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REDUCTION OF GHG EMISSIONS FROM SHIPS

Study of actual methane slip from newbuild LNG engine of a state-of-the art cruise ship

Submitted by Finland

SUMMARY

Executive summary:	This document reports the key findings of a methane emission study conducted on board a state-of-the-art LNG-powered cruise ship. The study is part of a large international research project (GREEN RAY) concentrated on mitigating methane slip from LNG powered engines.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 27
Related document:	Resolution MEPC 391(81)

Introduction

1 The use of liquified natural gas (LNG) as a shipping fuel has increased in recent years. While the use of LNG results in lower CO_2 emissions as well as its benefits in terms of air pollutants, the slip of unburned methane, the main component of LNG, has remained as a concern. While there are a few studies presenting onboard studies, overall, the number of studies on methane slip from new, state-of-the-art ships and engines is limited.

2 This document reports the key findings of a methane emission study conducted on board a state-of-the-art LNG-powered cruise ship during a normal operation. In this study, the term methane slip covers the methane that remains unoxidized in the combustion chamber and escapes to the exhaust duct. Possible escape to crankcase was not in the scope of the study. The study is part of a large international EU-funded research project GREEN RAY that concentrates on mitigating methane slip from LNG powered engines and its results has been submitted for publication in the *Atmospheric Environment X* (Kuittinen et al.).

Materials and methods

3 Emission measurements were conducted on board **MSC World Europa**, a state-of-the-art cruise ship fuelled by LNG during its one-week trip in the Mediterranean.

Figure 1: Itinerary of the studied cruise ship

4 During the measurement campaign conducted in May 2023, exhaust was sampled from one of the ship's five main engines. The engine studied was a Wärtsilä 46DF, 14-cylinder, 600 rpm, 4-stroke low pressure dual-fuel engine with an output of 16,030 kW. LPDF engines apply a pilot injection of liquid fuel to ignite the mixture of air and natural gas. During the campaign, the engine was mainly fuelled by LNG with the pilot injection of marine gas oil (MGO) but could also burn MGO to allow emission characterization during full MGO operation.

5 During the campaign, emission measurements were conducted both during steady engine load conditions and during normal engine operation when the ship was operating at open sea or arriving, residing, and departing harbours. Five steady load conditions were measured with both fuels, being 12, 25, 54, 75, and 80% for LNG operation and 10, 25, 54, 75, and 80% from MGO operation with ±2 %-unit accuracy. In case of LNG operation, the load conditions of 54% and 80% were repeated on two separate days.

6 The LNG used during the campaign contained 97.6 mol-% methane. The composition and properties of the used LNG were retrieved from bunkering report. A sample of the pilot fuel was collected on board and analysed for its C, H, and N content. The fuel compositions together with the fuel consumption were used to calculate the exhaust gas mass flow rate by the carbon balance method (e.g. ISO 8178 and NO_x Technical Code).

7 The continuous data of engine power and consumption of both main and pilot fuel were received from the ship owner in five minute time resolution and was applied in calculating specific emissions (as #/kWh) during steady load conditions. For studying the emissions under normal engine operation, the same load and fuel consumption data in 1s time resolution could be received from ship manufacturer. During these normal operation periods, no requests were made to ship personnel regarding engine use, but they operated the engine according to the momentary power needs of the ship to maintain the cruise schedule and the operations on board.

8 Methane slip was also calculated by applying weighting factors defined in the E2 and D2 test cycles for which the studied engine is certified. However, the engine loads were adjusted, utilizing the studied engine load conditions instead of the load conditions defined in the cycles (10, 25, 50, 75, and 100%). In addition, an "actual operation" cycle was developed, based on the eight months of engine data received from the ship manufacturer. For this, the

engine loads were extracted from the ship Data Acquisition System (DAS) in 1Hz time resolution for the eight-month period between 12 April and 15 December 2023 when the ship was operating in the Mediterranean. One-minute averaged data was used to calculate the profile of engine operation time on different load conditions. The relative time spent at different engine loads was then used for weighing the emission. During low engine load conditions of 20-35%, the engine utilization was observed to be transient as the load condition was being continuously adjusted during arrivals and departures from harbours. Therefore, an emission factor for methane slip during this "Normal 20-35% loads" operation was calculated based on measurements of four departures, two arrivals and one stop at sea. The normal operation emission factor was then utilized in the calculation of the actual weighted emission, whereas emissions at steady 25% load was utilized for the adjusted E2 and D2 cycles.

