FEATURE ARTICLE

Designing an integrated CO_2-EOR as CCUS cum blue hydrogen demonstration project: A step towards Net-Zero ONGC-2038

Gaurav Kumar Mishra[1], Rakesh Kumar Meena[1], Sujit Mitra[1], Sunil Kumar Sahu[1] and Balendra Singh Aman[1]

ABSTRACT

Carbon dioxide (CO_2) in the earth's atmosphere contributes significantly to global warming as a greenhouse gas. Carbon capture, utilization, and storage (CCUS) offers an innovative pathway to reduce carbon footprint through its use in enhanced oil recovery (EOR) and concomitant sequestration. Additionally, when the CO_2 is captured from steam methane reforming process, the generated hydrogen is categorised as blue hydrogen. This feasibility study uses such an integrated approach between the upstream and downstream sectors in the hydrocarbon industry that required novel multicompany collaboration. A mature oil reservoir in Gandhar oil field was screened to act as CO_2 sink whereas it was sourced from a Koyali oil refinery about 80 km away from Gandhar. Results from laboratory studies using slim tube apparatus and core flooding studies ascertained CO_2 miscibility with oil and significant incremental recovery. Numerical simulation predicts that CO_2-EOR can be very successful in this field. Studies have been carried out for designing of optimal surface facilities requirement for transportation of CO_2 from source to storage site, processing of injectant and handling of produced fluids. Further, techno-economic evaluation has been carried out considering the criticality of the project, its major challenges, and opportunities it provides both in the short term as well as in the long term. Resources and support required, e.g., the incentives, policies, etc. for successful implementation in such complex but critical projects are also highlighted.

KEYWORDS

Net-Zero, decarbonization, carbon capture, sequestration, CCUS, EOR, blue hydrogen

INTRODUCTION

Present atmospheric CO_2 concentration around 420 ppm is alarmingly high compared to the corresponding value in pre-industrial times resulting in unprecedented levels of climate change. Ensuring sustainable development goals (SDG) compliance of business and economy in exacerbating climate change scenario is the existential challenge mankind is grappling with today. This situation warrants adoption of groundbreaking ideas for transition of the energy sector. Carbon capture, utilization, and storage (CCUS) offers an innovative pathway to balance energy security and deep decarbonization of hard-to-abate industries, especially the hydrocarbon Industry. CCUS is a key element in the portfolio of technologies essential for keeping global warming within 2 degrees Celsius targeted by global agencies like the International Energy Agency (IEA). Subsurface injection of CO_2 has been carried out in the oil and gas industry for decades and is widely acclaimed as the most established CCUS pathway. When anthropogenic CO_2 captured for CCUS is sourced from hydrogen generation units of the steam methane reforming process, it results in low-carbon hydrogen, known as blue hydrogen. As the process reduces the overall carbon footprint, it is getting wider attention for adoption in many countries.

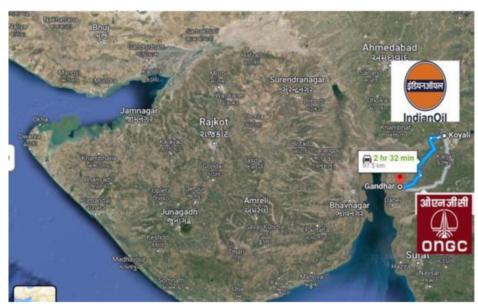

Figure 1. *CO_2 source (Koyali oil refinery, IOCL) and sink (Gandhar oilfield, ONGC)*

India's energy needs and its ambitious target to net-zero status by 2070 demand low-carbon development routes. India has performed well in its efforts towards transition to renewable energy. However, cutting down fossil fuel-based value chain carbon footprint is crucial

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[1]ONGC, India.

Emails: mishra_gaurav@ongc.co.in; kumar_mr@ongc.co.in; mitra_sujit@ongc.co.in; sahu_sk@ongc.co.in; aman-balendra@ongc.co.in

