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A Review of CO_2 Sequestration in Underground Geological Formations: Recent Developments and Potential Opportunities in the Niger Delta

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ABSTRACT

This paper evaluates the feasibility of CO_2 storage in depleted hydrocarbon reservoirs using 3-D seismic and well data with particular reference to the Niger Delta. CO_2 sequestration is a fundamental measure for decreasing greenhouse gas emissions. Based on the papers reviewed, the presence of reservoir-seal pairs, traps, faults, lateral continuity of reservoir, appropriate reservoir depth, developed hydrocarbon fields, and availability of massive hydrocarbon fields indicates a high potential for CO_2 sequestration in the Niger Delta. The paper concludes that the estimations of the injection rate and injection pressure are essential considerations for CO_2 sequestration and highlights the challenges and opportunities of future research.

Keyword: CO_2 sequestration, depleted hydrocarbon reservoir, Niger Delta

1. INTRODUCTION

Carbon dioxide capture and sequestration are gradually being taken as an essential and practical method of decreasing the emission of anthropogenic greenhouse gases on the earth [1]. There has been a recommendation that it is an immediately obtainable and scientifically feasible means of reducing CO_2 emissions [2], and it is speculated to have the prospective to make considerable reductions in carbon emissions from point sources [3]. The method involves the capture of CO_2 from a static source, its conveyance by pipeline, injection, and storage within the appropriate underground geological formation (Fig.1). The injection of CO_2 into depleted hydrocarbon fields is an age-old component of the enhanced oil recovery practice. It has been proven that CO_2 may be trapped within geological media. Three core types of storage media in geological formations are accepted; depleted oil and gas fields, un-mineable coal seams, and brackish aquifers. Every selection has advantages and disadvantages, mainly due to storage availability, location, capacity, and geological understanding. Every part contributes to the commercial and engineering challenges encountered.

The injection and storage of CO_2 use scientific ideals that have previously been developed and practiced by petroleum and gas companies [4]. The engineered injection of CO_2 for Enhanced Oil Recovery (EOR) projects started in Texas, USA in the 1970s and has become a regular practice in petroleum and gas companies. By the late 1990s, the underground storage of CO_2 was becoming a progressively attractive choice for oil companies producing from onshore oil fields with high natural CO_2 content [4]. On the contrary, the injection into appropriate underground formations explicitly for storage is still a comparatively new process. To fully understand the prospect of this method of lowering atmospheric CO_2 emissions, it has to be demonstrated to be environmentally safe, cost-effective and broadly applicable [4]. It has to take into consideration that there is a continuous increase of CO_2 in the air as a result of the rise in the use of hydrocarbon products (Fig. 2). As a means to guarantee public security and acceptance, it should be confirmed that the danger of leakage from planned storage reservoirs is little.

Proper and total comprehension of all the facets of underground CO_2 storage is, therefore, fundamental for the feasibility and success of CO_2 storage projects, as considered in this review. Cautious site selection, efficient regulatory oversight, an effective monitoring plan, and remediation methods to avert or control CO_2 discharge are requisite to mitigate the ramifications of leakage [4]. The long-term dependability of the cap rock is a foremost element in establishing the leakage threat during the site selection practice. Therefore, excellent and complete underground knowledge of prospective storage sites according to the facts of each situation and site-specific level is necessary.

1.1 Background to carbon dioxide sequestration

The storage capability of CO_2 is an approximation of the volume of CO_2 that can be stored beneath the surface formation. For the reason of uncertainties inbuilt into underground assessment, precise quantification of geological features is out of the question. Consequently, storage capability is always, at best, an approximation of the sum of all the quantities of CO_2 that can be stored [5].

Sequel to the actuality that CO_2 engineering is not fully fledged, there are small numbers of functional CO_2 storage projects which can give site precise information; thus, small and high-value capability estimates are generally reported. Immediately the CO_2 is injected inside a reservoir for storage, it acts distinctly depending on the storage environment, fluid features, injection rates, and trapping system involved. For safe, inexpensive and efficient storage, it is crucial to comprehend and predict the action of CO_2 to be injected at a specific site. To forecast the CO_2 behaviour and expected pressure/temperature changes after injection, simulation apparatuses are used.

Numerical simulations are applied to forecast the temporal and spatial motion of the injected CO_2 cloud; the consequence of geochemical reactions on CO_2 trapping and long-term porosity and permeability; cap rock and wellbore integrity; the consequence of increase or decrease in heat/compositional properties in the reservoir. Furthermore, it is also used to study the leakage pathways of CO_2 in the reservoir; the significance of resultant barriers; impacts of accidental hydraulic fracturing; the degree of rising migration of CO_2 along the outside of the well casing; effects of cement dissolution and implication of wellbore collapse. Effective monitoring can prove whether the monitored outcomes match the anticipated results from the simulation. This is largely essential at the inception stages of a project to standardize the representation and adjust the foundation of simulation for the long-term performance required. Simulation apparatus has been applied to examine pilot and industrial projects in association with the Weyburn, Frio, West Pearl Queen, and ECBM West Virginia.

