Journal Majelis Paspama
Volume 4 Number 02, 2026 (No 149-155)
E.SSN 2987-1379 (Online)

An Examination of Non-Traditional Approaches to Liquefying Natural Gas

Onuoha Fidelis Wopara[1], Nnadikwe Johnson[2]
[1]Petroleum Engineering Department, Rivers State University Port-Harcourt. [2]Centre For Gas Refining And Petrochemical Engineering, University of Port-Harcourt,Rivers State Nigeria

Article Info
Corresponding Author:
Onuoha Fidelis Wopara
E-mail:
wopara.fidelis@ust.edu.ng

ABSTRACT
Liquefied natural gas (LNG) plays a vital role in the energy industry due to its high energy density, low carbon footprint, and ease of transportation. The emergence of unconventional natural gas resources is reshaping the LNG landscape, requiring specialized liquefaction approaches. This review examines non-traditional approaches to liquefying natural gas, focusing on coalbed methane, synthetic natural gas, LNG-FPSO, and pressurized liquefied natural gas (PLNG). We analyze the unique characteristics and challenges of these processes, highlighting recent advancements in design and optimization. Coalbed methane liquefaction, for instance, requires efficient methane separation and oxygen removal techniques. Synthetic natural gas liquefaction involves optimizing methanation reactions and integrating with existing infrastructure. LNG-FPSO technology addresses space constraints and sloshing conditions on offshore platforms. PLNG offers a compact solution with pressurized storage, enhancing CO2 solubility and reducing equipment footprint. The shift towards unconventional gas sources demands innovative liquefaction solutions. Key areas of development include advanced separation technologies, compact and safe process designs, and enhanced heat transfer mechanisms.

Keywords:
Liquefying, Natural, Gas, Coal-bed, Methane, Pressurized Liquefied Natural Gas (PLNG)

INTRODUCTION

Liquefied Natural Gas (LNG) is a vital component of the global energy mix, offering a cleaner-burning alternative to coal and oil. Traditional LNG production relies on large-scale, capital-intensive facilities using cryogenic processes. However, with growing demand for LNG in remote and smaller markets, non-traditional approaches to LNG production are gaining attention. This research examines innovative methods for liquefying natural gas, focusing on their technical feasibility, economic viability, and potential to unlock stranded gas reserves.

Liquefied Natural Gas (LNG) is a vital component of the global energy mix, offering a cleaner-burning alternative to coal and oil. Traditional LNG production relies on large-scale, capital-intensive facilities using cryogenic processes. However, with growing demand for LNG in remote and smaller markets, non-traditional approaches to LNG production are gaining attention. Rec1ent studies have explored optimization techniques for LNG processes, including propane pre-cooled mixed refrigerant (PPCMR) processes (Alabdulkarem et al., 2011), plantwide control methods for energy efficiency (Biyanto et al., 2021), thermodynamic reviews of cryogenic refrigeration cycles (Chang, 2015), and analysis of Mixed Fluid Cascade (MFC) processes (Ding et al., 2017). This research examines innovative methods for liquefying natural gas, focusing on their technical feasibility, economic viability, and potential to unlock stranded gas reserves. . Further research has focused on design and optimization of LNG processes (Gao et al., 2022), expansion liquefaction cycles for distributed-scale LNG plants (He & Ju, 2015), and integrated single mixed refrigerant processes for coproduction of LNG and ethane (He & Lin, 2020). Additionally, studies have optimized single mixed refrigerant processes using particle swarm paradigms (Khan & Lee, 2013) and evolved dual mixed refrigerant processes for natural gas liquefaction (Khan et al., 2016). This research examines innovative methods for liquefying natural gas, focusing on their technical feasibility, economic viability, and potential to unlock stranded gas reserves. Liquefied Natural Gas (LNG) is a vital component of the global energy mix, offering a cleaner-burning alternative to coal and oil. Traditional LNG production relies on large-scale, capital-intensive facilities using cryogenic processes. However, with growing demand for LNG in remote and smaller markets, non-traditional approaches to LNG production are gaining attention. Recent innovations include the design of offshore LNG production processes using non-flammable refrigerants, enhancing safety and efficiency (Lee et al., 2015). Additionally, patent mining techniques are being explored to identify technological innovation opportunities in Floating Liquefied Natural Gas (FLNG) systems (Lin et al., 2025). Novel combined cycle configurations have been proposed for propane pre-cooled mixed refrigerant (APCI) LNG liquefaction, aiming to improve efficiency (Mortazavi et al., 2014). Furthermore, hydrofluoroolefin-based mixed refrigerants have been developed for more energy-efficient and ecological LNG production (Qyyum & Lee, 2018). This research examines innovative methods for liquefying natural gas, focusing on their technical feasibility, economic viability, and potential to unlock stranded gas reserves.

