MODELING OF SINGLE MIXED REFRIGERANT PROCESS FOR OFFSHORE NATURAL GAS LIQUEFACTION

SYED AHMAD FARHAN BIN SYED AB MUTALIB

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requirements for the award of the degree of
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Universiti Malaysia Pahang

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ABSTRACT

The main objective of this thesis is to model a single mixed refrigerant process for offshore natural gas liquefaction using ASPEN HYSYS as a simulation tools. The liquefaction process employed in this part is a result of modification of previous case done by C.W. Remeljeja and A.F.A. Hoadley (2004). This work is divided into two sections. First is to model the PRICO LNG process that published result. Second is to improve the model by adding the mixer in the mixed refrigerant stream after the separator. It allows two different phase of gas and liquid of mixed refrigerant to mix together before entering the LNG Heat Exchanger (cold box). The mixer also helps to maintain a constant flow rate of the stream to the cold box. The results are obtained after the system is converged. When modeling the PRICO process in Aspen Hysys, certain variables such as temperature and pressure at the streams entering and leaving the cold box cannot be changed directly. This will cause temperature cross and change of mixed refrigerant phase in the respected stream. As a result, by doing structural modification on the basic PRICO process specifically in case 3, the load duty of the compressor can be lowered significantly. After three different structural modifications discussed in this paper, the compressor duty to liquefy the natural gas can be reduced down to 82300.46 kW when compared to the base case. As a conclusion, structural modification in case 3 is the best model when compare case 1 and case 2 because it operates in lowest compressor duty. For the future improvement, a different structure modification can be done using case 3 as a base model, for example replacing the valve with a multiphase expander to generate electricity in this LNG liquefaction process.

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ABSTRAK

Objektif utama tesis ini ialah untuk membuat model simulasi pencairan gas asli gas ke cecair sesuai untuk digunakan di pelantar minyak dengan bantuan program simulasi ASPEN Hysys. Proses pencairan gas ini adalah modifikasi struktur asal daripada model yang dibuat oleh C.W. Remeljeja, A.F.A. Hoadley (2004). Kerja ini dibahagikan kepada dua bahagian. Pertama ialah membentuk PRICO berdasarkan C.W. Remeljeja, A.F.A. Hoadley. Kedua ialah menambahkan unit yang dinamakan penggabung pada aliran campuran refrigeran selepas ia melalui unit pengasing. Ini menyebabkan dua aliran berlainan fasa iaitu gas dan cecair supaya bercampur sebelum memasuki unit penukaran haba. Penggabung juga membantu untuk memastikan aliran yang stabil ke dalam unit penukaran haba. Keputusan didapati apabila sistem itu konverge. Sesetengah pemboleh ubah tidak boleh diubah secara terus kerana ia boleh mengganggu keseluruhan sistem. Selepas membuat tiga modifikasi ke atas model asal yang dibincangkan di dalam tesis ini, kerja kompresor untuk menyejukkan gas asli ke cecair boleh dikurangkan ke 82300.46 kW apabila dibandingkan dengan model asal. Kesimpulannya, modifikasi struktur pada kes 3 ialah model terbaik berbanding kes 1 dan kes 2 kerana ia beroperasi pada kompressor duty terendah. Sebagai penambahbaikan pada masa hadapan, modifikasi struktur boleh dibuat dengan menggunakan kes 3 sebagai model asas. Sebagai contoh, menggantikan injap dengan ekspander pelbagai fasa untuk menghasilkan elektrik di dalam proses ini.

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NOMENCLATURE

$\dot{m}_{NG}$	Natural gas flow rate
$\dot{m}_{LNG}$	Liquefied natural gas flow rate
$\dot{m}_{Ref}$	Mixed refrigerant flow rate
P_l (bar)	Compression pressure (high pressure)
P_h (bar)	Expansion pressure (low pressure)

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LIST OF ABBREVIATIONS

LNG	Liquefied natural gas
$\dot{m}_{NG}$	Natural gas flow rate
$\dot{m}_{LNG}$	Liquefied natural gas flow rate
$\dot{m}_{Ref}$	Mixed refrigerant flow rate
P_l (bar)	Compression pressure (high pressure)
P_h (bar)	Expansion pressure (low pressure)
FPSOs	Floating, production, storage and offloading units
FSOs	Floating, storage and offloading units
TLP	Tension leg platform
SPM	Single point mooring

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MODELING OF SINGLE MIXED REFRIGERANT PROCESS FOR OFFSHORE NATURAL GAS LIQUEFACTION

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CHAPTER 1

INTRODUCTION

1.1 World Natural Gas Demand

The worldwide energy demand has rapidly increased during the recent years and the available resources are becoming insufficient. According to Energy Information Agency (EIA) oil is no longer the preferred energy resource and other resources have become more viable as a replacement for it. One of the most important ways to obtain energy and is from the natural gas and its consumption could increase from 104 trillion cubic feet in 2005 to 158 trillion cubic feet in 2030. This is because natural gas produces less carbon dioxide than either coal or petroleum when it is burned. The government also implements a national and regional plan to reduce greenhouse gas emissions. These may encourage its use to displace other fossil fuels as well. Russia is the largest exporter of gas to Europe, and Norway is second. Norway accounted for 30 percent of all gas production in Western Europe in 2006. Norway ranks as the fifth largest producer and the third largest exporter on a world basis, despite the fact that it has only 1.6 percent of the world's proven gas reserves.

