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Artificial Intelligence Implementations Towards Shaping the Future of Digital World

EMISSION REDUCTION USING AMMONIA/DIESEL DUAL FUEL FOR MARINE DIESEL ENGINES IN GREEN PORT APPLICATION

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ABSTRACT

The utilization of green energy can significantly reduce emissions generated in ports using diesel fuel in vehicles, machinery, and ships. Emission reduction strategies are constantly being researched to replace older engines and install zero-emission power systems through the investigation of cleaner trends that can be employed in ports and surrounding areas. The continuous development of international trade and the increasing number of ships at ports lead to the extensive development of ports which will result in the use of more diesel engines contributing to environmental pollution by their emissions. Ammonia has gained great attention for its use in ICEs leading to their decarbonization and the reduction of GHG emissions. It is a liquid energy source that can be stored and transported safely. This paper studies the effectiveness of using ammonia and hydrogen as clean fuels for marine dual fuel engines. A computational analysis using Aspen Plus software is carried out to investigate the combustion process as well as the resulting pollutants including GHGs. The results show that the suggested dual fuel methods reduce CO2 emissions by 59.68%, and SOx emissions by 60%.

Keywords: emissions, internal combustion engines, ammonia, Aspen Plus.

1. INTRODUCTION

The maritime industry is a vital global economy, transporting over 90% of the world's goods. It generates billions of dollars in revenue annually, promoting regional and global connectivity. The industry also supports global security, stability, and sustainability by ensuring timely and quality goods reach their destinations. The maritime industry faces environmental challenges due to increased diesel engine use, climate change, and waste management [1]. Regulations by the International Maritime Organization (IMO) aim to reduce emissions and protect marine life. International shipping contributes to 3% of global greenhouse gas (GHG) emissions [2], [3]. Moreover, the emissions of the shipping industry pose significant dangers to both the environment and human health. Shipping is an essential component of the global economy, with billions of tons of goods transported by sea each year. However, the environmental impact of shipping emissions cannot be overlooked. One of the most immediate and visible dangers of shipping emissions is air pollution. Ships emit a variety of pollutants into the atmosphere, including sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), carbon dioxide (CO2), and volatile organic compounds (VOCs). These pollutants can have numerous adverse effects on human health [4]. The Intergovernmental Panel on Climate Change (IPCC) has identified shipping as a significant source of CO2 emissions, with the potential to exacerbate climate change and its associated impacts [5].

The shipping industry's reliance on fossil fuels and outdated technologies makes it a significant contributor to GHGs responsible for climate change. Pollutants such as SOx, NOx, and PM can harm marine ecosystems. These pollutants can also contaminate coastal waters, posing a threat to marine life [6], [7]. The IMO has established the International Convention for the Prevention of Pollution from Ships (MARPOL) to address the environmental impact of shipping emissions, including regulations on SOx, and NOx emissions [8]. However, enforcement of these regulations can vary between countries and regions, leading to inconsistencies in emission control measures and compliance levels. Ammonia, a green fuel, is being explored as a carbon-free alternative for internal combustion engines (ICEs) [9]. Experimental studies show that 84.2% of input energy can be provided by ammonia, increasing thermal efficiency and changing combustion modes [10], [11]. However, ammonia also increases NOx emissions and unburned ammonia. Diesel replacement with more than 35.9% ammonia is necessary to reduce GHGs [12].

Leilei Xu [13] investigated the use of ammonia as a carbon-free fuel in a Wärtsilä ammonia/diesel dual fuel engine. It was found that higher diesel usage reduced emissions by 70%. NO emissions are sensitive, and exhaust gas after-treatment systems are needed.

In 2022, T. Li *et al.* [14] studied the comparison between low-pressure injection dual fuel (LPDF) and high-pressure injection dual fuel (HPDF) modes which showed that the former case has the potential to achieve a higher indicated thermal efficiency, while the latter can significantly reduce the engine-out NH3, NOx and GHG emissions. Ammonia was employed for the HPDF engine, and the heat release rate (HHR) was controlled by the fuel-air mixing rate and resulted showed that liquid ammonia has the potential to provide more than 95% of the total energy injected. Compared with pure diesel mode, the HPDF mode can significantly reduce the equivalent CO2 with a little increase in NH3 emissions [15].