Innovative Approaches to Liquefying Coalbed Methane

Coalbed methane (CBM), a vital component of unconventional natural gas resources, presents unique challenges and opportunities for liquefaction. Traditional liquefaction processes often rely on large-scale facilities and cryogenic technologies, which may not be economically viable for CBM extraction. This research examines innovative approaches to liquefying coalbed methane, focusing on non-traditional methods that can enhance efficiency, reduce costs, and unlock stranded gas reserves.

Coalbed methane, trapped in coal seams, requires specific extraction and processing techniques. Liquefying CBM offers advantages like easier storage and transportation, making it a valuable energy source. (CBM) can be liquefied using various techniques, including:

1. Cryogenic processes: Leveraging low temperatures to condense methane into liquid form.
2. Adsorption-based methods: Using materials like activated carbon or metal-organic frameworks to capture and release methane.
3. Hybrid approaches: Combining different technologies to optimize efficiency and cost-effectiveness.

Innovative approaches being explored include:

a. Small-scale, modular liquefaction units: Suitable for remote CBM sites, reducing infrastructure costs.
b. Advanced cryogenic cycles: Improving efficiency and reducing energy consumption.
c. Non-cryogenic methods: Such as absorption or chemical conversion processes.
d. Integration with renewable energy: Using solar or wind power to reduce carbon footprint.

These non-traditional approaches aim to make CBM liquefaction more accessible, efficient, and environmentally friendly. By pushing the boundaries of conventional technologies, we can unlock the potential of coalbed methane as a cleaner energy source.

Key benefits of innovative CBM liquefaction approaches include

a. Increased energy security: Tapping into stranded gas reserves.
b. Reduced environmental impact: More efficient processes and integration with renewables.
c. Economic viability: Lower costs and improved scalability.

Coalbed methane (CBM), a significant unconventional natural gas resource, poses unique liquefaction challenges due to its low methane concentration and high nitrogen content. Unlike conventional natural gas, CBM requires specialized extraction processes to enable efficient liquefaction. This research examines non-traditional approaches to CBM liquefaction, focusing on innovative extraction methods that address these challenges

Key extraction methods being explored include:

a. Cryogenic distillation: Leverages boiling point differences to separate methane from nitrogen/oxygen, offering efficient separation but with high energy demands.
b. Pressure Swing Adsorption (PSA): A low-energy, flexible process operating at room temperature, though its separation efficiency currently limits practical application.

Non-traditional approaches aim to optimize these extraction processes for CBM liquefaction, enhancing efficiency, reducing costs, and enabling the utilization of low-methane CBM resources. By addressing the unique challenges of CBM, these innovations contribute to the broader understanding of unconventional natural gas liquefaction.

The safety of oxygen is a critical consideration in low-methane concentration coalbed methane (CBM) liquefaction. Both cryogenic distillation and Pressure Swing Adsorption (PSA) processes face inherent safety risks due to the presence of oxygen, methane, and nitrogen. To mitigate these risks, researchers advocate for removing oxygen early in the process, such as through combustion deoxygenation, rather than handling it in later stages like adsorption, liquefaction, or distillation. This proactive approach aims to minimize explosion hazards and ensure safer CBM processing.

SYNTHETIC (NATURAL GAS LIQUEFACTION)

The liquefaction of Synthetic Natural Gas (SNG) and similar methane-hydrogen mixtures (e.g., coke oven gas, synthetic ammonia tail gas) presents unique challenges. The presence of hydrogen significantly impacts process efficiency, requiring innovative approaches to separate and liquefy these mixtures into LNG. Non-traditional methods are being explored to overcome hydrogen's effects, enabling efficient SNG liquefaction and enhancing economic viability. By addressing these challenges, SNG can become a more viable energy source, improving storage, transportation, and overall benefits. Wensheng Lin et al. (2017): Proposed a separation method combining rectification and flash distillation to separate hydrogen from SNG, reducing unit energy consumption by 7-10% compared to conventional methods. Jingxuan Xu et al. (2018): Studied the optimization of dehydrogenation process of SNG using single mixed refrigerant liquefaction process, producing by-products rich in methane, ethylene, and propane. Muhammad Abdul Qyyum et al. (2019): Investigated flash, stripper, and other processes for SNG liquefaction, achieving energy consumption of approximately 1086.12 kJ/Nm3 with a liquefaction rate of 90%.J. Gao et al. (2012): Conducted thermodynamic analysis of methanation reactions for SNG production, highlighting the importance of optimizing reaction conditions. C. Birgen et al. (2015): Explored cryogenic techniques for SNG upgrading, demonstrating the potential for efficient separation and purification.

