SIMULATION AND ENERGY ANALYSIS OF PRE-COOLING LOOP IN LNG PROCESSES

by

Syazwan Ifwat bin Zulqurnain

Dissertation submitted in partial fulfilment
of the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

MAY 2014

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CERTIFICATION OF APPROVAL

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Syazwan Ifwat bin Zulqurnain (13402)

A project dissertation submitted to the

Chemical Engineering Programme

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Approved by,

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(Assoc. Prof. Dr Shuhaimi Mahadzir)

Universiti Teknologi PETRONAS

Tronoh, Perak

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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SYAZWAN IFWAT BIN ZULQURNAIN

ABSTRACT

Natural gas is one type of energy source that play an important part in supplying energy to the world and known to be the cleanest fossil fuel energy due to facts that it produce lower emission of sulfur and carbon dioxide. In the 1960, the first LNG plant has been built and the liquefaction process for natural gas has been introduced. During this process natural gas will be cooled down to -162°C at atmospheric pressure and the volume of liquid is reduced by 600 times of its gaseous volume. Liquefaction of natural gas has been the cornerstone of the LNG business since the transportation of natural gas to remote place becomes more economical viable. Despite the huge advantages of liquefaction process, the amount of energy consumed in producing LNG still considerably high. In the past decade, important amount of work has been focused on the design of LNG process. The aim of those work mainly focus on optimizing various developed LNG process.. This stage represents 40% of the work in the liquefaction process and it is important to reduced energy consumed in this stage of the liquefaction process. Due to the rapidly changing market conditions, escalating equipment costs, scarcity of resources for owners, contractors and suppliers, marginal projects will be put on the back burner but will continue to be evaluated for improved economics in the future. This paper proposed conceptual design strategies for improving total project design concepts for pre-cooling stage for Linde-Hampson cycle with a lesser energy consumption in the process. In this modification achieved 0.8% increment in productivity and specific power is reduced by 14%. It also gives lower LMTD reading while changes in heat exchanger effectiveness by 0.002. Besides that, this model study also uses less amount of refrigerant to achieve target natural gas outlet temperature.

ACKNOWLEDGEMENT

First and foremost, praised to the Al-Mighty for giving me the strength and patience in completing this Final Year Project 2 after facing with all the problems and challenges for the past several months.

I wish to express my sincere appreciation to my supervisor Assoc. Prof. Dr Shuhaimi Mahadzir for all his advice, support, guidance, and patience in guiding me throughout completing this project. He has been very a supportive supervisor and willing to share his knowledge in order to ensure I could learn and understand every single thing that I did in this project. I also wish to thank to both of my parent for their countless supports in motivating me to complete this project.

My gratitude is also extended to Final Year Project coordinators, Dr. Abrar Inayat for their efforts in planning the course structures so that all will be run smoothly. My appreciations is also given to all my beloved friends for all their motivations and supports which helps me a lot in order to make sure that my project ended successfully. This is also directed to W Muhamad Aminin bin W M Izzuddin and all my friends for their willingness to teach me in certain aspects of my project especially things that related to simulation using Aspen HYSYS. Last but not least, not to forget to those who directly or indirectly involved in my project. Thank you.

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CHAPTER 1

INTRODUCTION

1.0 BACKGROUND STUDY

Natural Gas

Natural gas was originally found as gaseous fossil fuels in the porous rock either in the term of natural gas only or with the accumulated petroleum (Speight J. 2007). It has properties of colorless, odorless and has complex mixture of hydrocarbon which can produce energy range between 900 to 1200 BTU (British thermal unit) per standard cubic feet (Wang X. 2009).

The component of natural gas is methane, ethane, propane, butane and higher hydrocarbon. Natural gas also contains other component such as hydrogen sulphide, carbon dioxide and nitrogen. Figure 2.1 shows the typical composition of natural gas.

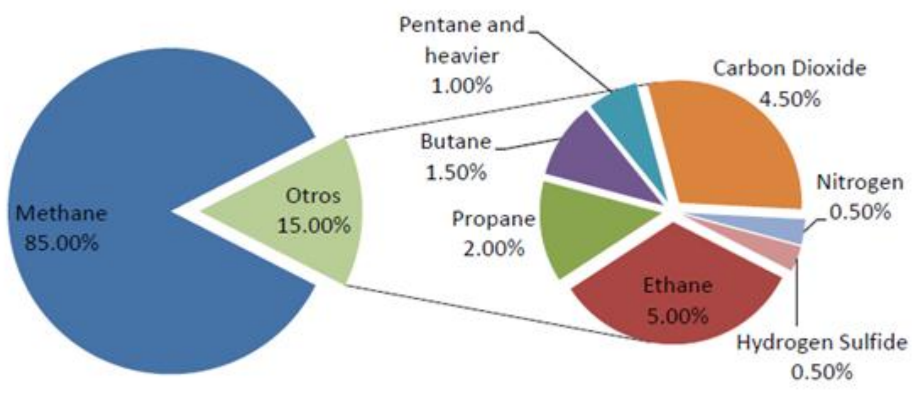


FIGURE 1: Typical Natural Gas composition (Taken from Speight J., 2007)

Liquefied Natural Gas

To produce liquefied natural gas, natural gas will be processed and cooled down until condensation at atmospheric condition. Methane as primary composition of natural gas made the bubble point temperature of natural gas at atmospheric condition low ranging from -163°C to -169°C. (Tusiani M. 2007). Bubble point temperature is defined as the state at a certain pressure in which the fluid is completely liquid and the first bubble of gas is formed. In comparison, one physical volume unit of LNG yields approximately 600 units of standard gas volume while it remains colorless, odorless, non-corrosive and non-toxic as in the gaseous phase. (Majzoub M. 2012).

The significant reduction in physical volume of liquid natural gas relative to gaseous natural gas reduces its transportation costs. It is the main aspects of LNG industries since it results more energy per volumetric unit allowing it to be transported in long distance economically.

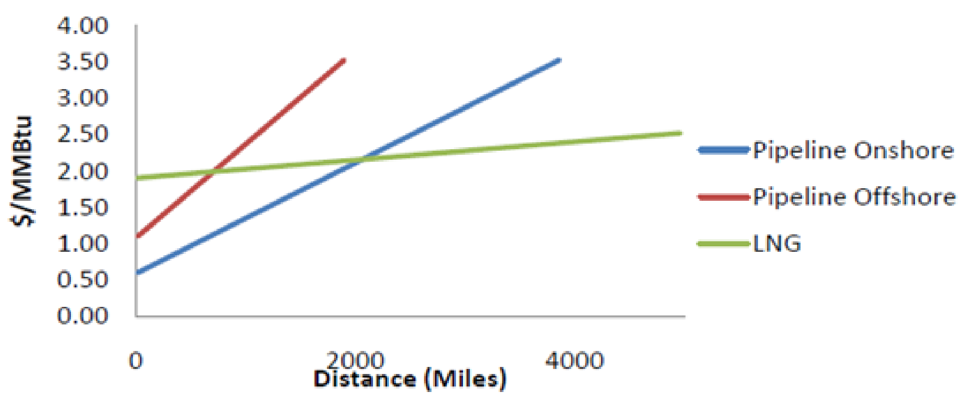


Figure 1.2: Natural Gas Transportation Cost (Majzoub M. 2012).

Natural Gas plays an important role in worldwide energy industry. The first base load LNG plant built was in Arzew, Algeria in 1960. This plant used cascade cycle for its liquefaction process using methane, ethane and propane as the refrigerant. (Paul B. 2009). This started the LNG export industries. It has been 54 years since the first LNG plant and during this time vast amount of work has been done to make the plant become more efficient and more profitable.

Trains is a number of parallel units in LNG production plant, while standalone liquefaction cycle means that one process trains can be shut down without affecting other trains. The capacity of a liquefaction train is primarily determined by the liquefaction process, the available size of the compressor and its driver, and the heat exchangers of the process (Majzoub M. 2012).

Natural Gas Liquefaction can be classified into two main groups. Figure 2.1 shows the natural gas liquefaction process classification.