In December 2022, M. E. Demir and F. Çıtakoğlu [16] aimed to bridge the gap between the urgency of decarbonizing global shipping with zero-carbon and sustainable ammonia fuel and the insufficient relevant knowledge. Problems such as low flame speed and high auto-ignition temperature lead to poor ammonia combustion, which presents a challenge for ICEs to operate in pure ammonia mode. Ammonia combustion can lead to higher NOx emissions than diesel-only combustion due to both fuel and thermal NOx generation, along with the production of N2O, which is much more potent than CO2 in terms of GHG emissions over a century [17]. Thus, advanced combustion strategies are crucial to mitigate these potent GHGs in ammonia/diesel dual fuel combustion for it to be a viable carbon-free fuel option in the future. To address these gaps, this study comprehensively explores the impact of ammonia energy fraction on combustion performance and emissions in an ammonia/diesel dual fuel engine.

2. METHODOLOGY

Simulation is an invaluable tool in the field of chemical engineering, particularly when it comes to studying the behavior of ammonia, hydrogen, and diesel fuel. Creating virtual models that mimic the complex interactions between these important fuels and their environments helps in predicting how they behave under various conditions without the need for costly and time-consuming real-world experiments [18].

Aspen Plus is a powerful process simulation software widely used in the chemical engineering industry for modeling and simulating complex chemical processes. Aspen Plus allows engineers to accurately predict the behavior of many fuels under various operating conditions. By inputting key parameters such as temperature, pressure, and composition, users can simulate the entire lifecycle of ammonia and diesel fuel combustion.

2.1. Diesel cycle

A simple simulates the ICE, containing a diesel fuel stream, a pump, an air stream, an air compressor, a compressed air stream, a reactor (R-GIBBS), and finally, an exhaust gas stream, as in Fig. (1).

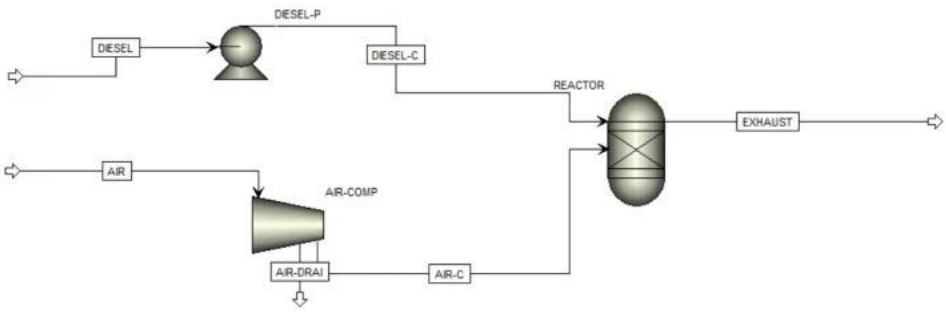

Figure 1: The operating conditions were set up to simulate those of an actual diesel engine (Table 1).

Table 1. Diesel cycle operating conditions

Stream	*Temperature (°C)*	*Pressure (bar)*	*Mass flow rate (kg/hr)*
Diesel	30	650	**540**
High pressure diesel	30	1200	**540**
Air	27	1.01325	**6000**
Compressed air	**30**	**2.5**	**6000**

2.2. Ammonia cycle

A cycle simulates the mixture of ammonia, in various percentages, with air before injection into the reactor [19]. The cycle includes diesel fuel stream, a pump, an air stream, an air compressor, a compressed air stream, an ammonia stream, an ammonia compressor, a mixer, a reactor (R-GIBBS), and finally, an exhaust gas stream as in Fig. (2).