Multiphase movement through porous media is significant for diverse applications, namely CO_2 sequestration and enhanced oil recovery. Virtually all perspective of underground engineering for power and environmental applications requires in-depth mastery of multiphase movement within mixed porous media. Instances include secondary oil recovery method, underground carbon sequestration, geothermal power production, seasonal storage of natural gas in subsurface formations, and gas hydrate formation in sedimentary deposits. These repeatedly involve the switch in location of a non-wetting invading fluid from a porous rock by a wetting fluid through the physical occurrence known as imbibition. The modelling of multiphase movement in order ways is yet a huge scientific challenge. To obtain the best replica of multiphase movement, a proper explanation of fluid relations namely capillary pressure and relative permeability, are unavoidable. The intricacy of numerical calculation in reservoir simulation practice will increase regarding these parameters. In some issues, these two properties will generate instability in numerical simulation. Numerical investigation of multiphase movement has continued to exist as a topic of concern, and there exists a rising collection of research work addressing this topic. The modelling of such a physical movement method primarily requires solving the mass and momentum conservation equations with respect to the equations of capillary pressure, saturation and relative permeability.

The injection of huge volumes of CO_2 inside the deep underground formation may be connected with a lot of geo-mechanical threats [6]. The fault or fracture region will act as a movement channel for CO_2 and a central point for rock collapse. The pressure rise inside the storage media might cause slip and dilation along these pre-existing faults and fracture regions. Injection-caused seismicity might lead to structural deformation and possibly fear among neighbouring people [7]. Additionally, CO_2 injection may initiate new hydraulic fractures within or near the injection region. These fractures may spread up into lower and upper cap-rock [6]. Consequently, shallow drinking water might be polluted by CO_2 seepage [8, 9]. In geo-mechanical areas, transformations in stresses and strains, ground deformations and possible threats such as new cap-rock fracture instigation and spread or pre-existing fault opening and slippage are significant for extensive and long-term CO_2 storage [10]. Consequently, it is of immense importance to consider the geo-mechanical threats and stability before beginning the action of CO_2 injection. The injection procedure of carbon dioxide (CO_2) into geological media can be measured as the immiscible displacement of an aqueous phase by a less dense and less viscous gas phase.

On account of the lesser density and viscosity of CO_2 relative to water, the injection of CO_2 will have a natural inclination to generate hydrodynamic instabilities, causing viscous fingering and gravity override. Therefore, numerical modelling is a necessary tool for the extensive execution of CO_2 storage in the subsurface. Consequently, it is of the essence to recognize a suitable numerical model idea for a specified challenge or enquiry. For instance, modelling the rise in pressure in the near-field of an injection well relies largely on viscous forces caused by the elevated velocities brought about by the injection.

It is possible to model this process without considering compositional effects or geochemical reactions. As already stated, when one is concerned about the future of CO_2 inside the reservoir over a distant period, it demands a more advanced model that permits simulating compositional effects and geochemical reactions.

With respect to numerical simulation, different aspects can control the computed large-scale permeability, notably the numerical method; for example, Finite volume (FV) [11] and Lattice Boltzmann Method (LBM) [12] are the two principal generally used approach for pore-scale movement assessment. It has been reported that the employed numerical method significantly controls the permeability resolution [13].

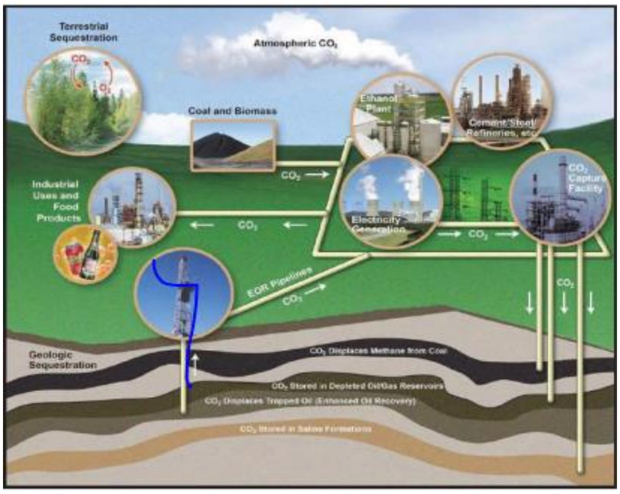

Fig. 1 Schematic of carbon capture and sequestration

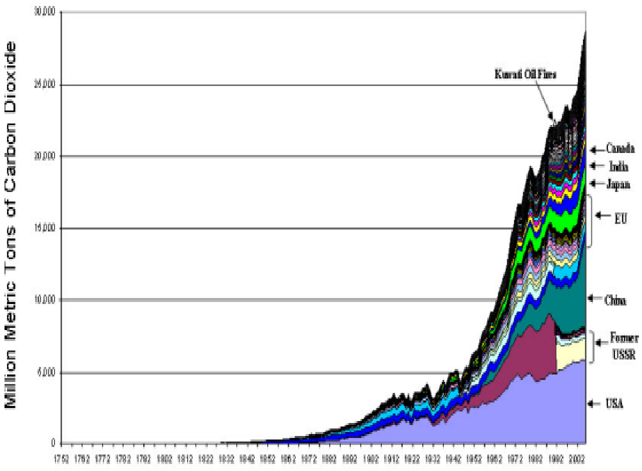

Fig. 2 World CO_2 emission

1.2 *Emerging realities of global CO_2 emissions*

The importance of a shift to low-emission advancement is a worldwide idea acknowledged globally (especially by the United Nations) as a proper genuine way to stabilize greenhouse gas accumulations with the attendant result of extensively alleviating the ramifications of climate change. The emerging reality of today is the occurrence of unprecedented rapid heating-up of the earth from specific individual actions due to the combustion of hydrocarbon-containing materials to generate energy which is negatively affecting both individual well-being and the environment. Nearly 200 countries met in Paris in December 2015 to draft a universal agreement to reduce CO2 emissions. The paramount goals in the agreement include [14]:

