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Natural Gas Utilization: Simulation of Steam Methane Reforming and Decarbonization by Diethanolamine Absorption for Hydrogen Production in Nigeria

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ABSTRACT

This study explores the integration of steam methane reforming (SMR) with diethanolamine (DEA) absorption for carbon capture, using CAPE-OPEN Flowsheet Environment (COFE) and Aspen Hysys for simulation, focusing on hydrogen production for energy use in Nigeria. The integration aims to optimize operational parameters, regenerate the DEA solvent, and produce hydrogen with minimal CO_2 content, offering a sustainable solution for hydrogen production. Simulation results show that the process significantly enhances hydrogen yield, increasing its concentration from 50.00 mol% in syngas to 60.13 mol% in sweet gas, while reducing CO_2 content from 7.10 mol% to 0.06 mol%. The lean DEA solvent was successfully regenerated, achieving 100 mol% purity after stripping. The study highlights the environmental and economic benefits of this approach, particularly in addressing the impact of natural gas flaring and promoting hydrogen as a cleaner fuel in Nigeria. It provides policy recommendations to support the adoption of SMR-DEA technology, emphasizing its feasibility and alignment with global sustainability goals, positioning Nigeria for improved energy efficiency and a reduced carbon footprint.

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1. INTRODUCTION

The global transition towards a low-carbon economy in recent years has underscored the importance of a two-pronged approach towards energy generation; exploring the potential of alternate sources, while mitigating emissions of greenhouse gases. The diversity and abundance of natural resources in Nigeria and the position of the country as the foremost fossil fuel producer and exporter in Africa means that the quest for sustainable energy solutions harbors enormous implications for economic development and energy security. For over half a century, Nigeria's hydrocarbon reserves have played a huge role in the country's economic growth, contributing to almost 6% of the total gross domestic product in 2023 [1], and over 76% percent of total exports in 2021 [2]. This dependence paints a challenging picture. Nigeria ranks fourth in Africa in carbon dioxide emissions, emitting a whopping 101 metric tons in 2021 [3].

Amidst the urgency of current circumstances, hydrogen production emerges as a viable alternative solution. Hydrogen is often referred to as "the fuel of the future", and for good reason. Being the most abundant element in the universe, hydrogen offers a carbon-free renewable energy source that may be produced via electrolysis, steam methane reforming, and biomass gasification. At over 200 trillion cubic feet, Nigeria has the largest natural gas reserves in Africa, and the ninth largest globally [4]. With the right investments, this vast resource base places Nigeria as an epicentre for hydrogen production soon, with natural gas serving as the primary feedstock. When used as fuel, hydrogen produces only water vapour as a by-product, as opposed to fossil-fuels which emit air pollutants and greenhouse gases [5]. The minimal environmental footprint of hydrogen as a fuel makes its use particularly appealing for addressing climate change and air quality degradation.

The volatility of global energy markets and over-reliance on fossil fuels constantly leaves the economy vulnerable to price fluctuations, supply disruptions and market uncertainties. The impact on economic stability is enormous, and oftentimes disastrous [6]. A solution which has remained obvious yet unexplored is a variegation of the energy mix and a subsequent reduction in dependence on imported fuels. Investment in hydrogen production presents a compelling opportunity to further enhance energy security. This also translates into industrial development and employment possibilities, as hydrogen production would require skilled and professional manpower to manage and maintain facilities, distribution networks and refueling infrastructure. Established industrial processes, such as solvent production, chemical synthesis and refining stand to benefit from integration of hydrogen, hence promoting value-added manufacturing.

When it comes to natural gas as a resource, the wasteful approach of producing companies in Nigeria deserves accentuation. Between 2010 and 2020, the estimated yearly flare was 7.83–17.5 billion cubic meters. Gas flaring continues to pose a challenge, despite regulatory initiatives and policy changes, with detrimental effects on the environment, public health, and sustainable development. However, hydrogen production using natural gas as feedstock presents a compelling opportunity to combat this issue and extract financial value from Nigeria's vast natural gas reserves.

1.1. Steam Methane Reforming for Hydrogen Production

Hydrogen production methods fall under three categories, according to the primary mechanisms involved in generation. These are electrochemical methods, which utilize electricity to split water molecules into hydrogen and oxygen by electrolysis, biological methods, which harness micro-organic metabolic activity to produce hydrogen through fermentation or enzymatic processes, and thermal methods, which involve the use of heat to drive chemical reactions, as is the case in steam methane reforming.