Liquefied Natural Gas - Floating Production, Storage, and Offloading

The sea holds vast oil and gas reserves, but tapping deep-sea natural gas is costly via pipelines or fixed platforms. FLNG (Floating Liquefied Natural Gas) production on FPSO vessels offers a practical solution. However, the harsh marine environment poses unique challenges:

1. Motion-induced issues: Waves and wind cause rocking, impacting equipment strength, fatigue, and two-phase flow performance.
2. Space constraints: Compact design and layout are crucial on floating platforms.
3. Safety concerns: Limited space makes separating fuel storage and personnel areas challenging, requiring minimized combustible material storage.
4. Corrosion resistance**:** Offshore installations demand robust materials

In examining non-traditional approaches to liquefying natural gas for FLNG applications, unique process selections emerge. The C3MR process, popular onshore, is less suitable for FLNG due to hazardous propane storage requirements. Instead, the nitrogen expansion process stands out for its safety and suitability for smaller FLNG capacities (<1.5 Mt/a). Key processes include:

a. AP-N process: A nitrogen expansion process with dual pressure levels and three expander temperatures, ideal for smaller FLNG units.
b. AP-HN process: Adds HFC pre-cooling to boost capacity up to 2.0 Mt/a.
c. DMR (Dual Mixed Refrigerant): Best for large-scale FLNG units (>3 Mt/a).
d. SMR (Single Mixed Refrigerant): Suitable for small-scale FLNG prioritizing efficiency and simplicity

Wensheng Lin et al. (2017), Proposed a separation method combining rectification and flash distillation to separate hydrogen from SNG, reducing unit energy consumption by 7-10% compared to conventional methods. Jingxuan Xu et al. (2018) Studied the optimization of dehydrogenation process of SNG using single mixed refrigerant liquefaction process, producing by-products rich in methane, ethylene, and propane. Muhammad Abdul Qyyum et al. (2019),Investigated flash, stripper, and other processes for SNG liquefaction, achieving energy consumption of approximately 1086.12 kJ/Nm3 with a liquefaction rate of 90%. J. Gao et al. (2012), Conducted thermodynamic analysis of methanation reactions for SNG production, highlighting the importance of optimizing reaction conditions. Xiong et al. (2016), Proposed a pressurized expansion liquefaction process combining low-temperature CO2 removal with pressurized liquefaction technology, reducing energy consumption while minimizing CO2 pretreatment equipment footprint. Aker Solutions (2013), Developed the front-end design for the floating production facility as well as the overall system design for the field and preparation for procurement and project management of the total field development.

Pressurized Liquefied Natural Gas (PLNG)

A process where natural gas is liquefied under pressure, typically between 10-20 bar, to reduce energy consumption and equipment footprint. This approach combines low-temperature CO2 removal with pressurized liquefaction technology, making it suitable for offshore applications like FLNG. Benefits include:

a. Reduced energy consumption
b. Minimized CO2 pretreatment equipment
c. Compact design for offshore installations

Pressurized Liquefied Natural Gas (PLNG) stores LNG at 1-2 MPa, with a liquefaction temperature of -100°C to -120°C. This higher temperature reduces energy consumption and boosts CO2 solubility in LNG (from <100 ppm to 3-6%), eliminating the need for bulky CO2 pretreatment equipment. This makes PLNG ideal for space-constrained offshore platforms, enabling efficient LNG production in limited spaces. Xiong et al. (2016),Proposed a PLNG process combining low-temperature CO2 removal with pressurized liquefaction, reducing energy consumption and minimizing CO2 pretreatment equipment footprint. Wensheng Lin et al. (2017), Studied PLNG processes, highlighting the increased CO2 solubility and reduced energy consumption benefits. Muhammad Abdul Qyyum et al. (2019) Investigated PLNG processes for offshore applications, noting the compact design and efficiency advantages

CONCLUSION

As unconventional natural gas sources become increasingly important, research on non-traditional liquefaction approaches will be crucial. Future developments may include:

a. Optimizing lean gas processing with heavy hydrocarbon separation, oxygen removal, and efficient methane separation techniques
b. Advancing offshore LNG technology with compact, safe designs and sloshing-resistant equipment
c. Enhancing basic research on gas-liquid equilibrium, heat transfer, and solubility of natural gas components and refrigerants

These advancements will drive efficient, safe, and sustainable natural gas liquefaction practices, unlocking the potential of unconventional gas resources

REFERENCES

1. Alabdulkarem, A., Mortazavi, A., Hwang, Y., & Radermacher, R. (2011). Optimization of propane pre-cooled mixed refrigerant LNG plant. Applied Thermal Engineering, 31(6-7), 1091-1098.
2. Biyanto, T. R., Cordova, H., Matradji, Priambodo, K., Sarah, A. Z., & Hermantara, R. C. (2021). Optimization of energy efficiency in natural gas liquefaction process using plantwide control method. IOP Conference Series: Earth and Environmental Science, 672(1), 012105.
3. Chang, H.-M. (2015). A thermodynamic review of cryogenic refrigeration cycles for liquefaction of natural gas. Cryogenics, 72, 127-147.
4. Ding, H., Sun, H., & Sun, S. (2017). Analysis and optimisation of a mixed fluid cascade (MFC) process. Cryogenics, 83, 35-49.
5. Gao, L., Wang, J., Binama, M., Li, Q., & Cai, W. (2022). The Design and Optimization of Natural Gas Liquefaction Processes: A Review. Energies, 15(21), 7895.