1. The commitment by countries to keep global temperatures at no greater than 2°C above before industrial revolution levels. A further motivating goal of 1.5°C is mentioned as this is touted as necessary to prevent low-lying island nations from disappearing as sea levels rise in a warmer climate. Current pledges indicate that global temperatures could rise by as much as 2.7°C if existing targets are maintained; therefore, experts are concerned that additional reductions will be needed.
2. Submission for review of a nation's self-determined emission reduction plan beginning in 2020 and every 5 years thereafter. Each plan must provide a successive improvement over the previous one. There is no official requirement that pledges must be reviewed or upgraded prior to 2030, although parties may do so voluntarily.
3. The requirement is that wealthy, developed countries give funding to poorer countries to help them transition to renewable energy and technologies that emit less CO_2.

Nigeria is a party to the 2015 Paris framework, a major watershed in the worldwide drive towards a changeover to low-emission growth. It acknowledged the lasting vision of a transition to Long-Term Low-Emission Development Strategies (LT-LEDS) as crucial for achieving sustainable industrial development through channels that yield reduced Green House Gas (GHG) emissions and other societal, commercial, and environmental profits.

The Paris agreement and Intergovernmental Panel on Climate Change (IPCC) Special Report of 2018 are unambiguous that Low Transition Strategies will play a significant part in the united goal to hold the upsurge in worldwide average temperature below 2°C. Following this target, a temperature rise of 1.5°C above previous or industrial revolution levels will involve international efforts to reduce GHG emissions to stabilize human-related emissions and removals by sinks in the second quarter of the century.

2. GEOLOGICAL SETTINGS OF NIGER DELTA

Following up on the disintegration of the African plate from the South American plate, the Niger Delta was established in the Paleogene [15]. The sedimentary series of the basin is predominantly initiated from the Precambrian crystalline basement rocks and the Cretaceous and Cenozoic basement-derived sedimentary rocks [16]. From the Cenozoic era through the mid-way Miocene, the Niger Delta basin was formed through different geologic activities which generated the deposition of sediments into the Gulf of Guinea from the Cenozoic to the Middle Miocene [17].

2.1 Lithostratigraphic of Niger Delta

The stratigraphic sediments of the Niger Delta basin are principally made-up of three lithostratigraphic sections [18]. These sections include the lower marine pro-delta Akata Formation, the median shallow-marine delta-front Agbada Formation, and the overlaying youngest continental, delta-plain Benin Formation [18]. These three formations widen across the entire delta (Fig.3).

The lower Akata Formation is Paleocene to Recent in age. It is made up mainly of pro-deltaic lithofacies, which contain marine shales with turbidite sands and continental slope channel fills of approximately 7 km in breadth [18]. It is usually thought of carefully as the source rock of the Niger Delta. The mid-way paralic Agbada Formation is Eocene to Recent in age [19]. It is principally made up of delta-front lithofacies, a mixture of sand and shale. The sandstone reservoir facies in this creation are predominantly shore-face and channel sands with small shales in the topmost part and repeated occurrence of sands and shales in the bottom part [18]. The Agbada Formation sand constitutes the reservoir inside the Niger Delta basin [18].

The topmost Benin Formation is Oligocene to Recent in age and made up of continental fluvial sands [18, 19]. The 2 km broad unit is commonly loose and contains white, fine to coarse, and pebbly, poorly arranged sands and is largely a productive aquifer in the area [16, 19].

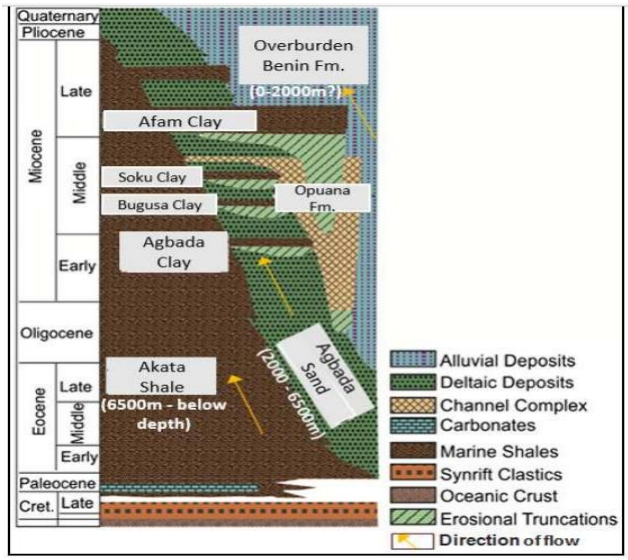

Fig. 3 Stratigraphic column of Niger Delta. Modified from [18]

2.2 Properties of oil and gas in the Niger Delta

The visible and chemical characteristics of the oil amidst the Niger Delta are extremely inconsistent, still down to the reservoir level. The oil inside the delta has a gravity value of 16-50° API, with the lighter oils having a greenish-brown coloration. Fifty-six percent of the Niger Delta has an API gravity between 30° and 40° [20]. Many oils are found inside one of the two categories. The first category is light paraffin-dependent, waxy oils from deeper reservoirs (wax content up to 20%, except a few usually within 5%; [18], high n-paraffin/ naphthene of 0.86). The second category of oils is biodegradable and from the upper part of the reservoirs. They possess lesser API gravity (average API of 26°; and are naphthenic non-waxy oils (n–paraffin/naphthene = 0.37). Biodegradation and washing are excessive in some Pleistocene sands of the Agbada Formation, generating additional heavy oils (API 8-20°). The oils with a smaller amount than 25° API forms only 15% of the Niger Delta reserves [20].

