Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-5, Issue-2, pp-28-35
www.jiengtech.com
Research Paper Open Access

Characterization of Niger Delta Natural Gas for Methanol Production

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ABSTRACT : *This paper is focused on the characterization of natural gas sourced from the Niger Delta region. Samples were obtained from different fields in Delta state. Gas compositional analysis was performed to gain insights into its components and their relative proportions. The results of the gas chromatography analysis confirmed that the natural gas samples labeled as T004 and T034 contained 89.61% and 85.34% methane, respectively. Further research was conducted across various locations in the Niger Delta region, including the Nigerian Agip Oil Company, Nigeria Liquified Natural Gas Limited, Ughelli, and Utorogu fields, revealing an average methane content of 80%. This study explored natural gas composition through compositional analysis procedures, highlighting the concentrations of methane, ethane, propane, and other hydrocarbons. The primary objective was to assess the suitability of Niger Delta natural gas for methanol production throgh identification of methane content and the impurities that could influence methanol production yield. The presence of impurities can adversely affect the catalyst or trigger undesirable side effects, hence reducing methanol production efficiency and purity. Subsequently, simulation was conducted using Aspen Hysys software, utilizing the composition data obtained from both the analysis and existing literature. The findings of this research confirm that Niger Delta natural gas possesses the necessary methane content required for methanol production. This work contributes to the establishment of the feasibility of harnessing the natural gas resources within the Niger Delta region for efficient methanol production.*

KEYWORDS *Niger Delta, Characterization, Natural Gas, Methanol.*

Date of Submission: 23-03-2024 Date of acceptance: 09-04-2024

I. INTRODUCTION

Nigeria is Africa's most populous country endowed with large and diverse energy resources such as crude oil, natural gas, lignite, coal, and biomass which can be used in the production of Chemicals. The reserves of crude oil and natural gas is about 36.2 billion barrels and 187 trillion standard cubic feet respectively. Nigeria is oftentimes referred to as a gas province with a substantial accumulation of oil that can last for another 41 years as at 2011 production levels. The gas reserve in Nigeria is ranked as the ninth largest globally with about 5150.6 billion cubic meters (bcm). The vast gas reserves occur as associated gas or non-associated gas which means crude oil trapped along with natural gas or natural gas in a reservoir with little or no crude oil. Although most of the gas reserves in Nigeria are found as associated natural gas (Otene et. al, 2016). Nigeria had approximately 200.4 trillion cubic feet natural gas reserves in the year 2019 although not so much has been done to increase the monetary value of those reserves (Oduwa and Ehiosu, 2021). Nigeria has the largest natural gas reserve in Africa although there is limited infrastructure in place to develop the sector. Natural gas in Nigeria is found along the country's coastal Niger Delta River (Ogbe, 2011). The Niger Delta region comprises of nine states namely, Cross River, Edo, Delta, Abia, Imo, Rivers, Bayelsa, Akwa Ibom and Ondo (Pius and Emaziye, 2012). The are more than 250 oil and gas fields in Nigeria with about 2600 producing oil wells, some of the fields include but not limited to Bonny, Bonga, Forcados, Qua Iboe, Escravos, Usan, Akpo, Agbami, Brass, Abo oil fields (Ogbe, 2011).

Nigeria has a proven natural gas reserve of 209.5 trillion cubic feet as of 1st January 2022 according to Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) (Wasilat, 2022). Natural gas was once an unwanted by-product which is a subcategory of petroleum that is a complex mixture of hydrocarbons with some quantity of inorganic compounds present in it. Due to the huge potential for gas utilization natural gas has become a useful commodity (Ogbe, 2011). Among all hydrocarbon energy sources, natural gas is the cleanest and most rich in hydrogen. It has high energy conversion efficiency when used for power generation.

Natural gas composition comprises majorly of methane with the remaining fractions consisting of mixture of heavier hydrocarbons such as ethane, propane, butane. Natural gas is primarily used as fuel and raw material for other chemical industries. Major quantity of natural gas obtained is transformed into electricity using gas turbines or internal combustion engines (Koturbash, 2021).

