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A study on the combustion and emission characteristics and safe operation of ammonia engine

Safety Aspects of New & Alternative Fuels

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ABSTRACT

Numerous efforts are continuing to reduce greenhouse gas (GHG) emissions to achieve net-zero GHG emission in the maritime industry by 2050. One of the most prominent ways for reducing GHG is using carbon-neutral fuels such as ammonia, methanol and hydrogen.

HD Hyundai group has developed an eco-friendly medium-speed engine using ammonia after finishing the development of a methanol-fueled medium-speed engine. Ammonia has a low viscosity and low calorific value 2.3 times lower than conventional diesel fuel. Particularly, it must be operated safely without any leaks, as it is harmful to the human body. Due to above properties, injection system, engine system is newly developed and modified.

In the engine combustion system, it must be decided whether to use high pressure or low pressure. Particularly, ammonia combustion is challenging due to difficult ignition, slow speed combustion and the emission of nitrous oxide, which has a high global warming potential, as well as ammonia slip. Therefore, it is necessary to develop an optimal combustion system for this.

In this study, tests were conducted on high-pressure and low-pressure combustion systems for ammonia engines. The high-pressure diesel cycle applied a high-pressure injector, while the low-pressure Otto cycle supplied ammonia through the head port. Engine power, efficiency, nitrous oxide, and ammonia slip were comparatively evaluated for each system.

For the safe operation of ammonia engines, ammonia sensors, ammonia detection tape, and infrared CCTV were applied. Ammonia treatment systems were also installed in the engine room to handle leaked ammonia and purged ammonia from the fuel supply facilities.

Through this study, the performance and emission characteristics of diesel and Otto cycle ammonia engines were identified, and the GHG reduction rate was confirmed. Additionally, the operational equipment that ensures safe operation without ammonia leaks was validated.

1 INTRODUCTION

Nowadays the environmental regulations are strengthened in the maritime industry. The International Maritime Organization (IMO) has introduced targets to reduce greenhouse gas (GHG) emissions to net-zero by 2050 compared to 2008 levels, alongside the adoption of the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) measures. These regulations require significant advancements in marine engine technologies and the appropriate alternative fuels to meet environmental and operational requirements. [1,2]

Traditional diesel engines, although reliable and widely utilized, face challenges in meeting stringent regulations due to their inherent dependence on fossil fuels and substantial carbon dioxide (CO_2) emissions. To address these issues, dual-fuel (DF) engine technology has emerged as a promising solution. DF engines can operate on both diesel and alternative fuels, such as liquefied natural gas (LNG), offering enhanced flexibility and reduced emissions. Compared to conventional diesel engines, DF engines operating LNG mode achieve higher thermal efficiency and produce lower levels of nitrogen oxides (NOx) and particulate matter emissions.

The adoption of LNG as a primary fuel in DF engines represents a significant advancement toward decarbonization. LNG provides a cleaner-burning alternative with reduced sulfur and carbon emissions. However, methane slip, which refers to the release of unburned methane into the atmosphere, remains a critical challenge to its environmental advantages. As the industry continues efforts to further reduce GHG emissions, attention is increasingly focused on alternative fuels, such as methanol, hydrogen, and ammonia. These fuels are either carbon-neutral or carbon-free, aligning more closely with the IMO's long-term objectives.

Among these alternatives, ammonia is increasingly recognized as a promising carbon-free fuel for marine propulsion systems.[3] However, the use of ammonia as a marine fuel presents several critical challenges. First, ammonia is highly toxic, requiring stringent safety measures to prevent leaks and ensure the safety of both the crew and the environment. Second, its lower volumetric energy density compared to LNG requires larger storage volumes or innovative storage solutions. Third, the limited infrastructure for ammonia bunkering poses logistical challenges to its widespread adoption. Fourth, ammonia's corrosiveness requires the use of corrosion-resistant components in fuel handling systems. Finally, ammonia has low auto-ignition property, and it characterized by its high ignition energy requirement and slow flame propagation, demands advanced combustion technologies to achieve efficient engine performance.

Addressing these challenges is essential to use the ammonia as a sustainable marine fuel. This study focuses on the development and validation of an ammonia-fueled engine equipped with advanced safety and after-treatment systems. The research improves the design of safety measures, such as gas detection and ventilation systems, and the engine efficiency, and the integration of robust exhaust after-treatment technologies to mitigate NOx emissions.

