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Research paper

Prospects of carbon capture technologies for enhanced oil recovery in Nigeria's oil and gas sector

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Abstract

Nigeria, a nation with abundance of natural resources, has over the years generated its major revenue from the export of crude oil, one of its leading natural resources, obtained from different Oil fields in various states of the country. Revenue generated from this export constitutes the greater percentage of the country's gross domestic product (GDP) as a result of the local and international transactions involved in the transportation of this product. A good percentage of these Oil fields have been exploited while some are yet to be utilized. However, it has become an issue of great concern that approximately 40% of the original oil in place (OOIP) have not been recovered and hence allowed to fallow in the reservoir. Carbon (CO_2) capture as an innovative technology to enhance the recovery of OOIP in Nigeria oilfields is proposed. Various oil recovery technologies as well as CO_2 capture technologies were studied and their advantages outlined on how the latter can be significantly used in enhancing a greater percentage (40% - 60%) of oil recovery over a given period of time and fallow period. Technologies such as primary, secondary (chemical/binary) and tertiary oil recovery methods respectively, were reviewed. Oil recovery between 5 to 25% of OOIP, 6 to 40% of OOIP, and an additional (5 to 25) % totaling 40 to 60 % OOIP, were identified from primary, secondary, and tertiary oil recovery processes respectively. Conversely, modified CO_2 injection EOR is suggested as a more suitable enhanced oil recovery (EOR) method for low-pressure reservoirs in Nigeria. Although it is capital intensive, CO_2 capture for EOR have posed less threat to the atmosphere with an equivalent economic improvement and pollution reduction from studied literature.

Keywords: *Carbon Capture; Crude Oil; Oil Recovery; EOR; Pollution.*

1. Introduction

Causes, effects and remediation of global warming have generated lots of research interest stemmed towards proffering lasting solution to sustaining our environment. This warming has not only posed threats to the ecological habitat, but also humans, plants, soil threshing organisms and other essentialities, hence the need for a prompt and effective solution. Asides this effect, global warming also causes other concurrent damages, ranging from natural disasters to increased coastal flooding, longer and more detrimental wildfire seasons, destructive health impacts, costly and growing health impacts, etc. Considerable evidences exist to prove that the highest portion of this warming is derived from the greenhouse gas emission exiting from the combustion of fossil fuel by high impact industries [4]. Industrial activities have resulted to an increasing level of carbon emissions in the atmosphere because of the growing level of industrialization and urbanization in many developing countries. This has also led to a significant growth in global atmospheric concentration of anthropogenic greenhouse gases, leading to global warming and climate change. Common greenhouse gases present in the atmosphere include water vapour, chlorofluorocarbons (CFCs), hydro fluorocarbons (HFCs), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).
According to Yoro and Daramola [26] carbon dioxide (CO_2) is primarily responsible for 76% of these emissions while methane accounts for 13%, nitrous oxide 3%, sulphur oxide 7% and Fluorinated gases 1% respectively. This draws concerns to lots of researches suggesting controlled measures for of this (CO_2) emission. Results from diverse researches across the globe have logically made us to infer that the coherent method of reducing adverse impacts of CO_2 emissions in an era of global warming is to employ decarbonisation procedures [15]. This decarbonisation procedure involves capturing carbon and storing it in a geological site [Carbon Capture and Sequestration (CCS)] or initiating Carbon capture and utilization (CCU) [i.e., capturing this carbon and utilizing it for oil recovery enhancement]. Capturing CO2 from large point sources is necessary to minimize the high concentration of CO_2 emitted into the atmosphere. It is important to reduce carbon emissions from industries even as they continue to provide transformational infrastructure and technologies that advances a net zero future. CCS involves capturing CO_2 from point sources of emissions and injecting it into geological formations, where it would be permanently retained [16]. While broad deployment of CCS has significant potential for carbon mitigation, there is growing interest in using the captured CO_2 in a way that can create economic value, often referred to as carbon capture for enhanced oil recovery (EOR) which will serve as an alternative for existing oil recovery processes. The largest use of CO_2 today most especially in developed countries; EOR, creates economic incentives for long-lasting CO_2 storage of large volume in geological formations. Apart from EOR, in recent years, CCU