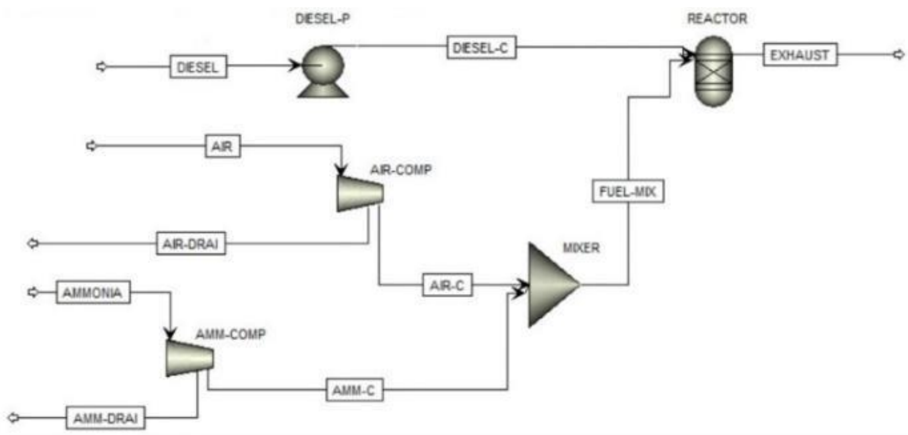

Figure 2 The operating conditions were set up to simulate the cycle of an actual ammonia/diesel dual fuel engine (Table 2).

Table 2. Ammonia/diesel cycle operating conditions.

Stream	*Temperature (°C)*	*Pressure (bar)*	*Mass flow rate (kg/hr)*
Ammonia	*27*	*1*	***27 - 324***
Compressed Ammonia	***30***	***2.5***	***27 - 324***

2.3. Hydrogen cycle

A cycle simulates the mixture of hydrogen, in various percentages, with air before injection into the reactor [20]. The cycle includes diesel fuel stream, a pump, an air stream, an air compressor, a compressed air stream, a hydrogen stream, a hydrogen compressor, a mixer, a reactor (R-GIBBS), and an exhaust gas stream as shown in Fig. 3.

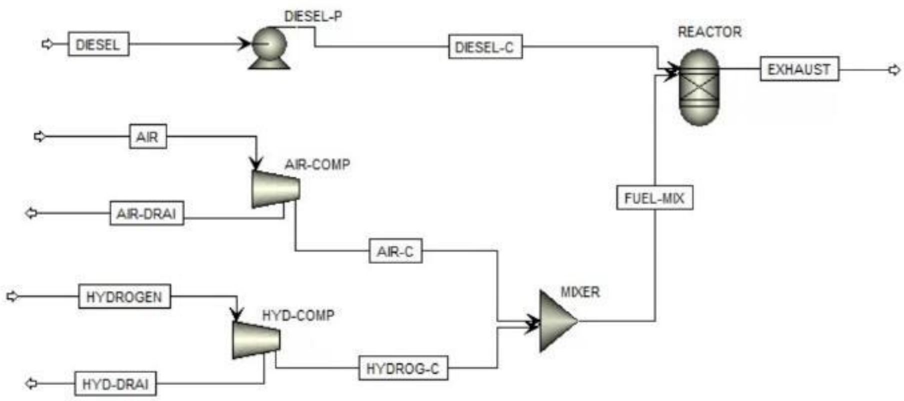

Figure 3. The operating conditions were set up to simulate the cycle of an actual hydrogen/diesel dual fuel engine (Table 3).

Table 3. Hydrogen/diesel cycle operating conditions.

Stream	Temperature (°C)	Pressure (bar)	Mass flow rate (kg/hr)
Hydrogen	27	1	**27 - 324**
Compressed Hydrogen	**30**	**2.5**	**27 - 324**

3. RESULTS

Utilizing ammonia and hydrogen as dual fuels alongside diesel in ICEs holds significant promise for reducing emissions and improving overall engine efficiency. The provided emission results depict the concentrations of various gases, including nitrogen (N2), CO2, sulfur (S2), and methane (CH4), at different ammonia and hydrogen concentrations ranging from 0% to 60%. These results provide valuable insights into the potential environmental impact of employing ammonia, or hydrogen/diesel dual fuel technology.