Table 1. Fuel properties

Characteristics (%)	Unit	Ammonia	Methane (LNG)	Diesel
Formula	-	NH_3	CH_4	$C_nH_{1.8n}$;C_8-C_{20}
Carbon contents	Wt%	0	75	86.88
Methane Number (Octane number)	-	>130	100 (120)	-
LCV	MJ/kg	18.6	50.1	42.7
Auto-ignition Temp.	℃	651	580	257
Critical point	℃ / bar	132.4 / 113	-82.3 / 46.4	-
Flash point	℃	132	-136	52 to 96
Vapor pressure @ 20℃	bar	10	344.7 (@38℃)	-
Flammability limit	Vol.%	15 ~ 28	5 ~ 15	1 ~ 5
Liquid Density @ 20℃	kg/m3	600	422.5[1)]	833~881
Sulfur content (%)	%	≈ 0	<0.06	Varies, <0.5 or <0.1
Laminar flame speed	m/s	0.05 ~ 0.1	0.35 ~ 0.45	0.005 ~ 0.02

2 PROPERTY OF AMMONIA

Ammonia is increasingly recognized as a carbon-free fuel alternative, particularly in the context of achieving the IMO's GHG reduction targets. Its unique properties make it a promising candidate for sustainable marine propulsion. However, these properties also introduce significant technical and operational challenges. Table 1 shows the differences between ammonia and conventional fossil fuels, such as LNG and diesel.

Ammonia is composed of nitrogen and hydrogen, emitting no CO_2 during combustion. These characteristic positions ammonia as an attractive solution for reducing GHG emissions, particularly in sectors where decarbonization is challenging, such as maritime transport.

Ammonia's lower calorific value (LCV) (18.6 MJ/kg) is significantly lower than that of LNG (50.1 MJ/kg) and diesel (42.7 MJ/kg), requiring a greater quantity of fuel to produce the same engine power. Additionally, ammonia has a high ignition energy requirement and a slow flame propagation speed, which can hinder efficient combustion. As a result, a larger quantity of pilot fuel is required to ignite ammonia effectively. And due to its lower laminar flame speed, ammonia engines are more suited to operate in diesel cycle engine rather than Otto cycle engines.

Ammonia is highly toxic and poses significant risks to human health and the environment in the event of leaks. It can cause irritation to the respiratory system and eyes at concentrations above 25 ppm. Thus, ensuring safe handling requires the implementation of robust safety measures, including advanced gas detection systems, effective ventilation, and comprehensive emergency response protocols. Additionally, ammonia's high reactivity with certain materials leads to corrosion in storage and fuel handling systems. The use of specialized, corrosion-resistant materials is essential to mitigate these issues and maintain equipment reliability.

Although ammonia does not produce CO_2 during combustion it can produce significant quantities of NOx which are harmful pollutants, nitrous oxide (N_2O) which is about 300 times more potent than CO_2 and unburned ammonia slip. To address this issue, effective exhaust after-treatment systems, such as selective catalytic reduction (SCR) and ammonia oxidation catalytic (AOC) are required to minimize NOx, N_2O and unburned ammonia emissions and ensure compliance with environmental regulations.

3 AMMONIA SUPPLY SYSTEM

The ammonia fuel supply system is composed of several major components, including storage tanks, fuel pumps, supply piping, and heat exchangers.

The liquid ammonia storage tank is designed to have sufficient capacity for 16 hours of operation based on the engine's Maximum Continuous Rating (MCR). The tank pressure is configured so that ammonia remains in liquid form under ambient conditions without separate cooling or heating devices. The tank is equipped with a pressure gauge, a thermometer, and a level gauge for ammonia, allowing verification of the liquid ammonia level inside. A safety valve is also installed to manage any pressure increase.

A two-stage ammonia pressure pump is employed to transfer ammonia from the storage tank to the engine while maintaining the engine's requisite operating pressure. Before being supplied to the engine, the ammonia passes through a heat exchanger to achieve the temperature required by the engine. Because ammonia vaporizes more easily than conventional liquid hydrocarbon fuels, it is crucial to prevent undesired vaporization within the supply system.

Some of the ammonia supplied to the engine is consumed, and the remaining ammonia is routed back to the supply system via a separator. The returned ammonia then passes through the pressure pump and is resupplied to the engine.

