OPTIMIZATION OF MIXED REFRIGERANT COMPOSITIONS FOR THE PRICO NATURAL GAS LIQUEFACTION PROCESS USING HYSYS OPTIMIZER

AHMED OMAR BASHARAHIL

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Science (Energy Management)

Faculty of Chemical and Energy Engineering
. Universiti Teknologi Malaysia

JANUARY 2018

This project report is dedicated to:
The Almighty Allah, for bestowing me the guidance and blessings.

My beloved mother and my father for their unconditional
love and unlimited support.

Hadramout Establishment for Human Development for granting me a full
scholarship to pursue my study.

My close friends, Maher & Saeed for their sincere supports, love and guidance
throughout the study phase.

ACKNOWLEDGEMENT

I would like to express my greatest appreciation to Associate Professor **Azeman Mustafa** who has monitored and supervised me throughout the process of this project as well as giving me constructive feedback on my work. I also appreciate the comments and constructive criticism from Dr **Azizul Azri Bin Mustaffa**, who helped me improve on the writing of this dissertation. I would also like to thank Universiti Teknologi Malaysia (UTM) for giving me the opportunity and facilities to perform this project which I have learned so much from.

I owe my deep gratitude to my family, especially my Mother, ***Fatima Mubarak***, my Father, ***Omar Mohammed*** and my three Sisters (***Warda, Marwa and Nasrin***) for their endless support, continuous prayers and inspiring me to follow my dreams.

I heartily thank my uncle, ***Said Al-Hinai,*** for his continuous support and taking care of the family during my study. I owe you a lot my uncle.

Not to forget my close friends, ***Saeed Al-Hadad, Maher Baslasel and Dr. Abdullah Bafqee***r, who supported, encouraged and motivated me in every way to complete my research. Your support means a lot.

ABSTRACT

To export natural gas to overseas, it has to be liquefied and transported by the LNG tankers. The liquefaction process of natural gas is an energy intensive process as it requires a huge amount of energy to liquefy the natural gas from ambient temperature to -160 ^{o}C. Therefore, reduction in energy consumption is highly recommended. The new introduction of Floating Liquefaction Natural Gas (FLNG) Vessels, which provide mobile gas processing, storage and offloading jetty, receives natural gas from different gas reservoirs that leads to the variation of natural gas compositions. The key challenge lies on developing an optimal mixed refrigerant range of the multi-feed gas composition of LNG plants. In this paper, an optimized mixed refrigerant range is introduced based on variation in feed composition in order to minimize the energy consumption. PRICO mixed refrigerant cycle is being adopted as a refrigeration cycle due to its simplicity, compactness and low investment. The feed composition data has been taken from different sources as stated in the literature. Aspen HYSYS software is used to simulate the PRICO process and HYSYS Optimizer tool is used to optimize the cycle. The findings show an overall compression power reduction of 30 % in three different NG compositions. A special case was introduced where the NG contains methane concentration around 67%. The results of the optimized special case show a compression power reduction around 44% and higher LNG liquefaction rate.

ABSTRAK

Untuk mengeksport gas asli ke luar negara, ia harus dijadikan cecair dan diangkut oleh kapal tangki LNG. Proses pencairan gas asli merupakan proses yang menggunakan banyak tenaga kerana ia memerlukan sejumlah tenaga dalam kuantiti yang besar untuk mencairkan gas asli daripada suhu ambien kepada -160 ^{0}C. Oleh itu, pengurangan dari segi penggunaan tenaga amat digalakkan. Pengenalan baru Kapal Pencairan Gas Asli Terapung (FLNG), yang menyediakan pemprosesan gas mudah alih, penyimpanan dan pemunggahan jeti, menerima gas asli dari takungan gas yang berbeza yang mengarah kepada variasi komposisi gas asli. Cabaran utama terletak dalam membangunkan pelbagai salur masuk komposisi gas yang mempunyai rangkaian penyejuk campuran yang optimum di loji LNG. Dalam kajian ini, rangkaian penyejuk campuran yang dioptimumkan telah diperkenalkan berdasarkan variasi dalam komposisi salur masuk untuk meminimasikan penggunaan tenaga. Kitaran penyejuk campuran PRICO telah diadaptasikan sebagai kitaran penyejuk disebabkan oleh kemudahannya, kepadatan dan pelaburan yang rendah. Data komposisi salur masuk telah diambil daripada pelbagai punca seperti yang dinyatakan di dalam literatur. Perisian Aspen HYSYS telah digunakan untuk mensimulasikan proses PRICO dan alat Pengoptimuman HYSYS telah digunakan untuk mengoptimumkan kitaran. Penemuan menunjukkan keseluruhan penurunan daya mampatan sebanyak 30% dalam tiga komposisi NG yang berbeza. Satu kes khas telah diperkenalkan di mana NG mengandungi kepekatan metana sekitar 67%. Hasil kes khas yang telah dioptimalkan menunjukkan pengurangan daya mampatan sekitar 44% dan pencairan LNG yang lebih tinggi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

