International Journal of Technology, Science and Engineering **ISSN: 2457-1016**

Vol. 7, Issue I, Jan-Mar 2024 http://www.bharatpublication.com/journal-detail.php?jID=25/IJTSE

Developing A Model To Determine The Optimal Blend Ratio Of Hydrogen In Natural Gas System Linked To Physical Properties

Astha

Delhi Technological University, Delhi

[1]*Received:25 Oct. 2023; Accepted: 29 Dec. 2023; Published: 24 Jan. 2024*

ABSTRACT

Natural gas systems are an integral part of global energy supply, but concerns about greenhouse gas emissions make it necessary to explore cleaner alternatives. Hydrogen, a clean energy carrier, offers potential for blending with natural gas to reduce carbon footprints. However, finding the best blending ratio involves carefully considering several factors, including physical properties like energy content, density, viscosity, flame speed, and safety parameters like leakage risks and material integrity. The study investigates these parameters to find an optimal blend ratio that balances emissions reduction with performance and safety.

A holistic experimental and computational approach has been adopted to explore the effect of hydrogen blending at different volume fractions, such as 5%, 10%, 15%, and 20% by volume. Key findings reflect that hydrogen blending up to a volume fraction of 20% guarantees minimal deviations from system performance while significantly reducing carbon dioxide emissions and managing safety concerns. In addition, the study accommodates safety assessments to ensure infrastructure compatibility and thereby act as a pathway to integration with existing natural gas systems. Modelling and simulation have been incorporated into the overall research scope to understand flow characteristics and combustion properties.

INTRODUCTION

Background

The recent horizon of energy development in the world is characterized by the shift in the consciousness of various nations to reduce impacts resulting from climate change and less dependency on fossil fuels. Natural gas, one of the key energy sources, has long been considered a relatively clean fuel compared to coal and oil. It emits less carbon dioxide during combustion. However, as the urgency to decarbonize increases, even natural gas systems are brought under the microscope for their greenhouse gas emissions contribution. To tackle these challenges, incorporating hydrogen, a zero-carbon energy carrier, into natural gas systems is emerging as an attractive strategy. The combustion of hydrogen produces only water vapour; hence, it is a cleaner source of energy with significant potential for reducing the carbon footprint of existing energy systems.

Hydrogen production technologies, like electrolysis based on renewable energy sources, have made considerable progress in recent years to produce green hydrogen with virtually no environmental damage. These advancements have accelerated the interest in hydrogen as a core component of future energy systems, especially blending it with natural gas for a transitional pathway toward a low-carbon energy future.

Problem Statement

Hydrogen does not blend with natural gas without difficulty. Hydrogen is a unique fluid that differs significantly from methane, the major component of natural gas. This affects the fuel mixture's energy content, flame speed, density, and viscosity, meaning the infrastructure for existing pipelines and combustion systems may need to be altered. In addition, the low molecular weight of hydrogen leads to a greater likelihood of leakage and safety concerns regarding

[1] **How to cite the article**: Astha (2024) Developing a model to determine the optimal blend ratio of Hydrogen in Natural Gas System linked Physical Properties; *International Journal of Technology, Science and Engineering*; Vol 7 Issue 1; 19-24

material embrittlement in pipelines and storage systems. The challenges notwithstanding, the benefits of blending hydrogen—reduced carbon emissions and resilience of the energy system—provide sufficient justification to conduct an exhaustive analysis to find the optimal blend ratio that best balances these conflicting factors.

Objective

This paper strives to find the ideal mix or ratio of hydrogen to natural gas based on physical properties of security, efficiency, and infrastructure capability. Based on key parameters such as energy content, flow characteristics, material integrity, and safety, this research will help provide a scientific basis for integrating hydrogen into natural gas systems. The outcomes will find their ways of influencing policymakers, engineers, and industry stakeholders while implementing a hydrogen blending strategy that will align with global decarbonisation goals.

