MAGNETIC FIELD INFLUENCE ON VISCOUS FINGERING INSTABILITIES IN ENHANCED OIL RECOVERY WITHIN INCLINED DOMAINS

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Viscous fingering can be counted as one of the major challenges in enhanced oil recovery (EOR), resulting in unstable flow patterns during the fluid displacement process. This instability often arises when a less viscous fluid is introduced into a porous material that has already been saturated with a more viscous fluid. In this research, we examined how a magnetic field impacts this viscous fingering instability in a two-dimensional homogeneous porous medium, inclined at an acute angle relative to the horizontal axis, with fluid displacement occurring in the negative x-direction. In contrast to horizontal setups, this inclined structure allows gravity to control flow direction, influencing the interface between displaced and native fluids. We used COMSOL Multiphysics 6.2 to simulate the injection of carbonated water into an oil-saturated, homogeneous, isotropic porous medium that adheres to Darcy's law, both with and without an externally applied magnetic field. The computational domain is designed to replicate inclined geometries at selected acute angles. The simulation findings demonstrate that the fingering patterns continue to be highly irregular and unstable in the absence of a magnetic field. Regardless, in all the tilted examples examined, the displacement front becomes smoother and more constant when a magnetic field is introduced. These results imply that by inhibiting finger branching and encouraging smoother fluid movement, magnetic fields can significantly reduce interfacial viscous instabilities. This stabilizing effect demonstrates how the implementation of a magnetic field can serve as a useful technique to improve oil recovery efficiency, especially in sloping domains. The findings support the use of magnetic field-based tactics in sophisticated EOR methods, particularly in reservoirs with non-horizontal alignments or complicated geometries.

Keywords: carbonated water, COMSOL Multiphysics 6.2, enhanced oil recovery, magnetic field, inclined porous media

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INTRODUCTION

In enhanced oil recovery (EOR) processes, a major problem is the viscous fingering instability, which occurs when a less viscous fluid is displacing a more viscous fluid in porous media. The result of this instability is the creation of erratic and inefficient displacement fronts, which decrease the efficiency of oil recovery by creating bypassed oil zones as well as by encouraging early breakthrough (Kumar et al, 2016). The conventional research is highly biased toward the horizontal porous space domains, but in nature, reservoirs are usually inclined with gravity which significantly influences the displacement fluid dynamics (Sahabandu et al, 2024). The inclination angle also influences the fluid interface (Sahabandu & Dewasurendra, 2024), which may lead to the enhancement of fingering phenomena. The research examines the effect of magnetic fields on viscous fingering instabilities when injecting carbonated water into an oil-saturated homogeneous isotropic porous medium at acute angles. The study uses Multiphysics simulation software COMSOL 6.2 to study phenomena with different physical conditions, focusing on the advantages of using magnetic field-assisted EOR methods in reservoirs with complex geometries, compared to traditional horizontal models.

METHODOLOGY

The study relies on the numerical simulation methodology with COMSOL Multiphysics 6.2 as the displacement of a fluid with a two-dimensional porous domain at predetermined acute angles to the horizontal axis. The porous medium is taken to be homogeneous, and isotropic and obeys the Darcy law of single-phase flow in the miscible displacement regime. The less viscous displacing fluid is carbonated water, which is injected at the inlet boundary, and the domain initially has oil, which is more viscous.

The computational domain simulates the inclined geometry wherein gravity can act on the fluid interface in the negative x-direction. The governing equations include conservation of mass, Darcy velocity relations (Kumar et al, 2016), including gravity and miscible fluids species transport (Weerasinghe & Sahabandu, 2025). The effects of the magnetic field are introduced as an exterior body force that influences the flow dynamics via magnetohydrodynamic coupling in accord with well-known MHD porous media flow models.

Two cases, namely, no magnetic field and the presence of a uniform magnetic field applied perpendicularly to the flow direction, are simulated. The methodology analyses fluid viscosities, injection rate, field inclination, and magnetic field strength to assess fingering patterns and displacement front stability, highlighting the potential of magnetic field-assisted approaches for increased oil recovery efficiency under actual reservoir conditions.

RESULTS AND DISCUSSION

The simulation results clearly visualize the effect of a magnetic field on viscous fingering instabilities during enhanced oil recovery in inclined porous media. Without a magnetic field, the fingering patterns remain highly distorted and unstable. However, with magnetic field intervention, the movement of the fluid interface becomes more Consistent and more stable in all the inclined scenarios examined. These findings suggest that magnetic fields can significantly reduce interfacial instabilities by suppressing finger branching and promoting smoother fluid displacement (see figure 1). This stabilization effect demonstrates the potential of magnetic field application as an effective tool to enhance oil recovery efficiency. The results support the implementation of magnetic field-based strategies in advanced EOR techniques, especially in underground reservoirs with complex geometries or non-horizontal alignments (see figure 2).

