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Conceptual design of ship-based carbon capture (SBCC) technology on-board of an LNG fuelled large crane vessel and LNG carrier

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Abstract

Ship-Based Carbon Capture (SBCC) is a promising decarbonization strategy for the maritime sector that can help curtail CO_2 emissions by at least 50% within 2050 [1]. In the EverLoNG project, SBCC technology will be validated and demonstrated on-board on the Sleipnir crane vessel of Heerema Marine Contractors and an LNG carrier from TotalEnergies, both fuelled by LNG [2]. In a previous work, a high level conceptual design of a CO_2 capture plant onboard the Sleipnir, considers a fictitious operational profile[3]. In this study, the operational profile of the Sleipnir vessel spanning ca. 2 years was used to design the SBCC process, and more detailed data analysis was performed for the entire vessel, per engine room and per engine, considering its dual-fuel operation. This abstract therefore mostly focuses only on the conceptual design for the Sleipnir vessel, whereas the full work to be presented at GHGT will also include the LNG carrier from TotalEnergies. The analysis involves optimizing heat integration strategies within the existing ship systems in order to provide the required heat for the capture plant in an efficient way. The solvent considered in the capture system is 30 wt% monoethanolamine (MEA).

The Sleipnir ship has 12 engines (8 MW each) divided over four engine rooms. Its operational data are analysed in Python. The vessel has dual-fuel engines running on either marine gas oil (MGO) or LNG. From the engine performance data, the specific fuel oil consumption (SFOC) and the specific gas consumption (SGC) are known for 25%, 50%, 75% and 100% engine loads from which correlations can be created to calculate the CO_2 emissions for respective fuel modes according to engine loads in operation. The total CO_2 emissions from the vessel spanning 2 years was calculated at 87 kton. The percentage of time in operation and the percentage of CO_2 emissions in a certain cumulative engine load (summing the MGO and gas engine loads) in 2 years of operation is shown in Figure 1.

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From Figure 1, it is evident that Sleipnir operates most of the time in the load range 4.5-15 MW and operates less often above the 15 MW range. Hence, the maximum load for the capture plant was chosen at 15 MW of equivalent power, and the capture system was designed accordingly. The CO_2 capture rate was limited by the amount of heat that could be recovered from the exhaust gases, without considering heat losses. High exhaust gas temperatures from the Sleipnir allows a relatively high amount of heat recovery from the exhaust gases to be used in the stripper reboiler. However, it is crucial to note that while the exhaust gases from LNG can be cooled to 135^0C, when operating with diesel (MGO, heavy fuel oil) the cooling is limited to 180^0C to avoid crossing the dew point of sulphuric acid (formed from the SO_x present in the flue gas)[4]. Figure 2 shows the amount of heat recovered for the diesel mode and LNG mode with respect to the engine loads, which plays a significant role in determining the CO_2 capture rates in the capture process. For the diesel mode, the maximum capture rate was limited to 77.5% (heat availability is the limiting factor) and for LNG mode of operation, it was set at 95% (limited by the design of the capture plant). These capture rates were used to then simulate the MEA-based capture process considering both the fuel cases in ProTreat® software.

For CO_2 compression and liquefaction, a model was developed in Aspen Plus v12 involving a two-stage CO_2 compression unit, with NH_3 refrigeration cycle with water-glycol mixture as an intermediate heat transfer medium. Water-glycol cycle is already used onboard the Sleipnir, and is extensively used in marine applications. This intermediate medium is required because heat exchange directly between LNG and CO_2 poses technical and safety challenges, such as imbalances between fuel demand & CO_2 supply of the engines, and risk of solidification of CO_2 product, because the LNG is stored at ca. -160 °C. Furthermore, the total electrical energy consumption of the capture, compression and liquefaction systems was determined. The Sleipnir has a central power system from which power can be utilized. This power has a CO_2 emission factor associated with it. Hence, considering the average unabated additional emissions due to electricity consumption for the entire operational profile, CO_2 avoidance is calculated to be 63.73% considering the diesel mode and 85.70% considering the LNG mode with average capture rates of 70% and 86% for the diesel and LNG cases respectively.

These results answer several questions relevant to: a) conceptual design for the MEA-based capture process, b) heat recovered from the flue gas, c) CO_2 captured based on the amount of heat recovered from the flue gas for the respective fuel modes, d) unabated emissions from electricity consumption, which finally allow for estimating e) a realistic CO_2 avoidance potential. This methodology of analysis and the results indicated/in progress will be useful to kickstart other actions in the EverLoNG project, namely concept design of the full-scale capture system, life cycle analysis and (full-chain) techno-economic assessment and also to further discussions on a regulatory framework for the technology. The holistic analysis performed in this project allows to estimate the true potential of SBCC in decarbonizing the shipping industry. By publishing this methodology and its results for two vessels, we hope to inform the industry stakeholders, as well as CO_2 capture technology providers, of the advantages and limitations of this emerging technology.

