www.ijarp.com ISSN 2456-9992 Page: 01-15

International Journal Advanced Research Publications

Research Article

Volume: 01

Issue: 03

STUDY ON THE EMISSION IMPACT FOR HYDROGEN INTEGRATION IN THE EXISTING NATURAL GAS SUPPLY OF BANGLADESH

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Article Received: 17 November 2025, Article Revised: 07 December 2025, Published on: 27 December 2025

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DOI: https://doi-doi.org/101555/ijarp.6086

ABSTRACT

The gradual blending of hydrogen (H_2) in natural gas (NG) networks has received global attention as a potential path to decarbonization. This research experimentally examines the emission of hydrogen-natural gas blends at varying hydrogen concentrations in order to evaluate the effects of hydrogen blending with currently supplied natural gas in Bangladesh. The laboratory flue gas analyses for gas mixtures containing 0–31.5 vol% hydrogen demonstrate that CO_2emissions are consistently reduced with increased hydrogen percentage, confirming the decarbonization potential of hydrogen blending, although slight NO_x variations were found, suggesting the need for combustion optimization. Lower hydrogen content in the blended gas has rapid impact on carbon dioxide reduction. No CO and SO_x emissions were detected for the blended Natural Gas and Hydrogen mixture burning. Life Cycle Analysis (LCA) of hydrogen blending with natural gas for Bangladesh context was made by openLCA which reflects the global warming potential (GWP) has a decreasing trend with the increasing of volumetric fraction of hydrogen in the natural gas and hydrogen admixture. The Eutrophication potential (EP) and Human toxicity potential (HTP) have the increasing trends with the increasing of volumetric fraction of hydrogen in the natural gas and hydrogen admixture.

KEYWORDS: Hydrogen-Natural gas blending, Emissions, Environmental impact, Life cycle assessment.

INTRODUCTION

A shift to low-carbon energy systems has been set forth to achieve the global climate goals in the Paris Agreement. The sixth assessment report from the Intergovernmental Panel on Climate Change ends with a sobering warning about the harm that greenhouse gases have already done to the Earth's atmosphere and that cannot be undone without taking drastic measures. [1]. The carbon footprint analysis has attracted a lot of attention as it is concerned over climate change and it negatively affects on our environment. It has been grown over the past few decades. Fossil power plants, which has a significant contribution to the carbon footprint, have come under fire for accelerating global warming [2]. Meanwhile, Bangladesh, like many other countries, is facing a huge energy crisis and the country's economic development has been threatened due to the lack of energy resources [3]. There are two challenges in dealing with energy crises. These are the increasing energy demand and minimizing environmental impact. To address this challenge, Bangladesh is preparing an integrated energy and power master plan based on the Net Zero Scenario (NZS). Under the NZS, Bangladesh is expected to achieve net-zero emissions of energy-based greenhouse gases (GHGs) by 2050 by using all available options and, if this is not sufficient, regulating energy consumption. Reaching net zero by 2050 requires extremely strict energy and environmental policies[4].