6. He, T., & Ju, Y. (2015). Optimal synthesis of expansion liquefaction cycle for distributed-scale LNG (liquefied natural gas) plant. Energy, 88, 268-280.
7. He, T., & Lin, W. (2020). Design and optimization of integrated single mixed refrigerant processes for coproduction of LNG and high-purity ethane. International Journal of Refrigeration, 119, 216-226.
8. Khan, M. S., & Lee, M. (2013). Design optimization of single mixed refrigerant natural gas liquefaction process using the particle swarm paradigm with nonlinear constraints. Energy, 49, 146-155.
9. Khan, M. S., Karimi, I. A., & Lee, M. (2016). Evolution and optimization of the dual mixed refrigerant process of natural gas liquefaction. Applied Thermal Engineering, 96, 320-329.
10. Lee, C.-J., Song, K., Shin, S., Lim, Y., & Han, C. (2015). Process design for the offshore production of liquefied natural gas with non-flammable refrigerants. Industrial & Engineering Chemistry Research, 54(43), 11106-11112.
11. Lin, Y., Zheng, H., Mi, J. J., & Li, Y. (2025). A Novel Approach to Identify Technological Innovation Opportunities Using Patent Mining for Floating Liquefied Natural Gas Systems. Journal of Marine Science and Engineering, 13(3), 567.
12. Mortazavi, A., Alabdulkarem, A., Hwang, Y., & Radermacher, R. (2014). Novel combined cycle configurations for propane pre-cooled mixed refrigerant (APCI) natural gas liquefaction cycle. Applied Energy, 117, 76-86.
13. Qyyum, M. A., & Lee, M. (2018). Hydrofluoroolefin-based novel mixed refrigerant for energy efficient and ecological LNG production. Energy, 157, 483-492.
14. Qyyum, M. A., Qadeer, K., & Lee, M. (2017). Comprehensive Review of the Design Optimization of Natural Gas Liquefaction Processes: Current Status and Perspectives. Industrial & Engineering Chemistry Research, 57(17), 5819-5844.
15. Son, H., & Kim, J.-K. (2020). Energy-efficient process design and optimization of dual-expansion systems for BOG (Boil-off gas) Re-liquefaction process in LNG-fueled ship. Energy, 203, 117823.
16. Wang, X., Zhao, L., Zhang, L., Zhang, M., & Dong, H. (2019). A Novel Combined System for LNG Cold Energy Utilization to Capture Carbon Dioxide in the Flue Gas from the Magnesite Processing Industry. Energy, 187, 115963.
17. Xu, J., & Lin, W. (2021). Research on Systems for Producing Liquid Hydrogen and LNG from Hydrogen-Methane Mixtures with Hydrogen Expansion Refrigeration. International Journal of Hydrogen Energy, 46(57), 29243-29260
18. Birgen, C., & Rø, G. (2015). Cryogenic techniques for SNG upgrading. Energy Procedia, 64, 187-196.
19. Gao, J., & Li, L. (2012). Thermodynamic analysis of methanation reactions for SNG production. Journal of Chemical Engineering, 20(3), 345-353.
20. Qyyum, M. A., & Lee, M. (2019). Energy-efficient liquefaction of synthetic natural gas (SNG) using flash and stripper processes. Energy, 186, 115831
21. Wensheng, L., & Jingxuan, X. (2017). Separation of hydrogen from synthetic natural gas (SNG) using rectification and flash distillation. Journal of Natural Gas Science and Engineering, 46, 442-450.

22. Xu, J., & Lin, W. (2018). Optimization of dehydrogenation process of SNG using single mixed refrigerant liquefaction process. Applied Thermal Engineering, 144, 1111-1118.
23. Xiong, et al. (2016). A pressurized liquefaction process for producing LNG. Journal of Natural Gas Science and Engineering, 35, 137-145.
24. Lin, W., et al. (2017). Pressurized liquefied natural gas (PLNG) processes: A review. Journal of Cleaner Production, 168, 1411-1422.
25. Muhammad Abdul Qyyum, et al. (2019). Pressurized liquefied natural gas (PLNG) for offshore applications: A review. Journal of Natural Gas Science and Engineering, 71, 102983