Nigeria currently has the largest natural gas reserves in Africa with an exportation of about 75% of its daily gas production. Natural gas in Nigeria has been utilized majorly in the transportation sector and some gas utilization projects. The infrastructure used is highly dependent on the location of the gas field which is either onshore or offshore. Natural gas is commonly extracted through vertical drilling although the application of horizontal drilling, hydraulic fracturing or acidizing coupled with the vertical drilling can expand the amount of gas that a well can access and increase productivity (Turgeon & Morse, 2012). Hydraulic fracturing which is otherwise known as fracking is a process where high pressure streams of water, chemicals and sand is used to split open rock formations. Horizontal drilling broadens the productivity of the well. When a well is drilled vertically from the earth's surface, horizontal drilling can be applied by directing to go sideways. Acidizing involves dissolving acidic components and inserting into the natural gas well thereby dissolving the rock that may blow the flow of gas. Drilling for natural gas can lead to leaks if drilling procedures are not followed and this can be hazardous since natural gas dissipates quickly into air. Natural gas is transported through pipelines that can be from 2 to 60 inches diameter (Turgeon & Morse, 2012). The chemical and physical properties of Natural gas are shown in Table 1.1. Natural gas is colorless, tasteless, odorless, non-toxic, shapeless, and lighter than air.

Table 1 Physical and chemical properties of natural gas

S/N	Property	Value
1	Molecular Weight of mixture	18.2
2	Boiling Point at 1 atm	-160 ^{O} C
3	Melting Point	-180 ^{O} C
4	Vapor density (air = 1) at 15.5	0.61
5	Liquid density (water = 1) at 0 ˚ /4 ^{O} C	0.554
6	Water solubility at 20 ^{O} C	Slightly soluble (0.1% - 1.0%)

Source: (Aregbe, 2017)

One of the key characteristics of natural gas is it availability as natural gas reserves are abundant worldwide. Natural gas has high methane content and high energy density which makes it an ideal feedstock for methanol production as well as an efficient fuel source. Natural gas contains low level of impurities such as sulfur and nitrogen which can interfere with the chemical reactions involved in methanol production. Based on the reservoir that the natural gas is extracted; the composition varies. Natural gas may contain different hydrocarbon and non-hydrocarbon constituent. Hence, the gas composition is never constant (James, 2019). Table 2 shows the composition of natural gas in the Niger Delta Region from Nigerian Agip Oil Company (NAOC) and Nigerian Liquified Natural gas company (NLNG).

Table 2 Composition of Natural gas from Nigerian Agip Oil Company (NAOC) and Nigerian Liquefied Natural Gas company (NLNG)

Constituents	Nigerian Agip Oil Company (NAOC) mol-%	Nigeria Liquefied Natural Gas Company (NLNG) mol-%
Nitrogen	0.61	0.113
Carbon dioxide	2.59	1.957
Hydrogen Sulphide	0.001	0
Methane	78.81	88.748
Ethane	10.46	4.402
Propane	4.62	2.572
Iso-butane	0.79	0.553
N-Butane	0.97	0.843
Iso-Pentane	0.31	0.265
N-Pentane	0.27	0.195
Hexane	0.21	0.174
Heptane	0.1	0.178
Octane	0	0
Nonane	0	0
Decane	0	0
Water	0.26	0

Source: (Nnamdi et. al., 2016)

Natural gas offers environmental benefits apart from its abundance and cost-effectiveness when it is utilized as feedstock for methanol production. On comparison of natural gas with other feedstocks for methanol production, it has been observed that natural gas has a lower carbon footprint. Fewer pollutants and emissions are produced when natural gas is used to produce methanol, thereby making it cleaner and more sustainable.

Over the years, natural gas has been used as feedstock to produce synthesis gas. After which the synthesis gas produced is catalytically converted to methanol at elevated temperature and pressure in a fixed bed reactor. The catalyst used in this case is alumina pellet coated with copper and zinc oxides (Lazonby, 2020).

Methanol is a clear, colorless liquid with mild odor. It dissolves readily on most common organic solvent. Methanol is the most basic and large-scale industrial chemical material to be produced only with natural gas and water. Methanol is an important feedstock for the, chemical, petrochemical and energy industry. Production of methanol globally was about 83million metric tons in 2015. (Blumberg et. al., 2017). Production of methanol commercially can be achieved using the following procedures synthesis gas production methanol synthesis and Methanol purification. The technologies used in the production of synthesis gas are steam methane reforming, heat-exchange reforming, autothermic reforming.