Hydrogen has emerged as a versatile energy carrier capable of reducing greenhouse gas emissions when blended with natural gas [5]. Countries worldwide are exploring hydrogen-enriched natural gas (HENG) systems to utilize existing infrastructure while minimizing investment costs [6]. As a clean energy source, hydrogen has become essential to this shift. Making the switch to a hydrogen economy is a creative way to meet energy demands and cut greenhouse gas emissions, especially in nations like Bangladesh. An alternative to fossil fuels that has the potential to accomplish these objectives is hydrogen as an energy source. Hydrogen is much more than just a clean alternative to burning fossil fuels because of its tight connection to electricity via fuel cells [7]. Since hydrogen is relatively similar to natural gas in terms of its combustion properties, co-firing in gas power plants can be considered [4]. Transitioning to hydrogen as an energy source represents a critical path to address environmental challenges while increasing energy security. The historic energy transition of the last 200 years was characterized by significant changes in primary energy sources and technological advances [8]. Hydrogen can be produced from a variety of renewable resources, it offers a versatile solution to reduce greenhouse gas emissions across multiple sectors. Particularly in the context of Bangladesh, the use of hydrogen in the natural gas network could facilitate a gradual transition to cleaner energy. This integration could reduce dependency on fossil fuels and support commitment to international climate goals and align with global movements towards sustainability. In addition, continued advances in hydrogen production technologies, for example through the use of modern electrolysis processes, promise improved efficiency and cost-effectiveness [9]. In Bangladesh, combining renewable energy technologies to create green hydrogen shows promise. Coastal plants that are hybrid and renewable along the Bay of Bengal, Kuakata, Sandwip, and St. Martin, Coxsbazer, and Chattogram show great promise in producing green hydrogen [10]. Collaboration between government agencies, private sectors and international partnerships is critical to build a thriving hydrogen economy [11]. This synergy not only enables the scaling of hydrogen technologies, but also promotes an innovation-friendly environment. Policies must adapt to recognize and facilitate this change, ensuring an integrated approach that includes regulatory frameworks, financial incentives and public awareness [12]. By prioritizing hydrogen in its energy strategy, Bangladesh can position itself as a front runner. Bangladesh can join global efforts in transitioning to cleaner energy. This alignment will help Bangladesh to combat climate change. Sustainable management of energy requirements is also possible with this strategy. To combat the impact of fossil fuel, global efforts focus on reducing greenhouse gas emissions through green energy, promoting sustainable practices [13]. To limit the global average temperature rise to well below 2°C above pre-industrial levels for pursuing efforts to limit warming to 1.5°C, in the Paris Agreement, each party submitted **Nationally Determined Contributions (NDCs)** outlining climate action plans to reduce greenhouse gas (GHG) emissions and enhance adaptation. Bangladesh and other developing countries submitted revised NDCs focusing on mitigation plus strong adaptation components. To achieve the goals of the Paris Agreement and NDCs-2021, Bangladesh has committed to reduce 5% carbon emission. It needs to modernize the industrial equipment as part of the gas supply transition which required to support the coordinated deployment of green fuel like hydrogen combustion systems at industrial and household sites. Burning hydrogen produces fewer pollutants because it is a carbon-free energy source. Thus, hydrogen could potentially mitigate societal and environmental problems such as global warming, air pollution, and climate change [14].

In recent years, efforts and research to combine hydrogen with natural gas have become increasingly concentrated. One useful technique to boost the amount of hydrogen in energy systems is to inject hydrogen into natural gas. The trend is to replace hydrogen with natural gas and to enrich pure hydrogen in pipelines, despite material limitations [15]. Various Authors like Saleem et al. (2022) [16], Luzzo et al. (2021) [17], Ozturk et al. (2023) [18] and so on conducted study to estimate emissions from the hydrogen-natural gas admixture. But no study has been done for emissions from the hydrogen-natural gas admixture in Bangladesh context. This research tried to find the impact of hydrogen integration in the existing natural gas supply of Bangladesh. The current study's primary contributions are listed below.:

- To calculate the emission of CO_2, NO_x, SO_x and CO, the hydrogen-natural gas admixture for the natural gas in Bangladesh for determining the emission impact of hydrogen integration in the natural gas network of Bangladesh.
- To ascertain the potential for a number of environmental effects, including global warming potential, Eutrophication potential and human toxicity potential life cycle analyses.

MATERIALS AND METHODS

To estimate how the presence of hydrogen in natural gas supply of Bangladesh impact on emission, an experimental arrangement was set up for the current study. The emissions from the burning of blended hydrogen with natural gas were determined by this innovative study's thorough experimental investigation.

The experimental setup was designed for the current work that prepares the blended mixture was made up of (a) flowmeters, (b) regulators and valves to control the flow, (c) sampling bag and (d) burning chamber and flue gas trap. The natural gas was supplied from the house hold gas grid of Dhaka City. Hydrogen was supplied from hydrogen cylinder. Pressure regulator and gas flow meter were installed to the hydrogen supply and natural gas supply line (Figure-1).

Figure 1-Experimental setup for burning of blended hydrogen and natural gas admixture to measure emissions.

The pressure at the hydrogen cylinder outlet and natural gas supply line were adjusted to control the flow of both gases which were observed by flow meters. The hydrogen and natural gas with regulated flow rate were injected to the mixing chamber 1 by separate inlet. The gases were mixed in the mixing chamber 1 and flown to the mixing chamber 2 for better mixing. A suction pump sucked the mixed gas with regulated flow control. The mixed gas was collected in the tedlar gas sampling bag for confirming the hydrogen and natural gas ratio. From the suction pump the mixed gas was sent to the burner within the burning chamber. The exhaust gas was trapped in the flue gas trap. A suction pump sucked the flue gas with regulated flow control. The exhaust gas was collected in the tedlar gas sampling bag from the outlet of the suction pump.