4 AMMONIA SAFETY SYSTEM

Ammonia fuel is highly toxic, requiring the implementation of robust safety systems for both ammonia fuel supply system and engine experimental system. Although ammonia has a distinctive odor that facilitates leak detection, its extreme toxicity has significant risks, including fatal accidents from inhalation. Therefore, comprehensive measures for leak prevention, detection, and treatment systems are indispensable.

Figure 1. Ammonia safety equipment.

To ensure the safety of the facility, special safety equipment has been deployed shown in Figure 1. Ammonia gas leak detectors have been installed throughout the fuel supply system. Additionally, ammonia detection tapes, which change color upon exposure to ammonia, have been used to pipe on junctions to facilitate leak detection. To resolve potential leaks, water spray systems have been installed. Containment systems have been implemented to prevent diluted ammonia solutions from leaking into the environment. And to manage large-scale leaks, ammonia storage and supply facilities are enclosed within barriers to prevent external release.

When ammonia is transferred from external storage to the engine system located in an enclosed engine room, various safety systems have been installed to mitigate and respond to leaks. Similar to the fuel supply system, ammonia gas detectors have been installed throughout the engine room. Since ammonia has a higher vapor pressure than atmospheric pressure at ambient temperatures and rapidly transitions to a gaseous state when released, gas detectors are placed near the engine and at the upper sections of the engine room, where ammonia gas tends to accumulate. However, since ammonia can react with atmospheric moisture to form smog, additional detectors have been installed at the lower sections of the engine room. Remote monitoring system also deployed within the engine room, allowing real-time observation of gas leaks and the surrounding environment as shown in Figure 2. Infrared camera has also been installed at pipe connections and engine fuel supply points to enhance leak detection capabilities.

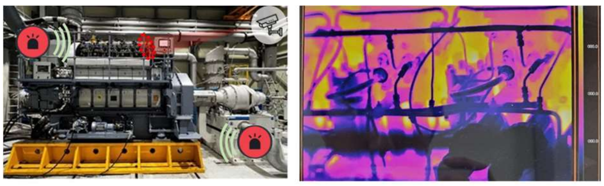

Figure 2. Ammonia leakage gas detector and infrared camera in engine room

To manage potential leaks, a ventilation system has been added to the engine room. During engine operation, the ambient pressure of the engine room is maintained below atmospheric pressure, ensuring that external air flows inward rather than engine room air escaping outward. All air inside the engine room is directed to an ammonia scrubber system through ventilation system. when ammonia leakage is detected, the ventilation system operates at maximum capacity to rapidly extract air from the engine room and process it through the ammonia scrubber system.

The ammonia scrubber systems are consists of two scrubbers. Each scrubber systems are designed for each purpose. The one for purging the fuel supply system and the other for ventilation of engine room. The scrubber for the fuel supply system is intended to handle large-scale liquid ammonia leaks, processing high volumes of leaked ammonia in a short time. Meanwhile, the scrubber for the engine room is designed to facilitate normal ventilation during engine operation and to ventilate rapidly in emergency situation such as ammonia fuel leak in engine.

Figure 3. Ammonia scrubber system

Access to the engine room and fuel supply facilities during emergency situation requires the use of personal protective equipment. Entry is strictly prohibited during engine operation to ensure safety.

By implementing these various safety systems, ammonia engine testing has been conducted without incident, even in emergency scenarios involving minor leaks. The systems functioned as designed, effectively mitigating risks and ensuring safe operation. These safety systems have been considered not only for land-based facilities but also for marine applications, providing a framework for safe ammonia engine operations aboard vessels.

5 EXPERIMENTAL METHOD

This study utilized a modified H22CDF LNG DF engine, considering the specific characteristics of ammonia fuel as shown in table 2. The considerations included ammonia's corrosive properties, density, LCV, bulk modulus, and ignition characteristics. Engine specifications were determined through detailed combustion and performance analyses.

Table 2. Specifications of DF engine

Specification	Unit	Value
Engine speed	RPM	900
Bore	mm	220
Stroke	mm	330
Compression ratio	-	16.2
BMEP	bar	22.9
Power	kW/Cylinder	215
Ammonia fuel Injection System: Mechanical Pump Line Nozzle (PLN) type		
Pilot fuel Injection System: Electronic common rail type		

To resolve the corrosion, a critical concern when using ammonia fuel, the replacement of all O-rings in both the engine and fuel supply systems with ammonia-compatible materials were required. Additionally, the density and LCV of ammonia fuel were considered when the specification of a fuel injection system were designed for achieving performance and output comparable to the original engine configuration.