As reported by [18], the associated gas within the Niger Delta is thermal in origin (delta C thirteen values of -36 to 40‰), with low CO_2 and N_2 constituents. Hydrogen sulphide is not a challenge related to Niger Delta gas; however, comparatively high mercury constituents have been revealed. Presently, 75 % of the gas exploited from the Niger Delta is released into the air-space, 5- 10% is reinjected to sustain reservoir pressure, and only 15% is sold out [21].

2.3 Niger Delta reservoir traps and seals

Nearly every identified traps in the Niger Delta sector are structural, while stratigraphic traps are not unconventional (Fig. 4). The structural traps were formed during the synsedimentary distortion of the Agbada paralic succession [22, 23]. Structural complications rose from the north (initially created depobelts) to the south (subsequently created depobelts) in reaction to the growing unsteadiness of the less-compacted over-pressured shale. This is due to the multiplicity of structural trapping parts, including those related to plain rollover structures, clay sediment channels, structures with numerous growth faults, antithetic faults, and collapsed crest structures [18]. On the sides of the delta, stratigraphic traps are possibly as significant as structural traps. In these areas, small sandstone deposits arise in the middle of diapiric structures. In the direction of the delta bottom (foot of distal slope), this irregular series of sandstone and shale slowly results in sandstone. The principal caprock in the Niger Delta is the alternated shale within the Agbada Formation.

The shale caprock gives three sets of seals—clay stains along faults, alternated sealing units contrary to which reservoir sands are placed as a result of faulting, and perpendicular seals [18]. On the sides of the delta, major erosional incidents of the initial to mid-way Miocene age formed canyons that are now clay-filled. These clays generate the upper seals for several significant offshore fields [18].

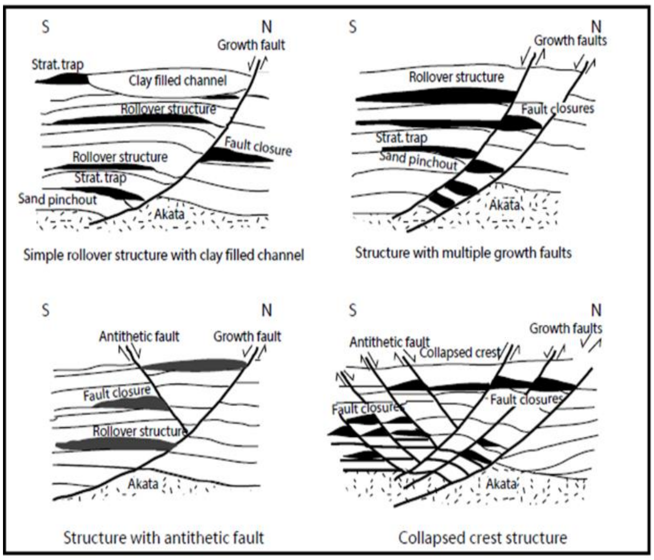

Fig. 4 Niger Delta reservoir field structures and associated trap types. Modified from [18]

3. POTENTIALS OF NIGER DELTA RESERVOIRS FOR CO_2 SEQUESTRATION

Carbon geo-sequestration is concerned with the capturing of carbon dioxide that is usually released into the atmosphere, changing it to a supercritical state, moving it to an appropriate site, and injecting it inside underground like depleted oil and gas reservoirs, far down saline aquifers, deep coal seams and salt caverns. This demands a site illustration of the geologic formations to account for the most favourable conditions for long-term storage that will care for the health and safety of persons and the surroundings. The description is a three-stage course that relates to the finding of the volume of the reservoirs to secure the proposed quantity of CO_2 over the extent of the injection activities, injectivity to take CO_2 at the speed of supply from the injection point, and containment which makes certain that it cannot escape from storage [24]. The three-stage course has been extensively considered in the Niger Delta [25, 29].

As a significant hydrocarbon contributor and greenhouse emitter in Africa, hydrocarbon discovery and production in Nigeria since 1957 has brought about a reduction and abandonment of some reservoirs in the Niger Delta, which might be utilized for carbon capture and underground storage to realize a decline in CO_2 release into the air-space in accordance with UN Framework Convention on Climate Change.

A comprehensive evaluation of the basin has disclosed the incidence of exceptional reservoir-seal pairs, very huge basin size, appropriate reservoir depth, developed oil and gas fields, reasonable faulting strength, and availability of massive hydrocarbon fields (Fig. 5). Furthermore, field range appraisal using 3D seismic volumes and well information has additionally unravelled significant potentials for underground storage of CO_2 in the basin [25, 29]. For example, prospective reservoirs show good porosity and permeability, traps, and seals, as identified in Figs. 5, 6, 7, and 8. Furthermore, well correlation shows reservoir-seal pairs are within a reasonable range for CO_2 storage. The well correlation investigation additionally proved that the reservoirs are laterally widespread that can permit the sequestration of huge quantities of CO_2 (Fig.9, 10).