Steam methane reforming (SMR) is an industrial process involving the reaction of methane and steam at elevated temperatures, typically between 700-1000 degrees Celsius in the presence of a nickel or nickel-alumina catalyst, to produce a mixture of carbon monoxide and hydrogen, known as syngas [7]. 45% of hydrogen produced globally derives from this process, and it is uniquely suited for the Nigerian energy sector as natural gas serves as its feedstock [8]. Historically, steam methane reforming was first used industrially in the early 20th century in the United States, another country with sizable natural gas reserves [9]. The initial demand was for development of explosives at the beginning of World War II, with the syngas product serving as an intermediate for the development of trinitrotoluene, or TNT [10]. Syngas production is the initial stage of the Fischer-Tropsch process, and it in turn serves as feedstock for further reactions, where it undergoes catalytic conversion into liquid hydrocarbons and other valuable products [11]. Over time, the importance of the Fischer-Tropsch process for Gas-To-Liquids (GTL) conversion, coupled with advancements in process engineering, has stimulated progress in SMR technology, and hydrogen production has benefited from this.

The equation of reaction is as follows.

$$\mathrm{CH_4 + H_2O \leftrightarrow CO + 3H_2}$$

The enthalpy change (ΔH) associated with the reaction per mole of reactants consumed can be calculated following Hess' Law; Where is the enthalpy of formation for each reactant or product. The enthalpies of formation for the compounds involved are;

(CO) = -110.5 kJ/mol

(H2) = 0 kJ/mol, the standard enthalpy of formation for an element in its standard state is 0

(CH4) = -74.8 kJ/mol

(H2O) = -241.8 kJ/mol

Substituting these values into the equation.

=[(-110.5 kJ/mol)+3(0 kJ/mol)] - [(-74.8 kJ/mol)+(-241.8 kJ/mol)]

= -110.5 kJ/mol + 316.6 kJ/mol

=206.1 kJ/mol

The high positive value indicates the strong endothermic nature of the reaction [12].

1.2. Water-Gas Shift (WGS) Reaction

To remove impurities from the mixture and separate hydrogen from carbon monoxide, the mixture undergoes purification processes such as the water-gas shift (WGS) reaction and pressure swing adsorption (PSA). In the water-gas shift reaction, the carbon monoxide in the syngas mixture is converted to carbon dioxide, which can then be captured and sequestrated [13].

The equation of the WGS reaction is;

$$\mathrm{CO + H_2O \leftrightarrow CO_2 + H_2} \quad (\Delta H = -41.2\,\mathrm{kJ/mol})$$

Steam methane reforming is very efficient, with a hydrogen yield of around 65-75 percent [14].

1.3. Carbon Capture Technologies

From an environmental standpoint, hydrogen production by steam methane reforming is more carbon-efficient than alternatives such as coal gasification and partial oxidation of hydrocarbons, due to the lower carbon content of natural gas and the catalytic facilitation of the reaction at lower temperatures and pressures. Carbon capture and storage (CCS) technologies integrated with SMR can mitigate carbon dioxide emissions, optimizing the sustainability of the process.

Carbon capture technologies refer to all the methods designed to reduce carbon dioxide emissions from industrial processes. The aim of carbon capture is to address climate change by attenuating CO_2 emissions from point sources (power plants, refineries and industrial facilities) before they are released into the atmosphere [15]. Emissions are typically captured before, during or after combustion. In pre-combustion capture, carbon dioxide is separated from the fuel before it is burned, offering significant cost-saving advantages and a higher concentration of CO_2 in the gas stream as compared to post-combustion capture methods.

Steam methane reforming utilizes various pre-combustion carbon capture techniques to separate carbon dioxide from hydrogen after the WGS reaction, such as absorption, chemical looping combustion (CLC) and membrane separation [16].

1.4. Diethanolamine Absorption

Diethanolamine (DEA) is a secondary amine belonging to the ethanolamines class with the chemical formula $C_4H_{11}NO_2$. The amine group ($-N(CH_2CH_2OH)_2$) and two hydroxyl groups (-OH) are attached to the ethyl carbon. Alkanolamines are characterized by their ability to selectively absorb acidic gases and are commonly used for capturing CO_2 from syngas streams for this reason [17]. During this process, the syngas containing carbon dioxide is passed through a DEA solution, and carbon dioxide molecules are selectively absorbed into the solvent, forming a chemical complex known as a carbamate. The equation of reaction is as given by (1).

$$\mathrm{CO_2} + \mathrm{DEA} \rightarrow \mathrm{DEA} - \mathrm{CO_2} \quad (1)$$

DEA-CO_2 represents the carbamate complex formed because of absorption.