The emission results show a trend in NOx emissions, with varying concentrations of ammonia. Typically, NOx emissions are a major concern due to their role in air pollution and adverse health effects. The data suggest that as the proportion of ammonia in the dual fuel blend increases up to 50%, the NOx concentration reaches a 4% increase, but after increasing the ammonia concentration to 60%, NOx concentration starts to decrease until approximately it reaches no change with slight fluctuations as shown in Fig. 4. Further analysis is needed to understand the mechanisms behind these variations and their implications for emissions control strategies.

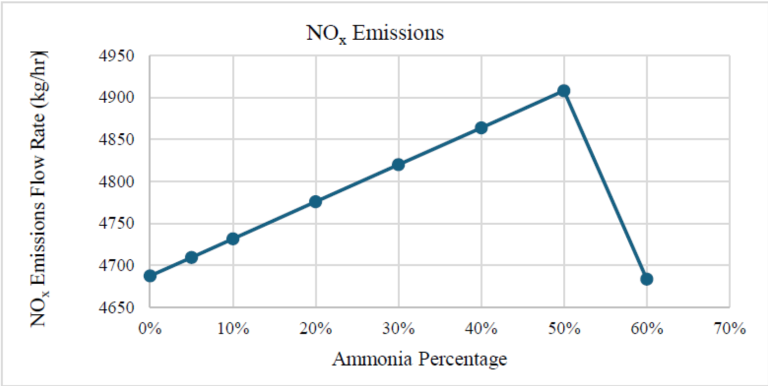

Figure 4: NOx emissions versus ammonia percentage.

CO2 emissions, a significant contributor to GHG emissions and climate change, exhibit a decreasing trend to 60% with increasing ammonia concentration as displayed in Fig. 5. This reduction in CO2 emissions is promising and aligns with efforts to mitigate climate change by transitioning towards cleaner fuel alternatives. However, it's essential to ensure that this reduction in CO2 emissions does not come at the expense of increased emissions of other pollutants.

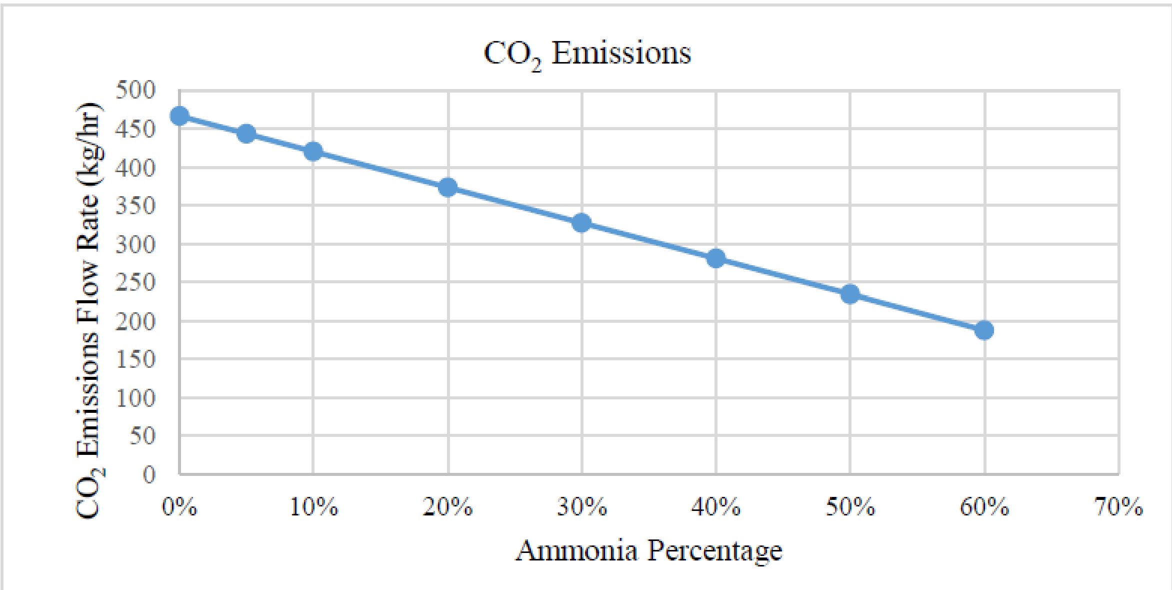

Figure 5: CO2 emissions versus ammonia percentage.