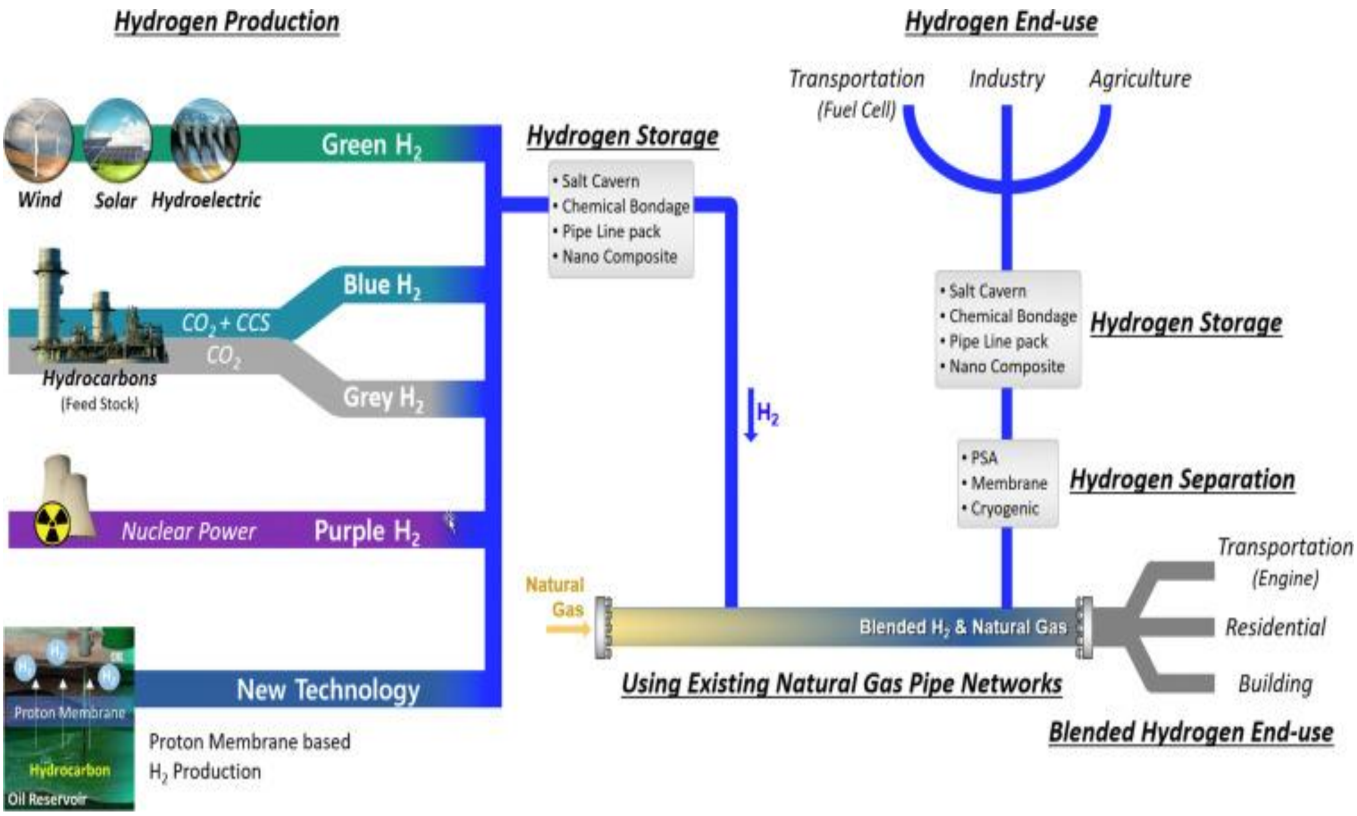

Fig 1: Feasibility analysis of blending hydrogen into natural gas networks

LITERATURE REVIEW

Hydrogen as an Energy Carrier

Hydrogen combustion produces only water vapour, making it an environmentally friendly fuel. Studies have highlighted its potential in reducing carbon emissions when blended with fossil fuels [4].

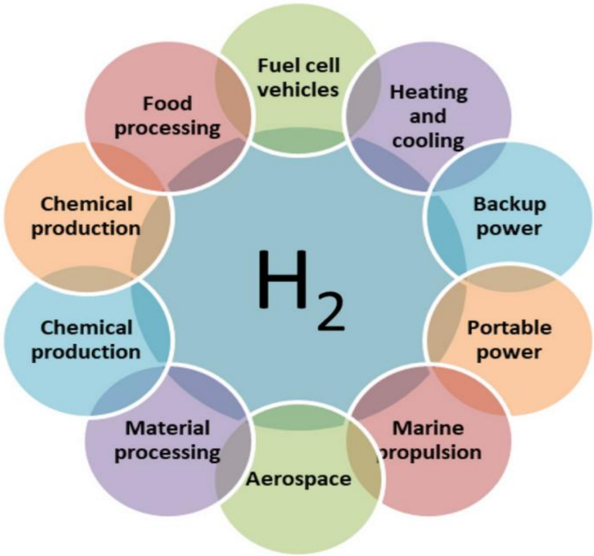

Fig 2: Hydrogen as an energy carrier: properties, storage methods, challenges, and future implications

Impact of Hydrogen Blending

Research has indicated that hydrogen blending influences major physical properties like calorific value and flame speed. For example, Wang et al. (2018) conducted a research experiment where they showed that the addition of 15% hydrogen reduces CO2 emissions by 10% and keeps the efficiency of the system intact [5].