II. MATERIALS AND METHODS

A. Materials

The materials and equipment used for this study include, natural gas samples obtained from wells in Delta State which is situated in the Niger Delta region, Gas Chromatograph Agilent 7890 with TCD-FID detectors based on ASTM D1945-96, Aspen Hysys software

B. METHODS

1. COMPOSITION ANALYSIS OF NATURAL GAS

Gas chromatography analysis is a physical and chemical separation analysis method. The components of natural gas were separated when they go through the chromatographic column and the detectors was used to change the concentration into the electrical signals and then recorded.

The main objective of the gas composition analysis was to obtain the percentage composition of each component as composition of natural gas varied from field to field from existing research.

2. SIMULATION OF METHANOL PRODUCTION FROM NATURAL GAS USING ASPEN HYSYS.

The Methanol plant was modelled using Aspen Hysys Software. Peng Robinson equation of state was used. For the simulation of methanol production from natural gas (natural gas composition for methanol production as shown in Table 3), the steam methane reforming chemical process was used. 100 MMscf/d of natural gas feedstock was supplied at a temperature and pressure of 30 °C and 2 bar, respectively. Using a single stage compressor, the natural gas was compressed to 15 bar to meet the requirements of the pre-reformer. The pre-reformer received steam to react with the natural gas at a temperature and pressure of 600 ° C and 15 bar respectively. The pre-reformer was modelled using a conversion reactor, which was configured to operate at 600 °C and 15 bar in order to convert the heavier hydrocarbon molecules in the natural gas stream into synthesis gas, which is made up of hydrogen and carbon monoxide product according to Equations 3.1 to 3.4

$${}_{2}\ {}_{6\,(g)} + 2\ {}_{2}\ {}_{(g)} = 5\ {}_{2(g)} + 2\ {}_{(g)}; \qquad \Delta H^{0}{}_{298K} = +374.3\ kJ\ mol \qquad 2.1$$

$${}_{3}\ {}_{8\,(g)} + 3\ {}_{2}\ {}_{(g)} = 7\ {}_{2(g)} + 3\ {}_{(g)}; \qquad \Delta H^{0}{}_{298K} = +497.7\ kJ\ mol \qquad 2.2$$

$$\mathrm{i} - C_4H_{10\,(g)} + 4H_2O_{(g)} = 9H_{2(g)} + 4CO_{(g)}; \qquad \Delta H^{0}{}_{298K} = +651.3\ kJ\ mol \qquad 2.3$$

$$n - C_4H_{10\,(g)} + 4H_2O_{(g)} = 9H_{2(g)} + 4CO_{(g)}; \qquad \Delta H^{0}{}_{298K} = +651.3\ kJ\ mol \qquad 2.4$$

Equilibrium reactor was used to model the reformer where methane present in the natural gas stream reacted with steam to produce synthesis gas product at a pressure of 15 bar and temperature of 850 °C with respect to equation 2.5 and equation 2.6.

$$CH_{4(g)} + H_2O_{(g)} = CO_{(g)} + 3H_{2(g)} \qquad \Delta H^{0}{}_{298K} = +651.3\ kJ\ mol \qquad 2.5$$

$$CO_{(g)} + H_2O_{(g)} = CO_{2\,(g)} + H_{2(g)} \qquad \Delta H^{0}{}_{298K} = -41\ kJ\ mol \qquad 2.6$$

The synthesis gas obtained was cooled to 60 °C using a cooler, liquid effluent water was then separated before the gaseous stream mixed with a recycle stream was passed through a jacketed plug flow reactor were methanol synthesis occurred at 40 oC and 15 bar. The plug flow reactor was modelled to obey equations 2.7 and 2.8.

$$CO_{2(g)} + 3H_{2(g)} = H_2O_{(g)} + CH_3OH_{(g)} \qquad \Delta H^{0}{}_{298K} = -41.2\ kJ\ mol \qquad 2.7$$

$$CO_{g} + 2H_{2(g)} = CH_3OH_{(g)} \qquad \Delta H^{0}{}_{298K} = -90.7\ kJ\ mol \qquad 2.8$$

The equilibrium expression in equation 2.9 for the methanol production was given by Turton. et al in 2012

$$K = 4.8 \times 10^{-13} \exp({}^{11458}/{}_{T}) \qquad 2.9$$

The product obtained from the plug flow reactor was flashed to 2 bar where the gas stream was compressed and sent as a recycle stream into the methanol reactor while the liquid product was sent to a distillation column for purification and collection.