to achieve net-zero objective. Enhanced oil recovery by carbon dioxide injection (CO_2-EOR) as CCUS meets energy security and emission reduction goals. This paper describes the collaborative efforts made by ONGC and Indian Oil Corporation Limited (IOCL) in designing India's first Integrated CO_2-EOR as CCUS cum blue hydrogen project. The project is undertaken through the aegis of a memorandum of understanding (MoU) between these two companies. The MoU envisages capturing CO_2 from IOCL's Koyali refinery and its utilization in Gandhar oilfield of ONGC, about 80 km away from the refinery (Figure 1). The novelty of the project includes not only low carbon footprint oil production but also production of blue hydrogen by sequestrating CO_2 captured. Low-carbon blue hydrogen envisaged to be produced in this project shall contribute to the National Hydrogen Mission announced by the government of India and shall be a cost-effective source of hydrogen until technology breakthroughs pave the way for at-scale production of green hydrogen, through electrolysis of water using renewable energy, in an economically viable way. The feasibility studies relating to incremental oil recovery, sequestration potential, carbon capture plant, trunk pipeline, surface facilities, etc., were carried out by both ONGC and IOCL for their respective parts. Laboratory and reservoir simulation studies conducted at IRS-ONGC have suggested that incremental oil recovery of around 10-15% can be achieved through sequestration of around 6 MMT of CO_2 with a requirement of 1500 tons per day. The CO_2 cost was estimated to be around USD 55-60 per ton. Although these studies suggested that the project is technically feasible, the project is very capital intensive and OPEX heavy like any other CO_2-EOR project using anthropogenic CO_2. Owing to the significance of CCUS, both from energy security and climate change mitigation perspective, such projects are amply supported by governments of many countries in the form of policy and grants to incentive deployment. India is yet to have its maiden CO_2-EOR as CCUS project. It is envisaged that such a venture could serve as a demonstration project, aiding to the understanding of the feasibility of CCUS from an Indian perspective and shall contribute immensely to deciding the fate of CCUS in India as well as that of blue hydrogen, which shares technological similarities with CCUS in its production process.

METHODOLOGY

For carrying out the feasibility studies of the CO_2-EOR as CCUS cum blue hydrogen project, the following broad steps were undertaken:

a) CO_2 source-sink matching

b) Screening of reservoirs for CO_2-EOR

c) Laboratory studies

d) Compositional numerical simulation

e) Feasibility study of capture plant, CO_2 transportation, and produced fluid processing facilities at oilfield

f) Techno-economical evaluation

a) CO_2 source-sink matching

Matching a large point source of carbon dioxide to its potential sink in an aging oilfield is a fundamental prerequisite of any CO_2-EOR as a CCUS project. A suitable source-sink matching not only ensures long term decarbonization of industrial source but also has a significant bearing on overall economic feasibility of the project. While on the one hand, Cambay Basin of western India is one of the oldest oil-producing basins of India, on the other, the western Indian region is also counted among the most industrialized regions of the nation. This makes the area a natural choice for scouting for source-sink matching. IOCL Koyali refinery, at an approximate distance of 80 km away from ONGC's western onshore field of Gandhar was found to be a suitable candidate for sourcing CO_2 for EOR.

Table-1: Reservoir parameters for CO_2-EOR

Depth (ft)	<9800 and > 2000
Temperature (°F)	<250, but not critical
Pressure (psia)	>1200 to 1500
Permeability (md)	>1 to 5
Oil gravity (°API)	>27 to 30
Viscosity (cp)	<10 to 12
Residual oil saturation	>0.25 to 0.30

b) Screening of reservoirs for CO_2-EOR

The screening criteria for CO_2-EOR as per National Energy Technology Limited (NETL), Department of Energy (DOE), USA is tabulated below (Table-1):

Based upon source-sink matching exercise and favorable reservoir and fluid parameters, a mature waterflooded Gandhar oilfield was screened to carry out further studies to ascertain feasibility of CCUS.

c) Laboratory studies

Minimum Miscibility Pressure (MMP), the lowest pressure at which the reservoir fluid and the injected fluid attain the miscibility condition, is a vital parameter for any gas based EOR project. The extent of incremental oil recovery achieved though CO_2- EOR method is a strong function of MMP. Once CO_2 becomes miscible, it leads to a reduction of interfacial tension to zero causing displacement efficiency to be very high. Additionally, attainment of miscibility or lack thereof also regulates the advent time of breakthrough of injected CO_2 at the producer wells. Hence, laboratory experiments were carried out in a slim-tube apparatus to determine the MMP for the Gandhar oil with CO_2 as the injected fluid. Laboratory studies indicated that CO_2 is miscible with reservoir oil at 240-250 kg/cm^2 which is lower than initial reservoir pressure, deeming CO_2-EOR to be technically suitable for the reservoir as evident from Figure 2 showing more than 90% incremental recovery upon injection of 1.2 pore volume of CO_2.