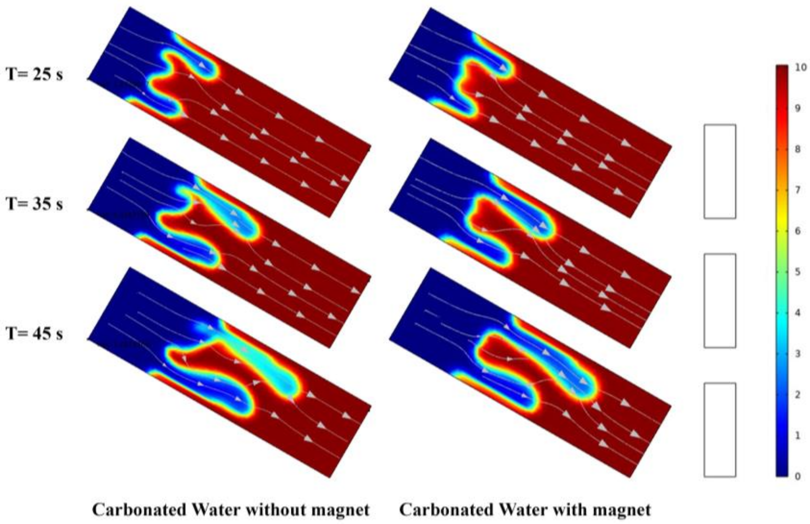

Figure 1: Spatio-temporal evaluation of fingering instability of carbonated water injection at T = 25 S, T = 35 S, and T = 45 s for an angle 30^0.

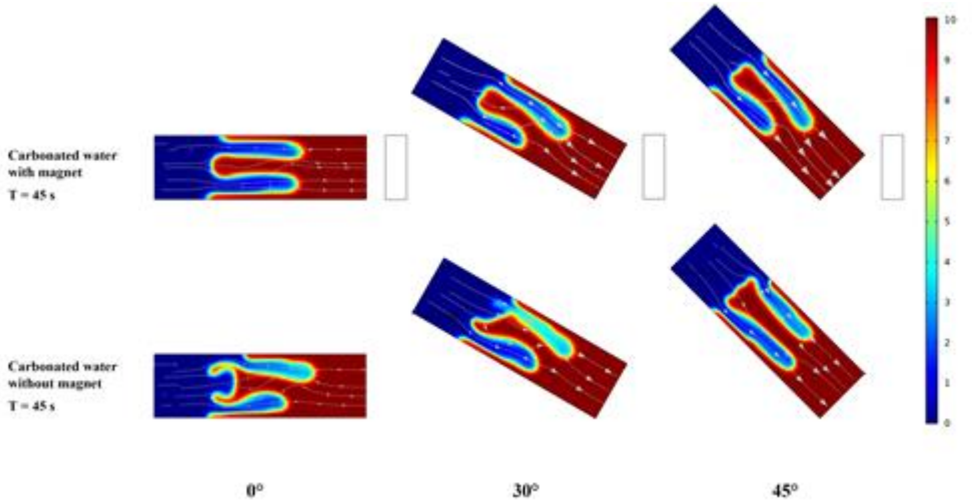

Figure 2: Spatio-temporal evaluation of fingering instability of carbonated water injection at T = 45 S for angles 0^0, 30^0, and 45^0.

CONCLUSIONS

This research showed that using a magnetic field during enhanced oil recovery (EOR) can help reduce problems caused by unstable fluid movement, known as viscous fingering. When carbonated water was injected into an oil-filled porous medium without a magnetic field, the water moved in irregular and unstable patterns. This means some oil was left behind, and recovery was not very efficient. However, when a magnetic field was added, the water moved more smoothly and evenly. This led to better coverage and more oil being recovered. The research also showed that the angle of the layers (inclined rather than flat) has a big effect on how the fluids move. Magnetic fields worked well even when the layers were not flat, which is important because real underground oil reservoirs are usually not flat. Based on these findings, we recommend that future oil recovery methods should include the use of magnetic fields, especially in areas with inclined layers. This can help improve the amount of oil that is collected and make the process more efficient. Further research should be done with real-world data and different types of fluids to test this method in more detail. This approach can be a low-cost, effective way to improve oil recovery in complex underground conditions.

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