Numerical Investigations on the Dissolution Characteristics of CO_2 in Fractured Porous Media using Density Driven Modelling

Manojkumar Gudala[a,b], Bicheng Yan[a,b], Shuyu Sun[b,c,d]

[a]Ali I. Al-Naimi Petroleum Engineering Research Center, Physical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900, Saudi Arabia

[b]Energy Resources and Petroleum Engineering Program, Physical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900, Saudi

[c]Computational Transport Phenomena Laboratory (CTPL), Physical Science and Engineering Division (PSE), King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900, Saudi Arabia

[d]Earth Science and Engineering Program, Physical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900, Saudi Arabia

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

InterPore2022 Hybrid

Contribution ID: 266

Abstract

In the present work, numerical simulation experiments were performed to examine the influence of fractures on the flow of dissolved CO_2 plumes using the density driven (i.e., convective mixing) model. Porous media domain with a size of 500 m by 200 m (x-z plane) was used in the present work. The impacts of fracture aperture, fracture angle and fractures intersection on the movement of CO_2 plumes have been investigated comprehensively. Single fracture scenarios with varied inclined angle and multiple fractures with horizontal, vertical and combination of these two were examined. We found that the fractures play a vital role by serving as superior flow pathways for water and CO_2 plumes. The distribution of CO_2 rich fingers is comparatively even at the top boundary of the computational domain without fractures, further it is extended into the fractured area. Porous media with fractures brings an active matrix-fracture mass transfer which results in rapid CO_2 dissolution. In the field scale model, 200 fractures are randomly generated with aperture varying from 1 mm to 5 mm, and length from 5 m to 50 m. Our results demonstrates that high connectivity of fractures leads to enhancement in the dissolution of CO_2 in the water

Keywords: CO_2 plume, porous media, Fracture, Dissolution, Density driven model

Introduction

Carbon dioxide (CO_2) emissions increasing rapidly due to the consumption of fossil fuels and their concentration in the atmosphere due to human and industrial activities. CO_2 storage in geological formations is one of the viable and secure solutions. The injected CO_2 in the porous media can be trapped in the physical and chemical mechanisms. Physical trapping occurs in the early stages of the CO_2 injection (Structural/stratigraphic and residual), and chemical trapping occurs later when CO_2 starts to dissolve in the brine (solubility) or interact with sedimentary rocks (i.e., mineral trappings) (Emami-Meybodi et al, 2015; Aminu et al, 2017; Kim et al.,2019).

In the dissolution trapping, mass transfer by molecular diffusion is a very slow process and takes a long time to dissolve CO_2 into the water/brine. CO2 dissolution into brine causes a rise in the density of water/brine from 0.1% to 1% (Garcia, 2001; Rezk and Jalal, 2019). The CO_2 saturated water/brine can superimpose the fresh water/brine, and it will lead to instability in the porous media. This process is known as density-driven natural convection. The convective mixing that occurs in this process expands the dissolution of CO_2 in water/brine, and replaces the continuous phase from water/brine to CO_2 saturated water/brine.

Objectives

- In the present work, a numerical model was utilized to investigate the impacts of fractures in porous media on the transport of dissolved CO_2 in porous media.
- The effects of the fracture angle, fracture aperture, and intersection of fractures were investigated on the density-driven CO_2 convection.

Mathematical formulation

The governing equations for convective mixing consist of continuity equation and convection-diffusion equation. The continuity equation for the porous media and fracture are given in Eq. (1) and Eq. (2)

$$\frac{\partial(\phi_m \rho)}{\partial t} - \nabla \cdot \left(\rho \frac{-k_m}{\mu}(\nabla p - \rho g)\right) = Q_m \quad \text{for matrix} \quad \ldots\ldots (1)$$

$$d_f \frac{\partial(\phi_f \rho)}{\partial t} - \nabla_T \cdot \left(d_f \rho \frac{k_f}{\mu}(\nabla_T p)\right) = d_f Q_m \quad \text{for fracture} \quad \ldots\ldots (2)$$