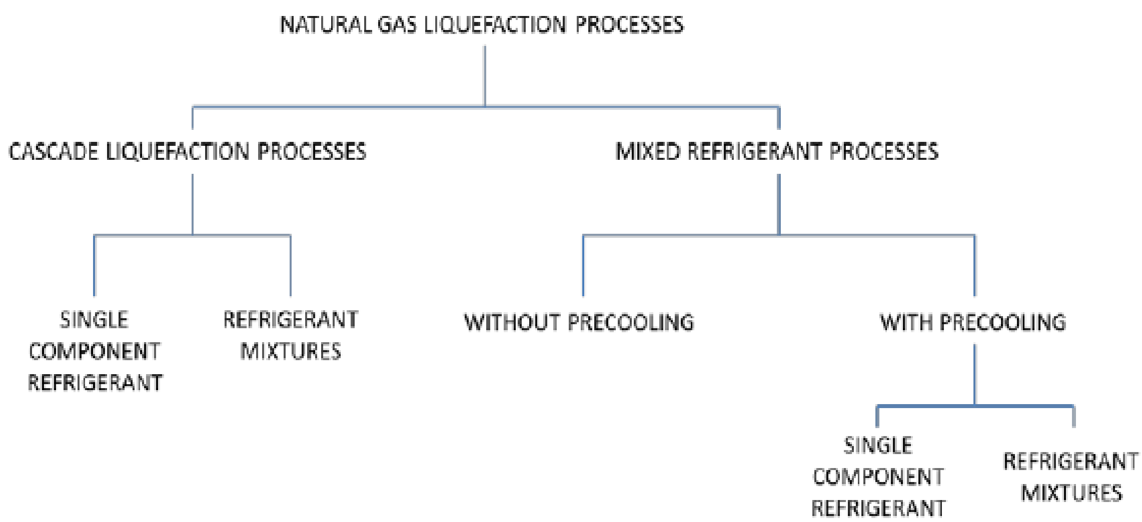


FIGURE 2: Classification of Natural Gas Liquefaction Process (Taken from Venkatarathnam G. 2008)

Motivation for This Research

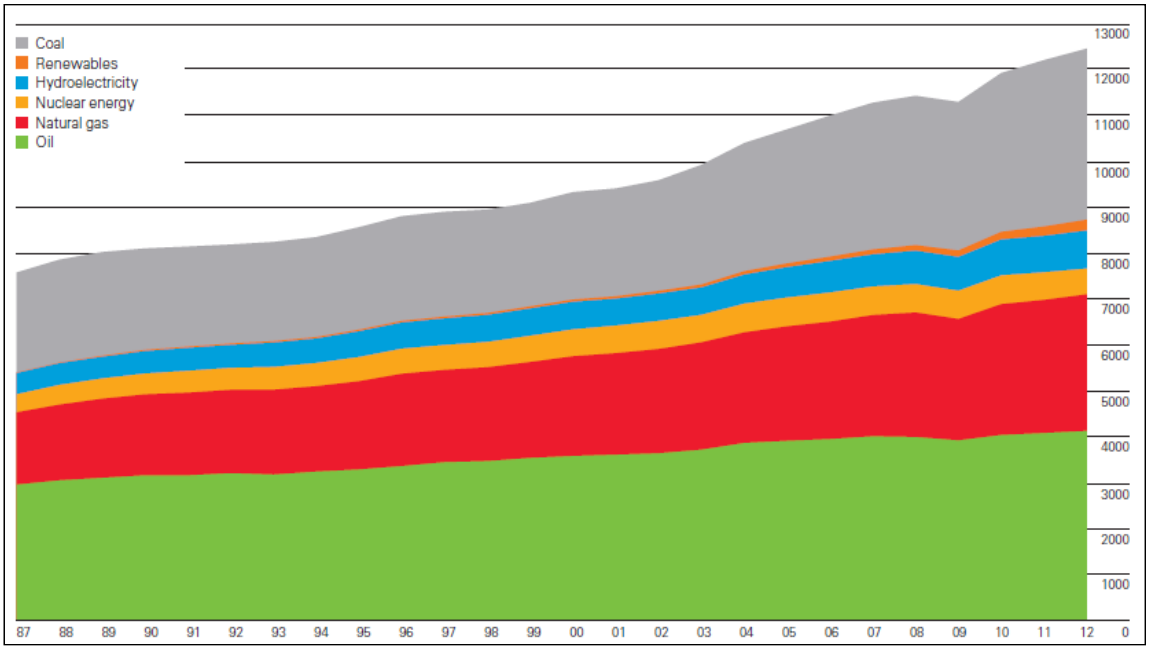


FIGURE 3: BP statistical review of world energy

Over the year, the demand in energy is increasing. Natural gas supplied a huge amount of energy to the world. Electric power generation is one of the recently growing applications of natural gas; it has become an attractive alternative fuel for new power generation plants because it offers low capital costs and favorable thermal efficiencies, with lower levels of potentially harmful byproducts that are released into the atmosphere (e.g.: Carbon Dioxide $CO2$) Likewise natural gas is used extensively for heating in both residential and commercial sites, while for industrial purposes it is mainly used as process fuel and feedstock (petrochemical). As a result of its increasing worldwide demand and undeniable environmental benefits compared to other fossil fuels, natural gas transport has become an important issue for the global energy supply. Most natural gas is transported from the wellhead to a processing plant, and thereafter, to final consumers in gas transport pipelines. However, at remote locations or when the distance between the gas market and the source is long enough, liquefying the natural gas for transport has been a major industrial operation. Optimization in its production stage will help save energy consumed. Study in this area is essential to ensure that energy is fully utilized. This study will help people to get better understanding in the LNG process.

2.0 PROBLEM STATEMENT

LNG process is energy intensive. Efficiency in this process become more important and there are many researcher focus on designing the LNG process such as APCI C3MR process, Prico process, Cascade, Linde–Hampson (Ho Nguyen 2012). In the design of LNG process, it is important to develop new method to save energy.

Most of the developed LNG processes have pre-cooling cycle in the first stage. In this stage, pure refrigerant or mixed refrigerant, usually light hydrocarbon such as propane or mixed of propane, is used and represents almost 40% of work done in liquefaction. Although it is an important stage in liquefaction, method in optimising this stage is still not well understood. basically because in most of the previous work about selection, thermal efficiency and energy consumption per mass unit of LNG (e.g. kWh/kg LNG) are the only benchmarks used to compare the different LNG technologies without mentioning the conditions of the judgment, such evaluations were made among others by Finn (2009), Shukri (2004) and Norshahida (2011) Therefore, analysis and optimizing in pre-cooling stage for various developed LNG process become very beneficial.

That kind of comparison can be misrepresentative because the design premises are not consistent from project to project. The efficiency of the refrigeration compressors, the ambient temperature of the region, the feed gas composition, temperature and pressure are some of the factors that may influence the process energy consumption.

3.0 OBJECTIVES

- To build up pre-cooling loop of three developed liquefaction process into HYSYS for further study.
- To validate and analyse propane as refrigerant in the simulated pre-cooling loop.
- To proposed modification in liquefaction technology

4.0 SCOPE OF WORK

The focus of this study will be put in pre-cooling loop of liquefaction processes, including the propane as refrigerant. By looking into detail the improvement of current liquefaction can be achieved.

CHAPTER 2

LITERATURE REVIEW

In the past decade, there are a lot of studies in this research area whether in determining the design of LNG process or optimizing the operating condition of developed process. All of those works may differ in method but it all has a similar target that is to minimize the energy consumption in LNG process.

Enhancement of the pre-cooling and Liquefied Natural Gas

Castillo and Dorao (2012) discussed about pre-cooling stage of LNG plants using propane or an ethane/propane mixture. In this work a thermodynamic evaluation of the pre-cooling system on the LNG technologies for selecting the suitable refrigerant type was presented. Pure propane and ethane/propane mixed refrigerant cycles were evaluated for a pre-cooling system using as base case a Linde–Hampson cycle. In this evaluation, the authors found that a pre-cooling system based on a propane cycle has the highest advantage temperature achieved (-36 degC) compared with an ethane/propane mixed refrigerant cycle.

