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Optimal design of organic Rankine cycle recovering LNG cold energy with finite heat exchanger size

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ABSTRACT

An optimization study, under a size constraint, was carried out for an organic Rankine cycle (ORC) combined with an LNG regasification plant for recovering LNG cold energy. Typically, many researchers approached to an optimization problem by assuming pinch point or minimum approach temperature difference. As a different point of view, the size constraint was considered in that resources such as thermal energy and equipment size are limited in a real problem. Given this situation, adequate allocation of finite resources is an important issue for the system to maximize performance. Thus, the aim of this study is to understand how to properly utilize the resources when LNG cold energy and total conductance of heat exchangers are limited. Accordingly, the influences of heat duty allocation, UA allocation, and superheating a turbine's intake on net power were mainly taken into account. Results indicate that, when total conductance for system design increases, the ORC should take more heat duty and total conductance should be weighted to an evaporator. In most cases, the size of heat exchangers should be weighted in the order of evaporator, condenser, and trim heater, provided that total conductance for system design is sufficiently available.

1. Introduction

Liquefied natural gas (LNG) has high energy density and releases much less carbon dioxide, SO_x, and NO_x relative to other fossil fuels. Besides, the shale gas revolution in the United States caused the price of natural gas to drop significantly. It accelerated the growth of LNG supply to the world. Owing to the benefits, the usage of natural gas recently accounts for just below a quarter of the primary energy consumption in the world. Many experts forecast that the transition to natural gas will continue for a few decades [1–3]. Before using natural gas, the regasification process, which vaporizes LNG to natural gas, is essential. With the growth of natural gas consumption, the total capacity of the regasification facilities in the world has increased to about 904.1 million tonnes per annum (MTPA) in 2019 [1]. In a conventional regasification system, seawater directly heats LNG. During the regasification process, LNG cold energy is mostly released to seawater without any utilization.

Since the importance of renewable energy and waste heat recovery (WHR) has emerged, the value of LNG cold energy as well as natural gas has been highlighted in the past decades [4]. Owing to its very low temperature, LNG cold energy is useful for applying to a range of applications requiring a cooling process [4–6]. Using the cold energy directly for the cooling process is effective in terms of energy loss. Nevertheless, thermal energy is less versatile relative to electricity. As a matter of fact, many researchers paid attention to a temperature difference between cryogenic and ambient temperature. They utilized the LNG as a heat sink of a Rankine cycle power system [7]. For this, the organic Rankine cycle (ORC) technology has been mainly used to convert the cold energy into electricity. The ORC system is favorable to exploit low-grade heat owing to the low boiling point of a working fluid [8,9]. Furthermore, the ORC system consumes less power compared to a Brayton cycle system because an organic fluid is pressurized in the liquid state [10,11]. Since Angelino [12] showed a possibility of the power cycles using LNG as a heat sink, many relevant studies have been performed on a variety of aspects in designing system configuration [13–16], selecting adequate working fluids [17–19], combining the other potential heat sources [20–22], etc. Besides, as advanced

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