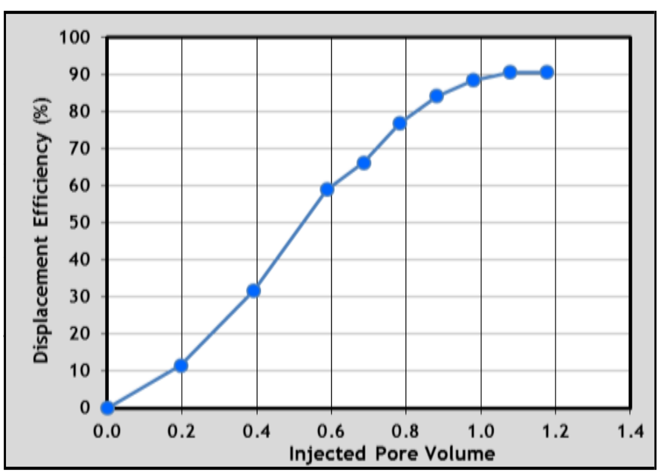

Figure 2. Experimental results of slim tube test.

After slim-tube test, a core flooding laboratory experiment was carried out. At first, water flooding was carried out followed by CO_2 injection and in the end water injection was done again as chase water. It was observed (Figure 3) that water flood recovery was 43.46%, CO_2 flood recovery was 14.92%, followed by 2.48 % of additional recovery from chase water injection.

These laboratory results suggested that CO_2 injection can be technically suitable for the field.

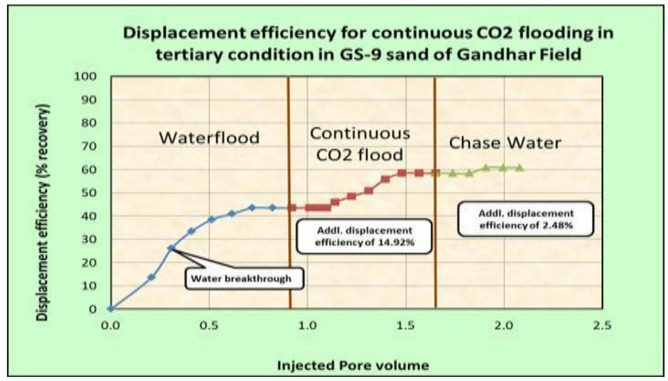

Figure 3. Experimental results of core flood apparatus.

(d) Compositional numerical simulation

The geocellular model (Figure 4) with all petrophysical properties was imported in the compositional simulator. The porosity and permeability distribution based on different rock types, residual oil saturation to water (SORW), residual oil saturation to gas (SORG), and Net-to Gross (NTG) were imported from the static model and were modified to compositional simulator compatible project file. The model was initialized using the different OWC's for four different blocks.

After the historical matching of the numerical simulation model, the model was simulated in predictive mode. The prediction runs are based on the liquid rate control mode having a BHP limit of 40 ksc while the injectors are put on rate control with maximum BHP limit of 280 ksc. The miscible residual oil saturation (SORM) has been considered as 0.05 for miscible CO_2 flood. The CO_2 injection rate has been constrained with unit voidage replacement ratio. Cut-off applied on producers are: liquid rate ~ 50 m^3/day, 99% water cut and 3500 v/v GOR. Numerical simulation indicated that CO_2 injection can be very successful in the field. Numerical reservoir simulation with dual objective of EOR and CO_2 storage is indicative of incremental oil recovery of around 10-15% with CO_2 requirement of 1500 ton-per-day and sequestration potential of around 6 MMT.

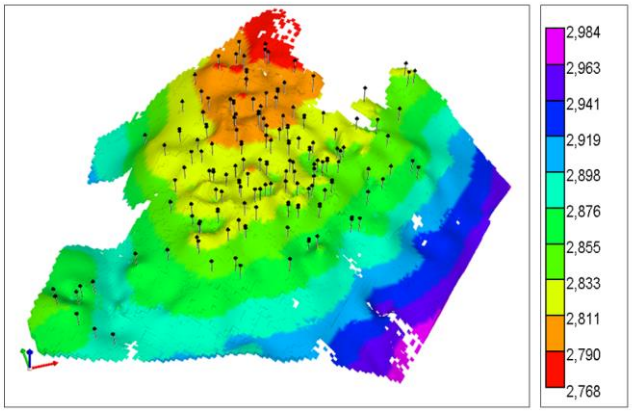

Figure 4. *Geocellular model of the CO_2 sink reservoir, depth(m). Pinheads in the figure represent well locations.*

(e) Surface facilities-feasibility

On surface facilities feasibility front, pipeline mode of transportation of captured CO_2 was found to be the most suitable. Pipeline design revealed that considering source-sink distance of 80 km, optimum pressure level of CO_2 transportation to be 100 kg/cm^2, with design parameters being Nominal Pipe Size (NPS) 8 inches and grade API-5LX70. Compression philosophy for pressuring CO_2 to well head injection pressure of up to 230 kg/cm^2 was split into 2 steps. First compression up to 100 kg/cm^2 using multi-stage compressor and beyond that using pump harnessing supercritical behavior of CO_2. In order to ensure closed loop operation for handling of produced fluid a hub approach with common CO_2 handling, separation and reinjection facilities is proposed.