The emission results also include concentrations of sulfur and methane. Sulfur emissions are known to contribute to air pollution and acid rain, while methane is a potent GHG. The data suggest that both sulfur and methane emissions decrease as the proportion of ammonia in the dual fuel blend increases. SOx emissions decrease by 60% while methane increases from 2.16×10-11 to 2.86×10-11 as displayed in Fig. 6.

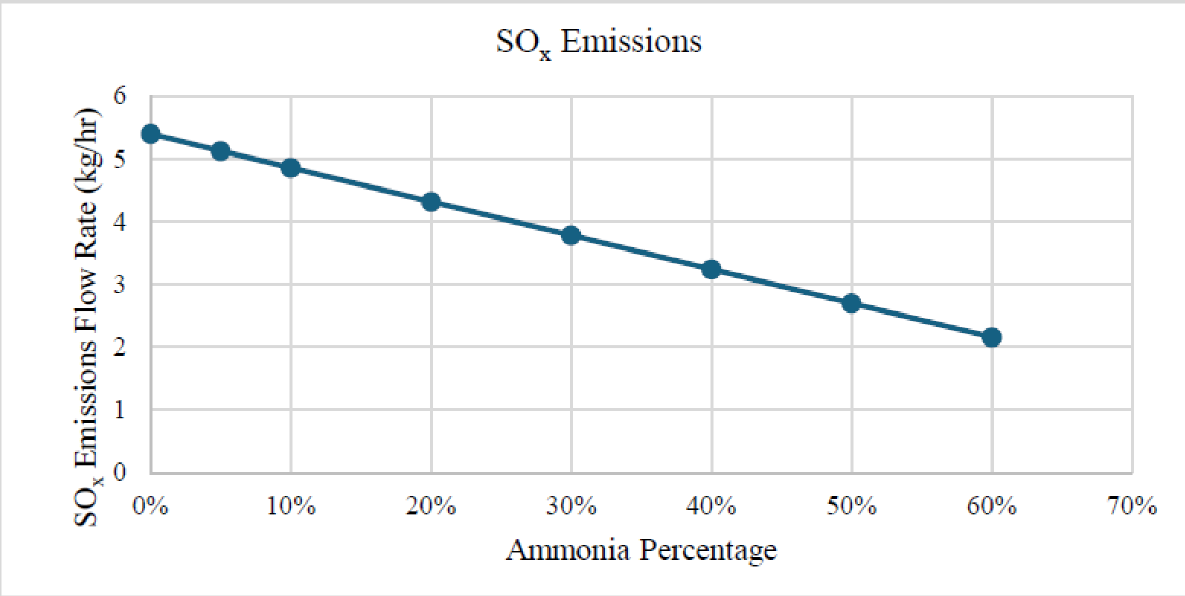

Figure 6: SOx emissions versus ammonia percentage.

The emission results suggest that NOx emissions exhibit minimal variation (a decrease of 5%) with increasing hydrogen concentration. NOx emissions are a significant contributor to air pollution and are regulated due to their adverse health effects. The relatively stable NOx emissions across different hydrogen concentrations indicate the potential of hydrogen/diesel dual fuel technology to mitigate harmful emissions as shown in Fig. 7.

