The Study on Natural Gas Liquefaction Cycle Development for LNG-FPSO

Sanggyu Lee\textsuperscript{a}, Kunhyung Choe\textsuperscript{a}, Chulgu Lee\textsuperscript{a}, Moonyong Lee\textsuperscript{b} and Young-myung Yang\textsuperscript{b}

a) R&D Division, KOGAS (Korea Gas Corporation), Yeonsu-Gu, Incheon, Korea
b) School of Chemical Engineering, Yeungnam University, Gyeongsan, Korea

ABSTRACT
With worldwide LNG demand increasing rapidly, LNG liquefaction plants and liquefaction processes are highly valued industry. Recently, there has been an increase in research and development of LNG-FPSO technologies in offshore liquefied natural gas (LNG) service instead of land-based LNG plants. While onshore LNG facilities have traditionally focused on power efficiency as a key criterion for process design and equipment selection, offshore LNG would require not only power efficiency but also safety and compactness. A new natural gas liquefaction cycle is proposed in this paper. The proposed cycle uses non-flammable refrigerants. Several natural gas liquefaction cycles using non-flammable refrigerants are suggested and compared to the proposed cycle in this paper. The liquefaction cycles using non-flammable refrigerants have an advantage in the view point of safety in the LNG-FPSO environment. The structure of the proposed cycle consists of carbon-dioxide pre-cooled and nitrogen expander liquefaction cycle. The proposed liquefaction cycle has the safety advantage with high power efficiency, therefore the proposed cycle could be suitable for the LNG-FPSO liquefaction process.

KEY WORDS:  natural gas; LNG; FPSO; liquefaction; non-flammable refrigerants

INTRODUCTION
The primary use of natural gas (NG) is as a fuel; it can also be a source of hydrocarbons for petrochemical feed stocks and a major source of industrially important elemental sulfur (Kidnay, 2006). Its clean burning and ability to meet stringent environmental requirements have raised the demand for natural gas (Elliott, 2005), which is supporting the rapid growth of LNG (liquefied natural gas) production capacity. Much of the world's gas reserves are in offshore fields (Sheffield, 2005), though onshore LNG processing is generally favored. Recently, offshore FLNG (floating LNG) or LNG-FPSO (floating, production, shipping and offloading) service is beginning to be explored instead of land-based LNG plants (Lee, 2010). FLNG plants must be safe, compact and energy efficient.

Thermodynamic process for the liquefaction of natural gas has evolved since 1970's (Barron, 1985; Roberts, 2002; Andress, 2004; Flynn, 2005; Venkatarathnam, 2008; Chang, 2009, Lee, 2010) in order to meet a number of challenges, including the demand of greater efficiency and larger capacity. A liquefaction system is primarily composed of a series of compressors, coolers, expanders, and heat exchangers. Natural gas is cooled-down to LNG temperature in thermal contact with closed-cycle refrigerant(s). In order to reduce the input power for liquefaction, it is crucial to reduce entropy generation due to the temperature difference between hot stream (including feed gas and hot refrigerants) and cold refrigerants in the heat exchangers. Since the feed gas is mostly a mixture of different hydrocarbons, its enthalpy varies nonlinearly with temperature along the liquefaction process. For high liquefaction efficiency, it is important to reduce the entropy generation due to temperature difference in heat exchangers. Generally mixed refrigerant (MR) cycles are effective in reducing the temperature difference with a small number of its equipments (Venkatarathnam, 2008). On the other hand, pure component refrigerant cycles are simple and easy in operation, but require a large number of refrigeration stages (Andress, 2004). Numerous liquefaction processes have been developed so far with different refrigerants and different cycles, but only a few are practically in use. The most popular liquefaction process under operation is based on propane pre-cooled mixed refrigerant (C3MR) cycle (Gaumer Jr., 1973) by Air Products and Chemicals Inc. Feed gas is pre-cooled to approximately -33 °C by multi-stage propane (C3) JT cycle, and then liquefied and sub-cooled to -150 °C by mixed refrigerant (MR) through a large spiral wound heat exchanger. An appropriate composition of MR allows liquefaction and sub-cooling of feed gas in a single heat exchanger over wide temperature range, leading to a high thermodynamic efficiency with minimum number of components. However, since the C3 cycle has to cool both feed gas and MR cycle, the thermal load of propane cycle becomes enormous, and the C3MR reaches a technical limit on the propane compressor for applications to 5 MTPA (million tons per annum) or greater. For substantial increase in liquefaction capacity, the cold end of C3MR cycle is recently equipped with nitrogen Brayton cycle. This three-cycle process (called