Majzoub (2012) proposed selection of the pre-cooling stage for LNG process. In the study, the author treats pre-cooling circuit as a standalone and then implemented in the liquefaction process. The propane precooled mixed refrigerant and the mixed fluid cascade are referred. Parameters studied are coefficient of performance, heat exchanger UA value, compressor power, suction volumetric flow and pressure ratio. The composition and condition for the model was based on Helgested and Venkratham work.The author also studied the suitable climate for LNG plant. The whole study was undergoing by using Aspen HYSYS® version 7.3.

Based on the obtained results, the author found the highly efficient configuration for natural gas liquefaction is in the warm climate conditions and modification of mixed fluid cascade process and propane pre-cooling instead of mixed refrigerant circuit.

Jensen and Skogested (2009) discussed about selection of controlled variable to determine the steady state. The author use MATLAB to observe the system's response when keeping the selected variable at constant set point in 2 modes of given feed and maximum feed in the single-cycle-mixed-fluid LNG process. The results found by the author for mode I (given feed) and mode II (maximum feed), its operating close to surge and at maximum compressor speed is optimal for the nominal operating point and in some of the disturbance regions. The selection of the controlled variable is equally important if one uses a model-based control structure such as model predictive control (MPC)

Castillo and Dorao (2010) discussed a procedure for defining a selection criterion for remote small LNG plants. The authors considered scenarios, LNG technologies as well as some economic tools such as CAPEX, OPEX, value present, internal rate of return, sensitivity analysis in the procedure. The authors found that area plays a major role in economical evaluation, but other factors have to be put into consideration as well as for the selecting process.

Optimization of Liquified Natural Gas and Energy Efficiency

Abdullah and Amir (2011) discussed about energy optimization in LNG C3MR process. The author utilized HYSYS to model the C3MR LNG plant. The power consumption comes from the compressors and seawaters pumps are calculated by using HYSYS. This model was connected with MATLAB for optimization. The model in HYSYS is treated as a black box in the optimization. Optimization process was carried out in two stages. First, MCR cycle optimization and then the propane cycle optimization were conducted. The optimization constraint is that the propane cycle pre-cools the MCR cycle. The authors found the total power consumption was reduced by 9.08% in their optimization.

Helgested (2009) discussed about optimization of C3MR process for liquefaction of natural gas. The authors build a simulation model of C3MR process by using UniSim design software. The process simulation was based on a process train with production capacity of 8.4MTPA(MegatonnePerAnum).Optimization of the built up model was carried out in the MATLAB. In this research, the author had problem as the UniSim design does not offer the desired accuracy for optimization and detailed analysis of the process. Although the self-optimization control structured for the process was not determined in this project, the procedure and simplifying assumption were discussed.

Shariq, Yoon, Amalia and MoonYong (2010) discussed about robust control of propane pre-cooled mixed refrigerant process for natural gas liquefaction. The author use Aspen HYSYS with Peng-Robinson equation of states property package to model C3MR process. In this study author found that the feedback loop that controls the refrigerant flow provides more robust and stable control in comparison to the prior proposed control strategy. The LNG temperature regulation is achieved with more stable and robust performance with minimum stress on MCHE.

Veink and Klein (2010) discussed the comparison between five base load LNG processes. The technology include are Propane/MR process, Cascade process a version of Dual Mixed refrigerant , a simple single mixed refrigerant process and a pre-cooled nitrogen expansion process. By using the same conditions like cooling medium, feed gas, standards and cost basis this process was compared. The author found that propane/MR process is the best choice among the process study in the tropical climate where the cascade process appears to be the expensive and at disadvantages.

Bujis, Pek and Nagelvoort (2005) discussed the advantages of Shell LNG Technology for 7 -10 Mtpa LNG trains. The Shell parallel mixed refrigerant process for large LNG trains has following advantages. The first advantage is Robustness through the application of well proven equipment without a scale-up of equipment. High reliability and availability of parallel line-up of the liquefaction. Lastly, the optimal power balance between the two liquefaction cycle (1:2) results in high efficiency.

Spilsbury, Nan Liu, Petrowski and Kennington (2006) discussed about evolution of Liquefaction Technology. This paper discusses the application of Air Products LNG technologies. Developed APCI technology was demonstrated in this paper such as C3-MR, SplitMRTM, and AP-XTM process technologies. In summary, Air Products natural gas liquefaction processes have been continuously evolving and meeting the needs of an expanding LNG business. Plant sizes have grown and even larger plant sizes can be built in the future if the market demands this.

Rodgers, Mortazavi and Eveloy (2012) discussed about the efficiency and production capacity of the propane cycle in the LNG plants utilizing sea water for process cooling. The author investigate several propane cycle enhancement approaches which rely on the use of gas turbine waste heat powered water/lithium bromide absorption cooling to either subcool propane after the propane cycle condenser, or reduce propane cycle condensing pressure through pre-cooling of condensing cooling water. Aspen Plus was used to predict the number of waste heat available from gas turbine exhaust gases over a range of operating conditions and to quantify the improvements in propane cycle performance obtained. The authors found that with the study case of LNG plant in the Persian Gulf, sub-cooling propane after the condenser by approximately 21°C relative to the base cycle was found to enhance the propane cycle total coefficient of performance and total cooling capacity by 13% and 23% respectively. Reducing propane cycle condensing pressure by reducing condenser cooling water temperature from 35°C to 15°C, resulted in enhancements in propane cycle total coefficient of performance and total cooling capacity of 63% and 22% respectively.

Seif Pawaga (2011) discussed about Sensitivity Analysis of Proposed LNG liquefaction process for LNG FPSO. In this research, he developed four process model for LNG process which is single mixed refrigerant (SMR), dual mixed refrigerant (DMR), Niche LNG (CH_4 and N_2 process) and dual nitrogen expander. The author then investigate the effect of quality of the feed gas composition, temperature, pressure, train capacity and product specification. Finally the author develops a strategy for selecting particular technology. The author use Aspen HYSYS for simulation purpose. From the research, the author founds that DMR specific power than nitrogen expander by 50%, Niche LNG by 41.6% and SMR by 9.6%. For the power consumption, DMR is lower than nitrogen expander by 54%, Niche LNG by 47.8%, and SMR by 9.6%. DMR also has lowest refrigerant flow rate than nitrogen expander by 157.6%, Niche LNG DMR by 96.4% and SMR by 30.9%.

Ho Nguyen (2012) discussed about optimization of operating parameters in LNG process. In this study, the author used Aspen HYSYS to build up the sub-cooling loop of AP-X process and then the author optimize the flow rate of pure nitrogen as well as mixed refrigerant in AP-X process. The author found that the optimum flowrate of nitrogen happens at 2500 kg/hr at plant capacity of 9.1 MTPA.The optimum capacity of the plant is 9.1 MTPA.

Hamid and Masoud (2012) discussed about energy efficiency of an industrial C3MR LNG base load plant by changing its refrigerants' components and their mole fractions in liquefaction and sub cooling cycles. The process is modelled by using the HYSYS® software. The PRSV equation of state is used for thermodynamic properties calculations both for the natural gas and the refrigerants. Two methods for modelling and optimization are explained and the results are compared. The first optimization method is done by a try and error method, which is based on the use of temperature vs. enthalpy diagrams or composite curves. In the second method, HYSYS® optimizer is used for optimization. The author found that by optimization of mixed refrigerants, it is possible to decrease the energy demand about 10.4 MW (5.36 %.).

CHAPTER 3

METHODOLOGY

The Methodology framework contains the following major task: Pre-cooling loop selection, HYSYS model development, Validation of data, Analysis of pre-cooling, and modification of pre-cooling loop.