The final paper will provide more details on the conceptual design of the Sleipnir case, and will also elaborate on the results of the LNG carrier case.

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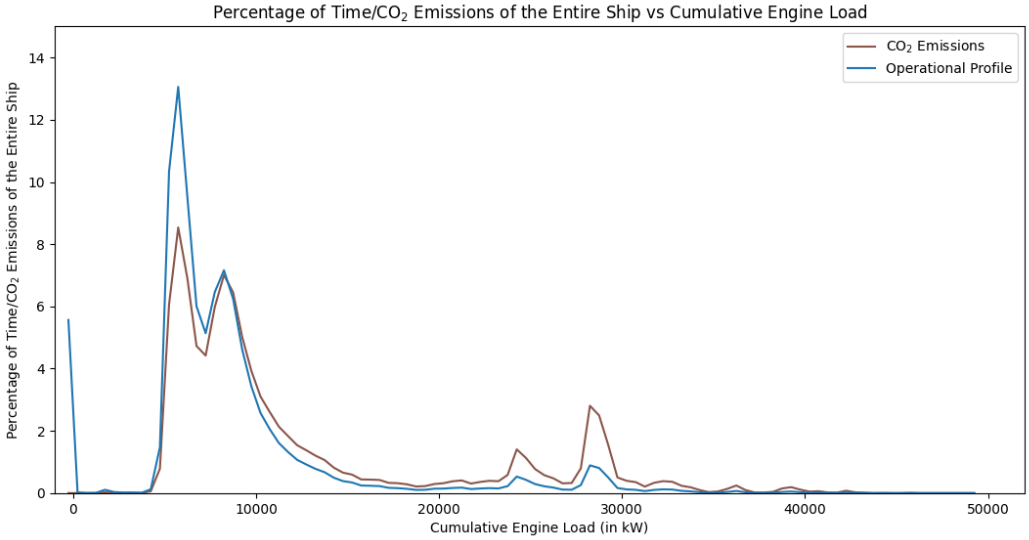

Figure 1: Operational Profile and CO_2 emissions from the Sleipnir vessel using 2 years of data

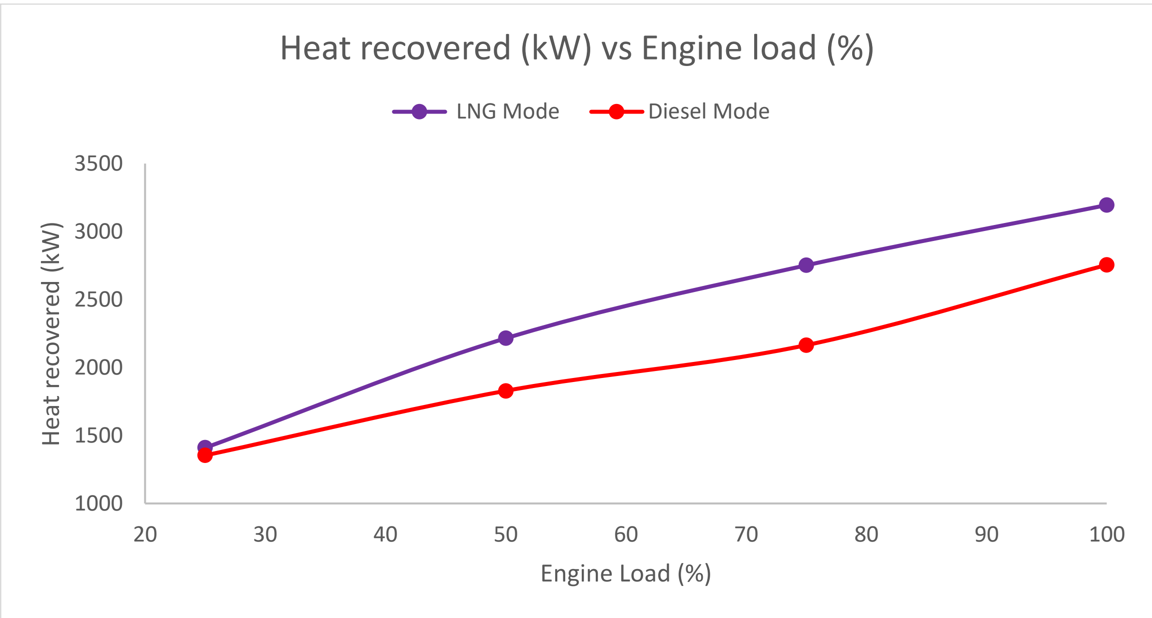

Figure 2: Heat recovered from the exhaust gases for Diesel and LNG modes of operation depending on the engine loads

Keywords: SBCC, Conceptual design, Operational profile, Dual-fuel engines

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