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Opinion

Developing Carbon Storage Technology to Combat Climate Change – Solving Industrial Engineering Problems

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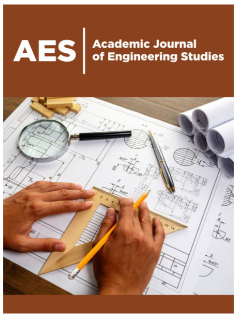

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Opinion and Document Novel Research in Science to Assist New Researchers

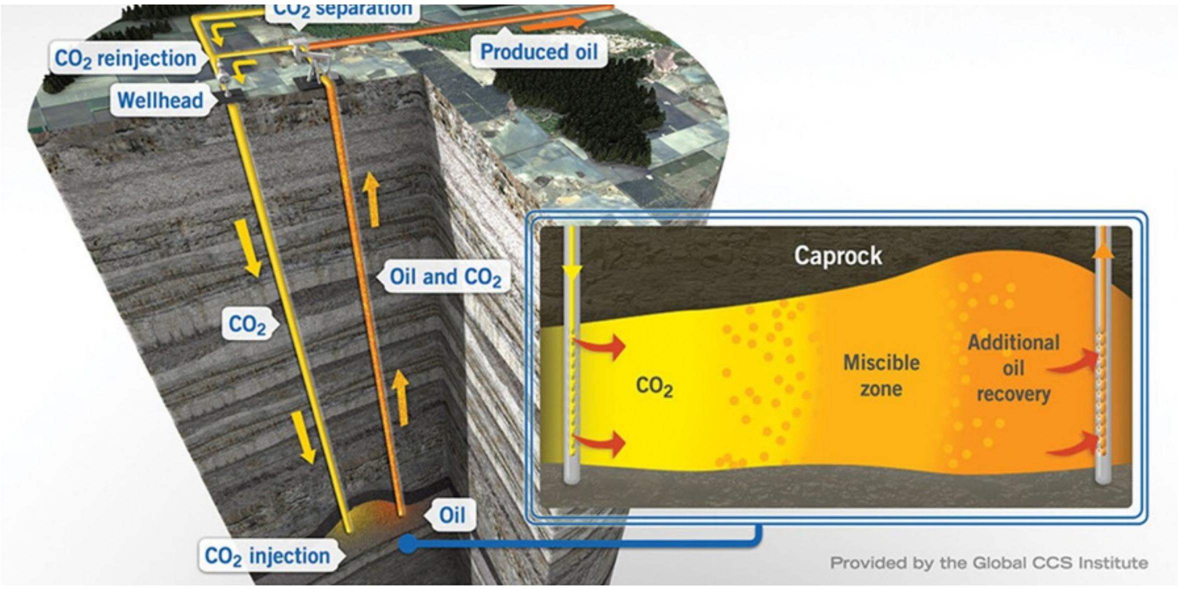
Energy production and consumption are key elements of modern economic growth. There is a strong correlation between energy consumption and economic growth [1]. Liquid fossil fuels are a key component of the energy mix, contributing up to 34% of worldwide energy usage [2]. While energy sources are diversifying, liquid fossil fuels are still a key energy source in developing countries such as India. The rapid development of the economy of many countries is expected to intensify the energy demand from fossil fuels. This will inevitably lead to increased CO_2 emissions. CO_2 emissions have been rising worldwide, reaching 36.3 billion tonnes in 2021 [2]. Annual fossil CO_2 emissions are increasing for major GHG emitters in the world. Bloomberg news mentions "Climate change is not a problem with a single solution. And it's not a challenge that any one group - governments, companies, scientists or individual citizens - can solve alone." Working together, we can build a healthier and more sustainable future for the generations to come. Utilizing a variety of technologies, e.g., solar, wind, geo-thermal, nuclear, extended batteries, and hydrogen, and strong government support, dedicated companies, universities and research centers, regulatory agencies and others, we have a great opportunity to solve this problem.

There are several low-carbon venture technologies available that include: DAC (Direct Air Capture), CO_2 EOR in conventional and unconventional reservoirs, CO_2 EOR in Transition Oil Zone (TOZ) and Residual Oil Zone (ROZ), CO_2 storage in aquifers (CCS), and use of CO_2 in plastics, biological conversion, and other usage. Direct geological storage includes injection of captured CO_2 into deep saline aquifers and injection into depleted oil and gas reservoirs. Many anthropogenic CO_2 projects are already operational or planned around the world, and there is a tremendous growth anticipated in this area.