A new Fuel Injection Equipment (FIE) system has been designed for ammonia fuel injection. This system maintains the external structure of the conventional HiMSEN engine diesel FIE, allowing the use of ammonia fuel without modifications to the HiMSEN LNG Dual-Fuel engine head design. The system is designed to allow both ammonia and diesel fuels to be injected from this single injection system. To enable proper injection of both fuels, the most significant change from the conventional fuel injection system is that the fuel injection valve nozzles are arranged in two rows instead of one. Therefore, the system is designed so that only the first row of nozzle holes opens during diesel mode, while both the first and second rows of nozzle holes open during ammonia mode. This ensures that the fuel injection duration for both fuels is controlled within an optimal range. Additionally, a sealing oil system has been implemented to prevent ammonia leakage. Prior to the engine application tests, the FIE system's performance was validated through functional tests on a test rig.

Figure 4. Ammonia FIE test rig

Due to ammonia's high autoignition temperature and autoignition energy, autoignition is infeasible without ignition source, requiring the use of pilot fuel for ignition. While LNG fuel typically requires only 1–2% of total energy as pilot fuel, ammonia fuel demands over 5% of total energy. Accordingly, the pilot injector specifications were adjusted to meet this requirement.

The LNG DF engine used a low compression ratio to accommodate gas-mode operation. However, for ammonia fuel operation under the diesel cycle, a higher compression ratio was employed, as ammonia does not take place knocking issues even at a compression ratio equal to or exceeding those of conventional diesel engines. The compression ratio was increased within the durability limits of the engine design.

Because of the distinct exhaust gas composition of ammonia engines, compared to conventional gas or diesel modes, the installation of additional exhaust gas after-treatment systems is required. The unburned ammonia slip required the integration of both a SCR system and an AOC. The AOC oxidizes unburned ammonia fuel in exhaust gas, preventing its release into the atmosphere. Unlike conventional SCR systems that use the urea to reduce the NOx emissions by reacting the NOx and urea, the ammonia present in the exhaust gas of an ammonia engine reacts directly with NOx, eliminating the need for additional urea injection. However, in cases where unburned ammonia is emitted at higher levels than NOx, unburned ammonia may remain after the SCR, it is needed to install an AOC.

The exhaust gases from an ammonia engine contain not only NOx but also components such as NH_3 and N_2O, which are absent in conventional engines. Consequently, standard exhaust gas analyzers are inadequate, requiring the use of a Fourier-transform infrared (FTIR) gas analyzer to analyze the NH_3 and N_2O emissions. An FTIR system was installed to measure and analyze NOx, N_2O, and ammonia slip.

6 AMMONIA ENGINE EXPERIMENTAL RESULTS

The ammonia engine tests were conducted with four key variables and detailed analyses were performed to evaluate the engine combustion and emission characteristics under each condition. The experiments were carried out at a high-load condition corresponding to 75% of rated power (BMEP 17.2 bar). The four variables were as follows:

1. Micro pilot (MP) injection pressure

2. Micro pilot injection timing

3. Micro pilot injection quantity

4. Exhaust Waste Gate (EWG) valve

Since the ammonia fuel injection system is mechanical, resulting in a fixed injection timing. The injection quantity was controlled by adjusting the actuator rack to maintain a constant engine speed corresponding to the engine output. Conversely, the micro pilot injection system allows for electronic control, enabling adjustments to injection timing, pressure, and quantity. Additionally, the EWG upstream of the turbocharger (T/C) was electronically controlled to control the temperature after T/C.

6.1 Micro pilot injection pressure

The effects of various MP injection pressures on engine performance and exhaust characteristics were investigated. Tests were conducted at MP injection pressures of 900 bar and 1100 bar. The MP injector is a high-pressure cylinder direct injection system that introduces a small quantity of diesel fuel into the cylinder to ignite the low reactivity fuel such as LNG, LPG, and ammonia fuel. With the same injection duration, higher injection pressure led to a greater quantity of fuel being injected. To maintain a consistent diesel fuel ratio, the injection duration was shortened under increased pressure to ensure the same amount of diesel fuel was injected.