The purified gas stream, free of carbon dioxide, is subjected to further treatment, while the carbamate goes through a series of heating and stripping processes, where the DEA is regenerated, and the carbon dioxide is released for storage and utilization. DEA has a high affinity for carbon dioxide, owing to its chemical structures and properties. The reaction is facilitated by the presence of the amine functional groups on DEA, which acts as strong Lewis bases and readily reacts with the acidic CO2 molecule [18].

DEA absorption is also compatible with existing industrial and chemical process operations, eliminating the need for significant modifications and retrofitting. Coupled with the comparative cost-effectiveness of DEA as a commercially available solvent, DEA absorption technology minimizes capital costs and remains a practical solution for industries to reduce carbon emissions while maintaining economic competitiveness.

1.5. Statement Of Problem

The research problem addressed in this paper examines the practical feasibility of combining steam methane reforming (SMR) with carbon capture by diethanolamine absorption for the manufacture of hydrogen as a fuel in Nigeria. Given the position of fossil fuels as the mainstay for energy demand and export in Nigeria, the negative impact of gas flaring and the largely untapped potential of natural gas utilization, this study spotlights the need for sustainable solutions in the energy landscape of the country and proposes hydrogen production and use as an environmentally preferable alternative.

1.6. Aim

The aim of this research is to comprehensively simulate the process of integrating steam methane reforming (SMR) with diethanolamine (DEA) absorption technologies for carbon capture, specifically focusing on CO2-free hydrogen production for energy use within the Nigerian context.

2. EXPERIMENTAL METHODOLOGY OF RESEARCH

2.1. Simulation Of Steam Methane Reforming

The steam methane reforming process was simulated on COFE (the CAPE-OPEN Flowsheet Environment), a chemical flowsheeting package on the COCO (CAPE-OPEN to CAPE-OPEN) simulation environment. COFE is a chemical engineering module that provides steady-state simulation of chemical processes.

The following assumptions were made during the simulation of the SMR process.

i. The flow rates of methane and water in the reformer are 100 mol each.

ii. The methane stream has been processed and desulphurized.

Firstly, the reactors, compressors, heaters and mixers to be used were inserted on the flowsheet workspace. This was done by selecting ‘unit operation’ from the ‘Insert’ drop-down menu on the taskbar. The SMR process was modeled as follows.

Inlet and outlet streams were connected through each unit operation.

Flowsheet settings were then pre-defined before operation parameters were set. These settings are divided into.

i. Property packages: To define the property package, click on settings under document explorer on the left of the workspace. Select ‘property package’ and then click Add. Here, select TEA. Create a new package, change the thermodynamic model set and add the reacting and product compounds of the process.

Reaction packages: Under settings, select CORN and create New. Create a new reaction for the SMR reformer, and define stoichometry, using a negative sign for reactants and a positive sign for products as shown. Input the calculated heat of reaction. The properties of each stream were then input.

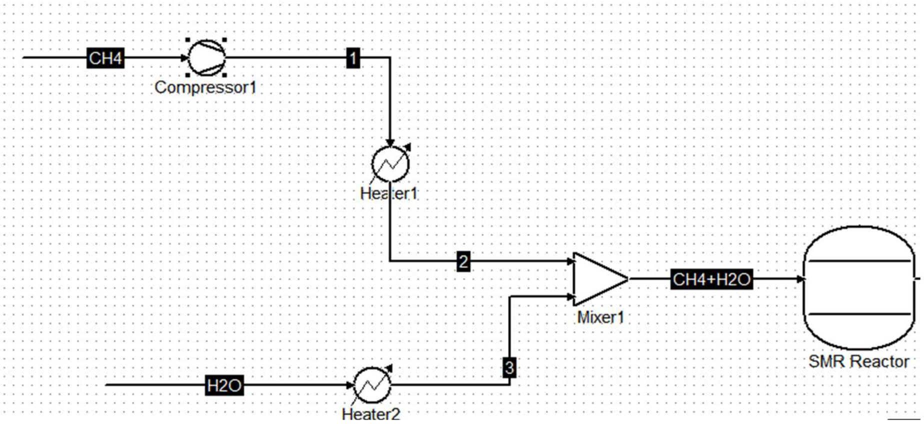


Figure 1: Steam Methane Reforming Simulation.