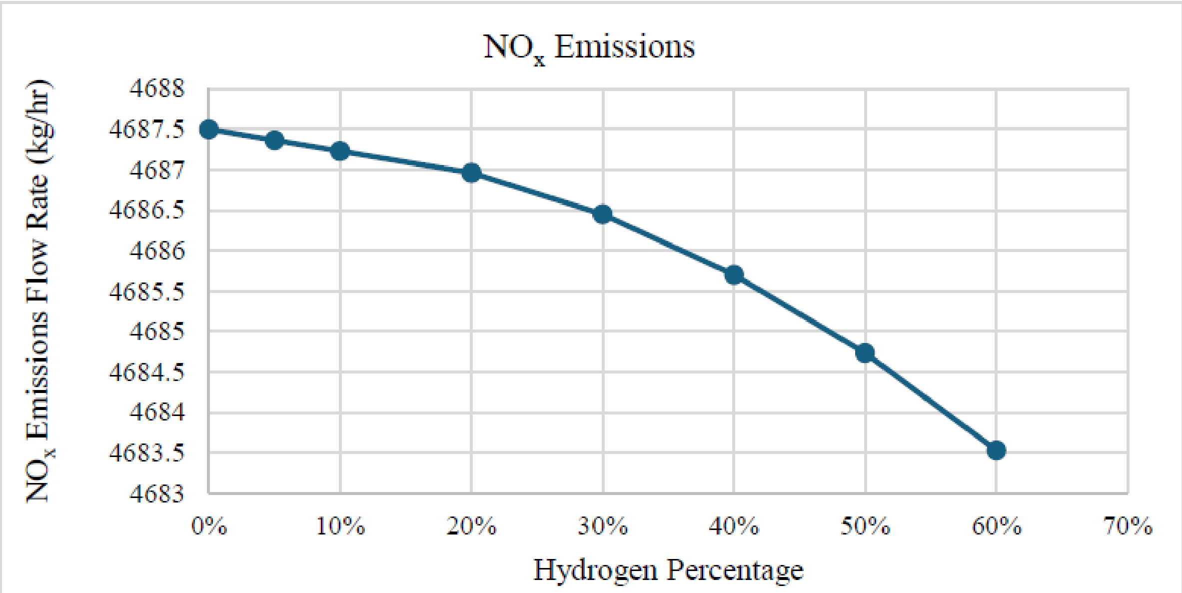

Figure 7: NOx emissions versus hydrogen percentage.

CO2 emissions show a decreasing trend of approximately 59.25% as the proportion of hydrogen in the dual fuel blend increases as shown in Fig. 9. However, it's essential to consider the overall lifecycle emissions associated with hydrogen production and distribution.

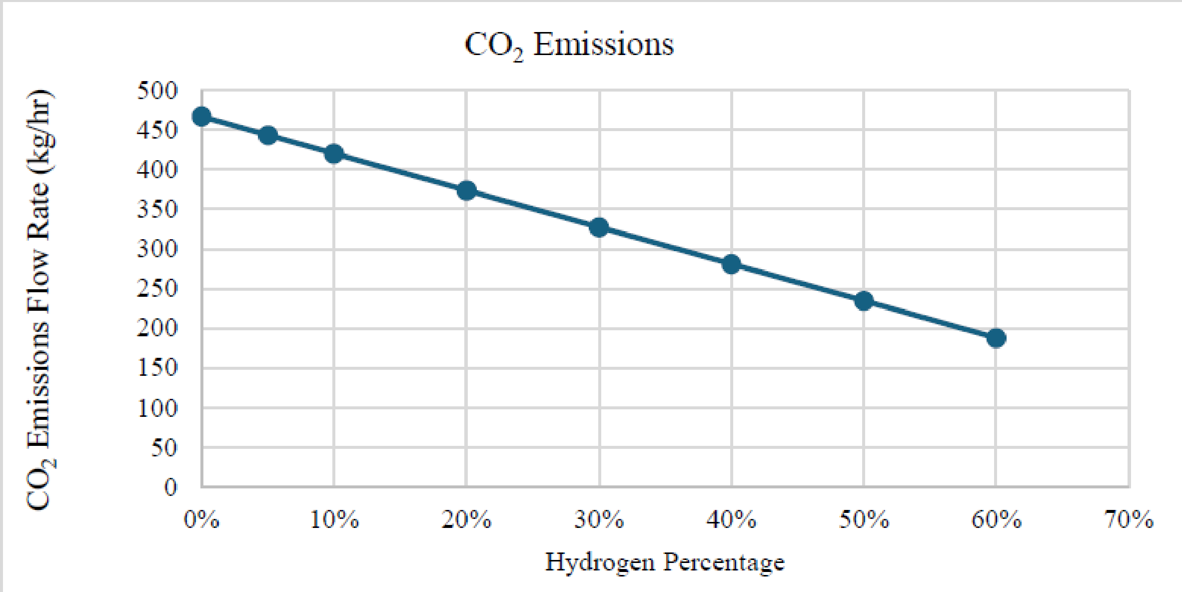

Figure 8: CO2 emissions versus hydrogen percentage.