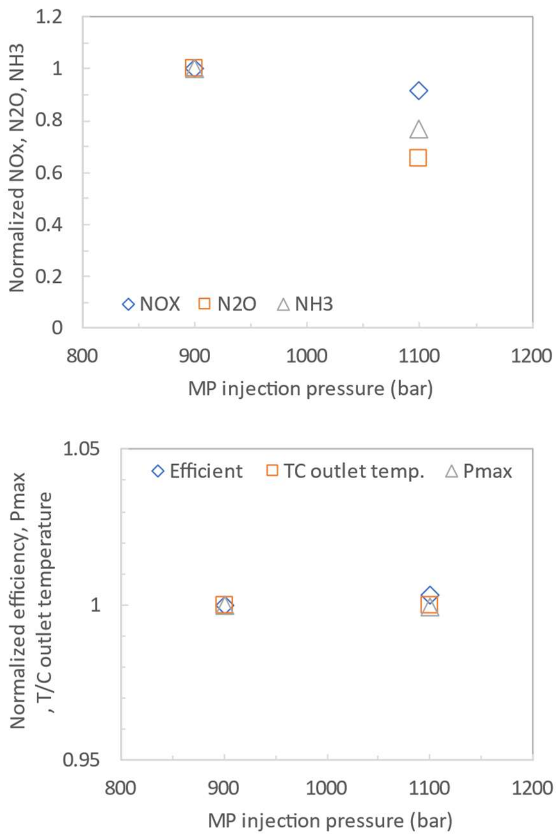

Figure 5. Emissions (NOx, N_2O, NH_3) and engine performance depending on MP injection pressure.

As shown in Figure 5, When the MP injector injection pressure was increased, engine efficiency was nearly the same. In comparison, emission performances were enhanced. The ammonia slip decreased by approximately 23%, and N_2O emission was reduced by about 35%.

Reducing N_2O emissions is particularly important, as N_2O has a global warming potential approximately 300 times that of CO_2. N_2O emission exhibits a trade-off relationship with NOx emissions. When combustion improves, NOx emissions increase while N_2O emissions decrease. Conversely, when combustion deteriorates, NOx emissions decrease, and N_2O emissions increase. Optimizing combustion to simultaneously reduce both NOx and N_2O emissions is an important goal in ammonia engine development.

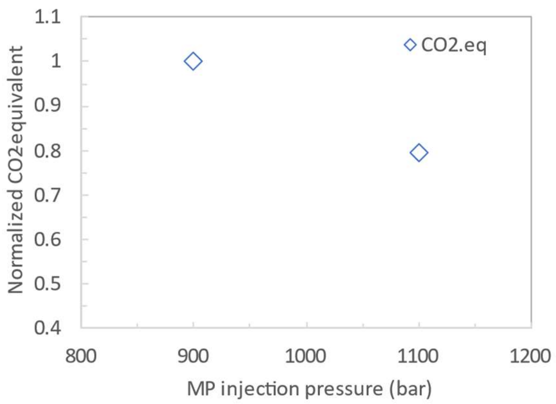

Figure 6. CO_2-equivalent depending on MP injection pressure.

pressure. Figure shows CO_2-equivalent (CO_2-eq) results depending on MP injection pressure. When CO_2 and N_2O emissions converted to CO_2-eq, the CO_2 emission was reduced to 20% by combustion improvement when MP injection pressure increased. These results can be attributed to improved atomization of diesel fuel and increased spray penetration at higher injection pressures. As the injection pressure increases, the shear force and drag force on the fuel droplet are increased and it leads to enhanced fuel atomization. This improvement in atomization resulted in better ignition and combustion of the diesel fuel. Also longer spray penetration allows the diesel fuel to be more evenly distributed within the cylinder, and it leads to improved ammonia ignition and combustion.

6.2 Micro pilot injection timing

The MP injection timing is one of the important factors influencing the combustion and exhaust characteristics of an ammonia engine. The results show significant variations in engine efficiency and exhaust emissions depending on injection timing. Advancing the injection timing resulted in a decrease in engine efficiency, while NOx and N_2O emissions increased. Ammonia slips initially decreased with advanced injection timing however it turned to rise again beyond a certain injection timing.