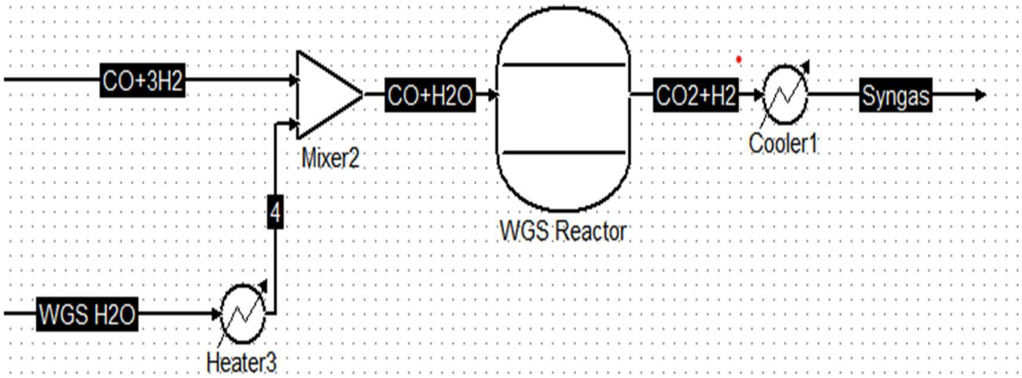


Figure 2: Water-Gas Shift (WGS) Reaction Simulation

It is important to note that when a stream goes through a unit operation, such as a compressor, heater or mixer, the effect of the unit on the stream should be calculated. This was done by clicking the unit and then 'calculate'. For the reformer, a reaction had to be specified. This was done by clicking on the reactor, going to 'edit', 'reactions' and then 'specify reactions. The previously created reaction was selected, and the reactor was set to operate at a temperature of 800°C.

The water-gas shift (WGS) reaction was then specified. The same steps for specifying reformer reaction were followed. A new reaction was created and stoichometry was defined. This reaction was then selected for the WGS reactor, and the reactor temperature was set at 450°C. The syngas was simulated to have relatively high carbon monoxide and dioxide contents, in order to demonstrate the efficacy of the chosen carbon capture method.

2.2. Simulation Of Carbon Capture by Diethanolamine Absorption

The simulation of the removal of CO2 from the syngas obtained from the SMR process model with the application of aqueous DEA as solvent was developed in Aspen HYSYS. Aspen HYSYS offers an extensive range of thermodynamic models, activity coefficient models and equations of state. The Acid Gas Chemical Solvent was selected for the process in the property package of Aspen HYSYS as it provides a comprehensive database of physical and chemical properties for solvents and solutes, including various amines (MEA, DEA, MDEA, etc.) and acid gases (CO2, H2S, etc.). The package has various combinations of equations such as the Electrolyte Non-Random Two-Liquid (Electrolyte-NRTL) Model 12 with all the important aqueous-phase equilibrium and kinetics reactions needed for rigorous calculations of the process. Peng-Robinson Equation of State (EOS) was incorporated for the vapor phases.

Table 1: Syngas Composition and Properties.

Component	**Syngas Composition (mol%)**	
Methane	14.3	
Hydrogen	50.0	
Carbon Monoxide	7.10	
Carbon dioxide	7.10	
Water	21.40	
Parameters	**Value**	**Unit**
Temperature	40	°C
Pressure	101.3	kPa
Flow rate	1422	kmole/hr

The table above shows the composition and properties of syngas post-SMR, which is 50% hydrogen, 14.3% methane, 7.1% carbon monoxide, 7.1% carbon dioxide, and 21.4% water (mol%). It flows at 1422 kmol/hr under atmospheric pressure (101.3 kPa) and 40°C.

Table 2: Aspen Hysys Unit Specifications.