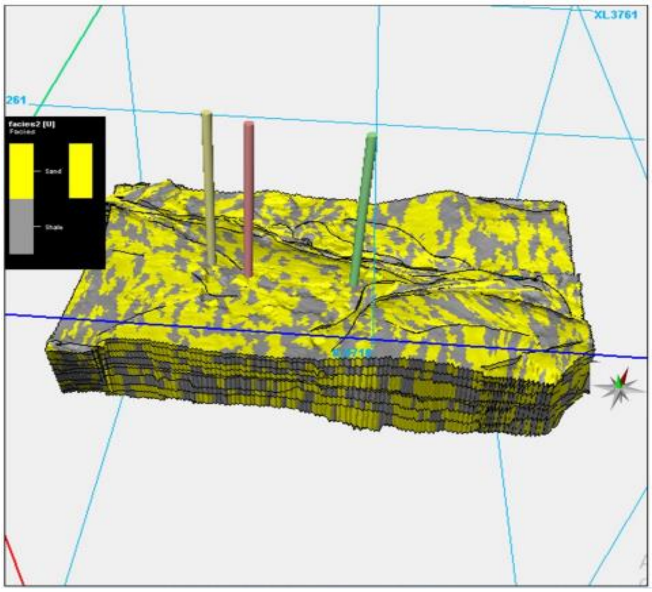

Fig. 5 3-D Reservoir model showing the distribution of sands and shales across all the mapped reservoirs [29]

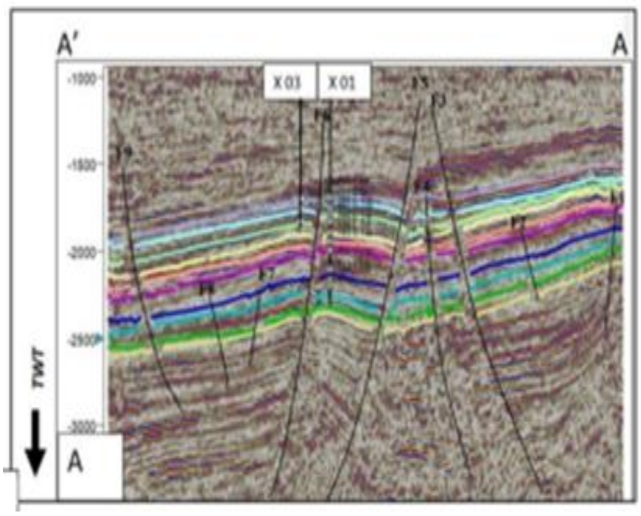

Fig. 6 Seismic section showing identified faults [29]

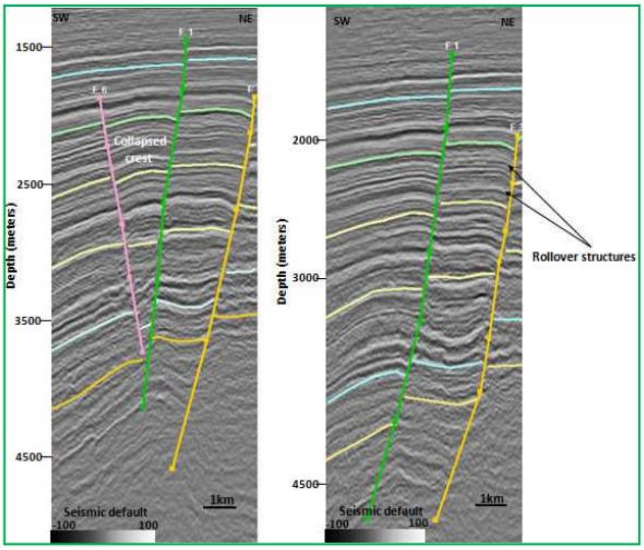

Fig. 7 Seismic section showing collapsed crest, rollover structure, and potential traps [28]

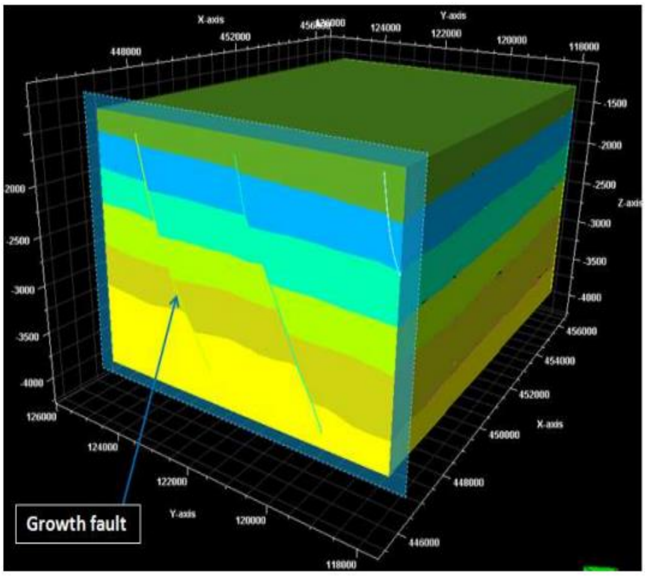

Fig. 8 3-D fault model illustrating simple growth fault structures in the area [28]