NG	-	Natural Gas
LNG	-	Liquefied Natural Gas
FLNG	-	Floating Liquefaction Natural Gas
MR	-	Mixed Refrigerant
MRC	-	Mixed Refrigerant Composition
SMR	-	Single Mixed Refrigerant
DMR	-	Dual Mixed Refrigerant
C1-C5	-	Methane, Ethane, Propane, Butane, Pentane
APCI	-	Air Products and Chemicals, Inc.
HX	-	Heat Exchanger
CD	-	Condenser
COL	-	Cooler
CM1	-	Compressor No. 1
CM2	-	Compressor No. 2
NMDS	-	Nelder–Mead Dowhill Simplex
TS	-	Tabu Search
VBA	-	Visual Basic for Applications
NLP	-	Non-Linear Programming
J-T	-	Joule–Thompson
LMTD	-	Logarithmic Mean Temperature Difference
MITA	-	Minimum Internal Temperature Approach

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Natural gas is a naturally occurring hydrocarbon gas mixture containing light- (methane and ethane), medium- (propane and butane) and heavy-weight (pentane and others) hydrocarbons, together with impurities (carbon dioxide, water and nitrogen), which are removed upstream (Nguyen and Elmegaard, 2016).

Natural gas is a non-renewable source of energy. Basically, it is a fossil fuel used as a souce of energy for heating, cooking, and power generation. It is also used as fuel for cars and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals.

Natural Gas is transported by either pipelines or liquefied natural gas carriers. The pipeline transportation needs low operation cost, but huge initial investment. It is popular in the gas transportation of large gas fields. However, for those small gas fields and long-distance transport, the gas has to be liquefied and transported by Liquefied Natural Gas (LNG) carriers to reduce the cost. Therefore, natural gas liquefaction technology is inevitable (Xu *et al.*, 2014).

LNG is produced by the liquefaction of NG from the atmospheric temperature to -160 0C. This liquefaction process is energy intensive, and a typical LNG plant consumes about 5.5-6 kWh energy per kmol of LNG produced. The liquefaction process consists of the following steps; Natural gas is received at ambient temperature and above atmospheric pressure. It is then precooled, condensed and subcooled down to -160 ^{o}C, and is finally flashed off to the storage conditions (Alabdulkarem *et al.*, 2011).

Several refrigeration processes for gas liquefaction have been developed over the last half century. The refrigeration process can be subdivided into the cascade, mixed refrigerant and expander based processes. The selection, in practice, of a process depends on considerations such as the system performance (compression duty), cost (equipment), size (heat exchangers), simplicity (item inventory) and safety (working fluid). It is therefore not possible to propose a suitable process for all applications, as different fields of application have different requirements. For example, mixed-refrigerant and expander-based processes may be preferred for small-scale applications because of their lower equipment inventory, while cascade, dual and propane-precooled mixed-refrigerant systems are preferred for systems where high efficiency is the prime criterion. Mixed-refrigerant processes attract a lot of attention because of their high efficiency and their use in many industrial applications, but the high number of degrees of freedom when designing such systems results in a complex problem (Nguyen and Elmegaard, 2016).

PRICO is one of the simplest MR processes; its flow sheet is shown in Figure 1.1. PRICO was first proposed by the Black & Veatch Company in the 1950s. There is only one throttle valve in the system along with two compression and cooling stages. This system has the benefits of simplicity, compactness and low investment, and it is therefore widely used in small and mid-scale LNG plants (Xu *et al.*, 2014).

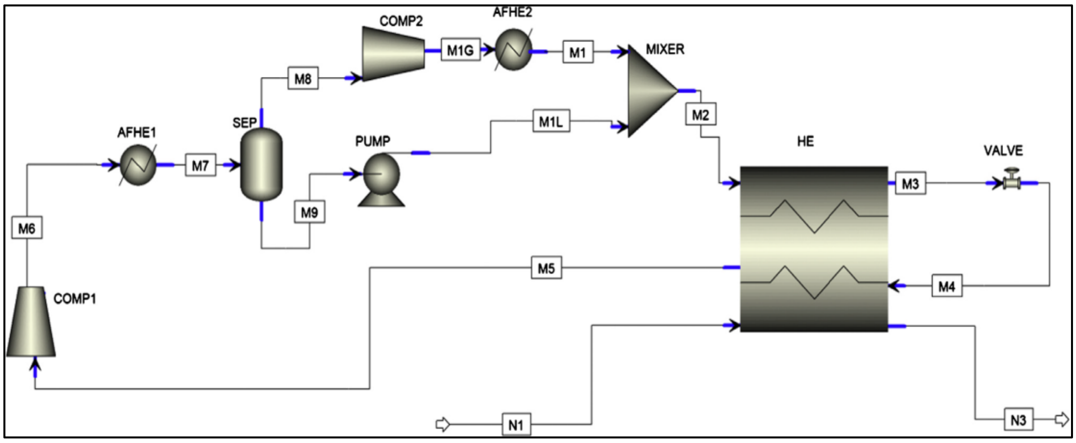

Figure 1.1 Flowsheet of the PRICO modelled by the Aspen Plus (Xu *et al.*, 2014)