The convection-diffusion equation for transport of dissolved CO2 in matrix and fracture are given in Eq. (3) and Eq. (4)

$$\frac{\partial(\rho c)}{\partial t} + \frac{\partial(\phi_m c)}{\partial t} + \nabla \cdot (D \nabla c) + (u \nabla c) = 0 \quad \text{for matrix} \quad \ldots\ldots (3)$$

$$d_f\left(\frac{\partial(\rho c)}{\partial t} + \frac{\partial(\phi_m c)}{\partial t} + \nabla \cdot (D \nabla_T c) + (u \nabla c)\right) = 0 \quad \text{for fracture} \quad \ldots\ldots (4)$$

The density of the mixture is defined as a function of concentration and volumetric expansion coefficient and given in Eq. (5) and Eq. (6).

$$\rho = \rho_{w,0}(1 + \beta_c c) \quad \ldots\ldots (5)$$

$$\beta_c = \frac{1}{\rho_{w,0}}\left(\frac{\partial \rho}{\partial c}\right) \quad \ldots\ldots (6)$$

Fracture geometry

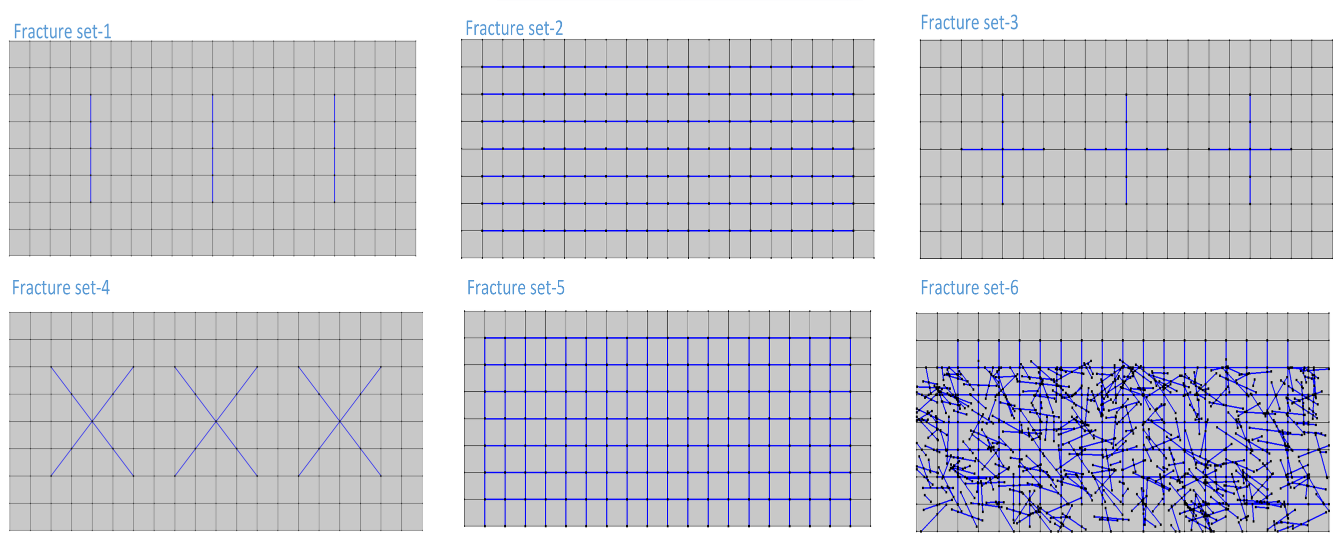

Fig. 1. Arrangements of fractures: Vertical, horizontal, brick fracture and randomly distributed fractures.