The analytical technique makes it possible to precisely measure the various components of gas mixtures. The composition of blended admixture were measured using gas chromatography. By separating components between a stationary phase and a mobile phase, gas chromatography enables the splitting of compounds according to their molecular characteristics. [19]. The properties mixed samples and exhausted gas samples were examined at the laboratory of Department of Chemical Engineering, Bangladesh University of Engineering and Technology along with their experts. The composition of the samples has been analyzed following the procedures described in Gas Processors Association (GPA) Manual (GPA Standard 2261-90, Ref. 1, GPA Standard 2172-86, Ref. 2). The samples were Analyzed by gas chromatograph (Agilent 7890B and Shimadzu GC – 14 B). Capillary column DB – 1 and Packed Column (Porapak Q) were used for composition analysis. The exhausted gas were measured by GASTEC gas detector tubes which are thin glass tubes with calibration scales printed on them. So, the concentrations of the substances (gases and vapours) to be measured can be directly read. GASTEC gas detector tubes operate on the colorimetric principle, which produces a colored stain when a particular chemical reagent inside a sealed glass tube reacts with a targeted gas. The color shift is caused by a fixed volume of air being drawn through the tube by a portable GASTEC sampling pump. The concentration of the gas is directly indicated by the length of this colored stain when compared to the scale printed on the tube [20].

Three impact categories as Global warming potential (GWP), eutrophication potential, and human toxicity potential (HTP) were examined. The following comprises the unit definitions for these impact categories. The Global warming potential (GWP) is measured in terms of kilogram of Carbon dioxide equivalents (kg CO_2 Eq). The Eutrophication Potential (EP) is measured in terms of kilogram of nitrogen oxide equivalents (kg NOx Eq). The Human toxicity potential (HTP) is measured in terms of kilogram 1,4-dichlorobenzene equivalents (kg 1, 4-DCB Eq.).

The software named OpenLCA 2.5.0 [21] is used for life cycle assessment. The life cycle assessment (LCA), is a method used to ascertain how the process and its consequent impact the environment throughout its life, from consumption to disposal. The LCA, a unique tool, helps decision-makers with environmental considerations by enabling the analysis and comparison of numerous scenarios. Emissions to ecosystems on land, in the water, and in the air are examined as part of the environmental performance assessment. However, there are some limitations with LCA. The accuracy of the findings depends on how easily accessible the data used in the analysis is. Furthermore, cost-effectiveness cannot be assessed using this method [22]. Using a range of assessment techniques, the environmental impacts of a system or consequent can be described and classified. This study classified and characterized the impacts in environmental aspects of various hydrogen mixing scheme using the CML2001 method. As a midpoint-oriented approach to impact assessment, a small group of researchers at the Leiden University Center of Environmental Science developed the CML 2001 [23]. The Dhaka, Bangladesh was been selected as experimental location in OpenLCA. To lower the experimental study's error, tests were conducted repeatedly and error analysis was carried out.

RESULTS AND DISCUSSION

A household burner was used in a burning chamber to test the gas emissions of hydrogen-natural gas admixture that contained various fractions of hydrogen by volume. A number of experimental tests using various hydrogen volumetric blending ratios were carried out. Parametric studies were carried out to investigate the impact of gas blend and emissions of CO_2, CO, and NO_x were measured. The composition of natural gas used in the experiments shown in the table-1. The hydrogen-natural gas content, molecular weight and their corresponding emission is summarised in the table-2.

Table 1- Composition analysis of natural gas used in the experiments (dry basis).

Sl. No.	Components	mole%	
1	Hydrogen		0.0495
2	Nitrogen		2.3469

3	Carbon dioxide			0.3479
4	Methane			94.3669
5	Ethane			2.0415
6	Propane			0.4843
7	iso-Butane			0.1361
8	n-Butane			0.0960
9	Neo-Pentane			0.0000
10	Iso-Pentane			0.0427
11	n-Pentane			0.0220
12	C6's	a) Paraffins		0.0494
		n-Hexane	0.0063	
		Isomers	0.0170	
		b) Napthenes		
		Methyl cyclopentane	0.0083	
		Cyclohexane	0.0113	
		c) Aromatic		
		Benzene	0.0065	
13	C6 +			0.0169
Total			100.0000	

Table 2-hydrogen-natural gas content, molecular weight and their corresponding emission of the mixed sample.