Table 3 Natural Gas Composition for Methanol Production

Component	T004	T034	NAOC	NLNG	S1	S2	S3	Ugheli	Kokori Field	Utorogu	Sapele
Nitrogen	1.13	0.73	0.61	0.113	0.35	0.04	0.59	0.00	0.16	0	0
Carbon dioxide	1.49	4.75	2.59	1.957	0.47	0.96	0.86	2.1	1.02	0	0
Hydrogen Sulphide	0	0	0.001	0	0	0	0	0	0	0	0
Methane	89.61	85.34	78.81	88.748	98.08	93.83	94.61	88.1	68.42	90.19	68.14
Ethane	5.51	6.22	10.46	4.402	1.02	1.74	1.57	6.3	7.65	6.94	14.22
Propane	1.34	1.69	4.62	2.572	0.05	1.68	1.17	2.1	11.27	2.09	10.27
Isobutane	0.29	0.4	0.79	0.553	0.01	0.65	0.44	0	4.42	0.414	3.23
N-Butane	0.29	0.4	0.97	0.843	0.02	0.43	0.29	0.3	4	0.361	2.38
Iso-Pentane	0.12	0.18	0.31	0.265	0	0.17	0.12	0	1.55	0.007	0.75
N-Pentane	0.08	0.12	0.27	0.195	0	0.21	0.14	1.1	0.94	0.005	1.07
Hexane	0.06	0.1	0.21	0.174	0	0	0	0	0.18	0	0
Heptane	0.06	0.05	0.1	0.178	0	0	0	0	0	0	0
Octane	0.01	0.01	0	0	0	0	0	0	0	0	0
Nonane	0.01	0.01	0	0	0	0	0	0	0	0	0
Decane	0	0	0	0	0	0	0	0	0	0	0
Water	0	0	0.26	0	0	0	0	0	0	0	0
Argon	0	0	0	0	0	0	0	0	0	0	0
Helium	0	0	0	0	0	0	0	0	0	0	0

All units in Table 2.1 are in mole percent.
NAOC (Nigerian Agip Oil Company), NLNG (Nigeria Liquefied Natural Gas Company).

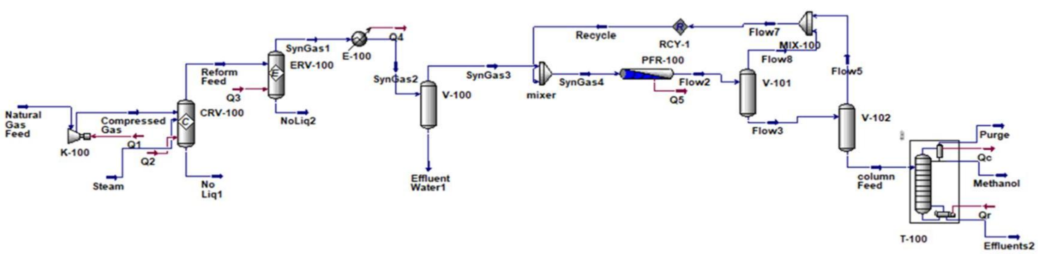

Fig. 1 Flow scheme of Methanol simulation via the Steam Methane reforming route from Aspen Hysys.