Results

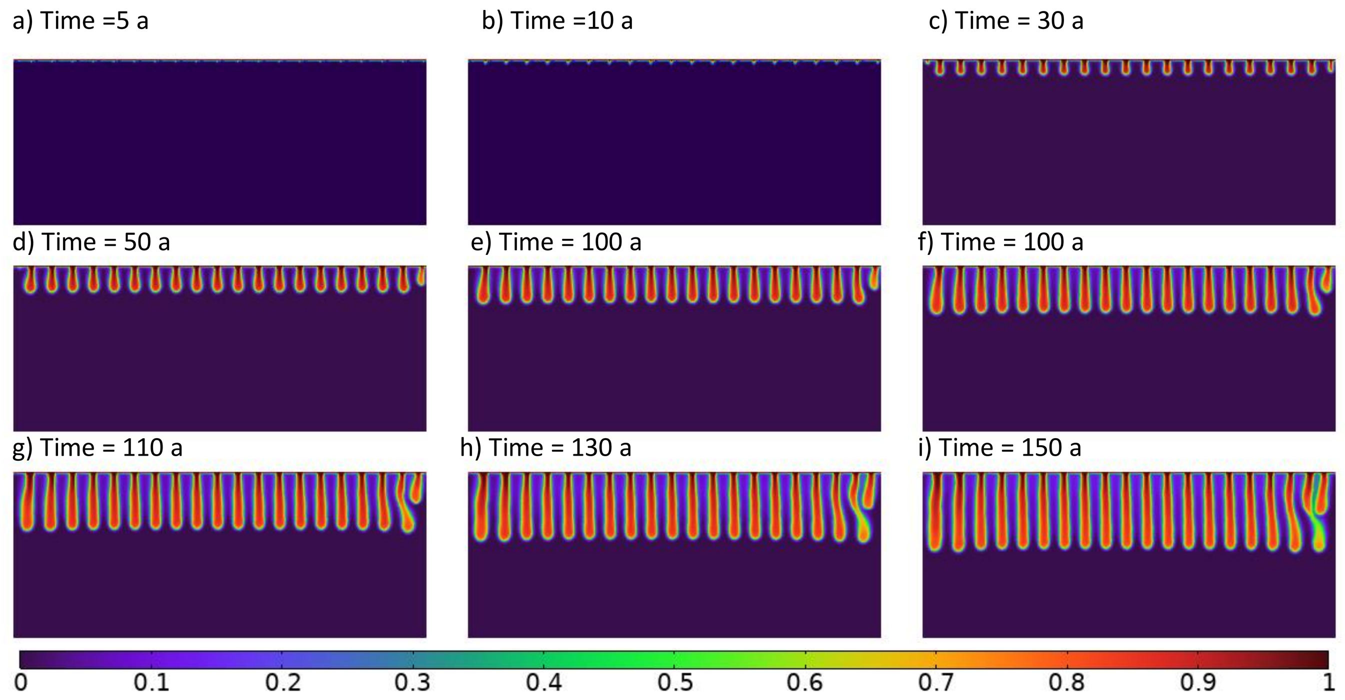

Fig. 2. Spatiotemporal variation of dissolved CO_2 (c/c_0) in homogeneous porous media

