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BCH modelling studies on biocementation process in mitigating leaks from a CO_2 sequestrated aquifer

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Global warming is having a severe impact on the climate of the earth. Minimising global warming is a significant challenge [1]. Geological sequestration is one of the ways to capture the most liberated greenhouse gas, such as carbon dioxide (CO_2), in deep saline aquifers. Due to the high heterogeneity in the caprock adjacent to aquifers, they often have discontinuities (i.e., fractures, faults) responsible for the leaks from the CO_2-sequestrated aquifer [2]. This scenario demands the sealing of discontinuities close to the CO_2-sequestrated aquifer. In recent times, Microbially Induced Calcite Precipitation (MICP), also known as the biocementation process, has proven its potential in cementing the pore spaces in soil and rock mass [3, 4]. The MICP process utilises bacteria to release enzymes and drives the precipitation of calcium carbonate with the hydrolysis of the urea. The biocement produced through this sustainable process has a binding ability and cements the soil/ rock mass. Thus, biocementation can be employed in plugging the leakage paths of the carbon storage aquifer. However, various scenarios must be tested before implementing the MICP technique in the field. Generally, Bio-Chemo-Hydraulic (BCH) domains influence the MICP process and significantly affect the calcium carbonate content with their coupled interdependency [4]. In addition, geosequestration also needs hydraulic modelling studies to better understand the transport of CO_2 plume migration in an aquifer [2]. Being a complex process, implementing MICP for sealing the leakage paths during carbon geosequestration becomes intricate. Therefore, coupled BCH modelling studies are conducted in the present work to evaluate the sealing ability of the MICP process to plug the leakage paths in the caprock.

A deep saline aquifer with high permeability was considered for carbon geosequestration and subsequent leakage reduction through the MICP process. The mathematical framework for the present work was acquired from Landa-Marbán et al. [2]. The framed problem comprises the fluid flow of two phases (i.e., water and CO_2) and the transport of biochemical species (i.e., microbes, oxygen and urea). The Darcian advection and Fickian diffusion were considered for advective and diffusive transport, respectively. The reaction of biochemical species was accommodated with a reactive term in the transport equation. The microbial processes considered during the transport of microbes are the attachment, growth and decay of the microbes. The biochemical reaction rate for urea hydrolysis was based on a first-order kinetic reaction rate using Michealis-Menten kinetics. The growth rate of microbes with oxygen consumption was followed as per the Monod kinetics. The detachment of microbes due to fluid flow in the pores occurs according to a power law related to Darcy's flow velocity. The calcite precipitation rate is considered to be the same as the urea hydrolysis rate, assuming a calcium-rich environment. A porosity-permeability relation with critical porosity and minimum permeability parameters was adopted for evaluating the changes in pore spaces over the biocementation process.

The current work considers two aquifers connected through a vertical leakage path in the caprock (Figure 1). The primary objective of the work is to plug the leakage path between the aquifers for long-term storage of carbon dioxide. The model geometry of the considered problem is detailed in Figure 1. The top and the bottom aquifers have the same hydraulic properties. However, the leakage path has a higher permeability. The CO_2 injection was performed before and after the treatment of the aquifer domains with the MICP process. The CO_2 injection was performed for 500 d to study the influence of the sealing capacity of the MICP process on the CO_2 front migration. For the MICP treatment, the left boundary of the bottom aquifer was subjected to biochemical

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injections. Initially, the microbes were injected into the aquifer, and the transport of microbes was further accommodated by water injection and no flow conditions. The oxygen and urea were injected consecutively with the same injection strategy to employ the MICP process. After completion of the biocementation process, the CO_2 was injected to observe the leakage rate.

The carbon sequestration into an aquifer with a preexisting leakage path resulted in the migration of CO_2 into the top aquifer (Figure 1). The modelling studies showed that the leakage fraction was 17% when normalised with the injection flow rate (q) at the end of 500 d of CO_2 injection. Later, the transport of biochemical species from the MICP process resulted in the precipitation of calcium carbonate near the leakage path. The MICP has proven effective in reducing the porosity and permeability of the leakage path, which is 100 m far from the injection point. Ultimately, the MICP treatment for sealing the leakage path reduced the leakage fraction to 0% by the end of the third treatment cycle.

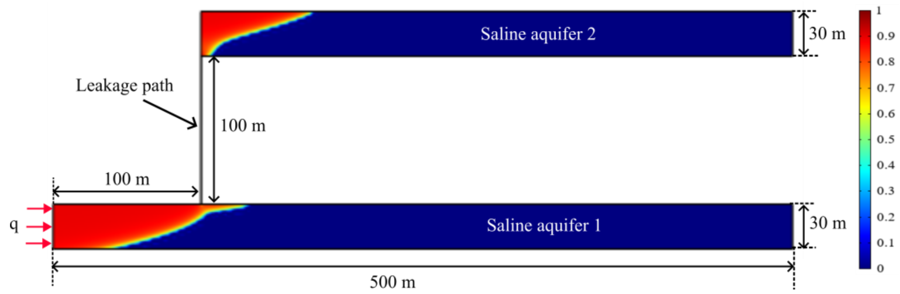

Figure 1: CO_2 saturation front migration through a leakage path between the aquifers (500 d)

Overall, the current study conducted the field scale modelling scenario on the biocementation process for leak mitigation from the CO_2-sequestrated aquifer. The study ascertained the influence of calcite precipitation on the leakage rate from a CO_2-sequestrated aquifer. The MICP process significantly influenced the carbon storage capacity of the aquifer by closing the discontinuity pores inside the caprock, similar to Landa-Marbán et al. [2]. The alterations in the porosity and permeability of the leakage path due to biocementation indulged in improving the carbon storage capacity of an aquifer. The study also recommends injection strategies for the biocementation process to accommodate more significant precipitation of calcium carbonate near the leakage zone. Further modelling studies are needed to understand the plugging mechanisms of the leakage paths for the long-term storage of carbon dioxide.

Data Availability Statement

The authors will make the data supporting this study's findings available upon reasonable request.

Contributor statement

Pavan Kumar Bhukya acquired the mathematical framework, developed the numerical model, analysed the results and wrote the abstract; Nandini Adla analysed the results and edited the abstract; Dali Naidu Arnepalli supervised the work, reviewed and edited the abstract.

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