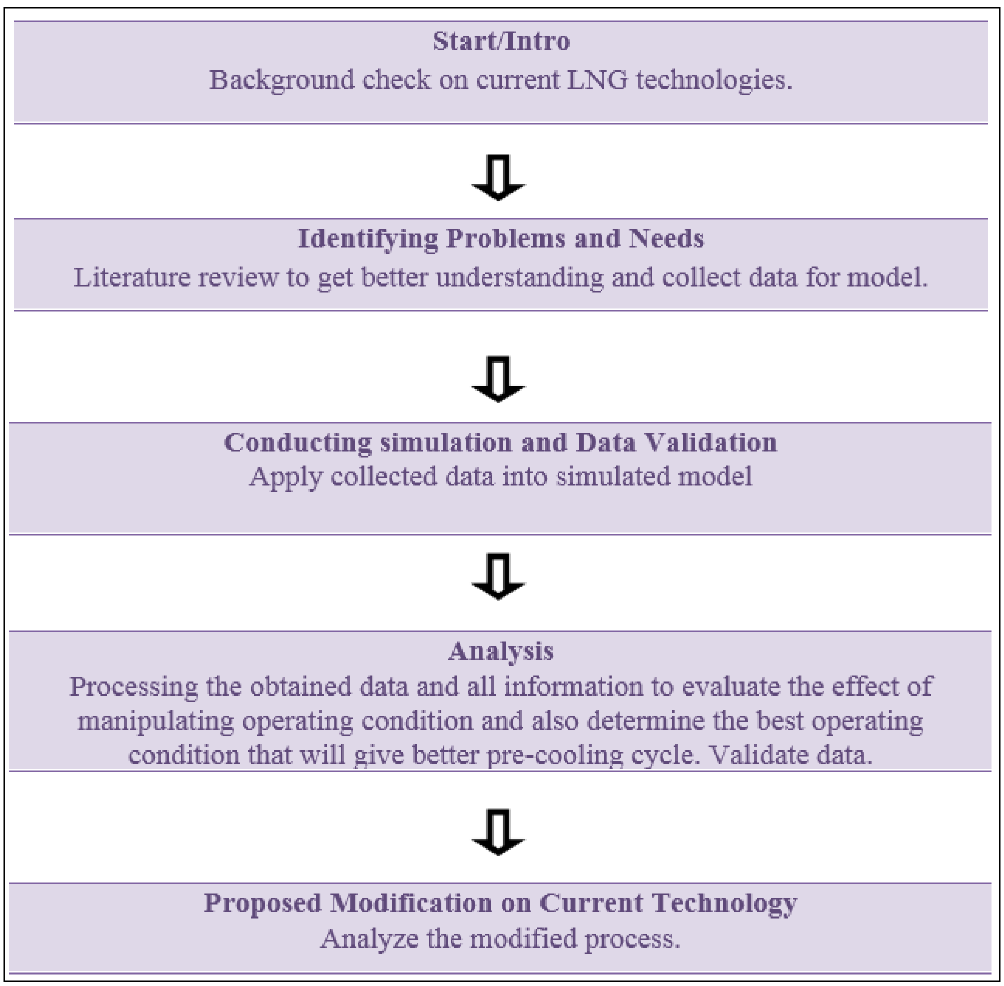


FIGURE 4: FYP Framework

In the first stage, literature review has been done thoroughly in order to understand the pre-cooling loop in liquefaction. There are many liquefaction technologies that use pre-cooling stage as their first stage in the process. To make research more significant, the comparison between liquefaction processes need to be done. From the literature review, three of the liquefaction process has been selected for comparison. The processes are Linde-Hampson, APCI and Cascade process. Selection of the processes are done by the most commonly used and data availability.

Simulations for the processes are done in ASPEN HYSYS® Version 7.3 and its running on Windows 7 (32bit) computer. The thermodynamic fluid package of Peng-Robinson was used as the basis of the simulation. A Weighted model is chosen as the heat exchanger calculation method, since the software developer states that it represents an excellent model to deal with non-linear heat curve problems such as the phase change of fluids. By selecting this model the heating curves are divided into intervals, and an energy balance is performed for each interval. A logarithmic mean temperature difference (LMTD) and UA value is calculated for each interval and the total UA is found by the sum of the values of the intervals.

The refrigerant used is only pure component refrigerant (only propane or C3) in simple cycle for precooling natural gas to 237 K (-36 °C), which is the reported minimum temperature that can be achieved with a propane precooling in order to avoid the risk of air entering the system (Pillarella, 2007).

For comparison purpose, of the parameter as set constant. Natural Gas composition is shown in TABLE 1 and parameter for simulation is shown in TABLE 2.

TABLE 1: Natural Gas Composition

Component	Mole Fraction
Methane	0.897
Ethane	0.055
Propane	0.018
n-Butane	0.001
Nitrogen	0.029

TABLE 2: Parameters for Simulations

	Parameter	Value
Natural Gas Inlet	Temperature	30 °C
	Pressure	40 bar
	Flow rate	100 kg/h
Cycle Parameter	ΔT_{min} Heat Exchanger	10 °C

Continuously, the simulation models are validated with literature review. Method of coefficient of determination is used. The coefficient of determination, denoted R2 or r2 and pronounced R squared, indicates how well data fit a statistical mode. It provides a measure of how well observed outcomes are replicated by the model, as the proportion of total variation of outcomes explained by the model (Steel, et al 1960). The value of coefficient of determination must more than 0.95 to be acceptable. In Chapter 4, the validated process is shown and graph is tabulated.

In the next stage, analyses on the models are done. With HYSYS Model, mass and energy balance of the pre-cooling loop can be performed quickly and precisely. Calculation of Log Mean Temperature Difference of Heat Exchanger (LMTD), Heat Exchanger Effectiveness, Specific Power and Productivity is calculated for each HYSYS model. The best model will be selected and further modification will be done based on the best model.

Modification of best model is proposed and the HYSYS model of this modification will be done. Using the same methodology, and with the help of HYSYS simulator analysis of this model will be done. Thus, the relationship can be built, and precious conclusion can be drawn up.

CHAPTER 4

RESULTS AND DISCUSSION

Validation Data

In this part, HYSYS model for processes will be shown and its validation. The HYSYS models are,

1. Linde- Hampson pre-cooling loop by Castillo and Dorao's work on the conceptual design of pre-cooling stage, Figure 5 and Figure 6

2. APCI model is from Majzoub's work on Evaluation and Selection of the Precooling Stage for LNG Processes, Figure 7 and Figure 8

3. Cascade model from Yoon's work on Characteristics of Cascade and C3MR Cycle on Natural Gas Liquefaction Process, Figure 9 and Figure 10

The validation graph is shown by comparing to the author results accordingly. In the next part the analysis of the model will be down and be tabulated in the Table 3.

