Pak. j. life soc. Sci. (2024), 22(2): 2725-2738 E-ISSN: 2221-7630;P-ISSN: 1727-4915

Pakistan Journal of Life and Social Sciences

www.pjlss.edu.pk

https://doi.org/10.57239/PJLSS-2024-22.2.00199

RESEARCH ARTICLE

The Room for Growth Applications of Carbon Dioxide Recovery Technologies in the Petroleum Industry

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ARTICLE INFO

Received: May 19, 2024

Accepted: Aug 23, 2024

Keywords

Petroleum industry

Climate change

Carbon dioxide

Sustainability

Carbon dioxide recovery

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ABSTRACT

One of main sources of energy in the world, the petroleum sector, also makes a substantial contribution to greenhouse gas emissions, with a focus on carbon dioxide CO2. The use of CO2 recovery methods in this sector is gaining a lot of attention as a result of growing social and governmental pressure to reduce climate change. The prospective uses and advantages of several CO2 recovery technologies, including CCS, CCU, and EOR are key Different fields of study look into technologies that can be used to control and reduce carbon dioxide emissions." this study. With CCS technology, we can capture CO2 from factories and store it safely in places like deep underground aquifers or old oil and gas wells. Another interesting use is CO2 injection enhanced oil recovery (EOR)...oil reservoirs to maximize crude oil extraction. This technique reduces emissions while concurrently increasing oil recovery. Rates and storing CO2 underground, yielding two benefits: resource optimization and emission reduction. By improving oil recovery and producing marketable goods, the petroleum sector and CO2 recovery systems can work together to significantly reduce carbon emissions while increasing economic returns. However, the deployment of these technologies faces technical, economic, and regulatory challenges. The paper discusses these obstacles and emphasizes the necessity for robust policy frameworks, technological innovation, and collaboration among industry stakeholders, government agencies, and academic institutions. By addressing these challenges, the petroleum industry can play a pivotal role in advancing CO2 recovery methods, contributing to global climate mitigation efforts, and transitioning towards a more sustainable energy future.

INTRODUCTION

The petroleum industry is a top contributor to CO2 emission, requiring cost-effective techniques to capture and mitigate these emissions. Carbon dioxide captures Combustion techniques, including post-combustion, pre-combustion, and oxy-fuel combustion. Aim to collect and separate CO2 from flue gases emitted during industrial processes. Membrane separation and ccs technologies can further reduce the industry's carbon footprint. Recovery of "Carbon dioxide injection is a method used in enhanced oil recovery., synthesis of valuable chemicals, synthetic fuel production, and construction materials, promoting a circular economy approach. These techniques aim to reduce industry's dependence on fossil fuels and promote sustainable practices.

1.1 CO2 Emissions In the oil and natural gas sector

The largest industry on the planet petroleum sector is mostly responsible for 42% of global CO2 emissions in 2018, which adds significantly to climate change and global warming. 5.1 billion tons of CO2-eq was produced by oil and gas operations in 2022, an increase of 2.8% from the previous decline brought on by COVID-19. (Tiseo. Oil and gas, 2018; IEA, 2023)

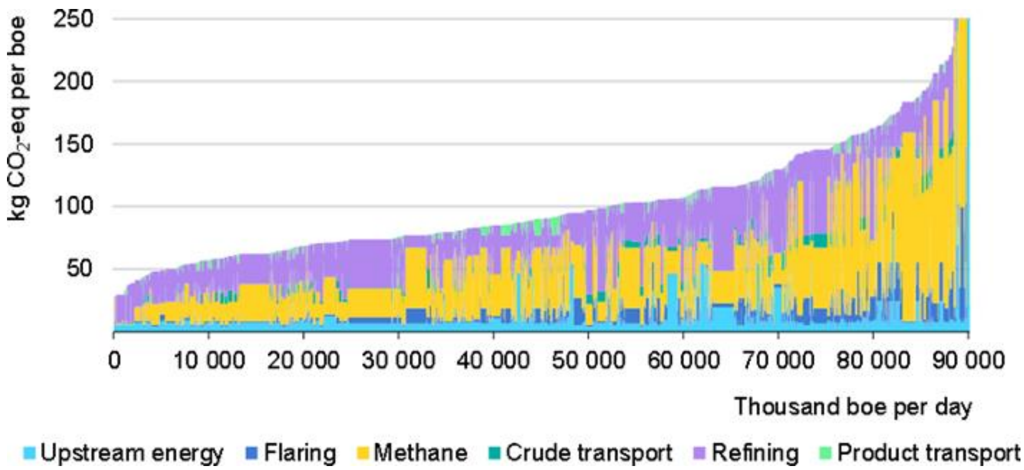

Figure 1: Range of scope 1 and scope 2 oil emissions intensities, 2022. (From IEA, 2023))