has increasingly become focused on converting CO_2 into carbon-based economically viable fuels and feed stocks, not merely for economic reasons but also because these products could reduce the use of their fossil fuel-based equivalents, act as a dense energy carrier for renewable electricity, and be important in a net zero emissions future [19]. Hence, in a country like Nigeria housing lots of carbon emitting industries and oil fields, it will be of great use if this method of CO_2-EOR is adopted in order to reduce gas flaring effects on the ecosystem and proffer improved percentage oil recovery. Hence, this research is centred on analysing diverse oil recovery process and prospecting CCU with further modifications in CO_2-EOR processes for optimum results in Nigeria.

2. Research overview

For decades, up until now, global warming has been one of the most prominent issues faced by the world at the local, national and global/international level. One obvious effect of global warming over the last 130 years (1880 - 2012) has been the incessant upsurge in temperatures across the globe. Awanthia and Navaratne [3], stated that, there has been an increase in globally averaged combined land and ocean surface temperature, pegged at 0.85^{o}C and have prospects for further rapid increment in years to come. Asides this effect, ongoing global warming results in other concurrent damages, ranging from natural disasters to increased coastal flooding, longer and more detrimental wildfire seasons, destructive health impacts, costly and growing health impacts and so on.

It is no news that increased greenhouse gas (GHG) emissions is the primary/major sources of global warming in our world today. Considerable evidences exist to prove that the highest portion of this warming is derived from the greenhouse gas emission from the combustion of fossil fuel by high impact industries [4]. Although there exists an ever-growing demand for energy required to support present day development and economic growth, the quest to maximize its benefit and minimize the drawbacks of available energy sources is gaining more significance. Several researches are ongoing on the creation of innovative alternatives to fossil fuels. While revolutionary breakthrough in terms of adequacy and sustainability of the green fuels emerging from these researches is much anticipated, temporarily, concerted effort in terms of result-oriented researches on ways of abating toxic emissions from burning of fossil fuels is also pertinent [16], [17]. End results from diverse researches across the globe have logically made us to infer that the coherent method of reducing adverse impacts of CO_2 emissions in an era of global warming is to employ decarbonisation procedures [15]. This process is what this present research tends to achieve. Decarbonisation, otherwise known as carbon capture from the chimney of high impact industries would be sequestered for utilization in EOR.

2.1. Global warming

One issue confronting developing countries in recent times is environmental degradation as a result of the indiscriminate atmospheric emission of CO_2 without appropriate emission control technologies [15]. Industrial activities have resulted in increasing level of carbon emissions in the atmosphere because of the growing level of industrialization and urbanization in many developing countries. This has also yielded a significant upturn in the global atmospheric concentration of anthropogenic greenhouse gases, leading to global warming and climate change. Common greenhouse gases present in the atmosphere include water vapour, chlorofluorocarbons (CFCs), hydro fluorocarbons (HFCs), methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2), and ozone (O_3). However, researchers have enumerated the four main greenhouse gases generating serious global attention today are CO_2, SO_2, CH_4, and N_2O [26].

Climate change results in a decline in global agricultural output due to low rainfall, fluctuation in seasons, and temperature rise while global warming is the long-term heating of earth's climate system. This heating has been observed right from pre-industrial times (1850 – 1900) till date, due to human activities, primarily fossil fuel burning [4].

Table 1: Greenhouse Gases and Their Sources [26]

Greenhouse gases	Sources	%Emission in 2019
Carbon dioxide (CO_2)	Combustion of fossil fuel, deforestation	76
Methane (CH_4)	Biomass consumption, Agricultural waste	13
Nitrous Oxide (N_2O)	Fertilizer use	3
Sulphur dioxide	Combustion of coal, oil, and diesel	7
Fluorinated gases (CFCs and HFCs)	Refrigeration	1

As observed in Table 1, greenhouse gas Carbon dioxide (CO_2) has the highest percentage emission and hence poses lots of threat to the atmosphere and surroundings.

