas Injection after Continuous CO2 Injection in a Multilayer Formation. *Energy & Fuels*, *30*(11), 8922–8931. https://doi.org/10.1021/acs.energyfuels.6b01307

Li, L., Khorsandi, S., Johns, R., & Dilmore, R. (2015). CO2 enhanced oil recovery and storage using a gravity-enhanced process. *International Journal of Greenhouse Gas Control*, *42*, 502–515. https://doi.org/10.1016/j.ijggc.2015.09.006

Mahmood, M. N., Sultan, Z., & Yousuf, N. (2016, December 31). *A Review on Smart Well Completion System: Route to the Smartest Recovery*.

Mansour, E. M., Al-Sabagh, A. M., Desouky, S. M., Zawawy, F. M., & Ramzi, M. (2019). A laboratory investigation of carbon dioxide-enhanced oil recovery by focusing on CO2-oil physical properties. *Egyptian Journal of Petroleum*, *28*(1), 21–26. https://doi.org/10.1016/j.ejpe.2018.10.004

Rogers, J. D., & Grigg, R. B. (2000, April 3). *A Literature Analysis of the WAG Injectivity Abnormalities in the CO2 Process*. SPE/DOE Improved Oil Recovery Symposium. https://doi.org/10.2118/59329-MS

Skauge, A., & Stensen, J. (2003, May 19). *Review of WAG Field Experience*.

Supply – Key World Energy Statistics 2021 – Analysis. (n.d.). IEA. Retrieved January 18, 2024, from https://www.iea.org/reports/key-world-energy-statistics-2021/supply

Taghavi, S., Aakre, H., & Moldestad, B. M. E. (2022, March 11). *Performance Analysis of Autonomous Inflow Control Valve in a SAGD Late Life Process with Non-Condensable Gases*. SPE Canadian Energy Technology Conference. https://doi.org/10.2118/208915-MS

Taghavi, S., Tahami, S. A., Aakre, H., Furuvik, N. C. I., & Moldestad, B. M. E. (2023, October 9). *Performance Analysis of Autonomous Inflow Control Valve in a Heterogenous Reservoir Using CO2 Enhanced Oil Recovery*. SPE Annual Technical Conference and Exhibition. https://doi.org/10.2118/215153-MS

Wang, J., Abiazie, J., McVay, D., & Ayers, W. (2008). Evaluation of Reservoir Connectivity and Development Recovery Strategies in Monument Butte Field, Utah. *Proceedings - SPE Annual Technical Conference and Exhibition*, *7*. https://doi.org/10.2118/116695-MS

Wang, Q., Yang, S., Lorinczi, P., Glover, P. W. J., & Lei, H. (2020). Experimental Investigation of Oil Recovery Performance and Permeability Damage in Multilayer Reservoirs after CO2 and Water–Alternating-CO2 (CO2–WAG) Flooding at Miscible Pressures. *Energy & Fuels*, *34*(1), Article 1.

Whorton, L. P., Brownscombe, E. R., & Dyes, A. B. (1952). *Method for producing oil by means of carbon dioxide* (Patent 2623596). https://www.freepatentsonline.com/2623596.html

World Energy Outlook 2023 – Analysis. (n.d.). IEA. Retrieved January 18, 2024, from https://www.iea.org/reports/world-energy-outlook-2023

Yan, Y., Li, C., Dong, Z., Fang, T., Sun, B., & Zhang, J. (2017). Enhanced oil recovery mechanism of CO2 water-alternating-gas injection in silica nanochannel. *Fuel*, *190*, 253–259. https://doi.org/10.1016/j.fuel.2016.11.019