By producing petrochemicals, refining oil, and extracting oil, the petroleum industry adds to greenhouse gas emissions. Along the supply chains for gas and oil, these pollutants originate from a number of places. 450 Mt of Oil productions in 2022, from getting it out of the ground to delivering it, led to CO2 emissions. CO2 emissions from gas flaring at oil-producing sites totalled 260 million tons. 270 Mt of CO2 were released during the extraction, processing, and transportation of natural gas. (B. Ata, et al, 2023)**.** Man-made sources of GHGs in the atmosphere:

Greenhouse gas emissions are primarily driven by a variety of sectors, with the following breakdown:

Power Generation It makes up 25% of emissions, mostly from burning fossil fuels. Deforestation contributes 20% of emissions, releasing both CO_2 and methane through the loss of trees and forest degradation.

Road Transportation is responsible for 13% of emissions, largely due to the burning of gasoline and diesel fuel.

The Oil & Gas Sector contributes 6% of emissions, primarily from the whole oil and gas pipeline, from getting it out to getting it to people.

More specific: Fertilizer Production accounts for 6% of emissions, with methane being released during the manufacturing process.

Livestock contributes 5% of emissions, primarily through methane released from animal digestion.

Cement Production accounts for 4% of emissions, with CO_2 released during the manufacturing process.

Air Travel contributes 3% of emissions, including both CO_2 and nitrous oxide (N_2O) from aircraft engines.

Steel and Iron Making accounts for 3% of emissions, with CO_2 released during the production process.

Waste and Garbage contribute 3% of emissions, with methane being released from the decomposition of organic matter in landfills.

When an oil barrel is burned by the final user, 75–80% some of the greenhouse gases it holds are emitted into the atmosphere. • During the upgrading and refining process, 12–15% emits

During the extraction and production of oil, 7–10% is released. 1-2 per cent is released while transporting crude oil.

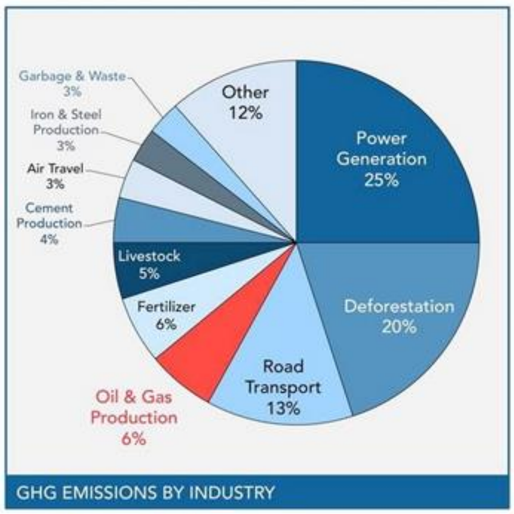

Figure 2: **GHGs emissions by industry. (From Air emissions. Oil Sands Magazine, 2018)**

2. Methods of carbon dioxide recovery

An increasing number of people are interested in carbon dioxide (CO2) recovery techniques as a result of the pressing need to slow down climate change, particularly in sectors like the petroleum industry that have substantial CO2 emissions. This study examines several CO2 recovery techniques, with an emphasis on Technologies for oil recovery and carbon management including Techniques such as enhanced oil recovery, carbon capture and storage, and carbon capture utilization. And utilisation. To ensure successful implementation, it is imperative to comprehend the mechanisms and uses of each of these strategies, as each one offers distinct opportunities and problems.