2.2. CO_2 as a major contributor to Global warming

Right from the inception of the second industrial revolution, characterized by mass production and electricity generation, energy production was largely dependent on the combustion of fossil fuels. Power generation, cement production, and fossil fuels usage in many homes have led to the emission of significant amounts of CO_2 to the atmosphere over the past decades [15]. Capturing CO_2 from large point sources is necessary to minimize the high concentration of CO_2 in the atmosphere. However, the natural sources of CO_2 are closely balanced by naturally occurring phenomena such as rock weathering as well as photosynthesis.

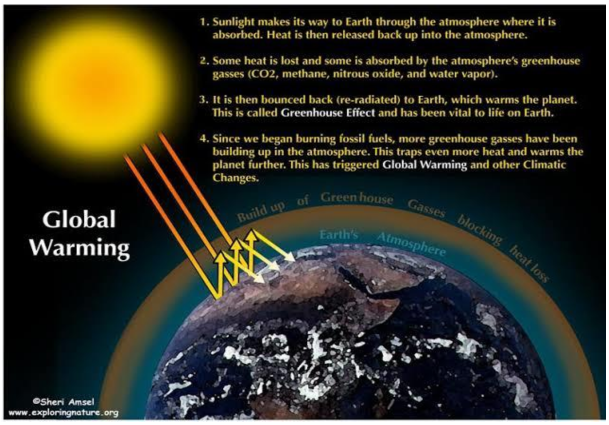

Fig. 1: Global Warming [15].

According to Yolo and Daramola [26], this balance has made the 260 atmospheric concentrations of CO2 to be as low as –280ppmv for 10,000 years before the start of the industrial era. The global fossil fuel estimate of CO_2 emission also increased to about 25,000 metric tons in 2002. Fossil fuels will still remain the primary source of energy which will be on the increase by over 90% [4], [26]. This reveals that global energy demand has been on the rise, and it is expected to intensify by over 67% by 2030. In view of this, it is necessary to identify the major sources of CO_2 emission and how to prevent it. Table 2 presents various CO_2 emission sources and methods of minimizing them.

Table 2: Major Sources of CO_2, Emission and Their Preventive Methods [26]

Sources	CO_2 emission (billion Mt)	Proposed preventive option
Anthropogenic/human sources		
Fossil fuel combustion engines	392	CCSU
Cement production plants	113	CCSU
Power generation (coal fired power plants)	279	CCSU, integration to methanol plant
Transportation	191	Blending fuels with biomass
Industrial manufacturing	178	CCSU
Land use changes	13	
Non-anthropogenic/natural sources		
Plant, animal and human respiration	7	
Ocean-atmosphere exchange	7	
Soil respiration and decomposition	1.54	
Volcanic eruptions	0.15	

As the knowledge of CO_2 emission mitigation is expanding, there is a need to update it with recent advances and future prospects that could result in a clean environment.

2.3. Global warming effects

According to the National Climate Assessment (NCA, 2018), human influences are the number one cause of global warming, especially carbon pollution caused by burning fossil fuels and the pollution capturing we prevent by destroying forest. The CO_2, CH_4, soot, and other contaminants released into the atmosphere act like a cover to the atmosphere trapping the sun's heat and warming the planet, evidence shows that 2000-2009 was hotter than any other decade in the past 1300 years.

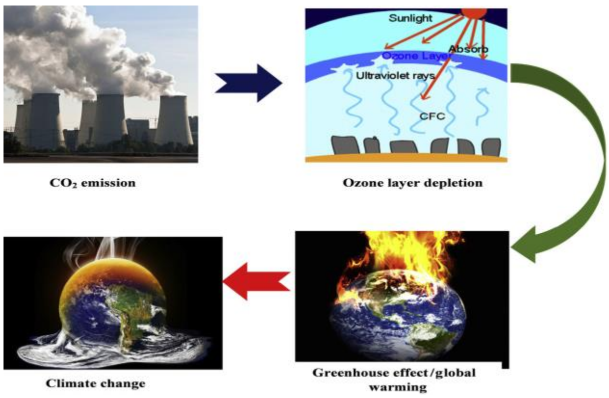

Fig. 2: Global Warming Stages [26].