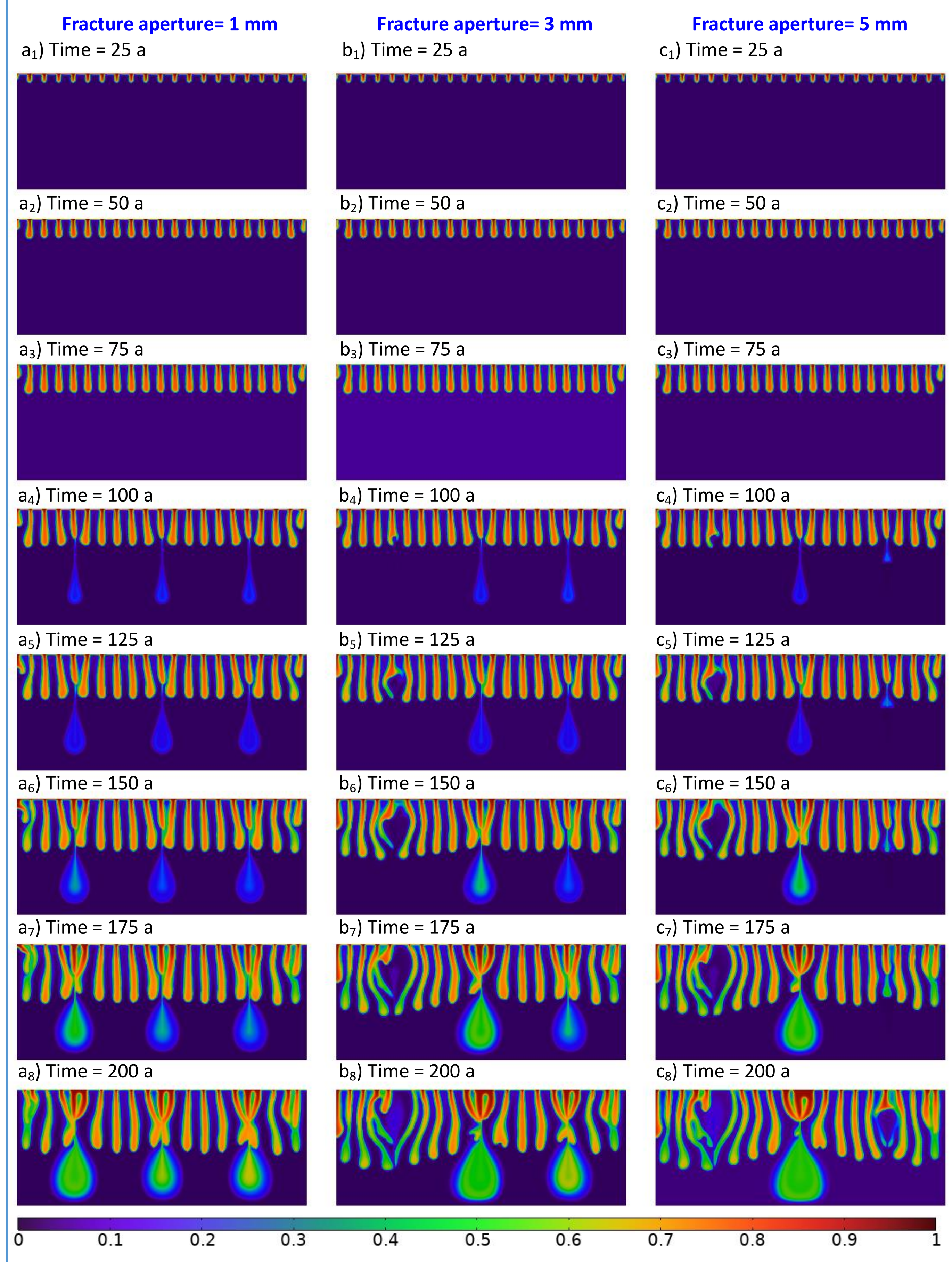

Fig. 3. Spatiotemporal variation of dissolved CO_2 in water (c/c_0) and impact of fracture aperture (Fracture set-1)