2.1Carbon Capture and Sequestration (CCS) by absorbing the carbon dioxide emissions produced when fossil fuels are burned for production of energy and industrial Carbon capture and storage is a technique used in these activities. (CCS) keeps CO2 from entering the environmentFollowing capture, CO2 is transferred and sequestered in geological formations beneath the Earth's surface. The International Energy Agency (IEA) states that extensive decarbonisation required to satisfy global climate targets cannot be achieved without CCS (IEA, 2020).

2.1.1. Technologies of Capture

The three primary phases of CCS are capture, conveyance, and storage. Various technologies can be employed to extract CO2: Post-combustion capture is a process used to separate and capture CO2 from flue gas emissions. Gases left over after burning fossil fuels. It is the most adaptable and may be adapted into power plants and industrial buildings that are already in place. An amine is a common solvent used in this process; it absorbs CO2 from the exhaust gases **(**Global CCS Institute, 2021).

Pre-Combustion Capture: In this method, the fuel Gasification of the feedstock results in the production of syngas, a mixture primarily consisting of hydrogen and carbon monoxide. This is subsequently combined with steam to create hydrogen and carbon dioxide. This method is more efficient because the CO2 is caught before the combustion process, but it usually requires additional infrastructure (Rubin, et al., 2015).

Oxy-Fuel Combustion: This method produces flue gas primarily composed of CO2 and water vapour by burning fossil fuels in pure oxygen as opposed to air. A somewhat pure stream of CO2 is left behind after the water vapour condenses which can be collected and stored (IEAGHG, 2020).

Transportation

Transportation CO2 needs to be moved to a storage location after it is caught. Pipelines are usually used for this, as they are seen to be the most economical and effective way to transfer CO2 on a wide scale. There are other options, such as shipping and rail or road transportation, although these are typically less cost-effective (NETL, 2021).

Storage

Injecting the captured CO2 into deeply subterranean rock formations is the last phase. Examples of potential storage locations for [insert what is being stored, e.g., Depleted oil and gas reservoirs and deep saline aquifers are considered suitable storage locations for captured carbon dioxide.

and unminable coal seams... To guarantee that the CO2 is kept safely in storage and doesn't escape into the environment, monitoring and verification are essential (Benson & Cole, 2008).

Possibilities and Difficulties: High costs, the necessity for substantial infrastructure, and the energy requirements for collection and compression are just a few of the difficulties that CCS faces. On the other hand, cost reductions could come via economies of scale and advances in capture technology. To further increase its potential for mitigating climate change, CCS can be used with renewable energy sources to produce negative emissions (IEA, 2020).

3. Benefits co2 recovery techniques

The petroleum industry, a major emitter of CO2, is focusing on CO2 recovery techniques to capture and recover emissions, thereby preventing their Minimizing emissions to the atmosphere and mitigating their consequences for climate change .The benefits are as follows:

- Reduction of greenhouse gas emissions
- Enhanced oil recovery
- Economic opportunities
- Corporate social responsibility

Economic Viability of CO2-EOR

In developed fields, CO2-EOR operations greatly increase oil recovery rates. The economic viability of this process relies on the feasibility of CO2 capture, taking into account its cost and availability of transportation infrastructure, and China's infrastructure investment in CCS. Dynamics in oil prices, production costs, and prospective income all affect profitability. (Hai, Y., et al., 2020; Martin-Roberts, et al, 2021)

Environmental Impact

Implementing CO2-EOR in onshore oil fields can have positive environmental implications. By using captured O2 originating from industrial sources or natural reservoirs. CO2-EOR can potentially reduce greenhouse gas emissions by sequestering CO2 permanently underground. This dual benefit of increased oil recovery and CO2 capture can contribute to China's efforts in combating climate change and reducing carbon emissions. However, the assessment should also consider the overall carbon footprint associated with CO2-EOR (Wei, et al, 2015), including the energy required for CO2 capture, transportation, and utilization.