Absorber	Value	Unit
Number of stages	20	
Top stage pressure	81.06	kpa
Bottom stage pressure	101.30	kpa
Heat Exchanger		
Shell side pressure drop	0.00	kpa
Tube side pressure drop	34.47	kpa
Stripper		
Number of stages	20	
Condenser	Full reflux	
Top stage pressure	65.00	kpa
Column pressure drop	2.00	kpa
Cooler		
Temperature	39	°C
Pump		
Discharge pressure	101.30	kpa

In the table 2, specifies units for CO_2 absorption from syngas using DEA in hydrogen production. The absorber (20 stages, 81.06–101.3 kPa) ensures effective CO_2 capture. The stripper (20 stages, 65 kPa, 2 kPa drop) aids CO_2 release and solvent regeneration. The heat exchanger and cooler manage temperatures and pressure drops, while the pump stabilizes system pressure. These optimize efficiency and process stability.

2.3. Carbon Dioxide Absorption

Lean amine was introduced into Tray 4 at the top of the absorber column while the syngas was fed into the column through Tray 18 at the stated conditions in [14]-[18]. Spacing of the two inlets in the absorber column is essential as it enhances interaction between the liquid and gas. The flow rate of the lean solvent was deliberately set higher than the syngas flow rate so as to increase removal efficiency of the solvent. The column was then set to operate at a high pressure and relatively lower temperature. The absorbate, also referred to as rich amine, exited as the bottom product while the sweet gas, free of CO_2, exited as the overhead product.

2.4. Solvent Regeneration

Rich amine was then passed through the tube side shell of the heat exchanger and heated to a high temperature. This heated stream passes the outlet of the tube and is directly fed into the stripper column. The stripping column, also known as distillation column, operates on low pressure/high temperature. The rich amine was fed into the bottom of the column and heated by the reboiler. At this high temperature, CO_2 is released and exits as the overhead product which is cooled by a condenser while the reflux is sent back into the column.

For further removal of CO_2 and vaporized water, the overhead product was passed into a component splitter. The vaporized water exits at the bottom and is fed into mixer to make up the lost solvent. The regenerated amine was passed into the shell inlet of lean/rich heat exchanger where heat is exchanged with rich amine. The stream is further fed into a pump to increase the pressure to mach to the inlet stream of the absorber, successfully completing the solvent regeneration process. The figure below shows the process architecture of the carbon dioxide absorption from the syngas and regeneration of the overhead absorption solvent.

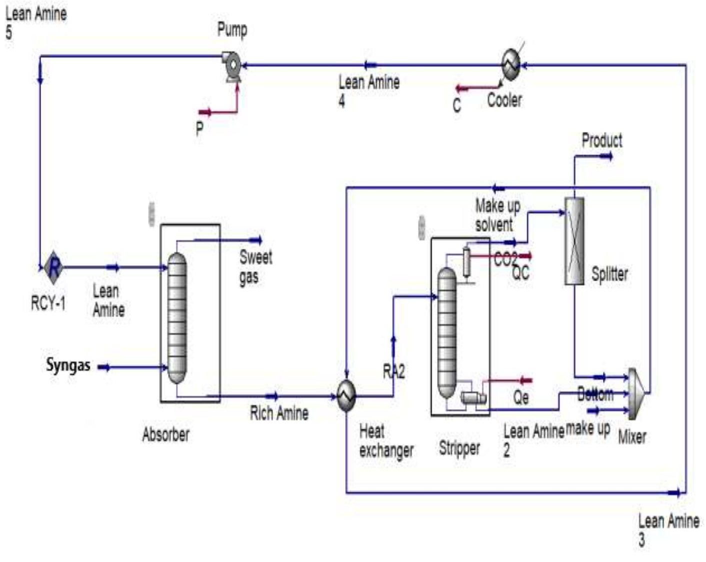
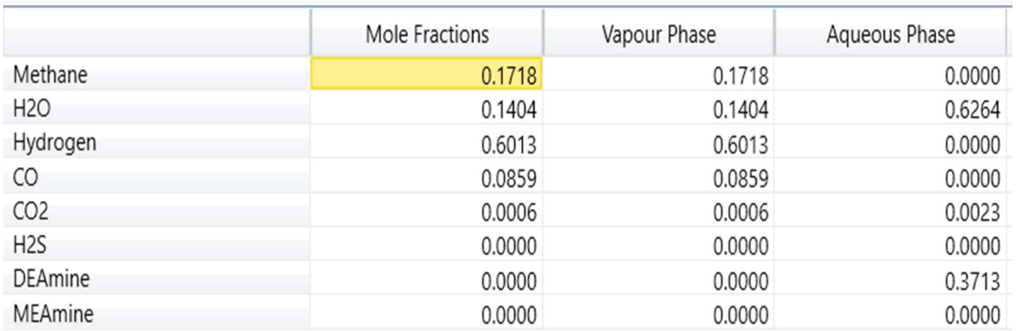


Figure 3: CO2 Capture and Solvent Regeneration.