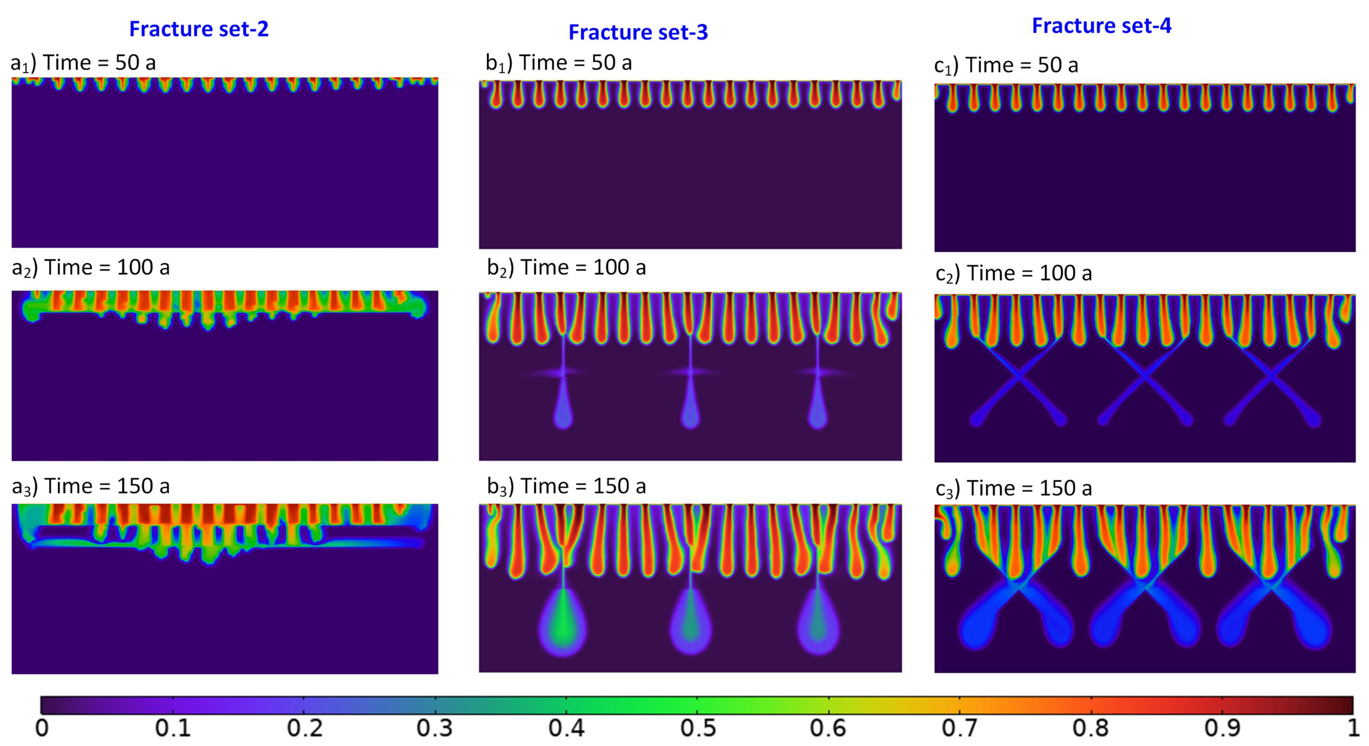

Fig. 4. Spatiotemporal variation of dissolved CO_2 in water (c/c_0) (Fracture set-2, Fracture set-3, and Fracture set-4)