3.1 Policy Implications

To improve oil output and energy security, the Chinese government is pushing sustainable energy technologies, such as CO2-EOR. The government should offer incentives like tax breaks, subsidies, and regulatory support to encourage this. Knowledge exchange and technological breakthroughs are contingent upon collaborations among research institutions, government agencies, and the oil sector. The efficacy of carbon dioxide injection for enhanced oil recovery has been proven by the Weyburn-Midale Field in Canada and Kern River, leading to a decrease in greenhouse gas emissions and an increase in oil output. According to Kuwait's case study on carbon capture technology, depending on the technology employed, the cost per ton of recovered CO2 might range from $30 to $60. Policymakers, investors, and industry specialists can use these studies to plan Kuwait's shift to a low-carbon economy. (Thomas, D. R. , 2003)

3.2 CCS Assessment

3.2.1 CCS: The Technical and Operational Problems

There are operational and technical obstacles to the petroleum The integration of Carbon Capture and Storage (CCS) technology within industrial sectors .Designing and building subterranean and subsurface storage reservoirs, which must endure high temperatures and pressures, is the primary technological challenge. For transportation, the recovered CO2 needs to be compressed to a high pressure, which takes a lot of energy and infrastructure. The creation of a legal framework, continuous monitoring, and safety management are examples of operational difficulties. Using cutting-edge technologies to increase efficiency or looking into different funding structures are two ways to find solutions. Large-scale projects require the construction of infrastructure, and a sustainable energy mix requires The synergistic integration of CCS and renewable energy technologies, specifically solar and wind power. (Martin-Roberts,2021; Mohammad, N., et al, 2021; Størset, S. et al, 2019)

3.2.2 Environmental Impacts of CCS

Carbon capture and storage is a viable approach for mitigating climate change, but its effects on the environment, society, and engineering must be carefully considered. Although there is little chance of CO2 leaks, the technology can lower emissions and lessen the effects of climate change. CCS can support the development of new technologies and jobs even with its high cost. However, community involvement and openness are required to address safety and public health concerns. For safe and effective CO2 recovery, engineering planning and design are essential, and advances in computer modeling, materials science, and geophysics can help CCS. (Harding, F.C,et al, 2018; Shaw, J.et al, 2009)

3.2.3 CO2 Assessment

Effect of CO2 Injection Rate: High injection rates can boost oil output, but they also raise expenses and necessitate additional CO2 facilities, according to the link between CO2 injection rate and oil production. High injection rates can also lead to CO2 back-migration and destroy reservoir cap rock. **(Tunio, S.Q., et al, 2011)**

Effect of Amount of CO2 Injected: In support of the anticipated association between CO2 amount and total oil output over a 15-year period, Azzolina's analysis finds a substantial relationship between CO2 injection volume and oil production augmentation.

Effect of Temperature: Oil production increases as a result of temperature-induced increases in CO2 kinetic energy and an active CO2 phase. When temperatures are high, this impact is more substantial than CO2 vaporizing. Productivity increases when reservoir temperature rises because oil viscosity decreases. Low temperatures and high pressures, on the other hand, are better for CO2-EOR processes because they reduce fingering and the effects of gravity override, which improves oil recovery. It is essential to comprehend how this parameter affects oil output in order to draw conclusions. (Abuov, Y. et al, 2022)

Impact of Total CO2 Injected: Following a review of the while all other parameters were kept constant: This is a more formal way of saying "while maintaining all other parameters at the same levels.

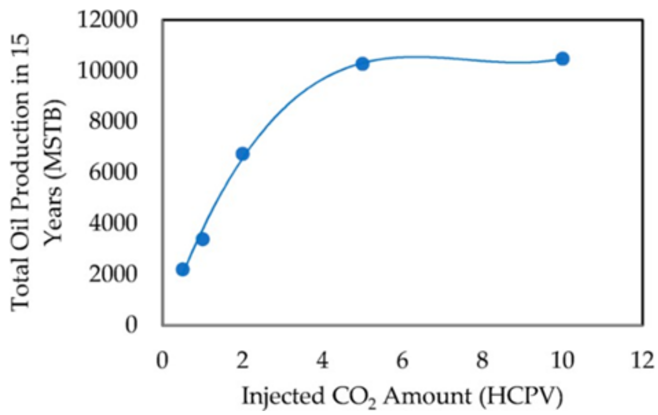

Figure 3: Variation in oil production according to CO2 injection volume. (From Tunio, S.Q., et al, 2011)

According to Comberiati and Zammerilli's earlier research, the figure indicates a notable increase in oil output with an increase in total injected CO2 from 0.5 HCPV to 10 HCPV. Accelerated CO2-induced mechanisms that enhance oil production are the cause of this rise. But after five HCPV, no more advantages are noted. (Tunio, S.Q., et al, 2011)

Effect of Temperature: To investigate the impact of temperature on oil production, the reservoir we changed the temperature from 20 °C to 500 °C, but kept the CO2 injection rate at 5 mmscf/day...