9 Emission measurements were conducted by sampling engine exhaust through a sonde installed to a connector port on the deck above the engine room, a few meters from the engine outlet. Methane was detected by gas chromatography and Fourier Transformation Infrared Spectroscopy (FTIR). In addition, carbon dioxide and carbon monoxide were measured with a nondispersive infrared analyser, nitrogen oxides by a standard method applying chemiluminescence detector and black carbon (BC) with the optoacoustic method.

10 Total greenhouse gas emissions as brake specific CO_2 equivalent emissions at steady load conditions were calculated and methane and BC were included in addition to CO_2. To convert methane and BC to CO_2 equivalents, the 100-year CO_2 equivalent global warming potential value of 28 was applied for methane and 900 Click or tap here to enter text. for BC. N_2O was studied but below the detection limit of the instrument and not included in the calculation.

Results

Methane slip

11 Methane slip was measured at five different engine load conditions and exhibited load dependency and overall low values compared to existing literature.

12 The methane slip values measured under steady conditions of 54-80% engine load were between 2.3-3.0 g/kWh, whereas increased brake-specific emissions of 10 g/kWh and 21 g/kWh were observed at lower engine loads of 25% and 12%.

13 Good agreement between the gas chromatography and FTIR methods was seen, and results from load conditions repeated on different days were in good agreement.

14 The measured methane slip values were within the lower range of all values reported in the literature from onboard studies on LPDF 4-S engines.

GHG emissions

15 Considering total GHG emissions, LNG combustion resulted in lower total CO_{2eq} at an engine load of 54% and above, in comparison to MGO combustion.

16 Total CO_2 equivalent GHG emissions were calculated by considering methane and BC emissions together with CO_2. At load conditions above 54%, 15-21% lower total CO_2 equivalent was achieved with LNG compared to MGO. At low engine load conditions of 12% and 25%, situation was vice versa and LNG combustion resulted in 9-11% increase in total CO_2 equivalent compared to MGO.

17 Without considering BC in total CO_2 equivalent GHG emissions, at load conditions above 54%, 14-18% lower total CO_2equivalent was achieved with LNG compared to MGO. At low engine load conditions of 12% and 25%, LNG combustion resulted in 14-31% increase in total CO_2 equivalent compared to MGO.

18 At higher load conditions, 54% and above, methane contributed 12-15% of the total CO_2 equivalent emission of the LNG combustion, but the contribution increased at low loads, being 32% at 25% load and 41% at 12% load condition. In the case of MGO operation, BC contributed 1-4% at loads between 25-80%, but also its contribution increased at low load to 15% of the total CO_2 equivalent. Without considering BC, the contributions of methane remained the same in the case of LNG operation, whereas in the case of MGO, CO_2 would contribute to 100% of the total CO_2 equivalent.

Methane slip during different engine operations

19 During normal engine operation, increased methane slip was observed at low load conditions, however, these conditions consist only a minority of the total engine operation time.

20 Normal operation of the engine was studied during several periods when the ship cruised at sea or arrived, departed or resided in harbours. While increased methane slip could be observed during low load conditions, considering the normal ship operation, the engine was operated on steady high load condition for prolonged periods when the ship cruised at open sea. During these periods, the load remained considerably stable and methane slip in the exhaust remained at a stable level as well. Considering the total cruise, during normal ship operation, only rare occurrences were seen where the engine was operated on a load condition below 20%.

21 To compare the increased and fluctuating methane slip observed during the transient engine operation during arrivals and departures, an emission factor (g/kWh, g/MJ) for these periods, limited to time periods when the engine ran on 20-35% load was calculated. The obtained average methane slip of 10.9 g/kWh (1.0 g/MJ) is about 11% higher than during steady 25% load, but considering the high standard deviation of 3.4 g/kWh this suggests that higher methane slip can be observed momentarily during these periods.