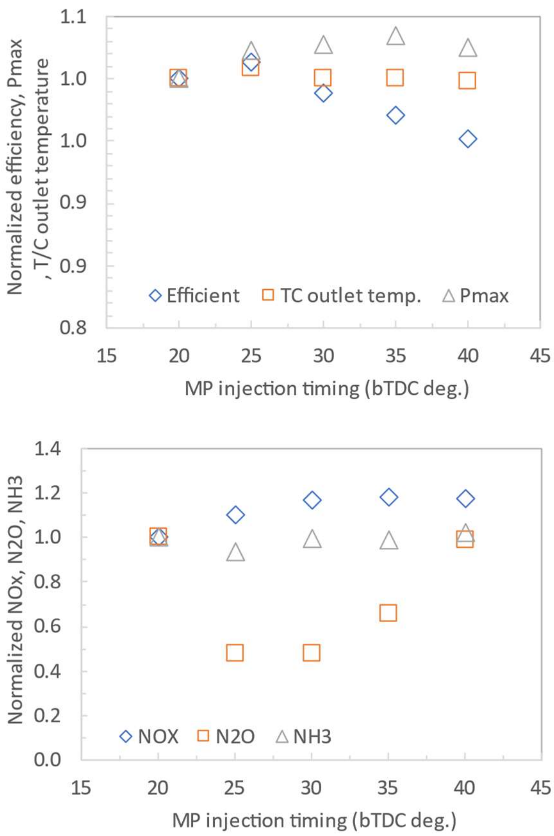

Figure 7. Emissions (NOx, N_2O, NH3) and engine performance depending on MP injection timing.

As shown in Figure 7, when the pilot diesel injection timing is advanced, the in-cylinder temperature and pressure at the moment of injection, as well as the air density are reduced. These conditions adversely affect the atomization of the early-injected pilot fuel, resulting in deteriorated ignition and combustion performance. This deterioration subsequently impacts the combustion process of the main ammonia fuel. However, ammonia slip, N_2O emissions, and efficiency all exhibited inflection points near injection timing at bTDC 25°, achieving optimal efficiency and exhaust gas performance at this range. It suggests the presence of an optimal injection timing between the pilot and ammonia fuels.

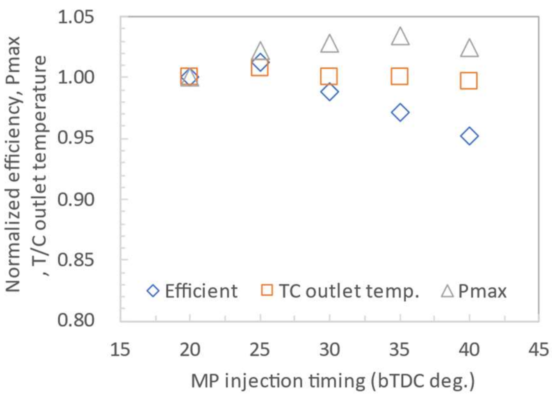

Figure 8. CO_2-equivalent depending on MP injection timing.

The combustion process involves the injection of diesel fuel into the cylinder, where it undergoes a mixing phase with air before ignition, a process that requires a certain amount of time. After this delay, the ammonia fuel is injected and it ignites due to the pilot fuel. The combustion then propagates throughout the cylinder.

These results show the certain importance of achieving a proper injection timing gap which is appropriate dwell between the pilot and ammonia fuels to optimize combustion and emissions performance.

6.3 Micro pilot injection quantity

The MP injection quantity test was conducted with the MP injection timing fixed. Increasing the MP injection quantity under a fixed injection timing effectively shortens the dwell time, defined as the interval between MP injection and ammonia injection. As a result, similar trend results were observed in the MP injection timing tests, a shorter dwell time led to simultaneous reductions in NOx emissions and engine efficiency. In contrast, ammonia slip initially decreased with increasing MP injection quantity however began to rise again beyond a certain MP injection quantity. N_2O emissions showed a consistent decreasing trend. Additionally, as the MP injection quantity increased, the proportion of ammonia in the fuel mixture decreased, and because of the property of the low combustion temperature of ammonia, which corresponded to a rise in the temperature downstream of the T/C.