(f) Techno-economical evaluation

The CapEx of the project is estimated to be around USD 600-700 million. At CO_2 estimated cost of USD 55-60 per ton, CO_2 accounted for around 70% of project OpEx cost. Integrated techno-economics shows a break even at oil price of USD 160-170 per barrel.

CHALLENGES

Criticalities of CO_2-EOR as CCUS can be categorized into technical as well as pertaining to commercial viability under current policy/fiscal scenario. Some of the criticalities include: high investment at source end to capture high purity CO_2, high upfront capital cost at oilfield end for requirements not limited to CO_2 compatible metallurgy for tubulars, pipelines and processing facilities, separation and handling of CO_2 produced along with reservoir fluids requiring dedicated additional surface facilities, increased OpEx and requirement of robust monitoring system During a CO_2-EOR process, injected CO_2 becomes miscible with oil and little CO_2 produced in the beginning. However, in due course of time, there is presence of CO_2 fraction in produced stream. Since this shall be a CCUS project, CO_2 from the produced stream of oil wells must be separated, compressed, and re-injected into the reservoir thereby avoiding escaping of CO_2 into the atmosphere resulting in closed-loop operation.

Establishing robust measurement and monitoring frameworks is a key requirement of CCUS projects. These monitoring frameworks are needed to provide confidence and certainty regarding the use of this technology as an atmospheric CO_2 emission reduction tool. It is the inclusion of dedicated Monitoring, Verification, and Accounting (MVA) or Measurement, Monitoring and Verification (MMV) program which is one of the key distinctions between a pure CO_2-EOR project and a CCUS project. Several surface, near surface and sub-surface technologies under the umbrella of MMV/MVA are required to be employed to generate baseline data, during injection and post injection monitoring & surveillance.

SUPPORT REQUIRED

Economic analysis of a CO_2-EOR as a mode of CCUS entails integration of cost to be incurred in the entire life cycle of the project. Cost of capture, compression, transportation, and injection is the first component of the operation. The second component is the cost of drilling of wells and building surface facilities for treating the produced fluid, separating the produced CO_2 from the stream and re-injection back to the surface. The third component is the operating cost (OpEx) of the capture to treatment recycling and monitoring. In absence of a firm business model of CO_2 delivery at the sink end and modalities of risk and reward sharing between various stakeholders in the entire value chain of CCUS operation, economic analysis at this stage has a high degree of uncertainty. The support required to accelerate the deployment of CCUS projects in India should include (a) policy framework for CCUS, (b) policy and incentives parity vis-à-vis other low carbon technologies, viz., renewable energy, (c) industrial hubs/clusters with collective carbon capture facilities, (d) inventive mechanism for carbon differentiated product, (e) carbon pricing, and last but not the least, (f) collaboration with other countries and global agencies.

CCUS : OPPORTUNITIES GALORE

CCUS forms the bedrock of energy transition strategies of oil and gas companies around the globe. Likewise, CCUS in India, offers opportunities to oil and gas companies to develop competitive advantage in this evolving sunshine sector, which is bound to get more prominence in the times to come. In line with international E&P companies, ONGC also considers CCUS to be a key component in its energy transition portfolio contributing towards its Net-zero 2038 vision.

CONCLUSIONS

CCUS is vital for combating adverse effects of climate change globally and for the oil and gas companies, in particular. As globally, such companies are embarking on their Net-Zero pathways, CCUS attains the center-stage of their energy transition strategies. CCUS not only enables significant reduction in carbon footprint of oil and gas value chain but also offers methodology for production of low-carbon blue hydrogen production. Success of CCUS in India will not only increase domestic oil production but also cater to address the national Net- Zero-2070 ambition. With the above efforts, ONGC in collaboration with IOCL on path bringing the dream of India's first CO_2-EOR as CCUS to its fruition. The learning curve from this mega project shall create a knowledge base to further expand deployment of CCUS in India, bringing a large portfolio of reservoirs under its ambit and opening gateway for pure sequestration projects in future. This study is aimed at disseminating novel multi company, integrated upstream and downstream collaborative approach to decarbonize the hydrocarbon industry. As CCUS is a complex and multifaceted subject, this paper offers a template for ideation and design of a CCUS project with identification of suitable technological options in the CCUS value chain.