With fossil resources continuing to be the primary source of energy consumption and increasing emphasis on greenhouse gas restrictions around the world, Carbon Capture, Utilization and Storage (CCUS) plays an increasingly important role in today's oil and gas operations to address and establish the low carbon technology. Nations with large energy demand like India and China can be especially benefitted from this technology to significantly support its environmental and energy self-reliance goals. With financial incentives to capture carbon, operators are venturing more into CO_2 EOR (Enhanced Oil Recovery) and storage projects. CCUS & EOR research at the Energy Industry Partnership team (EIP) at the University of Houston focuses on detailed study of CO_2 EOR in conventional and unconventional reservoirs including laboratory studies, reservoir characterization, dynamic simulation, and integrated reservoir-well facilities studies. EIP's fundamental research is complemented by field studies through active involvement in solving industrial engineering problems in Oil India's CO_2 EOR/Storage ventures, which is three phased.

Carbon storage projects focusing on saline reservoirs have significant uncertainties in terms of reservoir and seal characteristics. On the other hand, intelligent reservoir management of an oil and gas field from primary to tertiary recovery phases yields an understanding of its key properties. Hence, the use of mature or declining oil and gas reservoirs to store CO_2 significantly reduces subsurface uncertainties. CO_2 injection is a well-documented method for improving hydrocarbon production rates and increasing recovery. In light of climate concerns, using CO_2 injection for the dual objectives of enhancing oil recovery and carbon storage is an optimal choice. Our focused management clearly illustrates that a well-managed and monitored reservoir is better-prepared one to benefit from CO_2 injection based on the synergistic objectives of oil recovery and carbon storage.

One of the key mitigation strategies for excessive atmospheric carbon is injection into depleted oil reservoirs. Given the lack of CCUS incentives in India, CO_2 EOR is a commercially viable method to store captured CO_2. CO_2 injection into oil reservoirs is a well-known and practiced technique to recover additional oil beyond secondary and primary recovery techniques. It provides dual objectives: enhancing oil recovery and carbon storage (see Figure below that describes the CO_2 injection process). Reservoir Management (RM) is critical to ensuring injection success as it leverages an integrated understanding of the field and it “connects the dots” between primary, secondary and EOR/EOR+ phases.



Figure

Carbon Capture, Utilization, and Storage (CCUS) is one of the key strategies for CO_2 emission reduction and climate change mitigation [3-6]. CO_2 injection into geological formation commonly used in the oil industry provides dual benefits: Enhancing oil recovery and carbon storage. A well-managed reservoir is better prepared to benefit from CO_2 injection for the synergistic objectives of oil recovery and carbon storage [4,5]. Moreover, emerging data science technologies are modern trending methodologies to predict oil production performance and estimate CO_2 storage capacity, while reducing high computational time and high associated cost. Advances in computational capabilities have enabled development of surrogate models or proxy models in subsurface modeling [7]. Different types of machine learning algorithms are used to develop these models for prediction and optimization of hydrocarbon production in the oil and gas fields. Application of proxy models can be considered as modern approach to deliver time and cost-effective alternative for predicting CCUS performance and optimization [8].

The earliest successful CO_2 injection project was the SACROC flood in 1972 in the Permian Basin of US. Since then, multiple commercial-scale CO_2 floods have been performed worldwide. In these projects, the goal of CO_2 injection is to increase oil recovery. There have been recent efforts to incorporate geological storage as another objective [4,5]. For example, the Weyburn oilfield was the first CO_2 EOR and storage project, with a storage capacity of approximately 25 million tonnes [5]. There have been multiple studies addressing the co-optimizing of CO_2 EOR and storage [7,8]. Many of these studies have simplifying assumptions and fail to address practical challenges found in brownfields, such as uneven reservoir pressure, fluid saturations, and high free gas saturation.

Overcoming these challenges is critical to ensuring the success of the CO_2 storage process. There is a large amount of reservoir management expertise in successfully deploying and monitoring CO_2 injection projects. In this work, this reservoir management expertise is leveraged to design a successful carbon storage project. We demonstrate how learnings gleaned from primary phase data sources can be used to successfully design a carbon storage-focused CO_2 injection project. This is of relevance to many mature fields, particularly in Asia, with sub-optimal reservoir management practices, a lack of secondary phase data, or poor commercial incentives for carbon storage. We utilized our novel integrated reservoir management approach for a CO_2 EOR and storage.

Using various data sources such as seismic data and petrophysical information, a geomodel was constructed. It was also guided by dynamic data analysis. Calibration of the numerical simulation model was performed by history matching study integrating production, pressure, and petrophysical analysis. The calibrated model was used to optimize parameters for the CO_2 injection.

Conclusions from this study are:

1. Integrated reservoir characterization utilizing petrophysical and primary phase dynamic data (well logs, core data, production and pressure data) validates an understanding of sand continuity and injection locations for CO_2 injection. This approach allows reservoir managers to design a carbon storage project without prior injection data.
2. This work can be easily adapted to many of the existing mature oil fields, with similar geological characteristics. The size of the storage potential in both the oil reservoir and aquifer is huge. Increasing oil production through EOR makes the carbon storage projects economically viable.