3. RESULTS AND DISCUSSION

The sweet gas composition in Figure 4 shows a high hydrogen (60.13%) and methane (17.18%) content with minimal CO_2 and H_2S.The near-complete removal of acidic gases via DEA absorption ensures environmental compliance and smooth SMR operation.

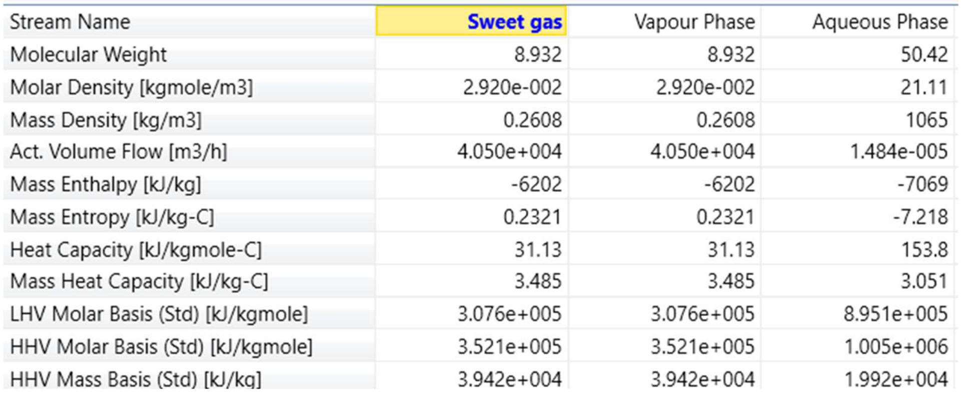


	Mole Fractions	Vapour Phase	Aqueous Phase
Methane	0.1718	0.1718	0.0000
H2O	0.1404	0.1404	0.6264
Hydrogen	0.6013	0.6013	0.0000
CO	0.0859	0.0859	0.0000
CO2	0.0006	0.0006	0.0023
H2S	0.0000	0.0000	0.0000
DEAmine	0.0000	0.0000	0.3713
MEAmine	0.0000	0.0000	0.0000

Figure 4: Sweet Gas Composition from Absorber.

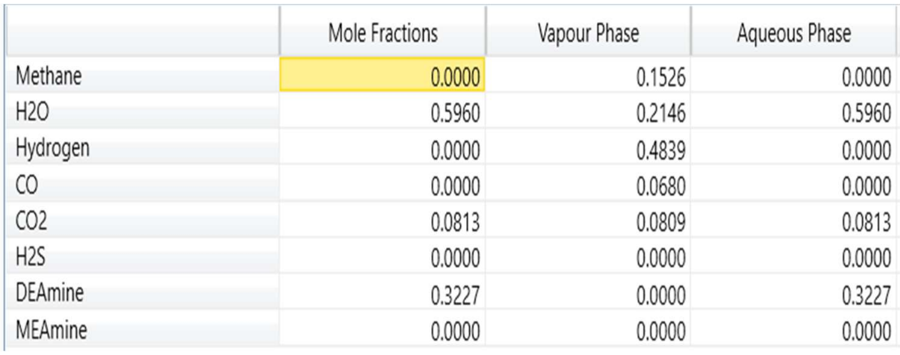
The sweet gas composition in Figure 4 shows a high hydrogen (60.13%) and methane (17.18%) content with minimal CO_2 and H_2S.The near-complete removal of acidic gases via DEA absorption ensures environmental compliance and smooth SMR operation.

The thermodynamic properties in Figure 5 indicate that the sweet gas is well-suited for SMR. Its low molecular weight (8.932) and high volumetric flow rate (4.05×10^4 m^3/h) support industrial-scale hydrogen production. The high calorific values (LHV: 30.7 MJ/kg, HHV: 39.2 MJ/kg) enhance energy efficiency, while the negative enthalpy ensures readiness for SMR's endothermic reactions, minimizing energy losses.The rich amine composition in Figure 6 shows effective CO_2 (0.0322 mole fraction) and H_2S (0.0252 mole fraction) removal by DEA, reducing emissions and preparing the feedstock for hydrogen production. Minimal methane and hydrogen losses ensure high process efficiency and protect SMR catalysts from sulfur poisoning.