Linde-Hampson Pre-Cooling

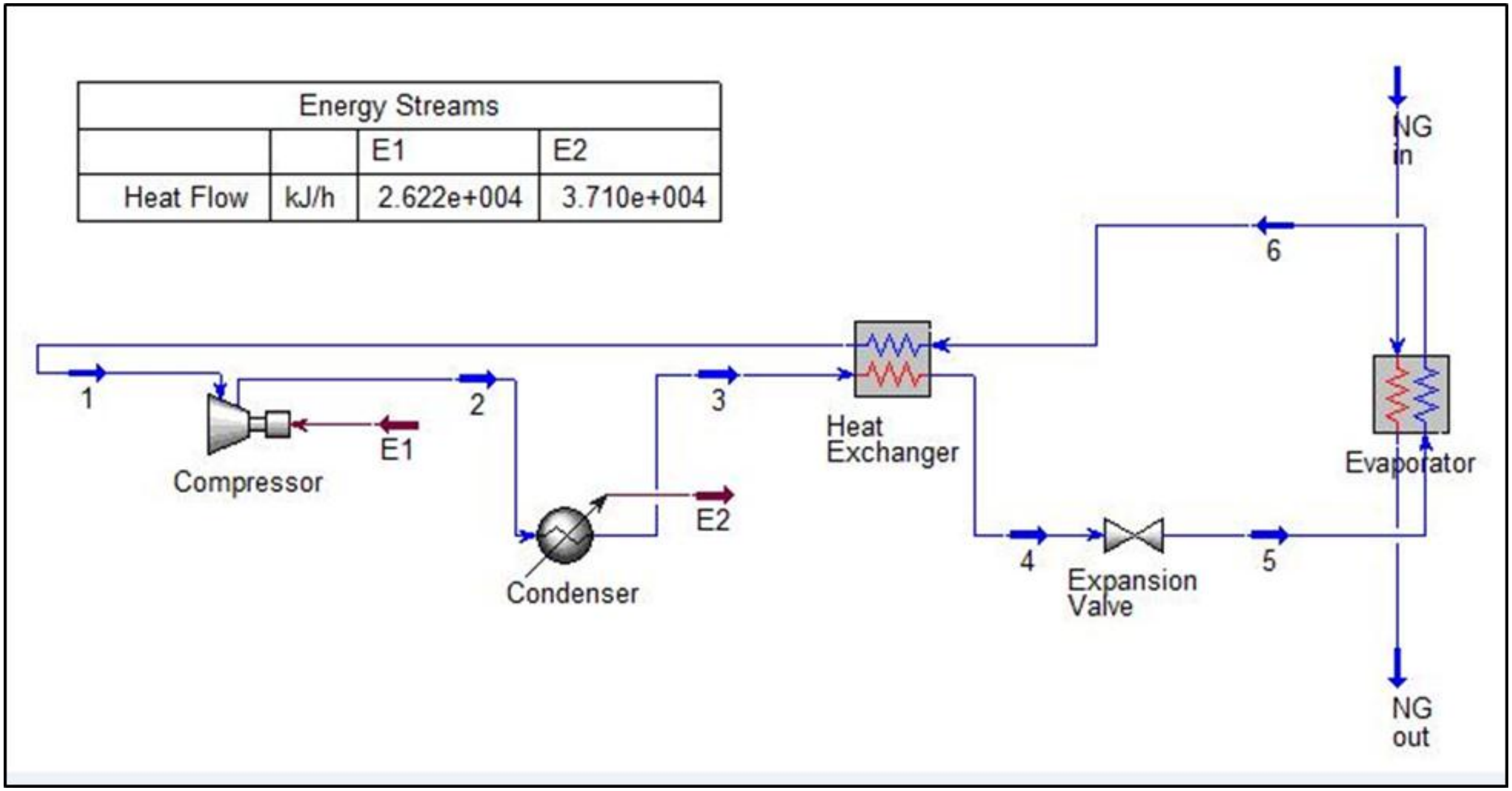


FIGURE 5: Linde-Hampson pre-cooling model in Aspen HYSYS

From the built model, the data is compared with other previous work.

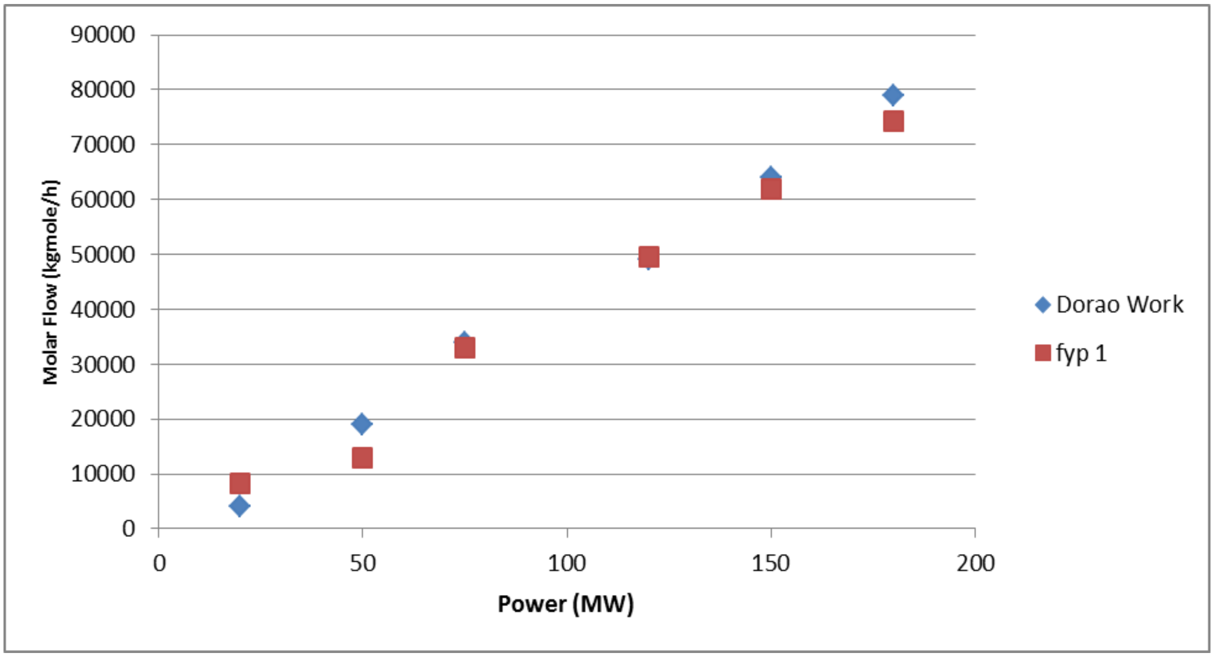
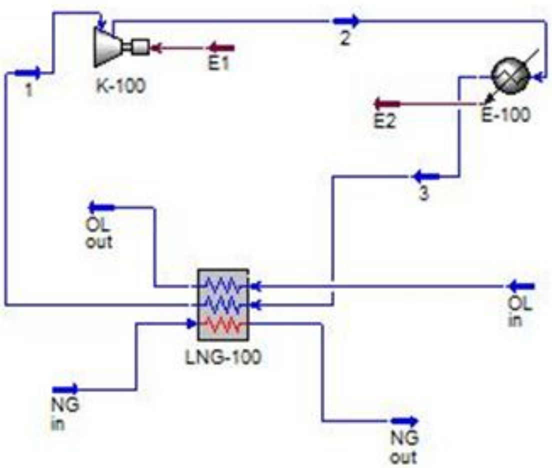


FIGURE 6: Molar Flow vs Power.

From tabulated graph in figure 4.2, the coefficient of determination is 0.98.

APCI



Energy Streams			
		E1	E2
Heat Flow	kJ/h	1.703e+004	2.497e+004

Compositions							
	NG in	NG out	1	2	3	OL in	OL out
Comp Mole Frac (Methane)	0.8970	0.8970	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0550	0.0550	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (n-Butane)	0.0010	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Nitrogen)	0.0290	0.0290	0.0000	0.0000	0.0000	1.0000	1.0000
Comp Mole Frac (Propane)	0.0180	0.0180	1.0000	1.0000	1.0000	0.0000	0.0000

Material Streams								
		NG in	NG out	1	2	3	OL in	OL out
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature	C	30.00	-36.00	20.00	118.8	-30.00	-67.11	10.50
Pressure	bar	40.00	38.00	1.260	10.91	1.260	1.260	1.260
Molar Flow	kgmole/h	5.647	5.647	2.268	2.268	2.268	3.570	3.570
Mass Flow	kg/h	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liquid Volume Flow	m3/h	0.3128	0.3128	0.1974	0.1974	0.1974	0.1240	0.1240
Heat Flow	kJ/h	-4.205e+005	-4.364e+005	-2.368e+005	-2.197e+005	-2.447e+005	-9569	-1544

FIGURE 7: Air-Product Chemical Inc (APCI) pre-cooling model in Aspen HYSYS

From the built model, the data is compared with other previous work.