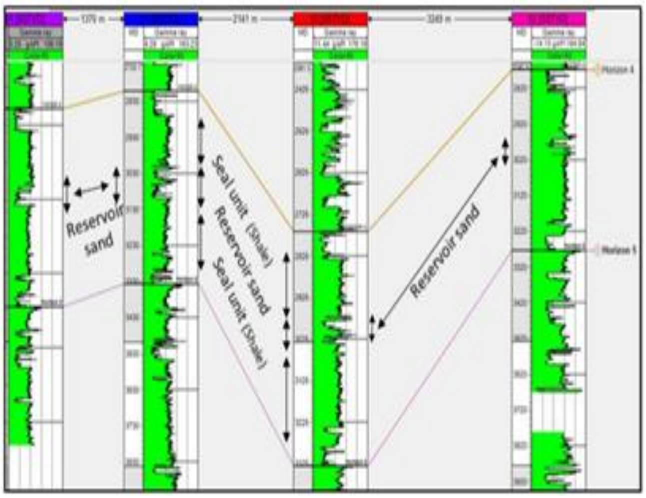

Fig. 9 Well logs interpretation showing identified reservoirs [29]

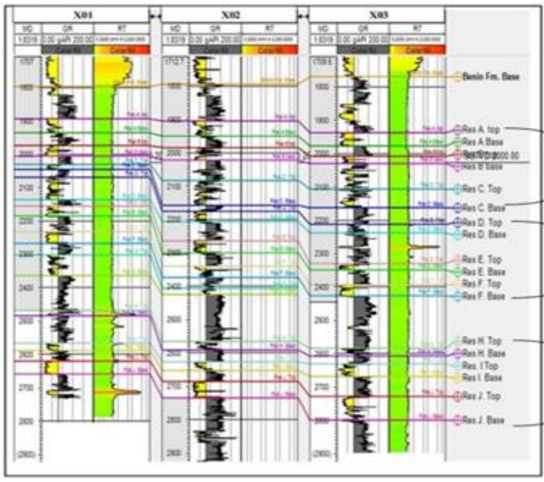

Fig. 10 Well correlation indicating lateral continuity of reservoir unit in field "B" [28]

4. TECHNICAL CONSIDERATIONS FOR FURTHER RESEARCH IN THE NIGER DELTA

Most papers on CO_2 sequestration in the Niger Delta reviewed only estimated storage capacity based on static models. The capillary pressure of sealing rock and the fragile point of the seal ought to be thoroughly examined as it determines the injection pressure that will be applied and then the storage capability of hydrodynamic trapping.

The exact approximation of the CO_2 storage capability must take cognizance of the pore space existing for CO2 storage and the pore fluid pressure increase caused by the distortion of in situ pore fluids. This is in disparity to static storage capability estimates that only accounts for the amount of the pore space open for CO_2 storage and give little or no attention to the pressure build-up issues. They also did not account for the cap-rock stability, a profound feature that can cause CO_2 leakage during migration. Consequently, additional study is considered necessary to determine the result of cap-rock stability during CO_2 migration. The following are essential technical considerations for CO_2 sequestration in depleted oil and gas reservoirs in the Niger Delta:

4.1 Dynamic reservoir modelling for CO_2 sequestration

Geological models describe the static features of the media. They are usually followed by dynamic reservoir models that investigate the result of fluid movement in an in-situ environment using diverse well arrangements [30]. Understanding the nature of underground description work, where incomplete data from distinct sources are incorporated to develop models of huge volumes of rock, results in a large scale of uncertainty all the time in geological models. Consequently, some possible geological issues need to be given attention during the investigation.

The probable results are generally overly controlled by matching the modelled movement to the measured field history (i.e., production) and producing measured models that are moved forward for subsequent predictions [31]. Conversely, the deficiency in knowledge with respect to CO_2 injection becomes a concern for model configuration. Similarly, CO_2 is a highly dynamic fluid under in-situ circumstances (usually supercritical) - CO_2 occasionally reacts swiftly with the residual fluids. It can have a geochemical and geo-mechanical influence on the geologic media. CO_2 blending with different fluids leads to changed multiphase flow behaviour that is not absolutely known within the Niger Delta.

Even if a significant sum of experience in CO_2 flow modelling has been acquired in decades of CO_2-EOR, storage-monitoring conditions involve a complex process when modelling all the coupled impacts of CO_2 flow inside the reservoir. This is an active topic of investigation from a framework of oil and gas flow reservoir engineering technology.

4.2. CO_2 trapping mechanisms in the Niger Delta

CO_2 sequestration is the long-term or enduring burial of CO_2 within the geologic media. Upon injection, the starting and main trapping or containment of this floating fluid are achieved by prevailing low-permeability cap rock (Fig.11).

The dispersal of CO_2, controlled by the pressures of injection or its buoyancy, means that the impending threat of buoyant fluid moving to a leakage channel through the caprock may arise during and after injection. This likelihood of seepage has shaped necessary research into a level of new fluid mechanical processes that eventually play an essential function in trapping buoyant CO_2 permanently [32]. CO_2 trapping systems depend on both physical and geochemical characteristics (Fig.11). A number of major factors determine the efficacy of a CO_2 trap:

1. Physical trapping systems, consisting of the shape of structural and stratigraphic traps;
2. CO_2 remaining gas trapping – the holding of CO_2 as a remaining phase;
3. Geochemical trapping system, including CO_2 dissolution in salt water, CO_2 that forms as mineral phases and CO_2 absorption (particularly in coal-bed formations).

