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Numerical Analysis of Phase Change and Forced Convection in Moving Ship LNG Fuel Tanks

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Extended Abstract

With the decarbonization era, the demand for alternative energy with low or zero carbon, such as Liquefied Natural Gas (LNG), ammonia, methanol and hydrogen, is increasing. Among them, LNG has recently been chosen as a feasible solution in the maritime industry, and many commercial ships fueled by LNG are entering operation. [1]

For its use as a fuel, LNG is carried in well-insulated fuel tanks. Fuel and cargo tanks onboard ships are categorized into independent tanks (Type-B and Type-C) and membrane tanks [2]. An independent tank can support itself structurally, with the addition of internal stiffeners, while a membrane tank must be supported by the inner hull structure of the ship. Even if tanks are heavily insulated with low-conductivity materials, heat ingress through the insulation is inevitable. LNG will evaporate due to the heat intrusion from the atmosphere, leading to Boil-off Gas (BOG). BOG is usually used as a fuel for marine engines, but this excess gas needs to be managed carefully to avoid wasting energy.

It is important to predict and manage BOG amounts as precisely as possible. There has been considerable research to predict BOG generation in shipboard tanks. Thermodynamic models, in which the conservation of mass and energy in the vapour and liquid phases are calculated, can readily provide the tank insulation performance and be compared to data from Computational Fluid Dynamics (CFD) and experimental models [3]. Such a thermodynamic model includes convective heat transfer correlations at the walls in contact with the LNG or BOG, and phase change models for stable conditions. However, a fuel tank onboard a ship is contantly in a transient state due to the wave-induced motions of the vessel, and so any model should include the effect of the movement of the LNG within the tank.

In this study, CFD analysis is performed to predict the phase change and the wall heat transfer of LNG in moving tanks. A Volume-of-Fluid (VOF) model is used to track the liquid-gas interface, and Lee's model is applied for the prediction of BOG generation at the interface. The tank is assumed to be vented so that the pressure remains constant. After reaching a steady state, a motion is applied to the tank by changing the gravity direction in the simulation. The change in the quantity of BOG is analysed to determine the effect of tank motions on BOG generation. In addition, convective heat transfer coefficients are derived from each wall of the tank, considering the flow of liquid and vapour inside the tank. The simulation results are compared with the correlations used in previous studies to evaluate their validity. With the results derived from this study, a modified thermodynamic model can be presented, enabling improved prediction of the BOG generated in tanks onboard vessels at sea in realistic maritime conditions.

References

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