This warming is varying the earth's climate system including its land, atmosphere, oceans, and ice in tremendous ways. The impacts of global warming span the physical environment, ecosystems and human societies. It additionally incorporates economic and social changes which stem from living in a warmer world. Diverse physical effects are already evident in our world today. They include; severe weather conditions, increased mortality rates, air impurities, increased rate of wildlife extinction, and higher sea levels etc.

2.4. History of carbon capture

The basic idea of capturing CO_2 and preventing it from being emitted into the atmosphere was first suggested in 1977; using existing technology in new ways. CO_2 capture technology has been utilized since the 1920s for separating CO_2 sometimes found in natural gas reservoirs from the saleable methane gas (CCS development sheet, 2016).
During the early 1970s, some CO_2 captured in this way from the gas processing facility in Texas (USA), was piped to a near- by geometric site and injected to increase oil recovery. This process, known as Enhanced Oil Recovery (EOR) has proven very successful and millions of tons of CO_2 both from natural accumulations of CO_2 in underground rocks and captured from industrial facilities are now piped into oil fields in the USA and elsewhere every year. Enunciated below is an overview of different options and supporting project.
Gas processing: Gas processing facilities, which extract natural gas from underground fields, often have to clean the CO_2 from the natural gas so as to enable it trade. These facilities therefore have to capture the CO_2 in large quantity before they have a useable commodity.
Power plants: Power plants that burn fossil fuels don't have to capture the CO_2 in order to produce electricity and the capture process will actually cost slightly more overall. So, capturing CO_2 from power plants is purely done for emissions reduction reasons.
Enhanced Oil Recovery (EOR): These projects have a use for the CO_2 captured in the processes stated earlier. This gives the CO_2 a value in monetary terms. The CO_2 is often extracted from the oil field along with the oil, but as it was expensive to purchase, this will be separated and can be used again to produce yet more oil. Finally, when all the oil has been extracted, the CO_2 can be left (stored) in the depleted oil field, thereby permanently preventing that CO_2 from being released into the atmosphere and hence contributing to greenhouse effect and global warming.

2.5. Decarbonization

Low carbon economy, low-fossil-fuel economy, or de-carbonized economy is an economy based on low-carbon power sources that therefore has a minimal output of greenhouse gas emissions into the atmosphere, specifically carbon dioxide [10]. The ultimate target is to achieve carbon neutrality, meaning a return to levels of CO_2 naturally present in the atmosphere prior to human intervention. The term decarbonization literally means the reduction of carbon. This process involves the conversion to an economic system that sustainably decreases and compensates the emissions of carbon dioxide (CO_2). The overall objective is to create a CO_2 free global economy. In this context, car manufacturers such as Volkswagen must commit to this goal alongside other economic sectors. According to the IPCC (Intergovernmental Panel on Climate Change), the transport sector accounts for approximately 14 % of the global greenhouse gas emissions with a potential to spike in years to come. This then calls for appropriate concerns from the Automobile industry in tackling this issue. Table 3 broadly enunciate the available CO_2 reduction strategies, their application areas, advantages and limitations.

Table 3: Existing Decarbonisation Procedures [14]

De-carbonization strategy	Application area/sector	Advantages	Limitations
Enhanced energy efficiency and energy conservation	Applied mainly in commercial and industrial buildings	Energy saving from 10% to 20% easily achievable.	Involves extensive capital investment for energy saving device installation.
Use of renewable energy	Hydro, solar (thermal), wind power, and biofuels highly developed	Use of local natural resources; low greenhouse emissions	Application may depend on local resources availability and cost.
Carbon capture and usage	Application to large CO_2 point emission sources.	It can reduce vast amount of CO_2 with capture efficiency > 80%.	CCS full chain technologies not proven at full commercial scale.

2.6. Industrial decarbonization

This process is very crucial as regarding the achievement of a livable climate future. Industrial activities such as manufacturing and construction are held accountable for roughly one-third of total greenhouse gas (GHG) emissions globally when including emissions associated with the electricity and heat purchased by industry – more than any other sector of the economy.
Even without indirect emissions, these processes contribute approximately one-fifth of global emissions. Fortunately, a combination of advanced technologies and well-designed policy now make it possible to achieve a zero industrial sector emission globally by 2050-2070 [2]. Diverse methods of industrial de-carbonization include; Carbon capture, air scrubbers, ultra-high efficiency gas turbines, power-fuel and automated power generation.

