ABSTRACT

Liquefied natural gas (LNG) is transported in large volumes (135,000 m^3 to 266,000 m^3) across continents by carrier ships where LNG is stored at ambient pressure as a saturated liquid at a temperature of around 111 K. Due to cryogenic temperature prevailing in LNG, heat from the environment enters the storage tanks through insulation and produces boil-off gas (BOG). BOG generation is incessant, and unless it is removed, the tank pressure rises beyond safety level. The onboard reliquefaction system reliquefies the BOG and sends it back to the storage tank, saving the calorific value of LNG cargo. Generally, an onboard reliquefaction system resembles small-scale onshore cryogenic natural gas liquefaction plants with a refrigeration cycle and a BOG cycle thermally coupled by heat exchangers.

In this thesis work, parametric evaluations of different existing variants of reverse Brayton cycle (RBC) based reliquefaction system is done with an aim to understand the impact of process parameters and design constraints that influence the performance of reliquefaction systems. Design, exergy based parametric analysis and optimisations of all types of reliquefaction systems are done with the aid of commercial software, Aspen HYSYS® V8.6. In addition to configurational modifications, the effect of pressure ratio of cycles, size of heat exchangers, isentropic efficiencies of compressors and turbines on the performance of the reliquefaction systems are also investigated. While condensing BOG that is rich in nitrogen, there are instances of venting some non-condensed part of BOG. The work proposed replacement of a liquid-vapour separator by a packed bed distillation column so that the vent gas is purified to less than a part per million of methane in it and near-pure nitrogen is fed back to the system. The study also proposed and evaluated the application of the Claude liquefaction cycle (and its variants), which use BOG itself as a working fluid for reliquefaction of BOG. Such systems are termed direct reliquefiers and they have the potential to reduce the power and size of the system much below the level of existing reverse Brayton refrigerator-based reliquefiers. The addition of environment friendly transcritical CO_2 cycle for precooling has helped to reduce energy consumption. Moreover, options for enhancing the performance of reliquefaction plants by capturing the cold exergy of LNG pumped and vaporised to two-stroke dual-fuel engines of LNG carrier ships are also evaluated.

The thesis proposed and evaluated novel energy-efficient configurations of onboard reliquefaction systems that completely condenses BOG generated in LNG carrier ships. All parameters are nondimensionalized to facilitate the application of the results to any capacity of LNG-carrying ships. The outcomes of the thesis may serve as an open resource for the designers of LNG boil-off gas reliquefaction systems, LNG carrier ship owners and researchers in this area.