III. RESULTS/DISCUSSIONS

Gas compositional Analysis result

The compositional analysis of the sample was performed using Agilent 7890 Gas chromatograph (GC) with TCD-FID detectors based on ASTM D1945-96. Table below shows the result from the Gas composition analysis:

Table 4 Gas composition results for T004 and T034

	Component	T004 Delta (mol%)	T034 Delta (mol%)
Nitrogen	2	1.13	0.73
Carbon dioxide	2	1.49	4.75
Hydrogen Sulphide	2	0.00	0.00
Methane	1	89.61	85.34
Ethane	2	5.51	6.22
Propane	3	1.34	1.69
I-Butane	$i - C_4$	0.29	0.40
N-Butane	$n - C_4$	0.29	0.40
I-Pentane	$i - C_5$	0.12	0.18
N-Pentane	$n - C_5$	0.08	0.12
Hexane	6	0.06	0.10
Heptane	7	0.06	0.05
Octane	8	0.01	0.01
Nonane	9	0.01	0.01
Decane	10	0.00	0.00

Methane a crucial feedstock used to create methanol and it is also main component of natural gas. It is evident from the outcome of the gas chromatography analysis as seen in Table 4 and exiting literature that the natural gas samples from the Niger Delta region have high methane content. Methane is a commonly accessible and consistent feedstock for methanol production. Consequently, Methanol yield increases as methane content in natural gas rises. To produce methanol, natural gas with a high methane content is preferred. Fig 2 below shows comparison of composition of natural gas in the Niger Delta Region

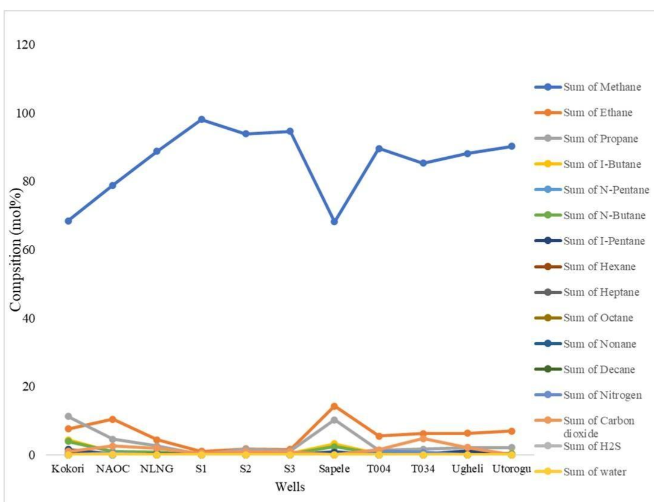

Fig. 2 Comparison of Composition of Natural gas in the Niger Delta

Methanol derived from natural gas has shown to have positive environmental effects, making it a better option than other feedstocks used to make methanol. Furthermore, in the Niger Delta region of Nigeria, natural gas is abundantly accessible, cost-effective, and can be sourced directly from pipelines and wells, ensuring a stable and secure supply. The simulation result of the amount of methanol produced in relation to the amount of Natural gas supplied using the same parameters and operation from the various location of consideration is shown in Table 5.

Table 5: Simulation results showing quantity of methanol produced from various locations

Well	Natural gas Feed (Kgmol/h)	Methanol Produced (Kgmol/h)
NAOC	4981	1000
NLNG	4981	1000
S1	4981	999.9
S2	4981	1000
S3	4981	1000
Ugheli	4981	1000
Utorogu	4981	999.8
Sapele	4981	1000
Kokori	4981	1000
T004	4981	1000
T034	4981	1000

IV CONCLUSION

The characteristics of natural gas can influence the methanol yield. For natural gas to be used as a feedstock for the production of methanol, it needs to undergo desulphurization in cases where there are sulfur compounds present as this Sulphur compounds can affect the catalyst used thereby leading to lower methanol yield. Natural gas with lower sulfur content is mostly preferred and ideal for methanol production. Also, the composition of natural gas especially the ratio of methane to other hydrocarbons can also influence the methanol yield. Natural gas from the Niger Delta region is suitable to produce methanol as it contains high content of methane and very low concentration of impurities. The yield of methanol obtained from natural gas samples within the Niger Delta region is high. Manufacturing of methanol from natural gas can benefit the environment immensely. Therefore, utilizing natural gas for methanol production other than conventional methanol manufacturing techniques that use fossil fuels can lead to fewer greenhouse gas emissions and a smaller carbon footprint. This supports the international attempts to move towards a more ecologically friendly and sustainable business practices. The favorable characteristics of Niger Delta natural gas make it an excellent feedstock for methanol production.

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