We present an integrated carbon storage focused development strategy for an actual mature oilfield. We leverage multiple analytical and numerical tools to perform an integrated analysis of a depleted stacked pay reservoir. The work uses real field data from multiple sources with over 30 years of performance. The reservoir has a storage potential of five million metric tonnes, with an incremental oil recovery factor of 11% of original oil-in-place.

Eliminating the waterflooding stage adds more tons of storage. Continual production of aquifer water also adds CO_2 storage annually. The research highlights the tremendous potential of over 50 fields for carbon storage in just one region. In addition, most of the reservoirs are underlain by large aquifers, providing potential for additional CO_2 storage.

CO_2 injection is a well-documented method for improving hydrocarbon production rates and increasing oilfield recovery factors. In light of climate concerns, there has been a significant push to utilize CO_2 injection for the dual objectives of enhancing oil recovery and carbon storage. Despite the proliferation of CCUS related literature, practical considerations related to reservoir management are rarely discussed. Intelligent reservoir management of a field from primary to tertiary recovery phases yields an understanding of key physical properties and mechanism that govern oil recovery. A well-managed reservoir is also better prepared to benefit from CO_2 injection for the synergistic objectives of oil recovery and carbon storage.

In this work, we address several underexplored and novel areas in CCUS research:

Optimization of primary and tertiary depletion plans to "prepare" a field for carbon storage, taking into consideration pressure, free gas saturation, and liquid phase saturation distributions. Design parameters include appropriate production/injection depths and pattern design/rates. Utilization of primary phase learnings to accelerate the reservoir into tertiary phase (skipping waterflooding) to maximize carbon storage.

Optimizing oil reservoir development for carbon storage is particularly important in countries with absent or nascent CCUS policies. In our work, we present an integrated carbon storage focused development strategy for a mature Indian oilfield. We leverage multiple analytical and numerical tools to perform an integrated analysis of a depleted stacked pay reservoir. The work uses actual field data from multiple sources with over 30 years of dynamic data. The reservoir has a storage potential of over 5 million metric tonnes, with an incremental oil recovery factor of 11% of Original Oil-In-Place (OOIP). Eliminating the waterflooding stage adds approximately 0.5 million tonnes of storage. Continual production of aquifer water adds an estimated 0.35 million tonnes of storage potential annually. The area has over 50 reservoirs at various developmental stages; this work highlights the tremendous potential of these fields for carbon storage with an integrated reservoir management approach. In addition, most of these reservoirs are underlain by large aquifers, providing potential for additional storage space for CO_2.

Phase 1 - University of Houston has identified reservoir candidates for CO_2 EOR feasibility study from a pool of 50 reservoirs, by employing patented advanced reservoir screening techniques. For a reservoir to be a good candidate for CO_2 EOR, remaining oil saturation has to be greater than 40%. Estimating mobility ratio, minimum miscibility

pressure and bubble point pressure values are as critical as considering geological characters of the reservoir such as lateral and vertical facies variations. Another practical and crucial factor in consideration is if the reservoir has been managed appropriately.

Phase 2 - CO_2 EOR Pilot Design: Laboratory Study, Simulation Study (3D Geological Modeling, History Matching, CO_2 EOR Simulation), Pilot Design (CO_2 Source Study, Facilities/Completion, Economic Analysis). Three-D geomodelling included full cycle of reservoir mapping, petrophysics and static modeling. The Minimum Miscibility Pressure (MMP), the lowest pressure at which the injected gas becomes miscible with the reservoir fluid, was studied in the laboratory using slim tube experiments. Furthermore, swelling tests, asphaltene precipitation tests and core flooding were also carried out in the EOR laboratory to understand the dynamics of a particular reservoir for the EOR applicability. Dynamic simulation included rigorous pressure-production history matching exercise followed by water injection and CO_2 EOR predictions. The CO_2 storage capacity of the reservoirs were investigated and optimum pilot injection patterns were determined along with economics and facilities studies. Consequently, local industrial sources for anthropogenic CO_2 were carried out in collaboration with the operator.

Phase 3 - CO_2EOR Pilot Implementation. To date, UH-OIL collaboration has developed two CO_2-EOR pilot designs, and reservoir management operations for preparation of CO_2 EOR is ongoing. Authorities in India have approved CO_2 injection in the first pilot. The encouragement from the progress of this study and the incentives by the government, other operators have also shown significant interest and activity on the ground. It is believed that the nation will be greatly benefitted in its energy and environmental goals with successful implementation of the fieldwide projects.

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