With the exclusion of CO_2 adsorption (exact to coals), each of these storage systems will be dynamic within the majority of the formations but to diverse levels, with their comparative significance being site-specific. There is substantial uncertainty about the speed and reaction involved in these systems. Recent scientific studies should undoubtedly be committed to expanding better knowledge of the processes involved in CO_2 trapping in the Niger Delta.

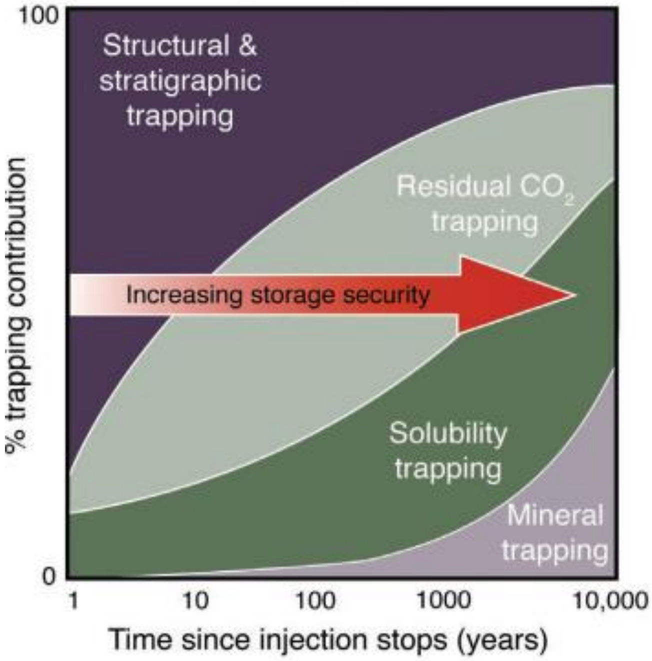

Fig. 11 A general representation of the evolution of trapping mechanisms over time [4]

4.3 Geomechanical stability and leakage risk

The function of faults and fractures and their effects on the containment of fluids and CO2 is complex and often not adequately understood. The existence of a fault does not entail a leakage threat, and most rock units are faulted and fractured in some way over geological time [33]. The crucial issue for CO_2 storage is whether faults or fractures may give leakage channels under the present-day geological environment. In addition to the essential shape of associated rocks and movement channels, this studies geo-mechanics, stress fields and fracture behaviour. A crucial element of CO_2 injection is the geo-mechanical reaction of reservoirs to the injected CO_2.

Current investigation has stated that injection at the levels needed to reduce human-related CO_2 emissions will unavoidably cause reasonable seismicity in regions of the outer layer that are seriously stressed. This raises important fluid dynamical questions: What is the pressure field related to the major injection of CO_2 due to reservoir characteristics and shape? How do we best observe and manage the reservoir pressures? If seismicity is instigated, is leakage possible and if so, what are the area distribution and scale of that leakage? It is also true that faults may possibly restrict the underground coverage of hydrocarbon accumulations.

Conversely, fluids do not directly move to the outside through faults that define the restrictions of hydrocarbon accumulations because faults are not unrestrained leakage channels to the outside. Little quantities sometimes gradually leak to the outside and sophisticated geochemical techniques are used to study these little quantities. The sealing rock is the foremost seal structure for CO_2 storage. While the hydrodynamic sealing capability of sealing rock has been repeatedly researched for hydrocarbon movement [34], no elaborate research has been devoted to the sealing capability for CO_2 storage in the Niger Delta. In practice, most CO_2-EOR storage operations employ the same assessment procedures and indicators [35]; nevertheless, the disparities connected to CO_2 storage are hardly ever discussed.

Furthermore, the structural or shape features of sealing rock, for example, the breadth, are yet to be appropriately researched [36]. The analysis of the geo-mechanics, stress fields and fracture behaviour in the Niger Delta reservoirs will help to predict the suitable injection rates, injection pressure and injection strategy for the CO_2 sequestration process

4.4 Effects of physical processes

The physical activities concerned are intricate and comprise the movement of CO_2 -rich phases due to capillary effects, buoyancy effects, CO_2 diffusion and CO_2 dissolution in the aqueous state, flow instability, and impacts from higher density and viscosity. The occurrences related to CO_2 injection, such as salt water displacement and transitory pressure impacts, are thought to be a possible risk to containment with potential effects on movement stability (Figs.12, 13). It is significant to observe that the subject of buoyancy-driven convection in fluid-saturated porous geologic materials has been getting growing interest considering its value in several hi-tech utilization and application relating to the surroundings[32, 37 and 38]. Exclusively, the calculated design concerning carbon dioxide (CO_2) sequestration into brine-filled geologic media has motivated a number of latest research on the subject [39, 40]. Considering the smaller density and viscosity of CO_2 related to water, an injection of CO_2 will lead to a propensity to generate hydrodynamic instabilities, causing viscous fingering and gravity override [41] (Fig.14).

These effects diminish immediately after injection stops, though the duration for injected CO_2 to steady will generally differ based on the geologic material's precise characteristics. Other occurrences, such as spreading fractures or reopening faults through the closed system, are more likely to happen during the process than after injection. The effects of these physical processes have not been adequately investigated in the Niger Delta.