Challenges in Blending

Key challenges include the compatibility of pipeline materials, storage issues, and the risk of leakage because of hydrogen's low molecular weight [6] [7]. Table 1 summarises the major challenges with hydrogen blending.

Table 1: Challenges of Hydrogen Blending

Challenge	Description
Material Integrity	Risk of hydrogen embrittlement in pipelines
Leakage Risk	Hydrogen's small molecule size increases leakage potential
Energy Content	Reduced calorific value per unit volume

METHOD

Experimental Apparatus

Hydrogen and natural gas were blended in predetermined volume ratios of 5%, 10%, 15%, and 20% for this experiment. An in-house-built gas mixing apparatus, which included high-resolution flow controllers for measuring the precise flow of the gases to be mixed, was used. The resulting blend was stored in pressure cylinders, and samples were drawn for analysis by gas analyzers.

Industry-standard measuring equipment determined calorific value, density, viscosity, and flame speed. A gas chromatograph combined with a calorimeter was utilized for the calorific value, while a digital gas density meter was used for determining density. A high-precision viscometer determined the fuel's viscosity. A controlled combustion chamber with high-speed cameras and thermal sensors monitored flame propagation during flame speed analysis.

Computational Modelling and Simulation

The computational modelling and simulations were done using ANSYS Fluent and MATLAB software to augment experimental observations. Hydrogen-natural gas blend flowing behaviour in the pipelines was studied using CFD. The impact of hydrogen blending on the efficiency and stability of the flow in pipelines has been examined using pressure, temperature, and velocity profiles in simulations.

Chemical kinetics simulations simulated energy content and flame characteristics. The Gas System Model (GSM) predicted changes in combustion efficiency, flame speed, and emissions at different hydrogen blend ratios. Sensitivity analysis identified critical parameters influencing system performance.

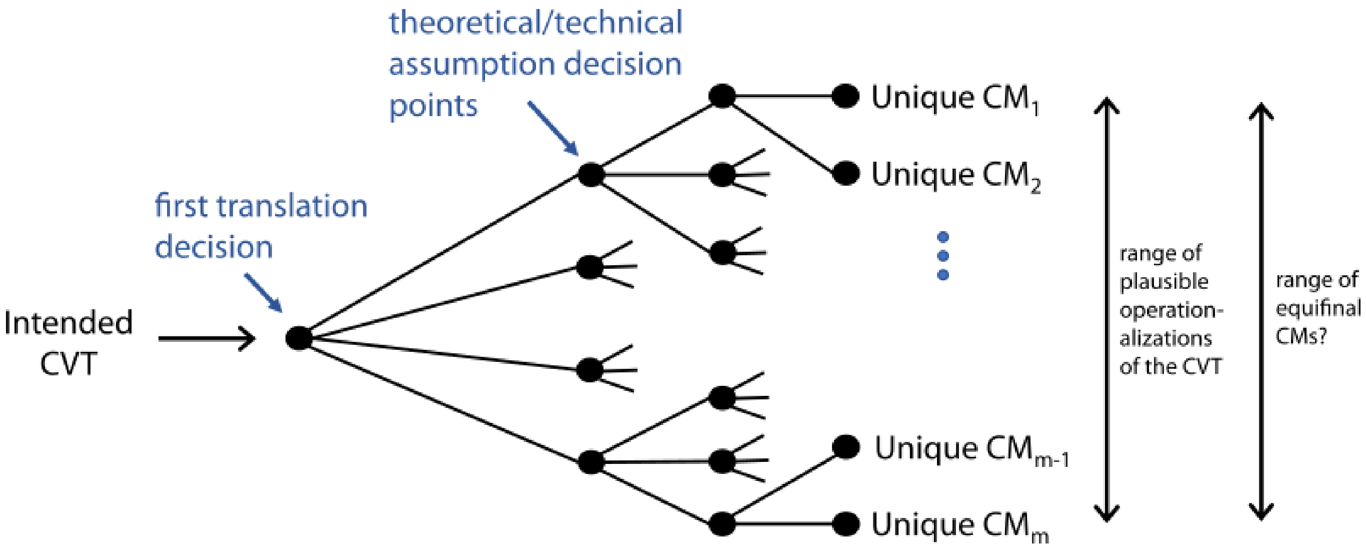

Fig 3: Computational Modelling and Simulation

Safety Assessment

Safety evaluations were integral to the study design. Hydrogen's lower molecular weight and higher diffusivity increase leakage risks in natural gas infrastructure. To overcome this, leakage tests were carried out in a controlled environment. The diffusion coefficients of hydrogen were measured to estimate potential leakage rates through pipeline materials.