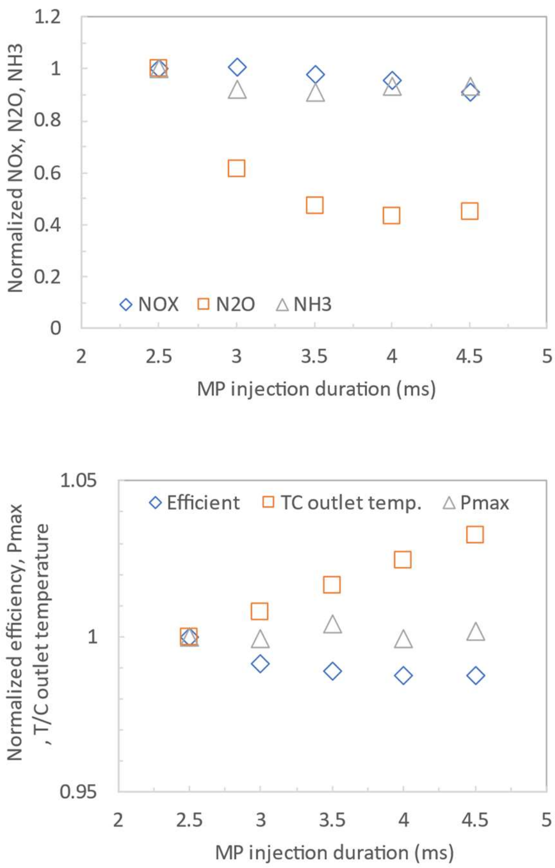

Figure 9. Emissions (NOx, N_2O, NH_3) and engine performance depending on MP injection duration.

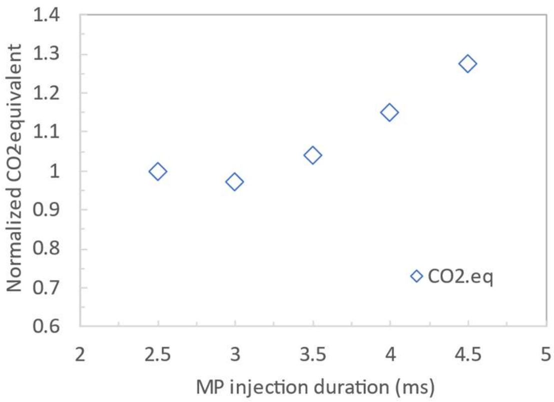

Figure 10 CO_2-equivalent depending on MP injection quantity.

Figure 9 and Figure 10 show the emissions and engine performance depending on MP injection quantity. The results indicate that, beyond the minimum quantity of MP diesel required to ignite the ammonia fuel, further increases in MP injection quantity had little to no positive impact on the performance of the ammonia engine. Additionally, excessive MP injection quantities were found to adversely affect engine performance. Based on these studies, the optimal MP injection quantity for achieving the best combustion and exhaust performance in an ammonia engine was validated.

6.4 Exhaust Waste Gate (EWG) valve

The EWG is a valve that diverts air from the turbine upstream to the downstream directly bypassing the turbocharger, typically used in DF engines to regulate the air-fuel ratio during Otto cycle operation. However, ammonia engines operate on a diesel cycle, so the need for air-fuel ratio control is not necessary. Instead, the EWG in ammonia engines serves an important role in maintaining the exhaust gas temperature required for catalytic reactions in after-treatment systems such as SCR and AOC.

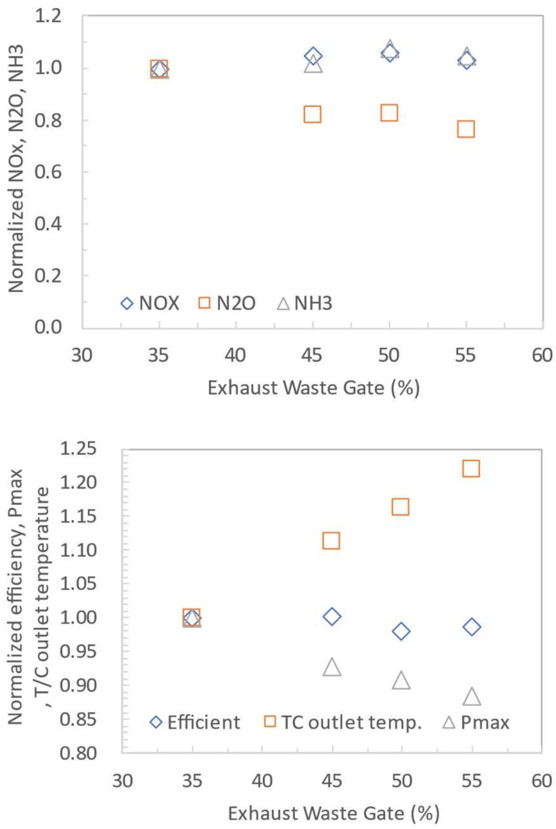

Figure 11. Emissions (NOx, N_2O, NH_3) and engine performance depending on Exhaust Waste Gate (EWG).

Due to the lower combustion temperature characteristic of ammonia fuel, exhaust gas temperatures are lower than those of conventional diesel or gas engines. Without EWG operation, the exhaust gas temperature may not reach the levels necessary for effective catalytic reactions in the after-treatment systems. Inadequate temperatures would hinder the SCR and AOC systems from effectively treating NOx and ammonia slip.