Sl. No.	Sample Name	H2 %	NG %	Moliculear Weight	CO2% in corresponding exhaust gas	CO in corresponding exhaust gas	SOx in corresponding exhaust gas	NOx (ppm) in corresponding exhaust gas
1	Sample - 1	0	100	16.97	1.5	Nill	Nill	3.46
2	Sample - 2	2.5	97.5	16.9	1.2	Nill	Nill	2.31
3	Sample - 3	3.2	96.8	16.64	0.8	Nill	Nill	6.3
4	Sample - 4	7.9	92.1	15.8	0.45	Nill	Nill	6.27
5	Sample - 5	13.8	86.2	14.95	0.4	Nill	Nill	3.5
6	Sample - 6	31.5	68.5	12.34	0.3	Nill	Nill	5.61

The amount of hydrogen and the amount of CO_2in the flue gas were clearly inversely correlated (Figure-2). Due to its lack of carbon atoms, hydrogen lowers the fuel mixture's carbon-to-hydrogen ratio, which in turn lowers the production of CO_2. The concentration of CO_2 was 1.5 percent at 0 percent hydrogen and decreased to 0.3 percent at 31 percent hydrogen. These findings are consistent with studies indicating hydrogen blending leads to lower CO_2 due to more complete combustion and reduced carbon intensity of the fuel [24][25]. The study reflects that adding more hydrogen in hydrogen-natural gas mixture reduced carbon dioxide (CO_2) emissions significantly. Small additions (upto 8%) of hydrogen result in significant drops in CO_2 emissions, but as the hydrogen content increases above roughly 20–30 percent, the benefits diminish. The nonlinear relationship is reflected in the decreasing curve [26]. At lower hydrogen additions, the emission reduction is most significant, plateauing at higher blends [27]. Blending hydrogen significantly lowers CO_2 emissions, demonstrating the possible environmental advantages [25] .

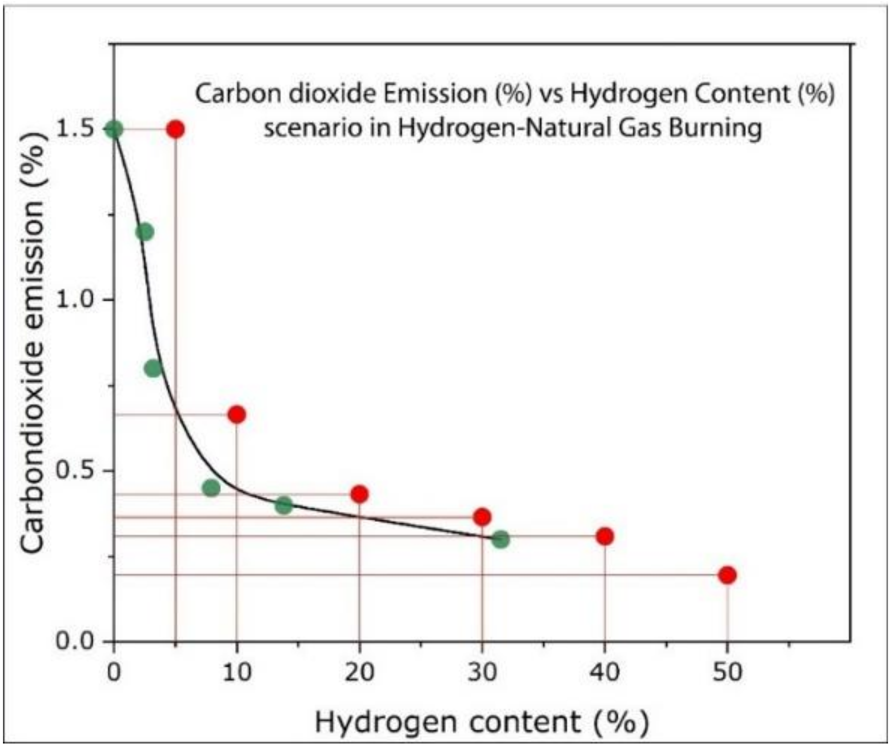

Figure 2- Carbon dioxide emission (%) trend with Hydrogen Content (%) in Hydrogen-Natural Gas Burning Scenario.