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1.2 Liquefaction of Natural Gas

Liquefied natural gas (LNG) is natural gas that has been cooled to the point that condenses to a liquid, which occurs at a temperature of approximately -161 °C, at atmospheric pressure. The liquefaction process reduces the volume of gas by approximately 600 times, thus it is more economical to store natural gas where other forms of storage do not exist, and to transport gas over long distances for which pipelines are too expensive or for which other constraints exist. There are several natural gas liquefaction processes used in the industry such as, pure fluid cascade process, mixed fluid refrigerant and mixed fluid cascade process. This paper studies a simple cooling cycle known as the PRICO process which uses a mixed fluid refrigerant.

1.3 Introduction to Cooling Cycles

In a refrigeration system, a heat is removed from low temperature region and transfers the heat to high temperature region. One of the most common refrigeration cycles is vapor compression cycle. It also used in most household refrigerators and in industrial refrigeration system. Basically, this process has four main components which consist of compressor, condenser, evaporator and an expansion valve. According to Jensen, Jorgen B., (2008) the process is shown in Fig 1.1 and also in a pressure-enthalpy diagram, Fig 1.2

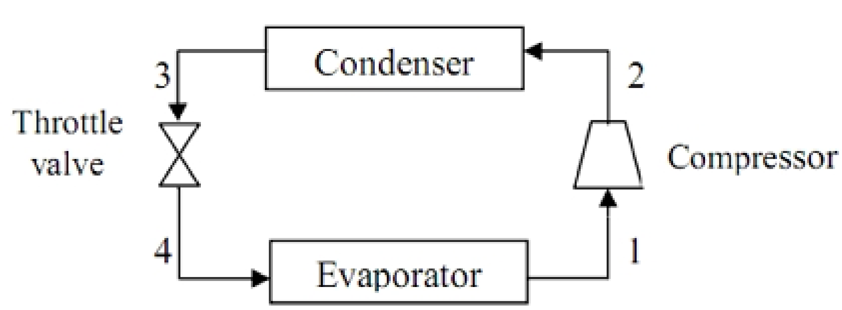

Figure 1.1 Simple refrigeration cycle of vapor compression

In step 4 to 1, heat is removed from the system to being refrigerated by the evaporation of the working fluid at low pressure (PL). The saturated vapor at Pl is then compressed to high pressure (Ph), step 1 to 2. In step 2 to 3, the substance is de-superheated and then condensed to saturated liquid at constant pressure. During this process, the working substance rejects most of its energy to the condenser cooling water. The cycle is closed by an irreversible throttling process in which the temperature and pressure decrease at constant enthalpy. In order to prevent liquid fed into the compressor, the vapor must be slightly superheated, ΔT_{sup}, at the outlet of the evaporator. The degree of superheating, ΔT_{sup}, stands for the temperature difference between the evaporator outlet temperature and the saturation temperature at given pressure. The refrigerant is sub-cooled at the outlet of the condenser, as we can see in Fig 1.2. The degree of sub-cooling (ΔT_{sub}) represents the temperature difference between the condenser outlet temperature and the saturation temperature at given pressure.

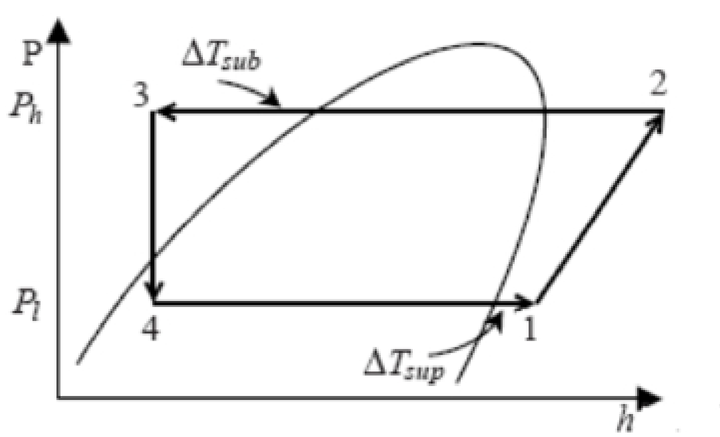

Figure 1.2 Pressure-enthalpy graph for a simple refrigeration cycle

The refrigeration cycle efficiency is the COP, coefficient of performance, and it is defined as:

$$\text{COP} = \frac{|Q_L|}{W_s} \quad (2.1)$$

Where QL is the heat removed from the system being refrigerated and Ws the power required by the compressor. The COP is restricted by the efficiency of Carnot, which is the theoretical 'minimum fraction of the cooling duty QL that must be added as mechanical work Ws'

$$COP_{carnot} = \frac{|Q_L|}{W_s} = \frac{T_L}{T_H - T_L} \quad (2.2)$$

Since, the Carnot efficiency results from the assumption of an ideal reversible process neglecting world items like frictional pressure drop in the system or slight internal irreversibility during the compression of the refrigerant vapor a real process, such efficiency cannot be achieved in a real process.

Some improvement of the cycle efficiency could be gained by replacing the isenthalpic throttling step with an isentropic expansion. While such an improvement is theoretically possible and is therefore appealing, usually practical considerations have to be taken into account. In the practice, liquids tend to become vapor during the expansion step, which affects the safety of the turbine. In order to avoid vapor formation in the liquid turbine, a combination of a liquid turbine and a valve is used to be employed.

1.4 Basic Design of Single Mixed Refrigerant Process for Offshore Natural Gas Liquefaction

Figure 1.3 shows the basic design of single mixed refrigerant process for offshore natural gas liquefaction. In this paper, we use the simplest mixed refrigerant process known as PRICO (poly Refrigerant Integrated Cycle Operations) process.

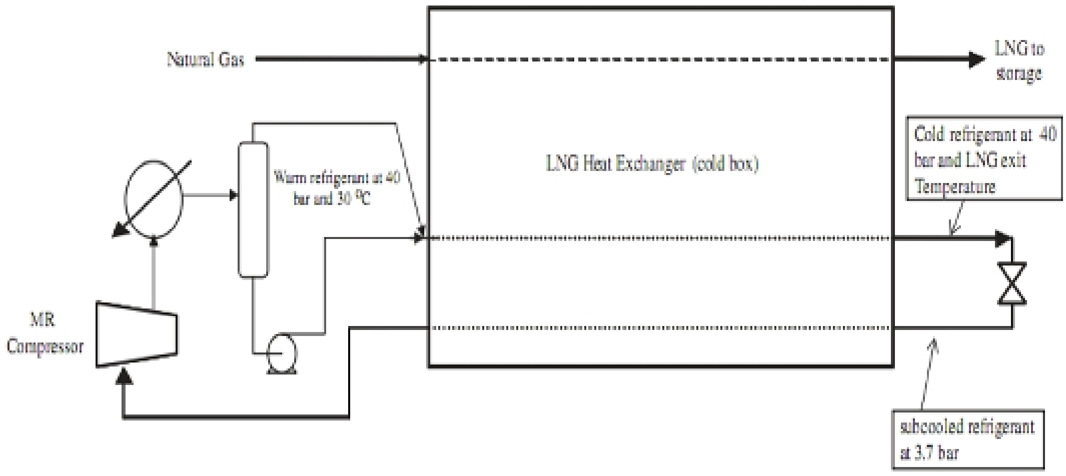

Figure 1.3 Single stage mixed refrigerant (SMR) flow sheet

1.5 Problem Statement and Objectives

Liquefied natural gas (LNG) is an attractive source of clean fossil fuel. However, it involves very high energy to liquefy the natural gas especially by the mixed refrigerant compressor. The objective here is to minimize the total duty for the refrigerant compressor. In this paper, we identify the base case and made some structural modification to the previous case done by C.W. Remeljeja, A.F.A. Hoadley (2004)

1.6 Scope

- First is to design the PRICO according to C.W. Remeljeja and A.F.A. Hoadley (2004).
- To do structural modification on the previous flow sheet.
- Add the mixer in the mixed refrigerant stream after the separator.
- Add another compressor to the process to reduce the work shaft load on one compressor.
- Add cooler after the compressor 1.
- To choose the best modified structure in terms of work needed to liquefy natural gas.

1.7 Rationale and Significance

Single mixed refrigerant system (SMR) such as PRICO SMR features a simpler machinery configuration and fewer maintenance problems when compared to other refrigerant system. A low temperature processes in liquefaction require heat rejection to refrigeration systems. The result is that the operating costs for such processes are usually dominated by the cost of power to run the refrigeration system.