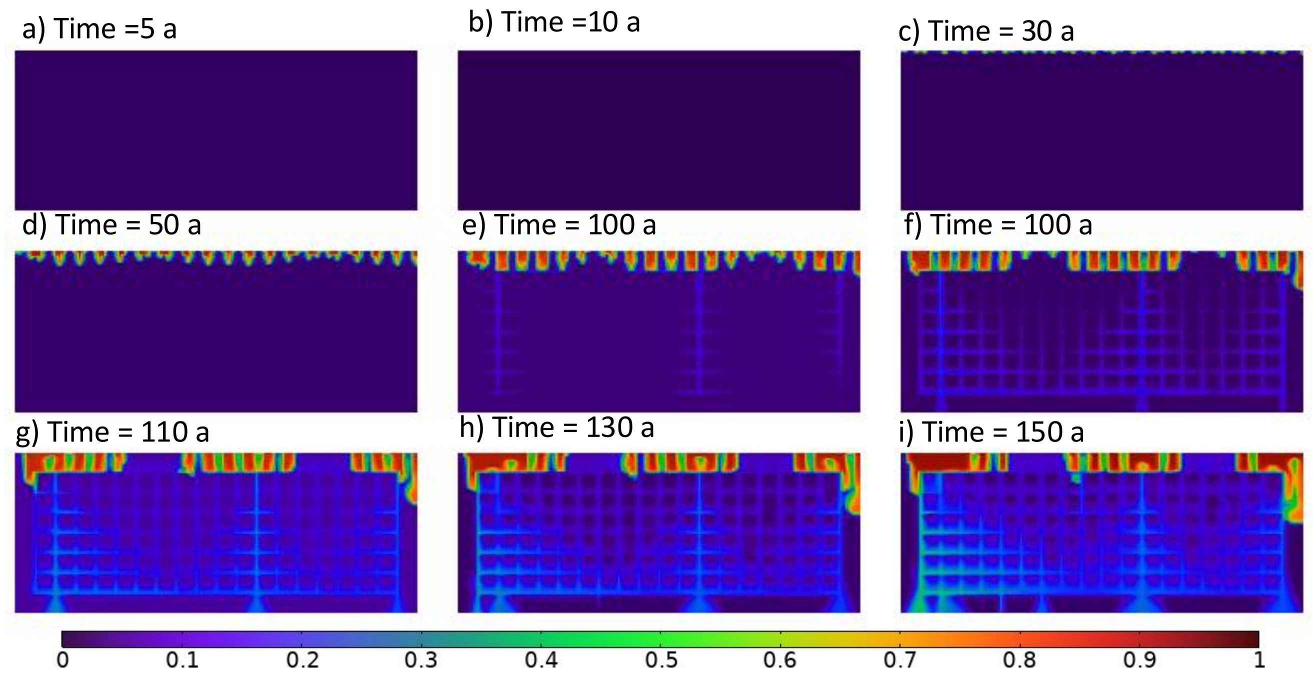

Fig. 5. Spatiotemporal variation of dissolved CO_2 (c/c_0) in water and impact of fracture aperture (Fracture set-5)