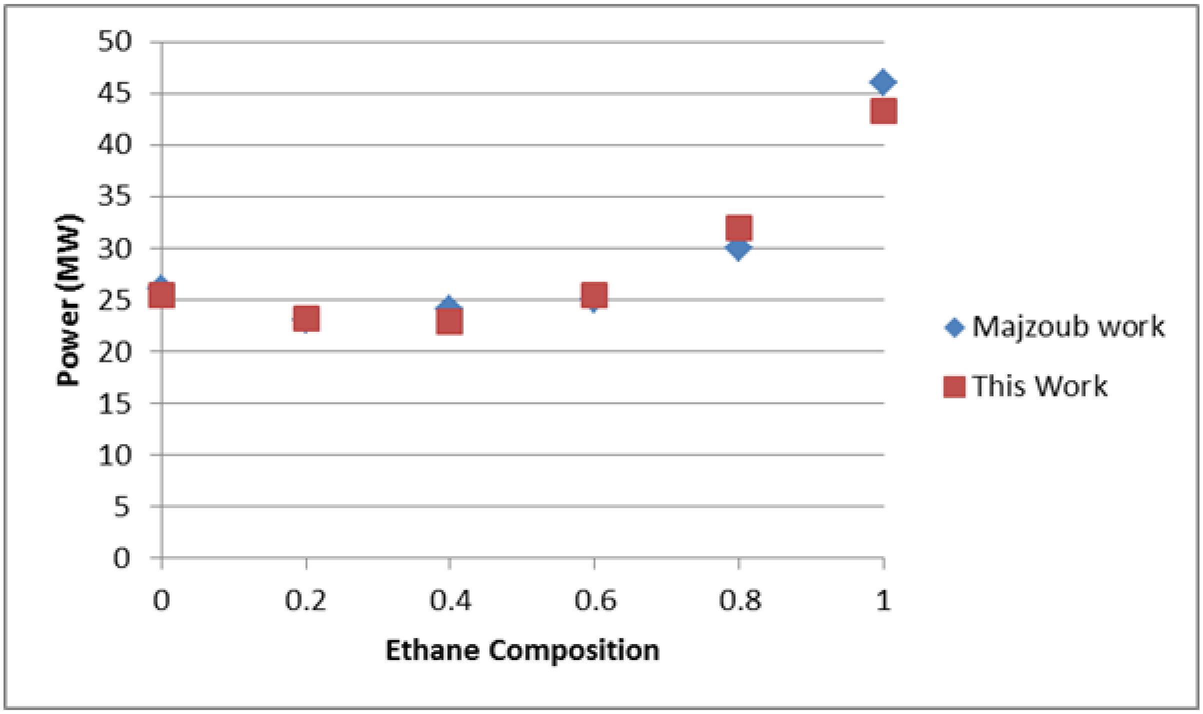
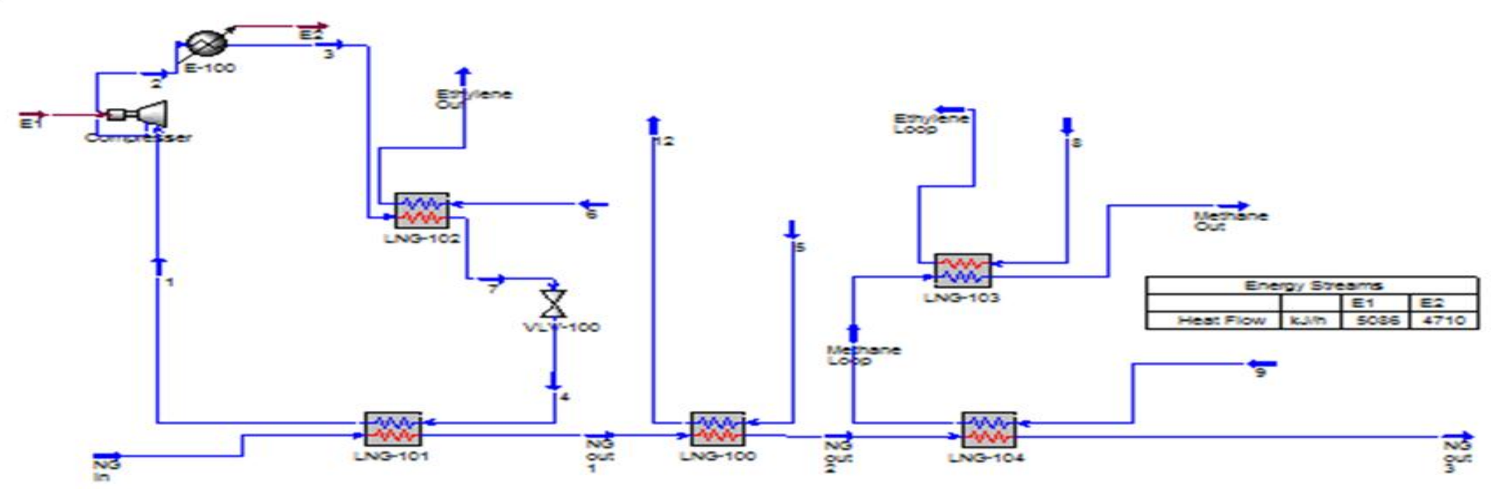


FIGURE 8: Ethane Composition vs. Power

From the tabulated graph, the coefficient of determination value 0.97. It is justifiable that the work data is fit to use.

CASCADE



Compositions									
	NG In	Methane Loop	Ethylene Loop	NG out 1	1	2	3	Methane Out	Ethylene Out
Comp Mole Frac (Ethylene)	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Comp Mole Frac (Methane)	0.8970	1.0000	0.0000	0.8970	0.0000	0.0000	0.0000	1.0000	0.0000
Comp Mole Frac (Ethane)	0.0550	0.0000	0.0000	0.0550	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Propane)	0.0180	0.0000	0.0000	0.0180	1.0000	1.0000	1.0000	0.0000	0.0000
Comp Mole Frac (n-Butane)	0.0010	0.0000	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Nitrogen)	0.0290	0.0000	0.0000	0.0290	0.0000	0.0000	0.0000	0.0000	0.0000
	4	8	9	NG out 2	NG out 3	12	5	6	7
Comp Mole Frac (Ethylene)	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	0.0000
Comp Mole Frac (Methane)	0.0000	0.0000	1.0000	0.8970	0.8970	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0000	0.0000	0.0000	0.0550	0.0550	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Propane)	1.0000	0.0000	0.0000	0.0180	0.0180	0.0000	0.0000	0.0000	1.0000
Comp Mole Frac (n-Butane)	0.0000	0.0000	0.0000	0.0010	0.0010	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0290	0.0290	0.0000	0.0000	0.0000	0.0000

FIGURE 9: Cascade pre-cooling model in Aspen HYSYS

For Cascade,

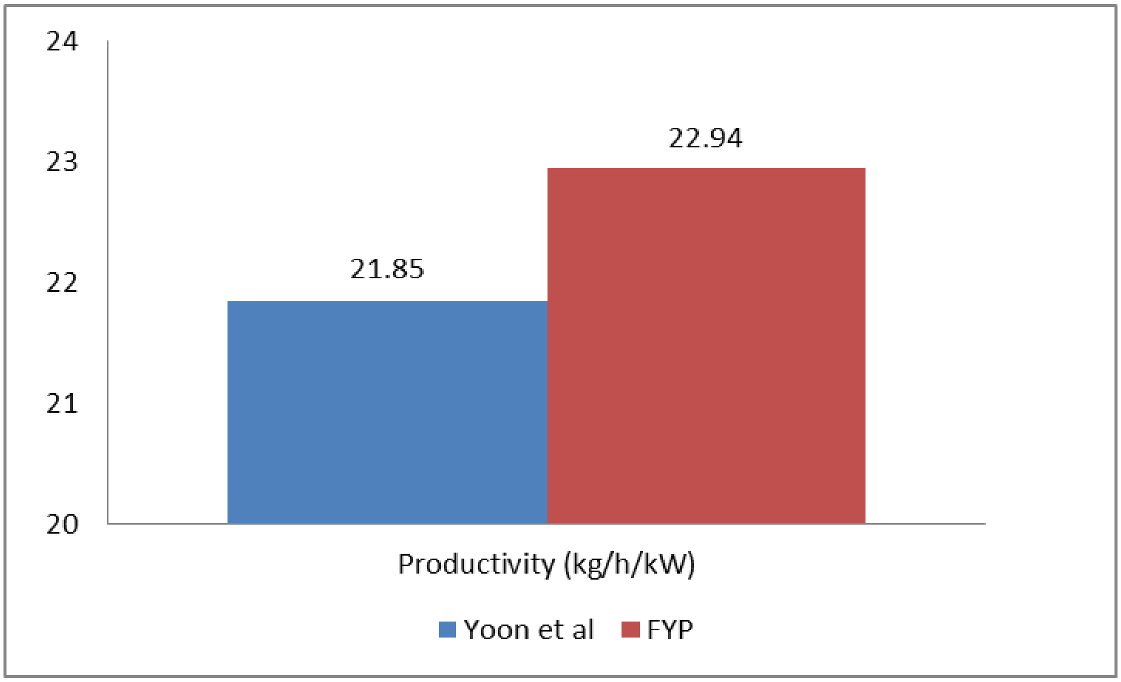


FIGURE 10: Cascade Productivity

This following equation is used in analysis,

For LMTD,

The log mean temperature difference (also known by its initialism LMTD) is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers. The LMTD is a logarithmic average of the temperature difference between the hot and cold streams at each end of the exchanger. The larger the LMTD, the more heat is transferred. The use of the LMTD arises straightforwardly from the analysis of a heat exchanger with constant flow rate and fluid thermal properties

$$LMTD = \frac{\Delta T_A - \Delta T_B}{ln\left(\frac{\Delta T_A}{\Delta T_B}\right)}$$