22 To further consider the normal operation, actual operation data for the engine during the eight months of operation was analysed. The engine was most typically operated on high load conditions of 80-85%, which contributed for 39% of the total operation time. The load ranges of 65-75%, 40-60%, and 20-35%, then contributed, respectively, for 21%, 31%, and 8% of the total operation time. The engine utilization at the lowest load conditions of 10-15% contributed less than for 1% of the operation time.

Methane levels and engine load profiles

23 The operation profile was also reflected in the share of emitted methane as 43% of the total methane slip during the eight-month operation resulted from the engine operation at the highest load range, followed by contributions of 19%, 27%, and 10% from the operation at 65-75%, 40-60%, and 20-35% loads. For this ship, the operation at 10-15% load then contributed for only 1% of the methane slip.

24 Considering the distribution of methane slip at different load conditions, a weighted emission factor for methane was developed, applying the engine load condition data retrieved from the specific engine on the ship during the first eight months of the ship operation. The weighted methane emission (in table 1) under real-world engine operation (actual) was 2.8 g/kWh (0.3 g/MJ) or 1.7% of the consumed fuel. For comparison, values were calculated for adjusted E2 and D2 cycles (based on measured load conditions) and also for the 50% engine load.

Table 2: Comparing weighted specific emission factors of methane and total GHGs including CO_2, methane and BC under the real-world operation (actual), according to adjusted E2 and D2 test cycles as well as at 50% engine load

	Real-world operation	Adjusted E2 cycle	Adjusted D2 cycle	50% load
Methane (g/kWh)	2.8	2.8	4.1	2.9
Methane (% of fuel)	1.7	1.7	2.3	1.7
Methane (g/MJ)	0.33	0.34	0.46	0.34
GHG (gCO2eq/kWh)	539	539	598	554
GHG (gCO2eq/MJ)	64	64	67	64

25 Resolution MEPC 391(81) on the *2024 Guidelines on life cycle GHG intensity of marine fuels (2024 LCA Guidelines),* gives the initial default emission factor of 3.5% for LNG Otto dual fuel medium speed engines. The methane slip weighted according to the actual operation profile of the engine in this study (1.7% of the fuel consumed) is 51% lower than the initial default value given in the 2024 LCA Guidelines.

Conclusion

26 This document reports the key findings of a methane emission study conducted on board a state-of-the-art LNG-powered cruise ship (as part of a large international research project GREEN RAY). These include:

.1 methane slip was determined from an LPDF 4-S engine on board a newly build cruise ship which was constructed in 2022. Load dependency of the methane slip, as well as other emission compounds, were observed. The methane slip emission factor from the newbuild engine varied from 2.5 to 21 g/kWh (0.27-1.33 g/MJ) at 80% to 12% loads, respectively, being in the lower end of values reported in the literature;

.2 in comparison to the MGO operation, total GHG emissions including CO_2, methane, and BC indicated that LNG use brings benefits at 54% load and above, but at lower loads, the benefits in terms of CO_2 and BC are undermined by the uncombusted methane;

.3 methane concentrations observed during normal engine operation indicated increased concentrations in the exhaust during arrivals and departures where lower engine loads are utilized and when loads are frequently adjusted. By following the engine activity profile during the eight months of ship operation on the Mediterranean, weighted emission factor for methane was developed, resulting in 2.8 g/kWh (0.3 g/MJ) for this specific ship. The weighted emission according to normal ship operation corresponds to 1.7% of the fuel use, which is lower compared to the initial default value of 3.5% given in the 2024 LCA Guidelines; and

.4 this weighted emission factor represents the activity of the specific cruise ship where the engine was operated at loads above 40% for more than 90% of the operation time. Similar activity may represent cruise ships with corresponding routes where rather short periods are spent arriving or departing harbours and ships navigate mainly at open sea.

Action requested of the Committee

27 The Committee is invited to note the information provided in this document.
