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Conceptual analysis of the precooling stage for LNG processes

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ABSTRACT

More than 95% of the installed LNG facilities by 2012 use a precooling cycle as the first stage of the process. In this work, a technical comparison between different precooling cycles for LNG processes is carried out through computational simulations using Aspen HYSYS®. The aim is to provide future developments with a clear idea of the technical advantages/disadvantages involved in the selection of the process for the precooling cycle. A three stage propane precooled cycle was found to be the most energetically efficient among the studied cases, even better than a two stage mixed refrigerant process (C_2/C_3) for both climate conditions, warm (25 °C) and cold (6 °C). However, due to the reduced power share that may be reached with a propane cycle temperature restriction, the mixed refrigerant precooling cycle is the preferred alternative under the cold climate condition.

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1. Introduction

Today, more than 85% of the worldwide primary energy consumption is being provided by fossil fuels, where natural gas represents only 24% [1]. Most natural gas is transported from the wellhead to a processing plant, and thereafter, to final consumers in gas pipelines. However, when the distance between the natural gas markets and sources is long enough; or very little volume of natural gas is present [2], liquefying the natural gas for transport has been widely implemented as a practical solution. Nowadays, more than 30% of the worldwide gas trading is done via Liquefied Natural Gas (LNG) [3]. The design of LNG processes involves different selection of equipment (i.e. heat exchangers, compressors, etc.), and multiple process definitions (i.e. type of refrigerant, pressure levels, temperature differences, etc.). Most of the developed liquefaction processes include a first stage that is well known as precooling stage, where the natural gas is cooled down to a temperature that, depending on the precooling technology, varies from −30 to −50 °C. One of the main differences between the precooling stages of the existing LNG processes is the use of mixed or pure components as refrigeration fluid. Around 85% of the currently installed trains use pure propane as refrigerant in the precooling cycle [4]. However, recently developed processes such as the Dual Mixed Refrigerant (DMR) and Mixed Fluid Cascade (MFC®) processes use mixed refrigerants in the precooling stage.

The advantages or disadvantages of using a mixed or pure component refrigerant in the precooling stage are not well understood. In some cases, the utilization of a mixed or pure refrigerant cycle in the precooling seems to be related to patentability issues of the technology more than due to efficiency or engineering aspects. Besides, previous works related to the LNG technology selection use the thermal efficiency and energy consumption (kWh/kg LNG) as a common benchmarks but for different process conditions [5–10]. That kind of comparison can be misleading because the design premises are not consistent from a project to another. The efficiency of the refrigeration compressors, the local ambient temperature, the composition, temperature and pressure of the feed gas, are some of the factors that may influence the process energy consumption.

The selection of a technology depends on different criteria, for instance it may be influenced by economic, environmental, financial, license or technical issues [11]. Since most of the economic data (i.e. equipment price, license fees, etc.) is treated as confidential, the scope of this work will be based on the technical comparison of the different precooling arrangements of the known LNG processes, however, costs can be highlighted from the power share of the process. The objective of this work is to explore the advantages or disadvantages that each precooling configuration may offer to the process and the project in general.

2. LNG technologies

Liquefied Natural Gas (LNG) is natural gas in liquid state at atmospheric pressure and temperatures around −161 °C. The volume of LNG is factor 600 times less compared to gas at standard conditions, which allows large volumes of LNG to be transported by sea in ships [12].

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During the first decades of the LNG industry, liquefaction process selection was uniform, Air Products and Chemicals, Inc. (APCI) was the dominant choice and is still the leading licensor; nevertheless in the last ten to 15 years a considerable diversification has been the trend, licensors such as ConocoPhillips (previously Phillips), Shell and Linde–Statoil joined their technologies to the worldwide capacity [10].

The main natural gas liquefaction processes can be broadly classified into two groups based on the liquefaction process used, as described in Fig. 1.

Within the processes that use a single component refrigerant in the precooling, an example of those that use a single component refrigerant in the rest of the cycles is the Conoco Phillips Optimized Cascade ® Process (POCP) [10]. A single component precooling process with mixed refrigerant liquefaction is the APCI propane precooled mixed refrigerant process (C_3MR) [13]. On the other hand, the processes with mixed refrigerant in the precooling are mainly represented by Shell's Dual Mixed Refrigerant and the Mixed Fluid Cascade (MFC®) developed by the Statoil and Linde LNG Technology alliance [14]. Finally, within the processes without precooling comes one of the simplest processes available, patented by Black and Veatch, Poly Refrigerant Integrated Cycle Operation (PRICO®) [15].

In the LNG process based on more than one refrigerant cycle, natural gas is cooled down in some steps as precooling, liquefaction and subcooling. Each step requires a given amount of energy in order to reach the LNG conditions. A balanced distribution of power loads (power share) in the process is desirable in order to take advantages of standard equipment inventories. In addition, the cost of the precooling cycle equipment is lower than the liquefaction and subcooling equipment because it is not required specials systems as spiral-wound heat exchangers or cryogenic materials (special alloys).