The study on NO_x emission for hydrogen-natural gas burning shows a non-linear trend. It decreases at low H_2 blends then sharply increases, and fluctuates for higher blends (Figure-3). When hydrogen is added, NO_x formation frequently rises because of higher combustion temperatures and more active radicals, particularly at moderate H_2 ratios. [28][29][30]. Although lean-premixed combustion and other advanced technologies can reduce these NO_x increases, conventional setups may see elevated NO_x once H_2 surpasses 5–10 percent [28][31]. The Spearman correlation among the data set of hydrogen content and the NO_x emission shows that a very weak positive correlation between hydrogen content and NO_x

emissions is indicated by Spearman Coefficient (ρ) = +0.09. This indicates that there is no statistically significant monotonic relationship between the percentage of hydrogen blended and the concentration of NO_x. The Pearson correlation between data set of hydrogen content and the NO_x emission shows that Pearson Coefficient r = +0.37 which reflects there is no strong linear relationship between hydrogen content and NO_x emission and the net effect is non-linear. Hydrogen blending effect on NO_x is not monotonic and non-linear manner. The trend is mainly determined by the burner design and equivalency ratio [32].

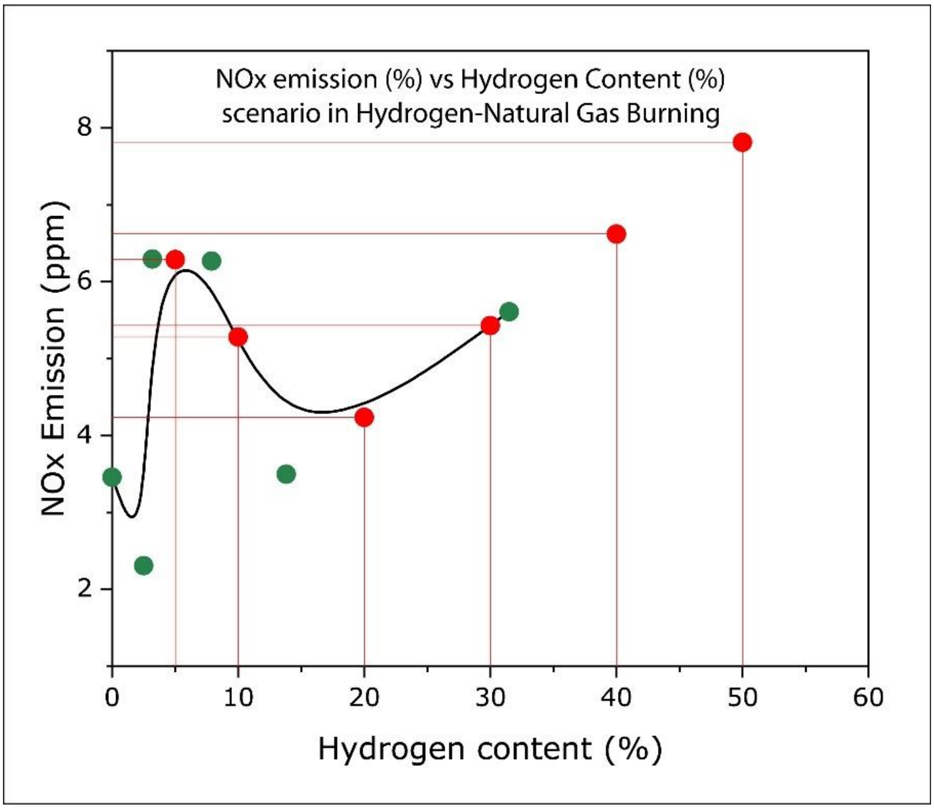

Figure 3- NOx emission (%) trend with Hydrogen Content (%) in Hydrogen-Natural Gas Burning Scenario.

The CO levels in the exhaust are completely absent (“Nil”) for natural gas and mixed gas which is due to more complete combustion [24][25]. The SO_x emissions are "Nil" for all blends since neither natural gas nor hydrogen contain sulphur [33].