CHAPTER 2

LITERATURE REVIEW

2.1 Single Mixed Refrigerant Process

The process considered in this work is a single mixed refrigerant process known as PRICO (poly Refrigerant Integrated Cycle Operations) process. The PRICO process has been studied from optimization perspective in several publications. (C.W. Remeljeja, A.F.A. Hoadley). These works deals with steady state optimization and there is no literature available on dynamic modeling and control structure design for PRICO process. The objective of this thesis is to use the model developed for PRICO process. Another important category of refrigeration systems to be considered is mixed refrigerant systems. Mixed refrigerants have an advantage over pure refrigerants because they undergo isobaric phase change along a range of temperatures within the dew and bubble temperatures of the mixture. The correct refrigerant pressures, flow rate and composition allows a good match between the process and refrigerant temperature profiles with a simpler configuration than multilevel pure refrigerant cycles (Del Nogal et al., 2006). Simple configuration of mixed refrigerant cycles results in less rotary equipment involved in the process, which adds additional value to the design in terms of the reliability of the operation.

2.2 Refrigeration Process

The conversion of natural gas into liquid is called liquefaction and is achieved through refrigeration. During refrigeration process, the natural gas is cooled to -161^{0}C (-259^{0}F) and it becomes a clear, colorless, odorless liquid. These liquefied natural gas, or LNG, is neither corrosive nor toxic. Liquefaction reduces the volume of natural gas by approximately 600 times compared to natural gas in gaseous state, making it more economical to transport over long distances by sea in specially designed ships. A refrigeration system removes thermal energy from low temperature region to high temperature region. In offshore natural gas liquefaction, the process consists of a compressor, heat exchanger (cold box), separator, mixer and valve. The natural gas is fed and is cooled at cryogenic condition at temperature -161^{o}C and pressure at 4000 kPa. The refrigeration is achieved by expansion and compression of single mixed refrigerant in the process. First the mixed refrigerant is being fed at the LNG Heat Exchanger (cold box) where it is being cooled at -156 ^{o}C. After leaving the cold box, the cold mixed refrigerant enters a expansion valve and it is further cooled into -170 ^{o}C. Then it enters the heat exchanger and the temperature is increased at 122 ^{o}C and the hot mixed refrigerant is compressed in a compressor. The outlet temperature and pressure after leaving the compressor is 153^{o}C and 3500 kPa. In offshore natural gas liquefaction, the mixed refrigerant is cooled using sea water as it is more economical and can be used abundantly.

2.2.1 Refrigeration Cycle

The number of cycles is a key factor in the success of liquefaction process. This cycle takes warm, pretreated feed gas and cools and condenses it into an LNG product. To make the cold temperatures required for the LNG, work must be put into the cycle through a refrigerant compressor, and heat must be rejected from the cycle through air or water coolers. The amount of work (size of refrigerant compressors, drivers and refrigerant flow rate) is a strong function of liquefaction process, feed gas conditions (liquefaction temperature), and cooler temperature. In the single cycle process, there is a single working fluid that can be compressed in a single set of compressors driven by a single driver. In terms of economies within the liquefaction train are realized when the capacity can be increased with

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number of cycles. When the number of cycles increases, the equipment count, space and complexity also increase. So the liquefaction facility process cost savings are reduced or lost. An example of a single cycle process is a propane refrigeration system. A refrigeration cycle is shown in Figure 2.0.

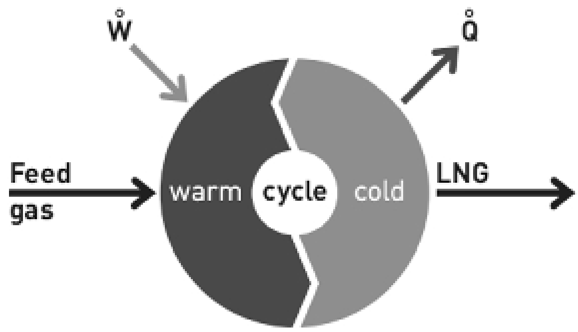

Figure 2.0 Single cycle liquefaction process

2.3 Gas Compression

Gas production operations often require compressors to raise the pressure of the gas. A gas compressor is a mechanical device that increases the pressure of the gas by reducing its volume. In gas processing operations, compressors are required for circulation of gas through the process or system. In natural gas liquefaction, multiple processing stages of gas compression are necessary to keep the pressure above a specified level. The gas compression facitilies that include gas coolers and suction scrubbers compress the gas by electrical motor-controlled compressors. These must usually operate at a constant speed with constant discharge pressure.

2.4 Types of Compressors

The two major types of compressors are positive displacement and continuous flow. Positive-displacement units are those in which successive volumes of gas are confined within some type of enclosure (compression chamber) and elevated to a higher pressure. This pressure elevation or compression can be achieved in two ways. By reducing the gas volume in the enclosure or carrying the gas without volume change to the discharge and compressing the gas by backflow from the discharge system.