A new technology is being introduced to the industry to replace conventional onshore liquefaction plants with Floating Liquefaction Natural Gas (FLNG). Offshore FLNG production vessels can best be described as a replacement to the traditional onshore liquefaction plant on an LNG tanker which also provides the storage capacity and the offloading jetty. In addition to the traditional gas processing facilities, the vessel will include the necessary processing and management of the fluids produced from the subsea wells.

FLNG offers many advantages over conventional onshore liquefaction plants. The advantages are it can be located at the offshore field avoiding the high cost of a subsea pipeline to shore, also, it Can be built in a shipyard with higher productivity and often lower labor rates than the construction of a conventional onshore liquefaction plant, besides that, its shipyard construction provides a higher confidence in delivery date than many onshore construction locations, also it can be leased avoiding the initial capital outlay. Moreover, the FLNG Can be redirected to another field when gas production declines enabling the asset to be reused and avoiding the full sunk cost experienced with an onshore plant which cannot be relocated. (Mokhatab and Wood, 2007).

1.2 Problem Statement

Liquefied natural gas is natural gas that has been converted to liquid form for ease of storage or transport. The liquefaction process of natural gas is an energy intensive process. The energy refrigeration section weights about 40% of the total operating cost for a base-load LNG plant (Zargarzadeh *et al.*, 2007). Therefore, reducing energy utilization in the liquefaction process is the key factor for LNG producers. The liquefaction process uses different cycles to liquefy natural gas. One of the most common cycles is mixed refrigerant cycle. Many researchers have studied the energy optimization of the mixed refrigerant cycle focusing on optimal design and composition. Using PRICO process, which selects the mixture of nitrogen and light hydrocarbons (C1-C5) as the mixed refrigerant, we can study the optimal refrigerant composition for the further energy optimization purpose using Aspen HYSYS as a simulation software and HYSYS Optimizer as an optimization tool. Moreover, the new technology, Floating Liquefied Natural Gas (FLNG), requires a typical range of the MRs since the compositions of the NG will fluctuate from a gas reservoir to another. The MR range will insure energy optimization mainly in the compressors.

1.3 Objectives

This study aims to:

1) Simulate the PRICO process using Aspen HYSY Software.
2) Develop a mathematical model for optimizing the liquefaction process of natural gas.
3) Identify the optimum mixed refrigerant composition range which gives the least energy consumption using HYSYS Optimizer.

1.4 Scopes of Study

To achieve the intended research objective, the scope of work has been drawn as followings:

1) Analysing the state- of- the- art procedure on Mixed Refrigerant cycle optimization including its features, gaps and potential improvements.

2) Data collection on PRICO process which covers the system descriptions, characteristics of the system and the previous improvements done to the system.
3) Simulating the PRICO process using HYSYS software.
4) Developing a mathematical model for optimizing the liquefaction process of natural gas.
5) Finding the optimal refrigerant mixture composition range which gives the least energy consumption using HYSYS Optimizer software.

1.5 Significance of This Study

Producing LNG is a highly energy intensive process, as required liquefaction temperatures are around -160 ^{o}C. for that reason, LNG producers are trying to reduce the energy consumptions because a small improvement in the efficiency will increase the process global competitiveness and have a huge cost and energy benefits. In this paper, an approach is adopted using PRICO cycle in order to minimize the energy consumption by optimizing the LNG mixed refrigerant compositions using HYSYS Optimizer software. Besides that, the new technology, Floating Liquefaction Natural Gas (FLNG), requires a set of range of mixed refrigerant due to the frequent mobility of the FLNG carriers thus the Natural Gas varies. The optimum range of mixed refrigerant will ensure the optimization of energy consumption. The novelty of this study lies on the adoption of Aspen HYSYS Optimizer as an optimization software.

REFERENCES

Alabdulkarem, A., Mortazavi, A., Hwang, Y., Radermacher, R. and Rogers, P. (2011). Optimization of propane pre-cooled mixed refrigerant LNG plant. *Applied Thermal Engineering*. 31 (6), 1091-1098.

