Integrating petrophysics and carbon capture, utilisation, and storage: navigating challenges and harnessing opportunities for climate change mitigation

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As the urgency to address climate change escalates, carbon capture, utilisation, and storage (CCUS) emerges as a pivotal technology for reducing atmospheric carbon dioxide (CO_2) levels. Central to the effectiveness of CCUS is the accurate characterisation of subsurface geological formations, a task where petrophysics plays a crucial role. The present review article delves into the integration of petrophysical analysis with CCUS, highlighting its significance in enhancing the efficiency of CCUS operations. By examining recent scientific research, methodologies, and case studies, the present review emphasises how petrophysics contributes to optimising site selection based on key properties such as porosity and permeability and advances monitoring techniques for tracking CO_2 injection and subsurface plume dynamics. The discussion highlights the significance of petrophysical properties in predicting CO_2 behaviour in geological reservoirs, which supports the enhancement of storage strategies and enhances the safety and reliability of CO_2 sequestration. This is particularly relevant in the utilisation phase, notably in enhanced oil recovery applications. The present article also identifies promising trends and emerging technologies in petrophysical analysis that are expected to enhance the effectiveness and economic feasibility of CCUS. By highlighting the integral role of petrophysics in CCUS, the present article promotes a deeper understanding of how interdisciplinary approaches can address the complexities of carbon management. Ultimately, incorporating petrophysical insights into CCUS not only boosts carbon mitigation potential but also drives the advancement of sustainable and efficient carbon management techniques crucial for a low-carbon future transition.

Keywords: Carbon capture utilisation and storage (CCUS), climate change mitigation, enhanced oil recovery, subsurface characterisation.

As the world grapples with the increasing challenges of climate change, the reduction of atmospheric carbon dioxide (CO_2) levels has become a critical objective for the global community[1]. Among the array of strategies proposed to mitigate these effects, carbon capture, utilisation, and storage (CCUS) emerges as a particularly promising solution[2]. CCUS encompasses a suite of technologies aimed at capturing CO_2 emissions from sources like power plants and industrial processes, utilising the captured CO_2, for example, in enhanced oil recovery (EOR), and ultimately storing it in geological formations, thus preventing its release into the atmosphere[3,4]. However, the efficacy and sustainability of CCUS technologies depend significantly on a nuanced understanding of subsurface geology, where petrophysics plays a pivotal role[5].

Petrophysics, the study of the physical and chemical properties of rocks and their contained fluids, provides critical insights into the porosity, permeability, and fluid saturations of geological formations, information that is indispensable for the successful implementation of CCUS projects[6]. These petrophysical properties determine the feasibility of a site for CO_2 storage, influence the behaviour of CO_2 once injected, and are crucial for monitoring the integrity and effectiveness of CO_2 sequestration.

Despite the recognised importance of petrophysics in CCUS, there remains a gap in the literature regarding a comprehensive review that integrates these disciplines. The present review article aims to bridge this gap by providing a detailed examination of how petrophysical analysis supports and enhances CCUS technologies. Through a thorough review of current research, methodologies, and case studies, this review elucidates the multifaceted role of petrophysics in the selection, optimisation, and monitoring of CCUS processes.

The significance of integrating petrophysical insights into CCUS strategies cannot be overstated. With global CO_2 emissions continuing to rise, the urgency to deploy effective and scalable carbon management solutions is paramount. CCUS offers a pathway to not only reduce emissions from existing sources but also to contribute to the circular carbon economy through the utilisation of CO_2 (ref. 7). However, the technical complexities, economic considerations, and environmental implications of these technologies necessitate a multidisciplinary approach that combines geoscience, engineering, and environmental science. In this context, petrophysics provides

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