2.7. Carbon capture technology

According to the International Energy Agency (IEA), carbon capture and storage (CCS) is an indispensable measure to substantially reduce CO_2 emissions to meet the target (26 $GtCO_2$/year by 2030) sought by the international community. CCS involves the capture of CO_2 from point sources of emissions and the instillation of this CO_2 into oil fields or saline aquifers, where it would be permanently retained [16]. While broad deployment of CCS has significant potential for carbon mitigation, there is growing interest in using the captured CO_2 in a way that can create economic value, often referred to as carbon capture and utilization (CCU). Transforming industrial processes through electrification, alternative chemistries, hydrogen combustion, and other non-fossil fuel technologies can lead to zero CO_2 emissions outcome, but these technologies are likely to leave a level of "residual" CO_2 emissions unaddressed until after 2060 [19]. This introduces the essence of CO_2 capture and permanent removal, either via geological storage or embedding carbon within industrial products.
Capture of carbon dioxide from industrial processes is a well-established technology and has been used in the oil refining and natural gas processing sectors for decades. There are many methods available for capture, which can be classified as follows; Adsorption, Absorption and Membrane Separation.
Absorption: In this carbon capture process, a liquid sorbent is used to separate the CO_2 from the flue gas. The sorbent can be regenerated through a stripping or regenerative process by heating and/or depressurization. This process is the most mature method for CO_2 separation [22].
Adsorption: unlike the absorption processes that utilizes a liquid absorbent, a solid sorbent is used to bind the CO_2 on its surfaces. Large surface area, high regeneration ability and high selectivity are the main conditions for sorbent selection. Typical sorbents include molecular sieves, zeolites, activated carbon, hydro-talcites, calcium oxides, and lithium zirconate [2], [22].
Membrane Separation: Membranes unlike sorbents can be used to allow only CO_2 to pass through, while excluding other components of the flue gas. The significant part of this process is the membrane which is made of a composite polymer of which a thin selective layer is bonded to a thicker, non-selective and low-cost layer that provides mechanical support to the membrane [13], [20].

2.8. Carbon capture processes

According to Leung et al., [14], CO_2 is formed during combustion and the type of combustion process directly affects the choice of an appropriate CO_2 removal process. Although CO_2 capture technologies are available in the market, there are costly in general, and contribute to around (70–80) % of the total cost of a full CCS system including capture, transport and storage [10]. Therefore, significant research and developmental efforts are focused on the reduction of operating costs and energy penalty.

CO_2 capture processes are typically categorized according to three main methods: (i) post-combustion, (ii) pre-combustion and (iii) oxy-combustion.

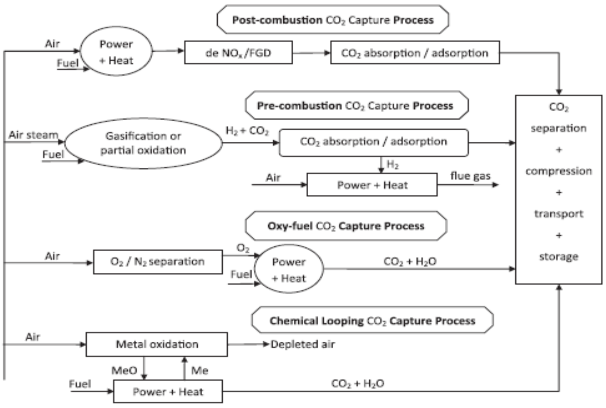

Fig. 3: CO_2 Capture Processes [14].

Pre-combustion: involves partial combustion of a fuel to produce carbon monoxide, which is then reacted with steam via the water-gas shift reaction to produce a mixture of hydrogen and carbon dioxide, which are then separated for subsequent use [19].

Post combustion: involves selectively capturing CO_2 from a flue gas produced during the combustion of fossil fuel and/or biomass in air [13]. The most common technique is chemical solvent scrubbing, for which there are decades of experience in the chemical and oil industries for the removal of CO_2 from gas streams, which is typically vented to the atmosphere [19].

