ABSTRACT

This study proposes a novel method which includes a Brayton cycle and a CO₂ Rankine cycle as well as a two-stage Rankine cycle. The two-stage Rankine cycle recovers the cold energy of the LNG separately in the liquid and gas phase zone with a mixed working fluid. In the Brayton cycle and CO₂ Rankine cycle, the combustion products are CO₂ and H₂O. The latent heat of the LNG gas-liquid two-phase zone is utilized to recover the CO₂ produced, thereby achieving zero emissions of CO₂ throughout the process. The energy efficiency of the whole process is 71.38%, and the exergy efficiency can reach 57.03%.

KEY WORDS: LNG; cold energy; BOG; CO₂; exergy.

INTRODUCTION

Natural gas is one of the cleanest fossil fuels with higher heat value and less pollutant production than other fossil energy resources. Therefore, liquefied natural gas (LNG) is increasingly attracting attention as a clean energy source. It is noteworthy that the LNG contains a considerable portion of the energy and exergy. If this cold energy is used to generate electricity, the power output is about 240 kWh/t (Chen, 2015; Zhang, 2016; Cao, 2016). LNG cold energy can be used not only for power generation, but also for air separation, seawater desalination, etc (Wang, 2014; Qiu, 2017; Mehdi, 2015; Stefanie, 2017; Wang, 2016; Luo, 2016; Mehdi, 2017). The heat leak makes some LNG vaporize, where the vapors generated are called boil-off gas (BOG). In order to operate safely, the BOG generated in the tank must be removed to maintain the storage pressure of 110-150 kPa in the tank. The BOG in the LNG terminal mainly has two different recovery methods, namely recondensation and direct compression, but has a high energy consumption (Li, 2011; Jiang, 2015; Xue, 2016).

The impact of greenhouse gases on the climate has attracted worldwide attention. The main technologies for CO₂ recovery and treatment are physical and chemical absorption, low temperature fractionation and membrane separation (Ma, 2012; Chen, 2014). The above technologies consume a large amount of energy and may result in a total power reduction of about 10%. Zhang et al. (Zhang, 2006; Zhang, 2003) proposed a supercritical CO₂ Rankine-like cycle and a CO₂ Brayton cycle with LNG as the cold source, which can realize CO₂ capture without consuming additional power. The net energy and exergy efficiencies are over 66% and 52% respectively. Xiong et al. (Xiong, 2010) proposed a CO₂ Rankine power cycle using LNG cold energy, and the exergy efficiency can reach 57.9%. Pan et al. (Pan, 2017) proposed a power generation system combining CO₂ capture Kalina cycle system (KCS) and organic Rankine cycle (ORC) using LNG cold energy. The recovery and exergy efficiencies of the system were 41.42% and 36%, respectively. Manuel et al. (Manuel, 2016) proposed a closed Brayton cycle to recover LNG cold energy and achieved CO₂ capture with a power generation efficiency of over 65%.

In this study, we propose a novel LNG fueled power plant which can recycle BOG efficiently and realize zero-CO₂-emission by segmented utilizing LNG cold energy according to the LNG evaporation curve. Compared with previous research work, this research has two new features. One is segmented utilizing LNG cold energy. The second is the integration of the CO₂ Rankine cycle and Brayton cycle. So the efficiency of the LNG cold energy is improved. The process includes a Brayton cycle and a CO₂ Rankine cycle as well as two-stage Rankine cycles which use the flue gas waste heat of the Brayton cycle as the heat source and LNG as the cold source to generate electricity. The cycle has both high power generation efficiency and extremely low environmental impact.

The Cycle Configuration

LNG gasification curve

Delivery pressure of natural gas varies with the different users. So the evaporation curve of LNG varies with the delivery pressure. Fig.1 shows the evaporation curve of LNG under different delivery pressures. Taking the evaporation curve of 4 MPa as an example, it can be divided into three sections which are the first section of liquid phase zone, the second section of gas-liquid two-phase zone and the third section of gas phase zone. In the gas-liquid two-phase latent heat zone, LNG continuously absorbs heat but the temperature remains basically unchanged. With the increasing of evaporation pressure, the gas-liquid two-phase zone gradually disappears. When the LNG delivery pressure is 7 MPa, the evaporation curve approximately a gradual upward curve.