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BIOGRAPHIES

Gaurav Kumar Mishra is a reservoir engineer at Oil and Natural Gas Corporation Limited (ONGC), with more than 13 years of experience in various facets of the E&P industry, spread across his two postings, initially at ONGC Assam and then at the Institute of Reservoir Studies(IRS), ONGC Ahmedabad. Currently, he is part of the core team responsible for the Carbon Capture Utilization and Storage (CCUS) projects of ONGC. He along with his team have carried out feasibility studies of CO_2-EOR as CCUS project in the Gandhar oilfield of ONGC, in collaboration with Indian Oil Corporation, also a public sector enterprise. Gaurav has been part of several Government of India initiatives in CCUS. He contributed to the preparation of "CCUS: Policy Framework and its Deployment Mechanism in India" by NITI Aayog, and "2030 CCUS Roadmap for upstream" under the aegis of the Ministry of Petroleum and Natural Gas (MoPNG).

Rakesh Kumar Meena, Chief Manager (Reservoir), is currently posted as Head of Heavy Oil development group, at the Institute of Reservoir Studies (IRS)-ONGC, Ahmedabad. He has 20 years of diverse reservoir engineering experience spread across multiple work centres of ONGC namely Mumbai offshore, Agartala and IRS. He is a reservoir simulation expert with a forte in EOR. He has designed a wide variety of EOR processes in ONGC including In-situ combustion, steam, polymer, ASP, etc. He has played a key role in the feasibility study, pilot design, planning, execution and monitoring of many of the EOR projects in ONGC, resulting in the rejuvenation of mature oil fields of ONGC. He has also led CCUS activities at IRS including designing of ONGC's flagship CCUS project in Gandhar area. Being a member of many committees related to CCUS and EOR, he has been actively contributing to development of these novel technologies in ONGC and India.

Sujit Mitra, Chief General Manager (Reservoir), is currently posted as subsurface manager at Rajahmundry Asset of ONGC. Prior to this, he was Head of Laboratories at the Institute of Reservoir Studies (IRS),ONGC, Ahmedabad. He is an O&G industry veteran with more than 25 years of experience. His expertise lies in field development, Enhanced Oil Recovery (EOR), and Carbon Capture, Utilization, & Storage (CCUS). He has played a critical role in the implementation of flagship EOR projects of ONGC, contributing immensely to all types of complex Enhanced Oil Recovery (EOR) projects of ONGC, namely thermal, chemical, and gas-based. Beyond his technical achievements, Sujit has been an active participant in several committees of the Government of India, contributing his expertise in matters related to EOR and CCUS. His insights have been invaluable in shaping policies and strategies that align with national interests and sustainable development goals.

Sunil Kumar Sahu, Chief Manager (Reservoir), is currently posted as Head of Petrophysical and Gas Injection & CCUS Laboratories, at the Institute of Reservoir Studies (IRS), ONGC, Ahmedabad. He has 18 years of diverse reservoir engineering experience. Prior to IRS, he also served as a part of subsurface team at Mumbai High Asset and Assam Asset, where he contributed immensely towards field development activities of some of the most iconic fields of ONGC namely Mumbai High and Rudrasagar. Currently, he is at the helm of establishing state-of-the-art CCUS laboratory at IRS, which has undertaken innovative laboratory studies using slim tube and core flooding apparatus analysing CO_2 injection behaviour in the porous media filled with reservoir fluids. Additionally, he is also In-charge of Health, Safety and Environment (HSE) and ISO at IRS. Under his leadership IRS has complied HSE norms laid down by ONGC and has also maintained ISO certification

Balendra Singh Aman, a graduate in Petroleum Engineering, joined Oil & Natural Gas Corp. in 2016 as an Assistant Executive Engineer (Reservoir). He started his career with Reservoir Field Services where he was tasked with reservoir data acquisition and interpretation e.g. pressure build up, pressure fall off, influx studies, etc. Subsequently he also worked with the subsurface team at Assam Asset; and as a team member he was associated with various activities, e.g. classical reservoir analysis, reservoir database management, and work-over candidate selection, planning and monitoring. He is currently working with Gas Injection & CCUS Laboratory at Institute of Reservoir Studies (IRS) and contributing to various studies which are being carried out by the laboratory such as Minimum Miscibility Pressure estimation and core flood studies in various modes.

Candy Cane Mountain, Quba, Azerbaijan. Part of the Greater Caucasus Mountain range, the Candy Cane Mountains earned their nickname thanks to their striking resemblance to the classic Christmas treat. The color of these rocks is a product of the area's unique geology. *(Photo courtesy: Ritesh M. Joshi)*