Oxy-combustion: involves combusting the fuel in a nearly pure stream of O_2 instead of air and results in a flue gas with high concentration of CO_2 and water vapor (H_2O) because it is not diluted by the presence of N_2 in the air. As a consequence, the concentrated CO_2 can then be relatively easily separated by a physical gas-separation method, eliminating the use of solvents and sorbents and the associated environmental impacts [14].

2.9. Enhanced oil recovery processes

Crude oil fields have long been in existence and some of whose potentials have not been fully harnessed thereby leaving some percentage tonnes of crude materials laying fallow on the soil bed. Lots of oil recovery processes such as primary (natural drive or artificial lift) & secondary recovery process exist and have so far been useful to a great percentage. In order to further enhance this recovering, the utilization of carbon absorbed from flue gases is encouraged. This carbon will be injected in to the oil field (geographical site) so as to stimulate the oil recovery process to a valued percentage, a little equivalent to the cost of running just a Carbon Capture and Storage (CCS) system.

2.9.1. Primary oil recovery processes

This recovery process is usually applied in the initial production phase, exploiting the difference in pressure between the reservoir and the producing well's bottom. This "reservoir natural gravity drive" forces the oil to flow to the well and, from then, to the surface. Pumps or other artificial lift are employed to maintain the production once the reservoir drive diminished, due to the oil/gas extraction, and the primary recovery is, generally, completed when the reservoir pressure is too low, the production rate is no more economical and the gas-to-oil or water-to-oil ratio is too high. The oil recovered from the well during the primary stage is typically in the range 5-25% of originally oil in place (OOIP), varying as a function of oil and geological characteristics and reservoir pressure [1].

2.9.2. Secondary oil recovery processes

This method is initiated when primary recovery methods are no longer effective and/or economical. In secondary recovery, fluids (typically water, but other liquids or gases can also be employed) are injected into the reservoir through injection wells in order to increase/maintain the reservoir pressure, acting as "artificial drive" and then replacing the natural reservoir drive. CO_2 has been tested with limited success in this context. Economic criteria are applied to conclude secondary recovery practices. The recovery factor for this kind of operations ranges from 6 to 30% of originally oil in place, depending on oil and reservoir characteristics [5], [22], [23].

2.9.3. Tertiary oil recovery processes

Also known as Improved Oil recovery (IOR), is applied in oilfields approaching the end of their life and can produce additional oil in the range (5-15) % of OOIP for light to medium oil reservoirs, lower for heavy oil reservoirs. These operations are applied so as to improve the oil flow in the reservoir, by altering its flow properties or its interaction with the rock. One of these techniques is EOR promoted by CO_2 injection.

There are three main types of enhanced oil recovery:

Thermal recovery: adds heat to the reservoir, in order to reduce the oil viscosity, through steam injection, in-situ combustion or hot water. Reservoir depth for steam applications is limited due to heat loss associated with wells. Steam Injection can be applied to shallow reservoirs (< 1,500m) of heavy oil deposits that cannot be produced economically by primary or secondary methods, due to their very high viscosity.

In-situ combustion finds application in reservoirs containing light oils (> 30 °API). Thermal methods are best suited for heavy oil and tar sands reservoirs.

Gas injection: these methods are based on the injection of gas (HC, N_2, Flue gas, CO_2) into the oil-bearing layer where, under high pressure and reservoir conditions, the gas will mix with the oil, decreasing its viscosity and displacing more oil from the reservoir. A very good oil recovery can be guaranteed if the reservoir pressure is higher than the minimum miscibility pressure (MMP) that is a function of temperature and crude oil characteristics.
Chemical injection: The addition of chemicals (e.g. polymers/surfactants) to the injected water improves the recovery efficiency, through the IFT reduction or increasing solution water viscosity. This technique never had a wide diffusion and is currently declining, due to the high cost of chemicals, limitations for temperature applications, depth and oil density (15-30 °API).
As EOR becomes more popular and common place, advanced technology is required to continually assess and monitor the condition of the oil remaining in the oil field. One such technological development is the introduction of Carbon dioxide, of which this research is concerned with.