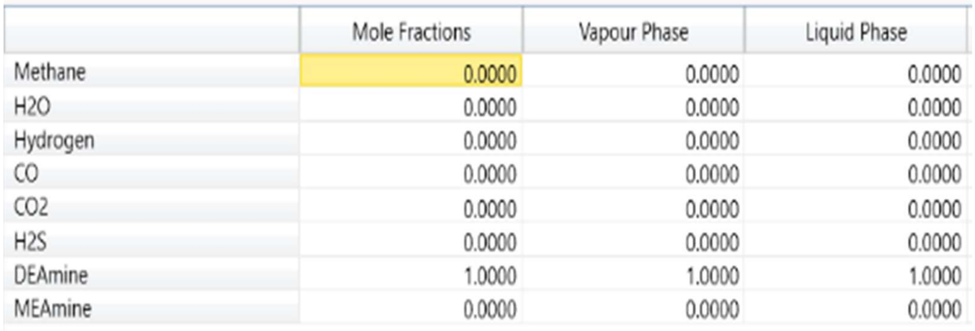
Stream Name	Sweet gas	Vapour Phase	Aqueous Phase
Molecular Weight	8.932	8.932	50.42
Molar Density [kgmole/m3]	2.920e-002	2.920e-002	21.11
Mass Density [kg/m3]	0.2608	0.2608	1065
Act. Volume Flow [m3/h]	4.050e+004	4.050e+004	1.484e-005
Mass Enthalpy [kJ/kg]	-6202	-6202	-7069
Mass Entropy [kJ/kg-C]	0.2321	0.2321	-7.218
Heat Capacity [kJ/kgmole-C]	31.13	31.13	153.8
Mass Heat Capacity [kJ/kg-C]	3.485	3.485	3.051
LHV Molar Basis (Std) [kJ/kgmole]	3.076e+005	3.076e+005	8.951e+005
HHV Molar Basis (Std) [kJ/kgmole]	3.521e+005	3.521e+005	1.005e+006
HHV Mass Basis (Std) [kJ/kg]	3.942e+004	3.942e+004	1.992e+004

Figure 5: Sweet Gas Composition.



	Mole Fractions	Vapour Phase	Aqueous Phase
Methane	0.0000	0.1526	0.0000
H2O	0.5960	0.2146	0.5960
Hydrogen	0.0000	0.4839	0.0000
CO	0.0000	0.0680	0.0000
CO2	0.0813	0.0809	0.0813
H2S	0.0000	0.0000	0.0000
DEAmine	0.3227	0.0000	0.3227
MEAmine	0.0000	0.0000	0.0000

Figure 6: Rich Amine Compostion from Absorber.



	Mole Fractions	Vapour Phase	Liquid Phase
Methane	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000
DEAmine	1.0000	1.0000	1.0000
MEAmine	0.0000	0.0000	0.0000

Figure 7: Composition of Lean Amine After Stripping.

Figure 7 shows the composition of lean amine after stripping, consisting entirely of pure diethanolamine (DEA) with a mole fraction of 1.000 in both vapor and liquid phases. This indicates successful regeneration of the amine, making it ready for reuse in CO_2 and H_2S absorption processes.

3.1. Discussion on Results

i. Absorber Overhead Product and Solvent Regeneration

From the composition of sweet gas exiting the top of the absorber as shown in Figure 4, it is observed that the overhead product is free of CO_2, which now constitutes a mere 0.06 mol%, as opposed to its composition in the syngas, which was 7.10%. Hydrogen yield also increases considerably, from 50.00 mol% in the syngas to 60.13mol% in the sweet gas after carbon capture. In Figure 7, it is also observed that the diethanolamine solvent is regenerated completely, as shown by the 100mol% composition of the amine after stripping.

ii. Natural Gas Utilization and Hydrogen Production

For a country blessed with an abundance of low-carbon natural gas, our management and utilization is abysmal. According to the National Oil Spill Detection and Response Agency (NOSDRA), oil and gas producing companies in Nigeria burnt 275.2 billion standard cubic feet of gas in 2023, culminating in a loss of around $1 billion [19]. Not only do these figures represent a missed commercial opportunity, but they also point towards the wanton impunity of producing companies when it comes to environmental appreciation and conservation.