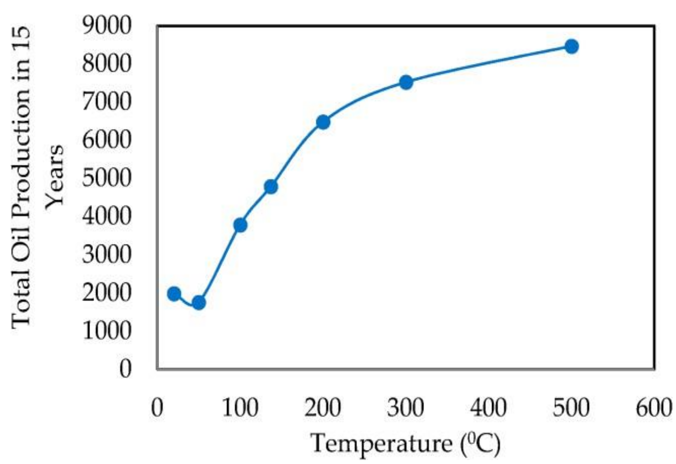

Figure 4: **Oil production fluctuates according to reservoir temperature. (From Tunio, S.Q., et al, 2011)**

Figure indicates that oil output seems to decrease The growth will stay the same until it hits about 50°C, then it'll start to grow faster as it gets hotter. After that. Comberiati and Zammerilli (Nasser, et al., 2023) found that oil recovery went down after the CO2 temperature reached 31.8°C and kept going down until it reached 55°C. Are comparable with the reduction in oil production with increasing temperature from 20 to 50 °C. These researchers claim that less interaction with oil occurs when CO2 begins to evaporate from the oil phase above the crucial temperature.

Impact of CO2 purity: Since injecting 100% pure CO2 is expensive, it is better to include a little amount of other gases (CH4 and/or N2) for financial reasons. It was also anticipated that CO2 purity would have a linear relationship with the rate of oil production, independent of the economic factor. The effect of infusing CO2 at purity levels of 60%, 70%, 80%, 90%, and 100% on oil production was the main focus of the study. The plan is to pump CH4 and N2, two commercially less expensive supplemental gases, in addition to the CO2 that is being injected (Nasser et al., 2023). In Figure 6, the effect over time is displayed.

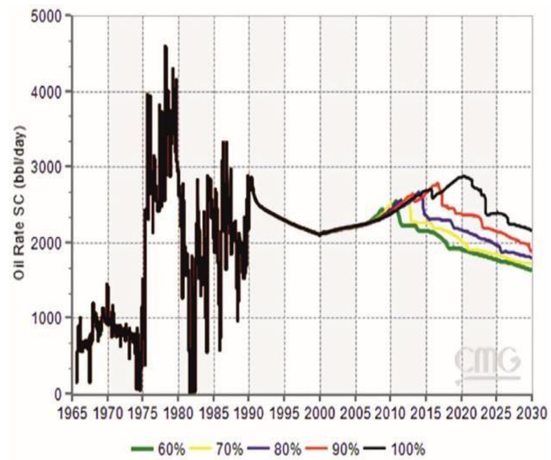

Figure 5: **The influence of CO2 purity on the rate of oil production (Nasser et al., 2023)**

Effect of soaking time: A study that varied the soaking times in a reservoir investigated the effects of injecting CO2. Longer soaking times raised oil production rates, although not much, according to the results. The more developed reservoir as a result of the closed production wells diverted CO2 to smaller pores, improving contact with the desired oil.