To resolve this issue, the EWG was utilized in the ammonia engine to control exhaust gas temperature before the after-treatment system. Increasing the EWG opening allows more air to bypass the turbine, reducing turbine work, lowering intake air pressure, and subsequently decreasing the air flow entering the combustion chamber. This bypassed air is directly expelled downstream of the turbine, effectively raising the temperature in the turbine's downstream region. For the ammonia engine, the EWG opening was increased to elevate the turbine's downstream temperature, ensuring optimal operating conditions for the after-treatment systems.

The test assumed that the required exhaust gas temperature for the after-treatment system could vary and adjusted the EWG opening accordingly. And, the effects of EWG opening on in-cylinder equivalence ratio and engine performance were analyzed.

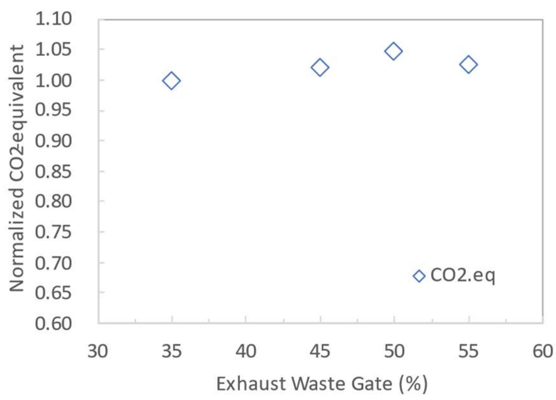

Figure 12. CO_2-equivalent depending on Exhaust Waste Gate (EWG).

As shown in Figure 11, when the EWG opening is increased, the in-cylinder temperature rises, resulting in higher NOx emissions. As the lambda is decreased, ammonia slip is also increased, and engine efficiency is slightly decreased. it indicates that reduced lambda negatively impacts ammonia combustion. N_2O emissions showed no significant changes depending on EWG valve positions, while the turbine downstream temperature increased. When CO_2-equivalent (CO_2-eq) emissions were calculated based on CO_2 and N_2O emissions, the results showed an increase in CO_2-eq as the EWG valve opening increased shown in Figure 12.

7 CONCLUSIONS

Various experiments were conducted on a high-pressure, direct injection with a multi-cylinder ammonia engine.

- Safety systems related to the characteristics of ammonia fuel were considered and installed. Ammonia detection systems, treatment systems, and other safety devices were fully implemented, and operational and procedural guidelines were established to ensure safe operation without incidents.

- Safety control logic for emergency engine shutdown scenarios was fully incorporated. In response to potential shut down situations in the fuel supply system and engine, measures such as engine room sealing, ventilation, fuel supply system purging, and scrubbing for ammonia fuel in the supply and engine system were performed, and the functionality of these systems was fully validated.

- Parametric studies were carried out under various operating conditions of the ammonia engine to evaluate combustion and exhaust performance. Important parameters such as engine efficiency, NOx, N_2O, and ammonia slip were analyzed.

- Experiments were completed to investigate the effects of MP injector parameters—such as injection timing, injection quantity, and injection pressure—as well as EWG valve opening on ammonia engine performance. The effects of each factor on engine operation were evaluated.

- Although the experiments were conducted using land-based equipment, the system was designed to meet maritime rules. Safety systems applicable to onboard systems were established, and the tests were completed in compliance with these standards. Based on this experience, the results will be applied to HiMSEN ammonia engine development.

8 DEFINITIONS, ACRONYMS, ABBREVIATIONS

AOC: Ammonia Oxidation Catalytic

bTDC: before Top Dead Center

CII: Carbon Intensity Indicator

CO2: Carbon Dioxide

CO2-eq: Carbon Dioxide equivalent

DF: Dual-Fuel

EEXI: Efficiency Existing Ship Index

EWG: Exhaust Waste Gate

FTIR: Fourier-transform infrared

GHG: Greenhouse Gas

IMO: International Maritime Organization

LCV: Lower Calorific Value

LNG: Liquefied Natural Gas

MP: Micro Pilot

N2O: Nitrous Oxide

NOx: Nitrogen Oxides

PLN: Pump Line Nozzle

SCR: Selective Catalytic Reduction

T/C: Turbocharger

9 ACKNOWLEDGMENTS

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