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Energy and Environment - Poster Display

http://doi.org/10.5339/qfarc.2018.EEPD1074

Simulation and Optimization of an LNG Plant Cold Section

Mary Anna Katebah*, Mohamed Mamoon Hussein, Easa Ismail Almusleh

Qatar University
* mary.katebah@qu.edu.qa

Simulation and Optimization of an LNG Plant Cold Section Mary Anna Katebah, Mohamed Mamoon Hussein, Easa I. Almusleh* Chemical engineering department, Qatar University Global energy demands are expected to rise by almost 30% in the next 20 years, with fossil fuels being the primary energy sources. The combustion of fossil fuels yields significant amounts of greenhouse gas emissions, predominantly CO2. Compared to its alternatives (coal and crude oil), natural gas is preferred primarily due to its cleaner burning. The most profitable method of transporting natural gas from the source of production is as liquefied natural gas (LNG). However, LNG plants are associated with relatively large energy demands (mainly compression power) that are costly and result in significant levels of CO2 emissions. Qatar is the largest LNG supplier world-wide, and the plans of increasing production place utmost importance on enhancing the efficiency of LNG plants. With current production of almost 78 million tons per annual (MTA), significant benefits, such as improved economics and lower CO2 emissions, can be achieved even with small efficiency improvements. It is also noteworthy that, for a given power consumption, higher efficiencies can potentially result in more production volumes. Therefore, optimization of LNG processes would assist the country in achieving the aspirations of the Qatar National Vision 2030 by sustaining both economic prosperity and the environment for future generations. Within the LNG chain, more than 75% of the CO2 emissions emanate in the processing plant, where nearly 80% of those emissions are sourced in the cold section of the plant which comprises of the natural gas liquids (NGL) recovery system, the liquefaction process, and the helium extraction and nitrogen removal units. Various natural gas liquefaction cycles exist that employ either pure refrigerant in cascade cycles, multi-pressure cycles, or mixed refrigerant cycles. Among all the available cycles, the propane pre-cooled mixed refrigerant

دار جامعة حمد بن خليفة للنشر
HAMAD BIN KHALIFA UNIVERSITY PRESS

Cite this article as: Katebah M et al. (2018). Simulation and Optimization of an LNG Plant Cold Section. Qatar Foundation Annual Research Conference Proceedings 2018: EEPD1074 http://doi.org/10.5339/qfarc.2018.EEPD1074.

(C3MR) system is the leading one in the LNG industry. Therefore, this research focuses on decreasing the energy consumption of C3MR and NGL recovery system with helium extraction (producing approximately 60 mol% crude helium) and nitrogen rejection units. Initially, a base-case model was developed for the cold section using Aspen PlusTM, a steady-state process simulation and optimization software. A degree of freedom analysis was carried out on the model to identify the operating variables available for optimization. This step also serves to identify the operational and design constraints. Next, a sensitivity analysis was conducted on the variables to construct the operating windows one may operate in and get reduced energy consumption. Parameters that were studied include: scrub column reflux and pressure, mixed refrigerant (MR) composition, propane evaporating pressures, LNG temperature (leaving the main heat exchanger), and helium extraction and nitrogen removal temperature and pressure values. Finally, sequential quadratic programming (SQP) optimization technique was employed to find optimal values for the operating variables that will result in global minimum energy consumption. In addition to this rigorous optimization approach, we have developed an effective shortcut method that can be used for optimization with minimum effort. The method was evaluated and found to be suitable for LNG and other cooling applications. Additionally, an exergy analysis was conducted before and after optimization to quantify the reduction in lost work for main process equipment as a result of the optimization. After investigating optimization options with minimal implementation costs, retrofitting options will be studied to further enhance the process. Simulation of the cold section was conducted for the production of almost 3.65 MTA of LNG. Sweet, dehydrated natural gas at 21ºC and 66 bar was pre-cooled by the propane cycle to around -27 ºC before entering a scrub column (i.e. distillation column) that separated the natural gas from the NGL's. Almost 12 thousand barrel/day of NGLs were produced and sent to a fractionation unit to separate ethane, propane and butane. Heavy hydrocarbons, primarily condensate (C5+) leaving the fractionation unit, can be either sold or sent to a close by refinery for further processing. The separated natural gas stream was further cooled and liquefied in the main cryogenic heat exchanger (MCHE) to temperatures near -140oC. The cooling in the MCHE was supplied by the mixed refrigerant, which was pre-cooled by the propane cycle. LNG then entered the helium extraction (producing almost 60 mol% crude helium) and nitrogen removal units to obtain desired LNG specifications. Final LNG product comprised of 0.7 mol% nitrogen, 90.7 mol% methane, 5.6 mol% ethane, 2 mol% propane, 0.92 mol% butanes, at a temperature and gross heating value (GHV) of approximately -161oC and 11.5 respectively. Simulation results showed that for the production of 3.6 MTA LNG, the cold section would require a total of around 131 MW of compression power. Main sensitivity analysis results showed that the mixed refrigerant composition was a key parameter in the cycle's performance. Other primary parameters affecting the energy consumption include the propane cycle's evaporation pressures and flowrates. Using the short cut method, optimization revealed that optimized MR composition resulted in almost 10% MR compression power and 6% plant operating cost savings, whereas new intermediate propane evaporation pressures, identified using detailed simulation, and flowrates decreased the propane compression power and operating costs by around 3.6%, and 2%, respectively. *Corresponding author. +974 44034148 E-mail address: e.almusleh@qu.edu.qa (E. Al-musleh).