A greenhouse gas's global warming potential (GWP) is a measurement of how much more heat it traps in the atmosphere over a given time period than carbon dioxide, indicating a major environmental impact (climate change) [34]. The GWP for emissions from natural gas burning is estimated to be 0.00066015 kg-CO_2 equivalent per mole of natural gas which has been reduced to 0.00013203 kg-CO_2 equivalent per mole of natural gas-hydrogen admixture with 31.5% hydrogen. It has a declining trend with the increasing of hydrogen content in the natural gas-hydrogen admixture (Figure-4).

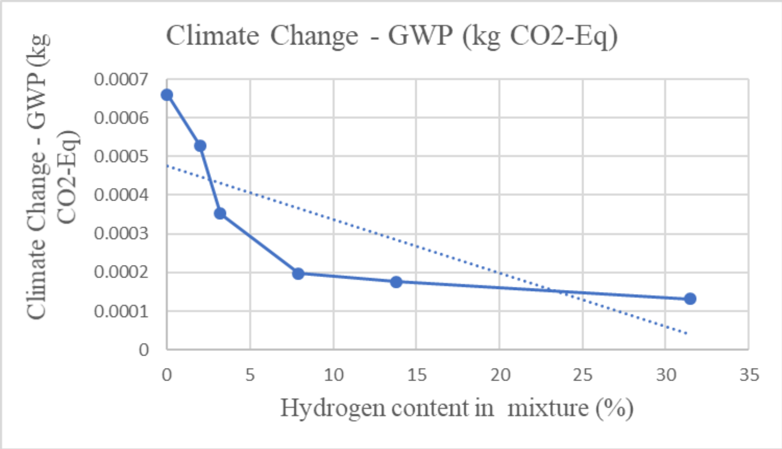

Figure 4- The change of the global warming potential (GWP) with respect to hydrogen blending ratios in the natural gas.

A substance's ability to cause excessive nutrient enrichment in water bodies, which can result in algal blooms, oxygen depletion, and harm to aquatic ecosystems, is measured by its eutrophication potential (EP) [35]. The EP for emissions from natural gas burning is estimated to be 0.0000002184 kg NO_x - equivalent per mole of natural gas which has been increased to 0.00000026 NO_x - equivalent per mole of natural gas-hydrogen admixture with 31.5% hydrogen. It has an upward trend with the increasing of hydrogen content in the natural gas-hydrogen admixture (Figure-5).

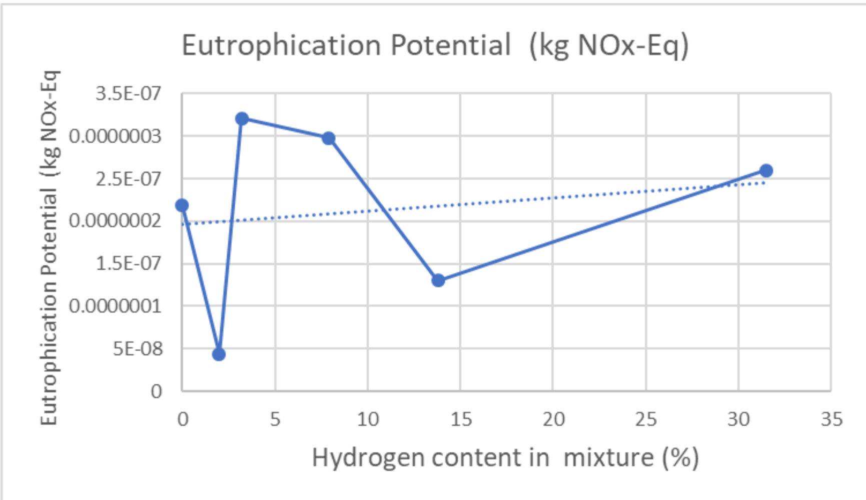

Figure 5- The change of the eutrophication potential (EP) with respect to hydrogen blending ratios in the natural gas.