For the purpose of this work, two of the technologies mentioned are of particular importance, the C_3MR and MFC®. The first represents the highest proportion of the worlds installed LNG production [10], and the latter is a recently developed technology that is mentioned to have a reduced energy consumption due to the use of refrigerant mixtures in cascade [16]. A brief explanation of the selected technologies is given below.

2.1. Propane precooled mixed refrigerant process (C_3MR)

This process consists of two main refrigeration cycles, a precooling cycle and a liquefaction-subcooling cycle. The precooling cycle uses propane as refrigerant; whilst the liquefaction-subcooling cycle is operated with a mixed refrigerant. A typical flow diagram of this process is depicted in Fig. 2.

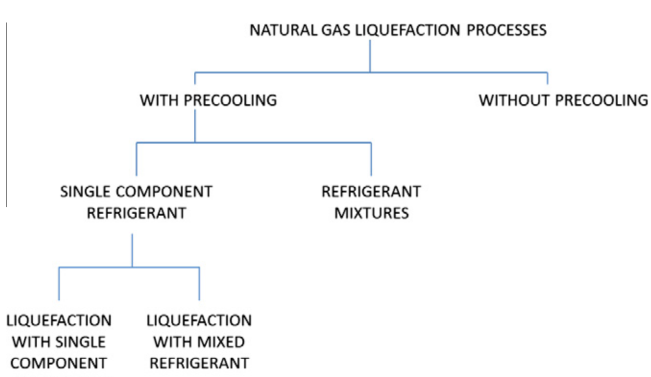

Fig. 1. Classification of natural gas liquefaction processes.

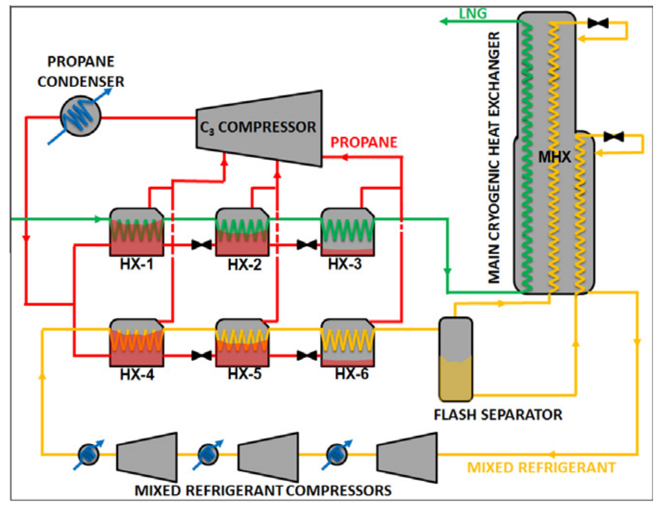

Fig. 2. C_3MR process diagram.

In the precooling, a multistage refrigeration cycle is used at three or four pressure levels to exchange heat with the gas stream and the warm mixed refrigerant, cooling both streams down to around −35 °C [17]. The fluid circulation in this cycle is provided by a multistage compressor (with side streams) that compresses the vapour propane from each of the pressure levels to a common outlet pressure. At this pressure the propane stream undergoes heat exchange until it becomes liquid in the condenser. Once condensed, the propane stream is throttled multiple times throughout the precooling heat exchanger network, where it is vaporized again.

In the liquefaction-subcooling cycle the rest of the process takes place; there the natural gas is further cooled down from −35 °C to around −160 °C by the mixed refrigerant. The partially condensed mixed refrigerant from the precooling cycle is separated into vapour and liquid streams in a flash separator [13]. After that point both streams flow into the main cryogenic (multistream) heat exchanger, where the liquid stream is extracted in the first section/bundle and is expanded to be recirculated on the shell side. The gas stream goes all the way through both sections/bundles and at the top is throttled and recirculated on the shell side in the same way. Inside the heat exchanger the streams are mixed again and vaporized prior to the compression process, which can be carried out with more than one compressor, for instance a two or three compressor arrangement with intercooling [13].

2.2. Mixed Fluid Cascade Process (MFC®)

Three mixed refrigerants are used in this process in order to perform the precooling, liquefaction and subcooling duties. In this process a multistream heat exchanger arrangement is used for the three main cycles. The precooling cycle cools down the natural gas stream as well as both the liquefaction and subcooling refrigerant to around −50 °C. The liquefaction cycle is responsible for cooling both the natural gas stream and the subcooling stage mixed refrigerant. Fig. 3 is the process flow diagram for the MFC®. The precooling cycle works as a multistage process since part of the refrigerant is throttled to an intermediate pressure, and used as the cold side in the first multistream heat exchanger. The rest is further subcooled in the second heat exchanger, to be expanded subsequently by means of a throttling valve. Once expanded it is used as the cold side in the second heat exchanger. Through both heat exchangers the precooling mixed refrigerant vaporizes while cooling the warm side streams; after vaporization the streams are compressed to be liquefied in the precooling condenser.

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