Aspelund, A., Gundersen, T., Myklebust, J., Nowak, M. and Tomasgard, A. (2010). An optimization-simulation model for a simple LNG process. *Computers & Chemical Engineering*. 34 (10), 1606-1617.

Bahadori, A., Mokhatab, S. and Towler, B. F. (2007). Rapidly estimating natural gas compressibility factor. *Journal of Natural Gas Chemistry*. 16 (4), 349-353.

Barclay, M. and Denton, N. (2005). Selecting offshore LNG processes. *LNG journal*. 10 (1), 34-36.

Hatcher, P., Khalilpour, R. and Abbas, A. (2012). Optimisation of LNG mixed-refrigerant processes considering operation and design objectives. *Computers & Chemical Engineering*. 41, 123-133.

HYSYS, A. (2004). Operations Guide: AspenTech.

Jensen, J. B. and Skogestad, S. (2008). Optimal operation of refrigeration cycles. *Norwegian University of Science and Technology, Faculty of Natural Sciences and Technology, Department of chemical engineering*.

Khan, M. S., Lee, S., Rangaiah, G. and Lee, M. (2013). Knowledge based decision making method for the selection of mixed refrigerant systems for energy efficient LNG processes. *Applied energy*. 111, 1018-1031.

Kim, J. W., O'Sullivan, J., Steen, A. and Halkyard, J. (2008). Global performance and sloshing analysis of a new deep-draft semi-submersible LNG FPSO. Proceedings of the 2008 *ASME 2008 27th International Conference on Offshore Mechanics and Arctic Engineering*, 881-889.

Lee, G., Smith, R. and Zhu, X. (2002). Optimal synthesis of mixed-refrigerant systems for low-temperature processes. *Industrial & Engineering Chemistry Research*. 41 (20), 5016-5028.

Mokhatab, S. and Wood, D. (2007). Breaking the offshore LNG stalemate. *World oil*. 228 (4), 139.

Morosuk, T., Tesch, S., Hiemann, A., Tsatsaronis, G. and Omar, N. B. (2015). Evaluation of the PRICO liquefaction process using exergy-based methods. *Journal of Natural Gas Science and Engineering*. 27, 23-31.

Nguyen, T.-V. and Elmegaard, B. (2016). Assessment of thermodynamic models for the design, analysis and optimisation of gas liquefaction systems. *Applied Energy*. 183, 43-60.

Nibbelke, R., Kauffman, S. and Pek, B. (2002). Double mixed refrigerant LNG process provides viable alternative for tropical conditions. *Oil & gas journal*. 100 (27), 64-66.

Okasinski, M. J., Bukowski, J., Liu, Y. and Wehman, J. (2013). Simulating Operational Transitions in a Nitrogen Recycle LNG Plant. Proceedings of the 2013 *Proceedings of the 17th International Conference & Exhibition on Liquefied Natural Gas (LNG17),*

Pham, T. N., Khan, M. S., Husmil, Y. A., Bahadori, A., Lee, S. and Lee, M. (2016). Optimization of modified single mixed refrigerant process of natural gas liquefaction using multivariate Coggin's algorithm combined with process knowledge. *Journal of Natural Gas Science and Engineering*. 33, 731-741.

Roberts, P. (2005). *The end of oil: on the edge of a perilous new world*: Houghton Mifflin Harcourt.

Shirazi, M. M. H. and Mowla, D. (2010). Energy optimization for liquefaction process of natural gas in peak shaving plant. *Energy*. 35 (7), 2878-2885.

Shukri, T. (2004). LNG technology selection. *Hydrocarbon engineering*. 9 (2), 71-76.

Songhurst, B. (2016). *Floating Liquefaction (FLNG): Potential for Wider Deployment*: Oxford Institute for Energy Studies.

Wang, M., Khalilpour, R. and Abbas, A. (2014). Thermodynamic and economic optimization of LNG mixed refrigerant processes. *Energy Conversion and Management*. 88, 947-961.

Xu, X., Liu, J. and Cao, L. (2014). Optimization and analysis of mixed refrigerant composition for the PRICO natural gas liquefaction process. *Cryogenics*. 59, 60-69.

Xu, X., Liu, J., Jiang, C. and Cao, L. (2013). The correlation between mixed refrigerant composition and ambient conditions in the PRICO LNG process. *Applied energy*. 102, 1127-1136.

Yang, C., Kaplan, A. and Huang, Z. (2003). Cost-effective design reduces C2 and C3 at LNG receiving terminals. *Oil & gas journal*. 101 (21), 50-53.

Yang, S. and WEI, J. (2011). *Fundamentals of petrophysics*: Springer.

Zargarzadeh, M., Karimi, I. A. and Alfadala, H. (2007). Olexan: a tool for online exergy analysis. Proceedings of the 2007 *17th European symposium on computer-aided process engineering Bucharest, Romania, computer-aided chemical engineering,*