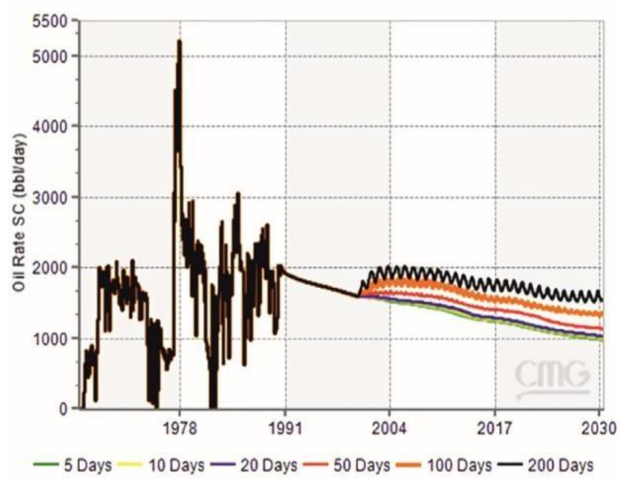

Figure 6: **Effect of soaking time on the oil production rate. (From Nasser, et al, 2023)**

4. Field examples

4.1 Field examples of CCS

Around the world, carbon capture and storage technology had been put into practice, proving its viability and efficiency in lowering CO2 emissions. This section presents a number of noteworthy CCS initiatives, highlighting their uses, successes, and contributions to climate change mitigation.

Project Sleipner CO2 Storage

Location: Norway's North Sea

Operator: Statoil, now known as Equinor.

Beginning in 1996

The Sleipner CO2 Storage Project, situated in the North Sea, is considered the world's first commercial-scale CO2 storage project. Implementation of carbon capture and storage technology. The Sleipner West field's natural gas production produces CO2, which is captured by the project. After that, the CO2 is extracted and injected into the Utsira Formation, a saltwater aquifer that is situated 1,000 metres below the surface of the ocean. Achievements: Since the project's beginning, more than 20 million tonnes of CO2 have been effectively injected and stored. The project has greatly advanced our understanding of CCS technology by yielding useful data on CO2 storage, monitoring, and verification (Torp & Gale, 2004**).** Carbon Capture and Storage in Boundary Dams Location of the Project: Saskatchewan, Canada

Operator: Saskatchewan Power

Commence 2014

The world's first fully integrated post-combustion CCS project on a commercial coal-fired power plant is the Boundary Dam CCS Project. By capturing CO2, Unit 3 of the Boundary Dam Power Station is kept from escaping into space by this initiative. Achievements: Every year, the initiative manages to seize about one million tonnes of CO2. The Weyburn oil field successfully combines CCS with EOR by using the captured CO2 for Enhanced Oil Recovery (EOR) (IEAGHG, 2015).

Quest for Capturing and Storing Carbon Location of the Project: Alberta, Canada

Operator: Shell

Commence 2015

The Quest CCS Project extracts carbon dioxide from the Scotford Upgrader's hydrogen production unit, which refines bitumen from oil sands. After that, the trapped CO2 is moved and pumped into a saltwater aquifer deep down.

Achievements: Since its beginning, the project has gathered and stored more over 5 million tonnes of CO2.

As a paradigm for upcoming CCS projects, Quest has achieved notable cost reductions and operational efficiency (Shell, 2020).

Location: Barrow Island, Western Australia; Project Name: Gorgon Carbon Dioxide Injection

Operator: BP

2019 is the start year.

One of the biggest natural gas projects in the world with a sizable CCS component is the Gorgon Project. Under this project, CO_2 is extracted from the Gorgon natural gas facility and injected beneath Barrow Island into a deep saline formation.

Achievements: During the course of its existence, the project hopes to store up to 100 million tonnes of CO_2 by injecting up to 4 million tonnes annually.

One of the biggest CCS projects, the Gorgon Project offers important insights on large-scale CO_2 storage (Chevron, 2020).

These real-world CCS project examples show how practical and efficient the technology is at lowering CO_2 emissions in a range of industrial settings. Each initiative advances the use of CCS technologies by offering insightful lessons on CO_2 capture, transportation, injection, and storage. The transition to a low-carbon future and the achievement of global climate targets depend on sustained investment in and research into CCS.

4.2 Field examples of EOR

Weyburn-Midale Field – Canada

Initiated in 2000, the Canadian Weyburn-Midale Field CO_2 Injection project sought to lower greenhouse gas emissions through the injection of carbon dioxide into oil reserves. The project, which is situated in southern Saskatchewan, aims to recover reserves and improve oil flow while showing the feasibility of carbon capture and storage technology**.** (B. Ata, et al, 2023)

EOR in the Kern River oil field (California)

In 1899, the Kern River heavy oil field was found close to Bakersfield, California. Due to the poor production of heavy oil in 1961—roughly 19,000 barrels per day—extra oil recovery was introduced in 1964 and 1966. Heavy oil output grew with the use of EOR, reaching 53,000 barrels per day in 1966 and reaching a peak of 141,000 barrels per day in 1985 before declining to 80,000 barrels per day (Braun, et al, 2019). The field has been producing for over a century, and EOR has contributed about 60% of the oil output.