2.10. Carbon capture utilization oil recovery processes

Recovered CO_2 can be stored into geological formations such as deep saline aquifers or fallow oil fields which have no other practical use, and oil or gas reservoirs. Geological storage is presently considered to be the most viable option for large CO_2 storage in required to effectively reduce global warming and related climate change [14]. A typical geological storage site can trap several tens of million tonnes of CO_2 trapped by different physical and chemical mechanisms. Suitable geological sites for CO_2 storage have to be carefully selected with general requirements such as appropriate porosity, thickness, and permeability of the reservoir rock, a stable geological environment and a cap rock with good sealing capability. Requirements such as distance from the source of CO_2, effective storage capacity, paths for potential leakage and in general economic forces may limit the feasibility of being a storage site [24]. The purpose of Carbon Capture and Storage (CCS) is to reduce emissions of greenhouse gases to the atmosphere as a climate change mitigation activity. However, given the comparatively high costs currently associated with CCS, coupling CCS with Enhanced Oil Recovery (EOR) could provide a critical financial incentive to facilitate development of CCS projects in the near term. Most of the CO2 injected into the reservoir for EOR remains permanently trapped under ground [8, 12]. It is this characteristic of EOR operations which makes them potential candidates for CCS project designation. CO_2 is captured from its source (e.g. a power plant), compressed to an initial pressure, before being transported to the oil field. On the field site, the transported CO_2 is re-compressed and then injected into the reservoir. Introducing water in the oil field helps to mitigate the losses as a result of the low viscosity and of the CO_2 considered initially. CO_2 and water injection leads to production of more oil [11], [6]. However, some of the injected fluids will also be produced. The produced fluids are separated at the surface in a separator, and the produced water is transferred to water-treatment facilities for re-injection. The oil is pumped to a refinery for further processing, after which the fuel and other by-products are obtained. The produced gas contains both CO_2 and the hydrocarbon gases released from oil. The produced CO_2 is normally re-injected into the reservoir.

2.11. Carbon capture EOR processes

Enhanced oil recovery (EOR) can be achieved using CO_2 injection through two processes: miscible or immiscible displacement, depending on reservoir pressure, temperature and oil characteristics.
Miscible Displacement processes: in this process, under suitable reservoir conditions (< 1,200 m) and oil density (> 22 °API) the CO_2 injected does mix completely with the oil into the reservoir, decreasing the interfacial tension between the two substances to almost zero (from 2-3 N/m2), to form a low viscosity fluid that can be easily displaced and produced. The recovery is typically in the range 4 to 12% of OOIP [9], [25].
Immiscible Displacement processes: in immiscible displacement, when reservoir pressure is too low and the oil density too high, the CO_2 injected does not mix with the oil within the reservoir, but causes the swelling of the oil, reducing its density, improving mobility and, consequently, increasing the percentage of oil recovered. In heavy and extra heavy oil reservoirs CO_2 and the oil form two distinct fluid phases, maintaining a separation interface all along the process. The oil recovery can reach 18% of OOIP [6], [18].

2.12. Economic importance of CO2-EOR process

The realization of EOR-CO_2 project is capital intensive, involving the drilling and/or work over of wells, the construction of a viable CO_2 transportation system, CO_2 gathering, compression, handling and recycling plants. Other costs are associated to the additional oil production, whose treatment is generally realized employing existing infrastructures, usually requiring just small adaptation.
However, the largest cost of the project could be associated to the purchase of CO_2 or to its purification/concentration. According to IPCC, the total cost of CO_2 sequestration ranges from 27 to 82 US$/tonne of CO_2 and is mainly associated to CO_2 capture, which constitutes the 80-90% of the total cost (25-75 US$/tonne for capture, 1-5 US$/tonne for transport and 1-2 US$/tonne for injection). Revenues generated from additional oil selling could offset the capital and operational costs of the process, especially if a cheap source of CO_2 is available. Moreover, contribution to revenues could derive in the future from fiscal incentives, like carbon credits, considering the storage of significant amount of CO_2 into the reservoir [1, 7].
From general study, one can infer that CO_2-EOR economic importance include; levelled cost of electricity, levelled cost of CO_2 derived products, net greenhouse gas emissions and avoidance of the cost of CO_2. It is worthy to note that the electrochemical conversion of captured CO_2 to products when coupled with an electrochemical capture system can deliver emission reduction as compared to a normal power plant system. CO_2 derived products include; carbon mono-oxide, formic acid, methanol, ethanol, ethylene and propanol [16].

