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A sensitivity analysis of a cryogenic carbon capture system on a LNG ship engine

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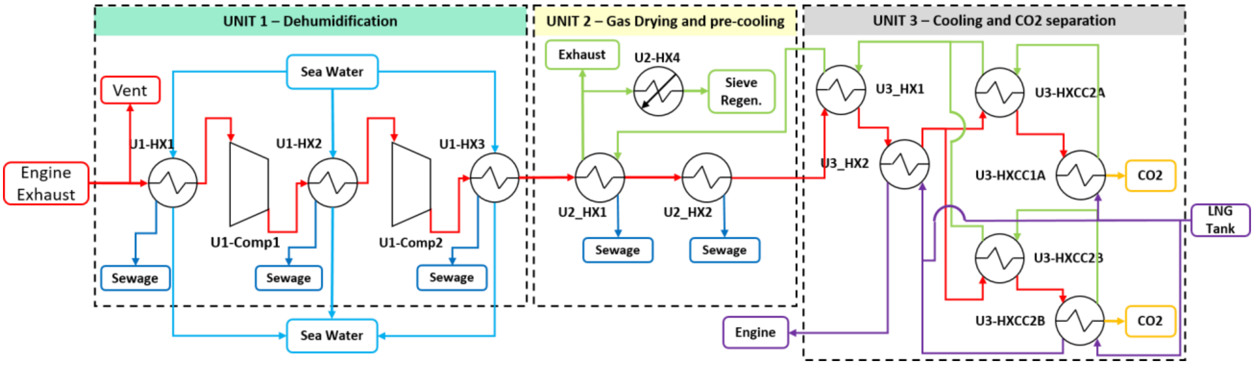
Abstract

Maritime shipping weighs for 3% of global CO2 emissions [1], [2], [3]. One of the most promising technologies to mitigate this issue is onboard carbon capture. Among the various solutions, amine-based and cryogenic systems are the two leading options [4], [5], with the latter being particularly advantageous when a cold source is available onboard [6], [7], [8]. As the United Nations Conference on Trade and Development [9] promotes novel fuels such like Liquefied Natural Gas (LNG), the potential of onboard cryogenic capture warrants further investigation.

This study examines the effects of a Cryogenic Carbon Capture (CCC) system on a LNG ship engine. The system is modeled using Simcenter Amesim [10] and comprises a CCC system placed between the engine exhaust and the atmosphere, featuring a bypass vent to allow partial treatment of the exhaust gas. The physical phenomenon separating CO2 from the mixture is desublimation, using the LNG fuel as a cold source. The model consists of three stages: a compressing, water-cooling and dehumidification unit to reduce cold power need, a drying unit to prevent water ice blockage, and a desublimation unit, or capture unit. Both units maintain a constant design regardless of the operating conditions. The system also includes cold recovery cycles.



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Sensitivity analysis, conducted on Air ratio, Engine load, Inner Pressure, Vent fraction and Relative Humidity, aims to characterise the impacts of engine states on the capture performances within a typical engine operating range. Results indicate that engine states significantly influence capture performances and power consumption.

Key findings include:

- Capture efficiency is highly sensitive to the treated volume of gas: as the volume increases, capture efficiency decreases, and energetic cost rises, regardless of the cause of volume change. The vent fraction significantly affects capture performance, with air-fuel ratio (lambda) and engine load also having notable impacts.
- CCC pressure has a minor influence, but the compression work required may negatively affect engine performance more than the additional cooling power needed for desublimation at atmospheric pressure.
- The cooling capacity of LNG is sufficient to cool exhaust gas and achieve desublimation conditions for most engine states.
- Ambient humidity has a negligible effect on capture performance.

Analysis highlights the need for strategic decisions regarding the use of the current onboard capture system.

Future optimization studies will focus on enhancing capture performance and minimizing engine power loss. This will involve exploring alternative system architectures, such as placing the CCC unit between the engine compressor and turbine, desublimating at atmospheric pressure, as well as conducting dynamic studies of standard engine commands to better represent typical shipping operations.

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Keywords: CO2 Cryogenic Capture ; LNG Ship Engine ; Marine shipping ; Desublimation