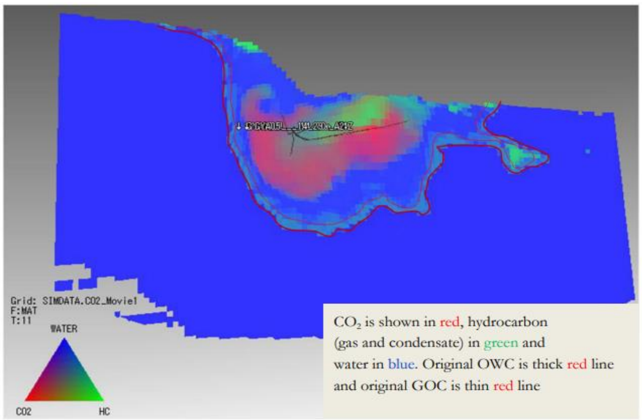

Fig. 12 CO_2 plume during injection 2029 [42]

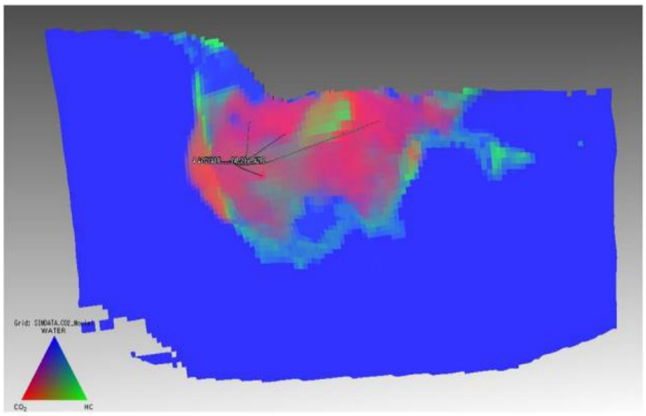

Fig. 13 CO_2 diffusion at the end of injection in the year 2055 with dissolution [42]

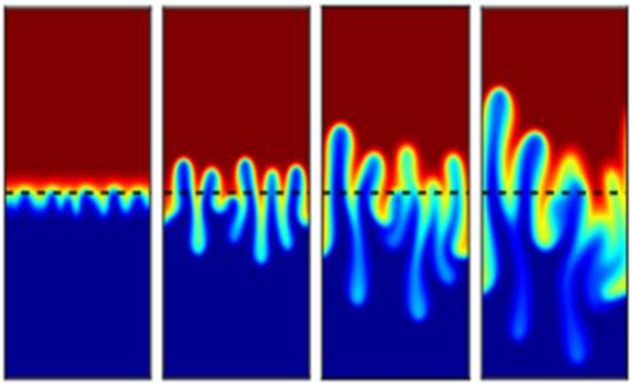

Fig. 14 CO_2 flow instabilities exhibiting fingering effects [41]

5. CONCLUSION

The results obtained to date within the various elements of site characterization and assessment of the feasibility of using depleted oil reservoirs for the sequestration of CO_2 in the Niger Delta show high potential. This will form the basis for numerical modelling of the long-term outcome of injected CO_2. The combination of these static and dynamic uncertainties depicts the framework necessary for understanding the storage efficiency factors that reduce the total theoretical capacity. A three-dimensional, three-phase, full-field numerical simulation model corroborated by the initial storage estimations and evaluated with different injection scenarios will help develop a range of capacity available for CO_2 storage in the Niger Delta.

Going forward, a research work that applies the principle of Dynamic Semi-Structured Multi-grid Meshes for Fast Numerical Simulation of Carbon Dioxide (CO_2) Storage in a depleted hydrocarbon reservoir in the Niger Delta should be investigated. This will involve continuing research on CO_2 Sequestration in Depleted Hydrocarbon Reservoir (CSDHR), requiring some vital but omitted issues in recent studies that need to be researched. In particular, the determination of desirable parameters, such as injection rate, pressure, depth, well orientation, and distribution, for optimal CO_2 storage efficacy with negligible leakage threat is crucial in this research.

There is a need to resolve the computational complexities involved in CO_2 underground storage projects when considering multi-component fluids involved in the sequestration process by applying a hybrid meshing system comprising a combination of saturated and unsaturated meshes as well applying the Dynamic Adaptive Mesh Optimization technique. It will also offer more significant knowledge of the onset of viscous fingering during immiscible displacement in porous geologic materials. In particular and very interestingly is the flow instabilities that may occur during the injection of CO_2 into a depleted hydrocarbon reservoir.

A number of challenges are connected to CO_2 capture, transportation and storage. The most remarkable challenges include the high cost connected with CO_2 capture due to the utilization of a huge amount of power by carbon capture technologies and the environmental impact such as amine-based scrubbing, which is a source of an increase in toxic effect in freshwater natural systems. Other challenges are the need to sustain a single-phase flow in CO_2 pipelines to avoid pressure drops along transportation lines and the validation of the viability of the geologic formation for CO_2 storage, which includes understanding the long-term fate of the injected CO_2 as well as environmental and safety concerns.

Some of the emerging opportunities in CO_2 extraction are carbon capture by means of biomass and soil, which is a practicable technique to enhance the capture of CO_2 and also preserve the crops, forests, grasses, soil and direct capture of CO_2 from ambient air as a technique to diminish the climate emergency.

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