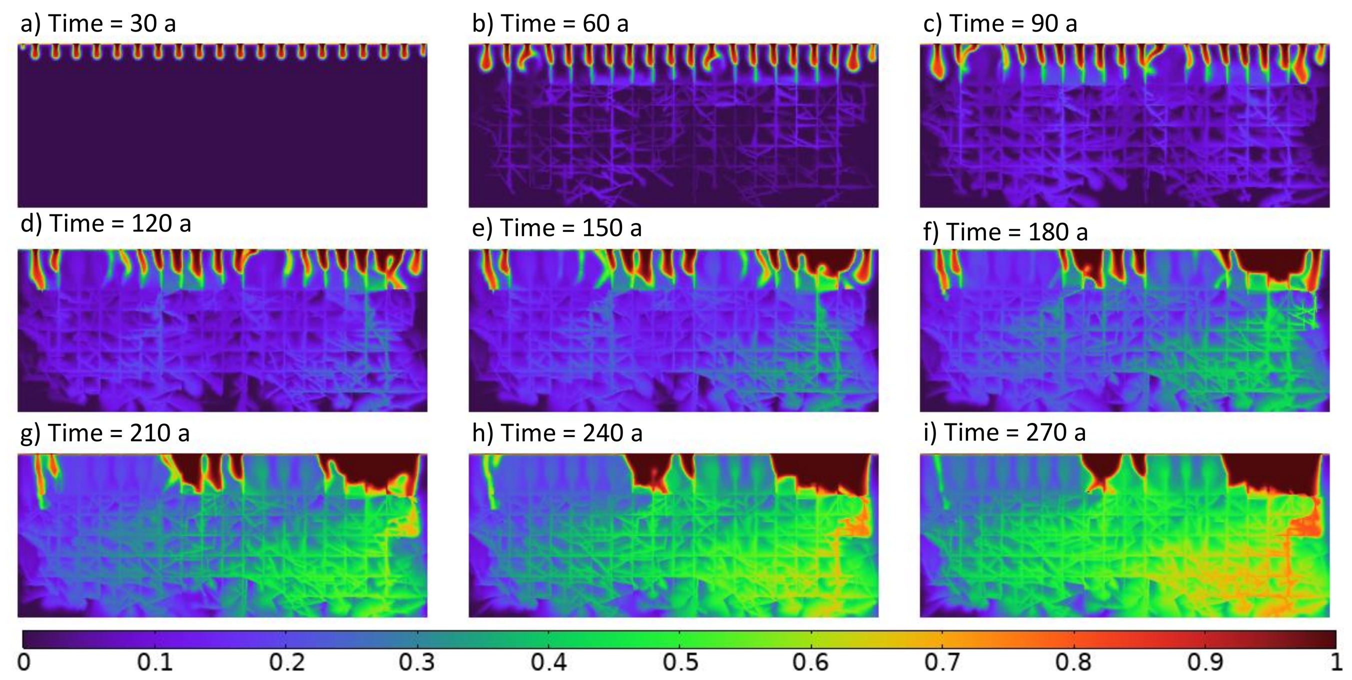

Fig. 6. Spatiotemporal variation of dissolved CO_2 (c/c_0) in water in large fractured porous media (fracture set-6)

CONCLUSIONS

The present work focused on the impact of fractures on the density-driven convection in the porous media for storing of CO_2 in two-dimensional model. Numerical simulations were conducted using the six fracture sets, which includes the orientation, intersections with different fracture lengths. The following conclusion were made based on the numerical investigations conducted.

It was found that the fractures playing an important role in the movement of CO_2 plume (i.e., fingers) in downward direction and movement of water in upward direction. Large number of fracture intersections crates eddy flows near the fracture and their intersections which improves the mass transfer between rock matrix and fracture. Furthermore, it will enhance the dissolution of CO2 in water. It was also found that the connectivity of fractures expands the amalgamation of CO_2 plume into to bigger plumes.

A geological formation containing complex fracture network with intersections facilitates the transportation of CO_2 to deeper sections within the formation. It will improve the dissolution of CO_2 in water compared to the homogeneous scenario and also improves the movement of fluid in the reservoir.

References

Aminu, M. D., Nabavi, S. A., Rochelle, C. A., & Manovic, V. (2017). A review of developments in carbon dioxide storage. *Applied Energy*, *208*, 1389–1419. https://doi.org/10.1016/j.apenergy.2017.09.015

Emami-Meybodi, H., Hassanzadeh, H., Green, C. P., & Ennis-King, J. (2015). Convective dissolution of CO2 in saline aquifers: Progress in modeling and experiments. *International Journal of Greenhouse Gas Control*, *40*, 238–266. https://doi.org/10.1016/j.ijggc.2015.04.003

Garcia, J.E., 2001. Density of Aqueous Solutions of CO2. Lawrence Berkeley National Laboratory, Berkeley.

Kim, M., Kue-Young, K., Han, W.S., Oh, J., and Park, E. (2019). Density-Driven Convection in a Fractured Porous Media: Implications for Geological CO2 Storage, Water resource research, 55 (7), 5852-5870. https://doi.org/10.1029/2019WR024822

Rezk, M.G., and Foroozesh, J., (2019) Study of convective-diffusive flow during CO2 sequestration in fractured heterogeneous saline aquifers, Journal of Natural gas Science and Engineering, 69, 102926. https://doi.org/10.1016/j.jngse.2019.102926

ACKNOWLEDGEMENT

Manojkumar Gudala and Bicheng Yan thanks for the Research Funding from King Abdullah University of Science and Technology (KAUST), Saudi Arabia through the grants BAS/1/11423-01-01; Manojkumar Gudala and Shuyu Sun thanks for the Research Funding from King Abdullah University of Science and Technology (KAUST), Saudi Arabia through the grants BAS/1/1351-01-01 and URF/1/4074-01-01.