The Nigerian government has implemented several measures to address gas flaring at oil-producing wells. The Associated Gas Re-Injection Act of 1979 mandates oil companies to submit detailed plans for gas utilization or re-injection, and the more recent Petroleum Industry Act (PIA), passed in 2021, emphasizes gas commercialization and provides fiscal incentives for investments in gas infrastructure [20]. The PIA introduces provisions that encourage investment in gas exploration, production, processing, and utilization. It prioritizes the development of gas infrastructure, including pipelines, gas processing facilities, and liquefied natural gas (LNG) plants. Companies that engage in gas flaring also face strict fines, designed to make flaring economically unattractive compared to gas utilization projects.

In March of 2021, the then President of Nigeria, Muhammadu Buhari, promulgated the decade between 2021 and 2030 to be "The Decade of Gas", and announced plans to source foreign investment and raise internal funding for the sector, up to an intended $26 billion [21]. While this ambitious plan still has a long way to go in infrastructure development and policy implementation, a strategic road map should include hydrogen production as a fuel, as the powerhouses of the world, in Europe, Asia and the Americas are making notable and confident strides in green hydrogen research and investment. Perhaps the most significant limitation to these efforts would be the cost intensive nature of electrolyzers and other heavy-duty equipment needed to split water into hydrogen and oxygen.

iii. Blue-To-Green Hydrogen

In a predictive statement ahead of the global target of net-zero carbon emissons by 2050, The African Development Bank estimates that Nigeria and Africa at large would require between $680 billion and $1.3 trillion to produce 30 to 60 million tonnes of green hydrogen [22]. The enormity of capital needed to execute any commercially viable green hydrogen project remains a temporary stumbling block, but the ongoing focus on gas utilization positions blue hydrogen production and use as a transitory solution.

Initiatives such as the Nigeria 4H2 (Nigeria for Hydrogen) project, recently lauded by Uche Nnaji, Minister of science, technology and innovation, should be supported and replicated, as they spark conversations and awareness. Nigeria should also look into international cooperation; Egypt, Kenya, Mauritania, Morocco, Namibia and South Africa, have formed the Africa Green Hydrogen Alliance, and though Nigeria recognizes the alliance, there has been no proactivity as regards becoming a member state. Neighboring Niger entered a mutual coalition agreement with Germany in 2020 to produce green hydrogen for export and eventual use [23].

iv. Enhancing CO_2 Absorption with DEA: Kinetics and Nanomaterials

Diethanolamine (DEA) is a well-established solvent for capturing carbon dioxide (CO_2) due to its strong reactivity and efficient kinetics. Its ability to absorb CO_2 effectively makes it a popular choice for gas separation processes. Recent studies have shown that adding nanoparticles like TiO_2, ZnO, and ZrO_2 to DEA solutions can further boost CO_2 absorption. These nanomaterials improve the mass transfer efficiency and increase the surface area for absorption, illustrating how nanotechnology can enhance DEA's performance in CO_2 capture [24].

In addition to this, research by Kierzkowska-Pawlak [25] has focused on the desorption and regeneration aspects of DEA in CO_2 removal. Her work highlights the importance of optimizing these processes, especially in stirred reactors, to improve overall efficiency in CO_2 separation. A separate study by Nunge and Gill revealed that DEA's CO_2 absorption is primarily controlled by reaction kinetics [26]. Their findings show that the absorption process follows a third-order reaction, which is strongly influenced by temperature but less so by mass transfer. Taken together, these studies emphasize the potential of DEA for CO_2 capture, especially when combined with kinetic improvements and nanomaterial-based enhancements.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

1. The process of SMR-DEA integration for hydrogen production was simulated using COFE and Aspen Hysys, with a comprehensive and replicable methodology detailed in the study.
2. The diethanolamine solvent used during absorption was completely regenerated, as shown by the 100 mol% composition of the lean amine after stripping.
3. The final product overhead product from the absorber was composed of a minuscule 0.06mol% of carbon dioxide and a hydrogen yield increase from 50.00 mol% in the syngas to 60.13mol% in the sweet gas after carbon capture.
4. Policy recommendations and initiatives for adopting SMR-DEA integration as a sustainable natural gas utilization method in Nigeria were suggested and discussed.

4.2. Recommendations

1. Alternative and innovative reactor designs for the methane reformer reactor and the water-gas shift reactor should be considered.

2. The practical and economic feasibility of hydrogen production, storage and transportation would capitalize on the value of this study.
3. Research into development of batteries and fuel cells that run on hydrogen is strongly encouraged.

DECLARATIONS

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