Where,

ΔT_A = temperature difference at end A

ΔT_B = temperature difference at end B

Effectiveness of a counter-current flow heat exchanger is calculated with,

$$E = \frac{1 - \exp[-NTU(1 - C_r)]}{1 - C_r \exp[-NTU(1 - C_r)]}$$

$$NTU = \frac{UA}{C_{min}}$$

Where,

NTU = Number of transfer unit

U = overall heat transfer coefficient

C = Heat capacity rates

For Specific Power,

$$\text{Specific Power} = \frac{\text{Total Heat Flow}}{\text{Refrigerent Mass Flow Rate}}$$

For Productivity,

$$\text{Productivity} = \frac{\text{Refrigerent Mass Flow Rate}}{\text{Power}}$$

TABLE 3: Analysis of Liquefaction.

Natural Gas Pre-cooling Technology	Flow Rate (kg/h)	Natural Gas Inlet Temperature (degC)	Natural Gas Outlet Temperature (degC)	Natural Gas Inlet Pressure (bar)	Natural Gas Outlet Pressure (bar)	Heat Flow inlet (kJ/h)	Heat Flow outlet (kJ/h)	delta H (kW)	Specific Power (kJ/kg)	Productivity (kg/h / kW)	Heat Exchanger LMTD	Heat Exchanger Effectiveness
APCI	100	30	-36	40	38	-420455.27	-436418.34	4.434	159.63	22.55	**7.83**	0.954
Linde-Hampson	100	30	-18.03	40	35	-420455.27	-431336.46	3.022	**108.8**	**33.09**	8.59	0.958
Cascade	100	30	-35	40	38	-420455.27	436145.78	4.358	156.91	22.94	8.411	0.933

The modified Linde-Hampson cycle is proposed. The proposed modification is as in figure 4.9. In this modification, valve (VLV-100) is added before heat exchanger. The natural gas parameters are set as the study model. In table 4.10, analysis of this modified process is shown. This modification achieved 0.8% increment in productivity and specific power is reduced by 14%. It also gives lower LMTD reading while changes in heat exchanger effectiveness by 0.002. Besides that, this model study also uses less amount of refrigerant to achieve target natural gas outlet temperature. In figure 4.8 the relation between refrigerant flow rate vs. natural gas outlet temperature is plot.