Sulfur and methane emissions decrease significantly with increasing hydrogen concentration to 60%. On the other hand, methane increases from 1.06×10-29 to 2.64×10-27 as illustrated in Fig. 10. This reduction in emissions highlights the environmental benefits of hydrogen as a clean and sustainable alternative fuel.

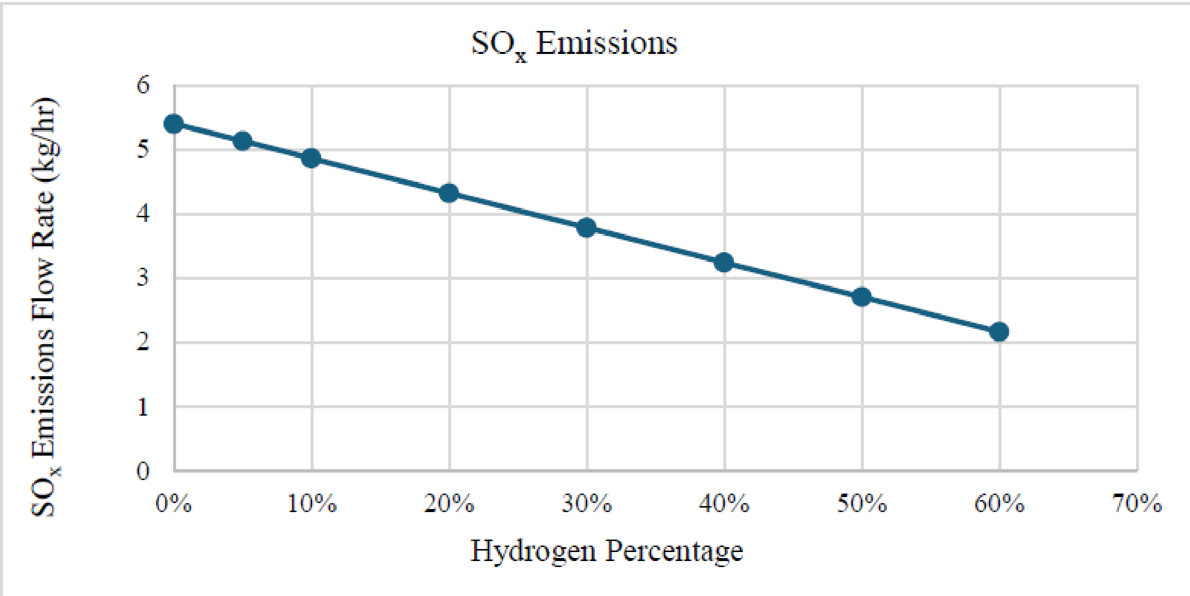

Figure 9: SOx emissions versus hydrogen percentage.

4. CONCLUSIONS

It is essential to prioritize research, development, and investment in infrastructure to enable their widespread adoption. Overcoming technical, economic, and regulatory barriers will be critical in realizing the full benefits of these alternative fuels and accelerating the transition towards cleaner, more sustainable energy. In conclusion, harnessing the power of these fuels can drive positive environmental, economic, and social outcomes, paving the way for a brighter and more sustainable future for generations to come. The emission results illustrate the complex interplay between fuel composition and emissions characteristics in ICEs utilizing diesel dual fuel technology. These findings underscore the potential of ammonia and hydrogen as clean and sustainable alternative fuels with results showing that CO2 emissions decreased by 59.68%, and SO emissions by 60%, while also highlighting the need for continued research and development to realize its full environmental benefits.

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