Material compatibility testing investigated the effect of hydrogen on common pipeline materials, carbon steel and stainless steel. ISO/TR 15916 standards on mechanical stress and hydrogen embrittlement tests were applied to samples before analysis to determine the maximum allowable hydrogen concentration in safe operation.

Data Analysis

The experimental and simulation data were analysed using statistical tools to establish trends and correlations. Regression analysis was applied to quantify the relationship between hydrogen concentration and changes in physical properties. The results were validated by comparing the experimental outcomes with the predictions of the simulation, ensuring that they were robust and accurate.

Emissions Analysis

Emission measurements were carried out to assess the degree of environmental improvement by hydrogen blending. Combustion experiment exhausts were sampled and analyzed with the aid of gas analyzers to measure the changes in carbon dioxide (CO2), nitrogen oxides (NOx), and unburned hydrocarbons (UHCs). Each blend ratio was evaluated and reported compared to baseline emissions levels of pure natural gas combustion.

RESULTS AND DISCUSSION

Physical Property Changes

Calorific Value

The calorific value decreased by increasing the amount of hydrogen from Table 2. A blend of 20% hydrogen reduces energy content by 15%.

Table 2: Calorific Value at Different Blend Ratios

Blend Ratio (H2:NG)	Calorific Value (MJ/m3)
0:100	38.0
5:95	36.2
10:90	34.5
20:80	32.3

Density and Viscosity

Hydrogen's lower molecular weight significantly reduced the blend's density, enhancing pipeline flow efficiency. However, viscosity changes were minimal, ensuring smooth transport.

Safety Considerations

Leakage risk increased with hydrogen concentration, necessitating stricter monitoring protocols. Material integrity tests showed that steel pipelines could safely accommodate up to 20% hydrogen by volume without significant embrittlement [9].

Environmental Impact

Blending hydrogen reduced CO_2 emissions proportionally, with a 20% blend achieving a 16% reduction in emissions. This aligns with global decarbonization goals outlined in the Paris Agreement [10].

CONCLUSION

The optimal hydrogen blend ratio for the natural gas system is close to 20% by volume, balancing emissions reduction, changes in physical properties, and safety concerns. The present work showcases the feasibility of hydrogen blending as a transition pathway toward decarbonizing natural gas systems. Based on experimental and computational methodologies, the present study provides valuable insights into the physical and operational consequences of hydrogen blending.

The results thereby call for an advanced pipeline structure and material composition compatible with high hydrogen concentration contents in the not-too-distant future. System integrity, leakage risk safety protocols, and continuous real-time monitoring will also need to be improved. Finally, policy and regulatory frames of reference must meet technological realities before widespread application occurs.

This study contributes to the comprehensive long-term vision of sustainable energy systems by providing a detailed analysis of the feasibility of hydrogen integration. Future work should focus on long-term field trials, higher hydrogen concentrations, and the economic implications of large-scale implementation. Such steps are crucial to accelerating the transition toward a low-carbon energy future and meeting global climate objectives.

REFERENCES

[1] J. M. Ogden, “Hydrogen energy systems: A pathway to sustainable energy,” *Energy Policy*, vol. 29, no. 11, pp. 909-921, 2001.

[2] B. S. El-Sharkawi, “Hydrogen blending in natural gas pipelines: Prospects and challenges,” *Renewable Energy*, vol. 36, no. 5, pp. 1251-1257, 2013.

[3] K. T. Lee et al., “Effect of hydrogen on natural gas combustion,” *International Journal of Hydrogen Energy*, vol. 40, no. 45, pp. 15680-15691, 2015.

[4] A. T. Hoang and D. N. Pham, “Hydrogen’s role in decarbonizing energy systems,” *Applied Energy*, vol. 253, pp. 113601, 2019.

[5] Y. Wang et al., “Hydrogen-natural gas blending: A study on combustion properties,” *Fuel*, vol. 216, pp. 500-508, 2018.

[6] J. Melaina et al., “Blending hydrogen into natural gas pipeline networks,” *NREL Report*, 2013.

[7] P. Middleton et al., “Pipeline integrity with hydrogen blends,” *Journal of Pipeline Engineering*, vol. 14, no. 3, pp. 230-241, 2021.

[8] International Organization for Standardization, “Basic considerations for the safety of hydrogen systems,” ISO/TR 15916, 2020.

[9] A. C. Clark and B. R. Smith, “Material compatibility in hydrogen pipelines,” *Materials Performance*, vol. 53, no. 8, pp. 34-41, 2014.

[10] United Nations Framework Convention on Climate Change (UNFCCC), “Paris Agreement,” 2015.