Russian oil fields EOR

Numerous EOR procedures have been applied in Russian oil fields; nonetheless, it is challenging to determine the precise number of EOR projects that have been carried out. Russian oil production grew 2.5–2.8 times between 1996 and 2000, according to figures from oil corporations. 81–82% of the additional oil produced in Russia now comes from chemical EOR procedures, with current EOR oil production estimated at 17–18 MM tonnes.(IEA. , 2015b).

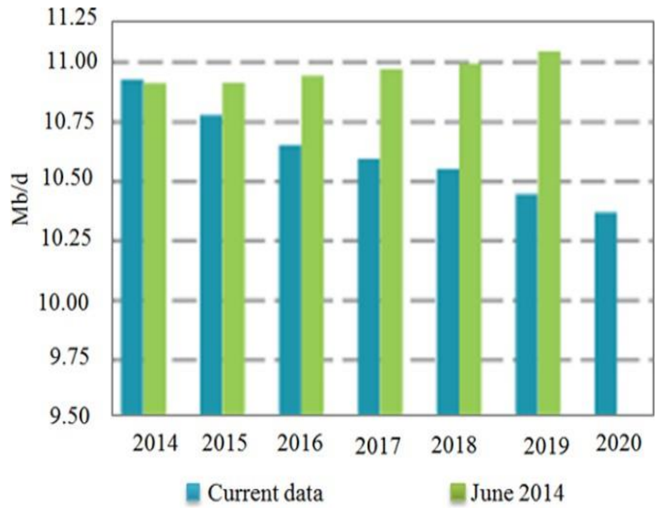

Figure 7: The IEA Oil Market Report (OMR) offers insights into the current state of Russian oil production. (From Nelder C., 2011)

Thanks to improved extraction methods, Oman, the Middle East's biggest producer of natural gas and oil, has recovered since 2007. EOR projects accounted for 16% of Oman's oil production in 2016, which is more than five times the production in 2012. **(Shandrygin, A., 2008)**

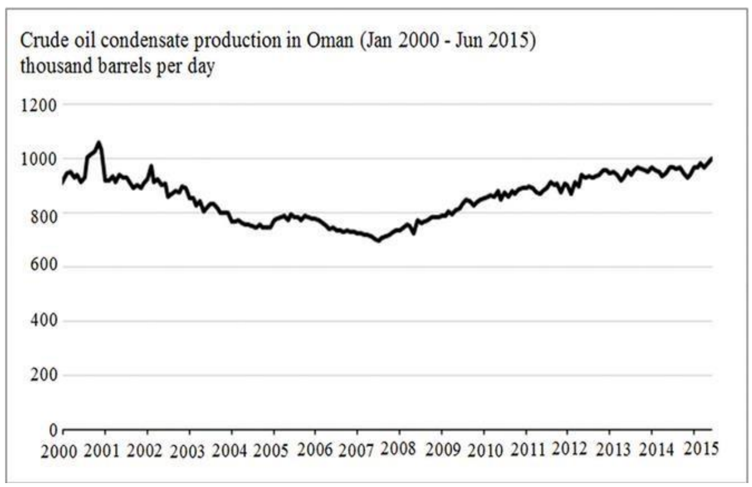

Figure 8: EOR impact on Oman Oil Production. (From Shandrygin, A., 2008)

The application of Enhanced Oil Recovery (EOR) techniques in the U.S. Permian Basin.