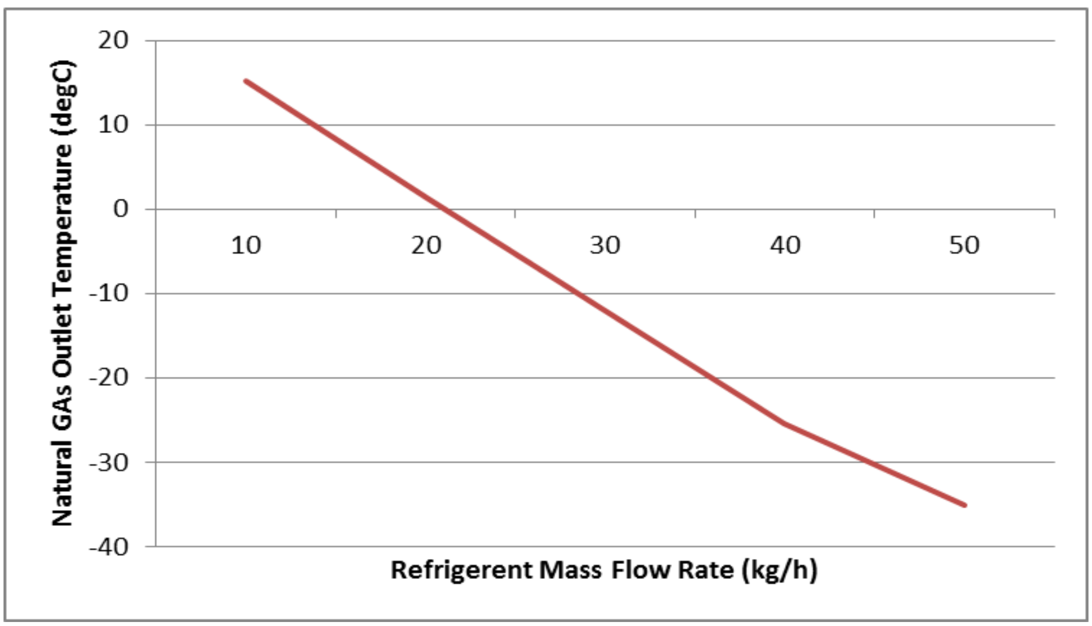


FIGURE 11: Refrigerant Mass Flow Rate vs Natural Gas Temperature Outlet

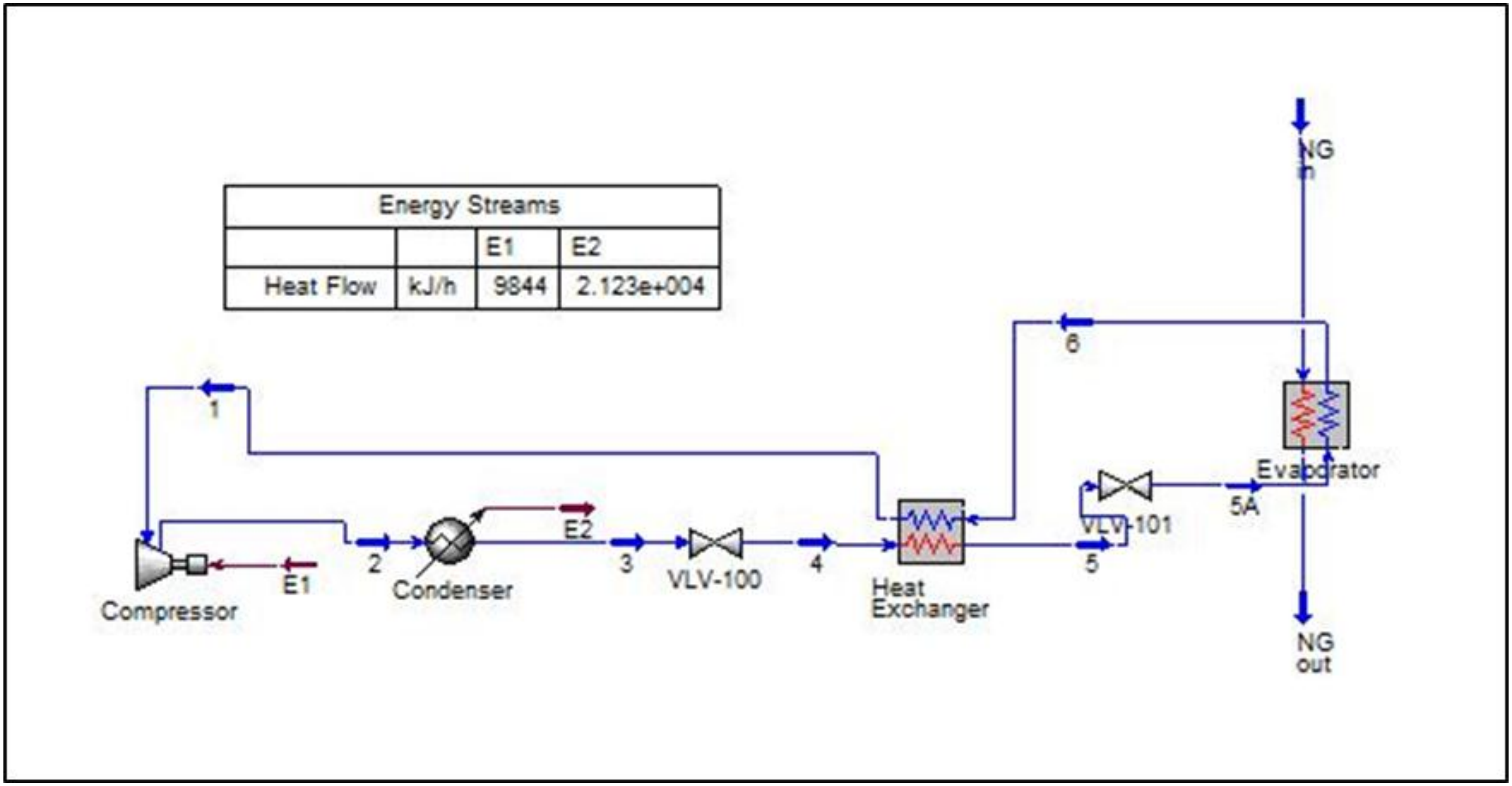


FIGURE 12: Modified Linde-Hampson in ASPEN HYSYS

TABLE 4: Modified Linde-Hampson and Linde-Hampson Analysis

Natural Gas Pre-cooling Technology	Flow Rate (kg/h)	Natural Gas Inlet Temperature (degC)	Natural Gas Outlet Temperature (degC)	Natural Gas Inlet Pressure (bar)	Natural Gas Outlet Pressure (bar)	Heat Flow inlet (kJ/h)	Heat Flow outlet (kJ/h)	delta H (kW)	Specific Power (kJ/kg)	Productivity (kg/h / kW)	Heat Exchanger LMTD	Heat Exchanger Effectiveness
Linde-Hampson	100	30	-18.03	40	35	-420455.27	-431336.46	3.022	108.81	33.09	8.59	0.958
Modified Linde	34.43	30	-18.03	40	38	-420455.27	-429806.14	-2.597	93.51	36.01	7.875	0.956

CHAPTER 5

CONCLUSION

The objective of this project has been achieved and modified liquefaction process has been proposed. Comparison of liquefaction processes is shown by built the simulation model. Validation of data is proved to be in acceptable value. This project has followed the scheduled properly.

The main differences related to technical performance between modified Linde-Hampson or conventional Linde-Hampson configuration for the precooling cycle of LNG process were addressed through this report. These configurations were studied for the precooling cycle; a single stage refrigerant process was used and it is found to be the less beneficial in terms of LMTD, heat exchanger effectiveness, productivity and specific power.

Optimization in Liquefaction is interesting and challenging work. Over the time, researcher looks up an opportunity to improve technology to save more energy and to make process more profitable. However due to the time constrain of this project, economic analysis between these two processes couldn’t be done.

To expand the work, economic analysis of this project will be a great idea. Study by using mixed refrigerant and relationship between other important parameter such as compressor workload and optimum temperature will make this study more understandable.

REFERENCES

1. Abdullah, A., and Amirl,M.(2010). *Optimization of propane pre-cooled mixed refrigerant LNG plant*. Applied thermal engineering. Volume 31. Issue 6-7. Pages 1091-1098.

2. Aspelund, T. Gundersen, J. Myklebust, M.P. Nowak, A. Tomasgard (2010), An optimization-simulation model for a simple LNG process Comput Chem Eng, 34 (10) pp. 1606–1617

3. BP statistical review of world energy 2013,. <http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy-2013.html> Retrived from 15 January 2014

4. Castillo, L and Dorao, C.A., 2012, "On the conceptual design of pre-cooling stage of LNG plants using propane or an ethane/propane mixture," *International Journal Energy Conversion Management* 65: 140-146.

5. Ho Nguyen , T. H. 2012, *Optimization of Operating Parameters in LNG AP-X Process* Bachelor Thesis, Universiti Teknologi Petronas, Malaysia.

6. HYSYS, A., User's Guide. Aspen Technology. Inc., Burlington, Massachusetts, 2007.

7. Jensen, J.,B., Skogested, S. (2009) *Single-cycle mixed-fluid LNG process Part II: Oprimal operation.* The 1st Annual Gas Processing Symposium. January 2009, Doha, Qatar.

8. Justin, Yu, Stephan and Leo K., *Innovation in Natural Gas Liquefaction technology For Future LNG Plants And Floating LNG Facilities* , Proceedings of International Gas Union Research Conference, 8 – 10 October 2011, Seoul

9. Majzoub, M.D. 2012, *Evaluation and Selection of the Precooling Stage for LNG Processes,* Master Thesis, Norwegian University Of Science and Technology, Norway

10. Marak, K., A., Neeraas, B., O. (2011) *Comparison of expander processes for natural gas liquefaction.* Retrieve on 21 February 2012 from www.kgu.or.kr/download.php?tb=bbs_017&fn=PO1

11. Norshahida, R. 2011, *Feasibility Study Of LNG Pre – Cooling System Using Carbon Dioxide As A Refrigerant,* Bachelor Thesis, Universiti Malaysia Pahang, Malaysia

12. Paul B. and Rob K.N, *Liquefaction Technology: Development through History* Proceedings of the 1st Annual Gas Processing Symposium, 10-12 January 2009, Doha

13. Pillarella, M., et al. The C3MR Liquefaction Cycle: Versatility for a Fast Growing Ever Changing LNG Industry. 2007

14. Rodgers, P., Mortazavi, A. (2012) *Enhancement of LNG plant propane cycle through waste heat powered absorption cooling.* Applied thermal engineering. Volume 48. Pages 41-53.

15. Seif P., S., 2011, *Sensitivity Analysis of Proposed LNG liquefaction process for LNG FPSO,* Master Thesis, Norwegian University Of Science and Technology, Norway

16. Steel, R.G.D, and Torrie, J. H. (1960). *Principles and Procedures of Statistics with Special Reference to the Biological Sciences.* McGraw Hill, pp. 187, 287.)

17. Speight J. G. 2007, *Natural Gas: A Basic Handbook*, Gulf Publishing Company, Houston.

18. Tusiani M.D. and Shearer G. 2007, *LNG:A Nontechnical Guide,* Penwell Corporation, Tulsa

19. Ulvestad, M.E., Transportation of natural gas: the impact of price variation on the choice between LNG and pipeline infrastructure, 2011, M.E. Ulvestad: Oslo.

20. Van de Graaf, J.M., Pek, B. *Large-capacity LNG trains – The Shell parallel mixed refrigerant process.* Business briefing: LNG review 2005 (2005)

21. Venkataratam G. 2008, *Cryogenic Mixed Refrigerant Process*, Springer, New York.

22. Wikipedia, Liquefied Natural Gas. < http://en.wikipedia.org/wiki/Liquefied_natural_gas> Retrived from 15 January 2014

23. Xiuli W. and Michale J. 2007, *Advance Natural Gas Engineering*, Gulf Publishing Company, Houston

APPENDIX

FYP I

Activity / Week (date)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	13/1	20/1	27/1	3/2	10/2	17/2	24/2		3/3	10/3	17/3	24/3	31/3	7/4	14/4
Topic Selection	■	■						Mid Semester Break							
Preliminary Research Work (Basis theory of project)		■	■	■											
Extended Proposal Submission					■	■									
Proposal Defense Presentation							■		■						
Seminar (Oral Presentation)									■	■	■				
Second Phase Research Work (Data Gathering for HYSYS simulation)					■	■	■		■	■	■	■	■		
HYSYS Simulation Trial		■	■	■	■	■	■		■	■	■				
Analysis HYSYS Simulation Result												■	■		
Summarized all analysis data into presentable formed													■		
Prepare Presentation Slides													■	■	
Submission Interim Report															■
Oral Presentation															■

FYP II

Activity / Week (date)	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
	19/5	26/5	2/6	9/6	16/6	23/6	30/6		7/7	14/7	21/7	28/7	4/8	11/8	18/8	25/8
Project Work Continues								Mid Semester Break								
Submission of Progress Report																
Project Work Continues																
Pre-EDX																
Submission of Draft Report																
Submission of Dissertation (soft bound)																
Submission of Technical Paper																
Oral Presentation																
Submission of Dissertation (Hard bound)																