

LNG Cold-energy-assisted Onboard CO₂ Capture and Liquefaction for Dual-Fuel Marine Engines

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Abstract

Onboard carbon capture and storage have emerged as a promising pathway for reducing carbon dioxide emissions from existing and future marine propulsion systems. However, the practical implementation of onboard carbon capture is strongly constrained not only by capture efficiency, but also by downstream CO₂ conditioning, liquefaction, vent control, and liquid CO₂ storage operability. This study proposes and evaluates an integrated onboard carbon dioxide capture and liquefaction system for a dual-fuel marine engine, with particular emphasis on CO₂ conditioning, multistage compression, deep cooling, phase separation, and liquid CO₂ storage. The process was developed and assessed using Aspen HYSYS V12.1 under steady-state conditions. A comprehensive sensitivity analysis was conducted to identify the effects of deep-cooler outlet temperature and separator pressure on CO₂ liquefaction yield, vent-gas formation, and system energy demand. The proposed system was investigated over an engine load range of 50-110%, corresponding to exhaust-gas flow rates of 1.288-2.863 kg/s and CO₂ concentrations of 3.65-6.67%. The model was evaluated at a CO₂ capture ratio of 90.3%, representing a deep-decarbonization operating condition for marine applications. The results reveal a distinct liquefaction threshold governed primarily by the deep-cooler outlet temperature. Near vent-free operation can be achieved when the deep-cooler outlet temperature is lower than approximately -24.58°C. The pressure-temperature feasibility analysis further indicates that near vent-free liquefaction requires a separator pressure above 190 kPa at -24.7°C, whereas operation at -22.45°C remains infeasible within the investigated pressure range of 1600-2200 kPa. These findings demonstrate that deep-cooling intensity is the dominant control variable for suppressing CO₂-rich vent slip and maintaining stable liquid CO₂ production. The pressure sensitivity analysis shows that increasing the compressor discharge pressure from 1500 to 2500 kPa raises the compression power from 34.8 to 80.23 kW at -21°C, without producing a corresponding improvement in liquefaction yield or vent suppression under throttled control. This indicates that compression pressure mainly acts as an energy-penalty parameter rather than a performance-enhancing variable under the investigated conditions. By identifying threshold-based deep-cooling setpoints, defining a separator pressure temperature feasibility envelope, and quantifying CO₂-rich vent slip as a system-level loss term, this study provides an operability-oriented design framework for onboard CO₂ liquefaction. The results highlight the importance of integrated downstream conditioning and liquefaction control in improving the feasibility of shipboard carbon capture and storage systems for dual-fuel marine engines.

Keywords

Onboard OCCS, CO₂ Liquefaction Operability, Deep Cooling Threshold, CO₂ Slip Minimization, Vent-flow Suppression

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