The US Permian Basin has successfully used Emission Reduction techniques since the early 1970s, beginning with two sizable CO2-EOR operations in 1985. Since then, other CO2- EOR projects have been undertaken; in 2010, production rates reached 200,000 b/d. The incremental oil output from CO2-EOR activities was 186,000 b/d in 2012 and 241,000 b/d in 2015; by 2020, production is expected to reach 301,000 b/d. (Kuuskraaa V., et al 2013)

CO2-EOR technology in onshore oil fields in China

According to China's economic assessment, CO2-EOR can raise production yields, accelerate oil recovery rates, and bring in more money. By storing carbon dioxide underground, cutting greenhouse gas emissions, and reaching national emission objectives, it also helps mitigate the effects of climate change. However, implementation calls for large infrastructure and technology expenditures; as technology advances and economies of scale are reached, costs should decrease. (Wei, et al, 2015)

CCS in Kuwait

The study examined the possible advantages and financial viability of introducing Carbon Capture and Storage in Kuwait's oil sector. It was discovered that using already-existing oil wells as storage locations might lower expenses and make money from CO2 captured. However, cooperation across stakeholders is required to handle issues like infrastructure development, technological adaption, and regulatory frameworks. (IPIECA, 2013)

5. CONCLUSIONS

3.5% of daily oil output is accounted for by the rapidly expanding worldwide market for emission reduction. Nowadays, 40–60% of the crude oil produced worldwide is produced using CO2. Operators aim to maximise both CO2 and oil recovery for each tonne of CO2 injected. CO2-EOR can utilise over 90% of global oil reserves; by 2050, a 0.1–1.8 Gt CO2 yearly utilisation rate is anticipated. EOR may maximise CO2 recovery rather than extracting oil, cutting expenses and emissions. EOR is commercially viable at oil prices of roughly $100 per barrel, based on -$100 per barrel of oil, if CO2 can be produced at $60–$45 per tonne. In the petroleum business, carbon emissions can be greatly decreased and oil recovery can be raised by combining enhanced oil recovery with carbon capture and storage. EOR pumps fluid into reservoirs to boost oil recovery, while CCS collects CO2 emissions from industrial activities. This strategy decreases drilling operations, boosts oil recovery from current wells, and prolongs the life of mature oil fields. On the other hand, difficulties include expensive implementation, technological problems, legal restrictions, and problems with public opinion. The petroleum industry places great importance on the economic feasibility of Carbon Capture and Storage and Emission Reduction technologies. These CO2 capture, transport, and storage systems have the advantage of improved oil recovery rates and potential revenue from the sale of CO2 that is recovered. On the other hand, implementation might be expensive. The price of oil has an impact on their economic feasibility as well. High oil prices can have significant advantages, even though low prices might make them more challenging. However, long-term policies and carbon price plans can make CCS systems more economically viable. Government incentives and regulations limiting carbon emissions may also contribute to their economic viability.

There are still unexplored and underdeveloped research areas regarding CCS and EOR.

To evaluate the economic viability of CO2-EOR, a cost-benefit analysis should be carried out, taking into account variables such as CO2 capture, transportation expenses, oil recovery rates, anticipated prices, project duration, and prospective profits.

Despite the lengthy history of CCS use, research on long-term CO2 behaviour and storage stability in geological reservoirs is essential, particularly for active or emerging sites.

Further study on CO2 injection and monitoring tactics is required. Optimizing injection and monitoring strategies for EOR operations is critical to lowering costs and environmental impacts.

Notwithstanding its ability to lower greenhouse gas emissions, CCS and EOR have an environmental impact that necessitates thorough evaluations to identify hazards and effects on soil, water, and air quality.

For the creation of sustainable energy, research on alternate technologies for storage and conversion—such as direct air capture and mineral carbonation—is essential.

In the country's onshore oil fields, a technique known as CO2-EOR—which makes use of CO2 collection infrastructure—can improve energy security, optimise oil recovery, and lower pollution. Nonetheless, in order to optimise the advantages, policy support, project economics, and environmental effects must be thought about. Profitability is a major impediment to broad implementation of carbon capture and sequestration, despite its critical importance to human life and economic advancement. Clear legislative requirements, including carbon pricing and emission reduction targets, are necessary for the safe adoption of CCS. Financial incentives can be helpful, but high operational expenses remain a major obstacle to the adoption of CCS. Technologies for CO2-EOR phase injection are likewise being improved, as is our knowledge of the variables that affect reactions. Prolonged large-scale deployment of CO2-EOR is encouraged by promising results from field trials that point to a possible commercial application. Results from field trials that point to a possible commercial application.

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