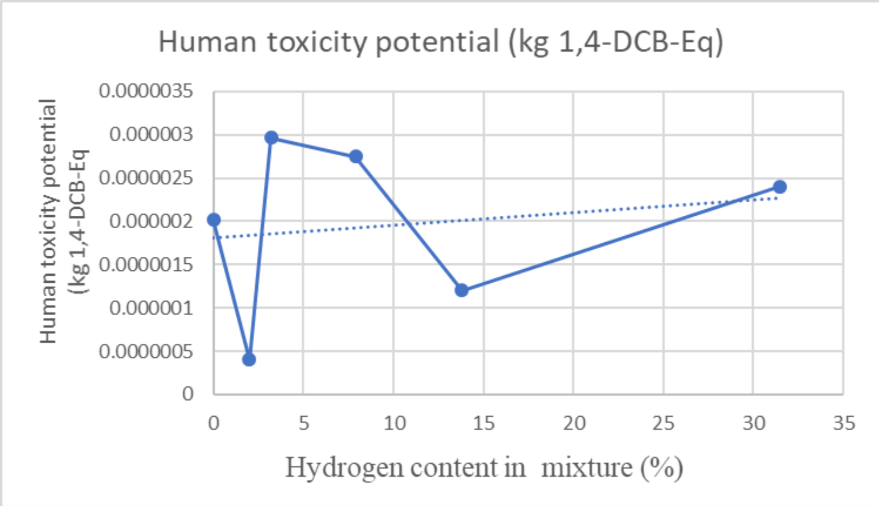

Figure 6- The change of the human toxicity potential (HTP) with respect to hydrogen content in the natural gas-hydrogen admixture.

A quantitative indicator that assesses the possible harm of a chemical released into the environment is the Human Toxicity Potential (HTP). In addition to taking into consideration different routes such as ingestion, inhalation, and skin contact, it takes into account a chemical's intrinsic toxicity and possible exposure dose. By weighing emissions in toxics release inventories and life-cycle assessments, HTP enables a consistent comparison of a substance's effects on human health [36]. The HTP for emissions from natural gas burning is estimated as 0.000002016 kg 1,4-1, 4-Dichlorobenzene- equivalent per mole of natural gas which has been reduced to 0.0000024 1,4-Dichlorobenzene equivalent per mole of natural gas-hydrogen admixture with 31.5% hydrogen. It has an upward trend with the increasing of hydrogen content in the natural gas-hydrogen admixture (Figure-6).

CONCLUSION

This study examines the environmental effects of the blends of natural gas of existing distribution network and hydrogen with different ratio. The volumetric content of hydrogen percentages of 0, 2.5, 3.2, 7.9, 13.8 and 31.5 are utilized in the tests. The burning product such as CO_2, CO, NO_x and SO_x emissions were measured. This experimental study demonstrates that hydrogen blending in natural gas significantly reduces CO_2emissions without generating CO or SO_x. Lower range (upto 8%) of hydrogen content in the blended gas has rapid impact on carbon dioxide reduction. The behavior of NO_x varies irregularly with the blending ratio but has a increasing trend. A detailed life cycle analysis is also performed for several blending scenarios. The global warming potential has been reduced for natural gas – hydrogen admixture with shows a declining trend with the increasing of hydrogen content. The eutrophication potential has been increased for natural gas – hydrogen admixture and shows an upward trend with the increasing of hydrogen content. The human toxicity potential also increased for natural gas – hydrogen admixture shows an increasing trend with the increasing of hydrogen content. Based on the results, hydrogen and natural gas admixture could be a positive supplement to Bangladesh's primary energy supply and assist the country in meeting its decarbonization goals.

ACKNOWLEDGEMENTS

The BPI Director General of Bangladesh Petroleum Institute (BPI) named Khen Chan is acknowledged for helping with institutional finance to Md. Sahiduzzaman for this portion of his Ph.D works. The Head of Department of Chemical Engineering, BUET is thanked for experimental and analytical support. The Chairman of Applied Chemistry and Chemical Engineering (ACCE) Department, University of Dhaka, respected supervisors Dr. Mohammad Mainul Karim, Professor, ACCE, DU, Prof. Dr. Mohammad Ismail, VC, NSTU and Dr. Kawnish Kirtania, Professor, Chemical Engineering, BUET are thanked for their precise guideline. Monika Akter, my beloved wife, is also thanked for providing working environment at home.

CONFLICTS OF INTERESTS

The authors affirm that none of the work described in this paper could have been influenced by their known competing financial interests or personal relationships.

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