3. Nigeria as a case study

Nigeria is known to be the largest oil and gas producing nation in Africa. Crude oil ranging from less dense specific gravity (S.G) and high dense (20-25 S.G) oil is found here, mostly along the Niger delta basin. The Niger delta region in Nigeria is a home to lots of oil reservoirs and oil producing industries/refineries with vast exports totaling about 98% of overall valued production. According to the Energy information administration (EIA), the country's proven reserve is estimated between 16 and 22 billion barrels, having a total of 159 oil fields and 1481 oil wells in operation.

With so much potential as these, a lot is still very possible to be achieved as regarding drilling of left-over crude oil in an already existing well. Having exhausted the use of the conventional primary and secondary oil recovery processes 2/3 of discovered reserves are usually unproduced, a lot of oil can still be recovered by utilizing the enhanced oil recovery process.

As discussed in the above literature, utilization of CO_2 enhanced oil recovery has proven to be very effective both in advanced/developed and developing countries in different continents of the world. CO_2 injection into oil reservoirs is widely accepted as an effective Enhanced Oil Recovery (EOR) technique, and has been used in the oil industry for over 40 years. Being a country with lots of high carbon emitting industries; power plants, cement factories etc., with daily gas flaring activities, utilization of a suitable capture technology and process and not just storing them but using this environmental waste for economic growth is evidently of high importance.

From reviewed literature, adsorption technology with post-combustion capture process have proven to be effective over time and as such can be a good suggestion for a developing country as Nigeria. In the southern region of the country situates a less dense oil capacity field known as the bonny oil field. Named after the Bonny community, this area harbors all the oil extracted onshore in Rivers State for export purposes. Other oil fields include Agbami field producing 140,000 barrels per day (bpd) while housing 400 million tonnes of oil, Akpo oil field producing 150bpd, Oloibiri oilfield producing 5000bpd and housing 41 million barrels and interestingly recoverable oil pegged at 20 million barrels, etc.

In a view to optimizing this existing drilling process, CO_2 – EOR is encouraged. But then again, a more than effective method of recovering oil is the utilization of CO_2 with additives such as alcohol, polymers or surfactants. This method is termed "modified CO_2 injection". Modified CO_2 injection refers to the injection of CO_2 premixed with one or more chemical additives that enhance miscibility between CO_2 and oil. This research work as included in one of its objectives is to study how these chemical additives, affect interfacial tension (IFT) between CO_2 and oil, minimum miscibility pressure (MMP), and oil recovery. IFT from previous studies has been reported to be low using modified CO_2 than using pure CO_2. The various classes of additive have been found to bring about different reductions in MMP, with polymers attaining a reduction of (7.4–7.6) MPa, alcohols 9.4 MPa, and surfactants (1–6.1) MPa. However, these classes provided comparable increases in oil recovery. Studies attribute the increase in oil recovery to enhanced displacement efficiency that occurred during modified CO_2 injection.

From studied research, according to Saira and Le-Hussain [21], Ethanol-treated CO_2 injection is found superior to pure CO_2 injection in displacement efficiency, sweep efficiency, and CO_2 storage.

Improvement in CO_2 storage and oil recovery is notable at lower pressures, which suggests that modified CO_2 injection is more suitable for low-pressure reservoirs.

4. Conclusion

An overview of oil recovery processes has been stated clearly above. Diverse processes such as primary, secondary and tertiary existing methods have being weighed and observed with substantial improvements of recovered oil in the reservoir. A cost rewarding and environmentally friendly concept as such should be adopted by the South-South region of Nigeria and utilized for gross value retention and capacity pruning. This of course is the future of Nigeria clean energy right before the emergence of full renewable energy option.

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