

The Study on Natural Gas Liquefaction Cycle Development

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ABSTRACT

With worldwide LNG demand increasing rapidly, LNG liquefaction plants and liquefaction processes are a highly valued industry. Recently, there has been an increase in research and development of LNG-FPSO technologies for 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 structure of the new cycle is based on the SMR (Single Mixed Refrigerant) liquefaction cycle which has a very simple structure, and butane and/or pentane have been added to the refrigerant to increase the efficiency of the cycle. In the proposed cycle, a distillation column is used to separate mixed refrigerant into HK (Heavy Key) and LK (Light Key) components. HK refrigerant is used for pre-cooling the natural gas, and the natural gas is liquefied and partially sub-cooled by LK refrigerant in the cryogenic range of the heat exchanger. Since the proposed liquefaction cycle has a simple structure with high compactness and power efficiency, the proposed cycle could be suitable for the LNG-FPSO liquefaction process.

KEY WORDS: natural gas; LNG; FPSO; liquefaction; SMR; distillation

INTRODUCTION

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) 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 $-35\text{ }^{\circ}\text{C}$ by multi-stage propane (C3) JT cycle, and then liquefied and subcooled to $-150\text{ }^{\circ}\text{C}$ 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 AP-XTM) allows decreasing the propane and MR flow rates so as to achieve a capacity up to 8 MTPA (Roberts, 2002).

Another successful liquefaction process under operation is based on cascade cycle (Andress, 2004) by Conoco Phillips. The process consists of three JT cycles, which use methane (C1), ethylene (C2), and propane (C3) as pure component refrigerant. Each JT cycle has two or three stages of refrigeration to reduce the temperature difference in heat exchangers. Since no mixture is used, the process is simple, easy, and robust in operation. The cycle also has disadvantages of its huge process size and large number of equipments.

The simplest structure of natural gas liquefaction process is SMR (Single Mixed Refrigerant) process, because the process has only one series of compressors and a heat exchanger that covers the whole range of natural gas liquefaction from atmosphere temperature to