Process Simulation and Analysis of Methane Refrigeration Cycle for LNG Vapour Recovery

by

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15712

Dissertation submitted in partial fulfilment of
the requirements of the
Bachelor of engineering (Hons)
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Unversiti Teknologi PETRONAS,

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Perak

CERTIFICATION OF APPROVAL

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Approved by,

____

(Associate Professor Dr. Shuhaimi Mahadzir)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

September 2015

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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MOHAMED OWNALLA MOHD. MEKKI

ABSTRACT

Liquefy Natural Gas (LNG) is the liquid phase from the Natural gas that extracted and purified. Natural Gas manufacturer turns gas to liquid to make more storage space and to make transportation easier. To turn the natural gas to liquid, the gas needs to cool down to -160°C. The real challenge is not to make the gas liquid the real challenge is to keep the gas liquid because the temperature difference with surround is big which is made some of the liquefied natural gas to vaporize again. Engineers found some techniques to re-liquefy the gas. This research paper explains some of the available thermodynamics cycles and how it works. Moreover, it will cover the economic side and how to optimize the process and make it more efficient with low consumption in money and energy. This study has been done through Aspen HYSYS (simulation base) for few cycles to choose the best cycle. This study will consider Malaysia environment as the surrounding environment for the project. This project will cover only the simulation method.

ACKNOWLEDGEMENT

I would like to start off by expressing my heartfelt gratitude to my supervisor throughout the period of Final Year Project, Associate Professor Dr. Shuhaimi Mahadzir, whose guidance and knowledge has benefited me extremely. And thanks for University technology PETRONAS for providing us the required tools and environment.

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CHAPTER 1
INTRODUCTION

1.1 Background

1.1.1 Liquefied Natural Gas (LNG)

Liquefied Natural Gas (LNG) is the extracted gas from the earth as result of compressed creatures for thousands of years. The LNG is main substance is Methane CH_4 as it considered as the highest percentage on it. The pure natural gas that extracted from earth has small amount of Mercury Hg, Carbone Dioxide, dust, acid gases, helium, water, CO_2, 3% Propane C_3H_8, 4% Butane C_4H_{10}, 6% Ethane C_2H_6 and 86% Methane CH_4. The first process is removing all the extra stuff to make it pure and ready for the process. The LNG always converted to liquid form to ease make storage and transportation process more efficient and easier. The reason for liquefying is to reduce the volume by 1/600 of the natural gas volume in the gaseous state. The LNG has no odour or colour it also considered non-toxic and non-corrosive material. The Hazards of the LNG are flammability after it flash to vapour (gaseous state), freezing because it stored and processed in very low temperature and asphyxia. The LNG is normally liquefied at approximately −162.75 °C (110.4 °K) and its maximum transportation pressure is usually around 25 kPa (4 psi).

The LNG process is started first by extracting the gas and transported to a processing plant. The raw gas will be purified by removing all the condensates such as water, mercury, oil, mud, dust as well as other gases such as helium He, CO_2 and H_2S. The amounts of mercury will be traced from the gas stream to keep mercury from amalgamating with aluminium in the cryogenic heat exchangers. The gas is then cooled down in stages until it form Liquefied Natural Gas (LNG). After that, the LNG will be kept in storage tanks until it loaded and shipped.

LNG has advantages of less volume comber to the normal compressed natural gas that is because the density of Liquefied Natural Gas is 2.4 greater than that of Compressed

Natural Gas. That is makes LNG more efficient to transport for far distances where pipelines is not easy to install or not economic to install it. Therefore, special designs for the LNG tanks and ships and pipelines are used in liquefying and transport the LNG. The reason for transporting the LNG for long distance is to splay the natural gas to different markets or from the platform to the market after it gasified again. The natural gas can be used in in energy motors, electricity, cooking, heating and some transportation use natural gas as fuel. In 2020 the percentage of producing LNG will increase to 10% of the worldwide production of the crude oil.

1.2 Problem statement

The Natural Gas after being extracted from the earth(1) will be go through treatments stages and liquefying process (2) to make it easier to store and to be transported . The problem that faces a lot of companies is to store (3) the Liquefied Natural Gas because the big amount of LNG will boil of (Vaporized) which is considered as lost and a safety issue. This is because the vapour will increase the pressure in the storing chamber or the tank. Therefore, refrigeration process (4) has been attached to the LNG tanks to re-liquefy the boil of gas to be used again. The refrigeration process can be way expensive if not been studies well to optimize the process and the cost.

The refrigeration process has been founded long time ago but since it been founded it has been developed much. That is because it cost a lot the production amount is very low more over it need as much as smaller size as possible because in some cases it has to be installed in the platform in the middle of the sea to ease the transportation of it to the land specially when the pipeline can cost a lot for long distances. By 2020 the LNG production should be increased to 10% the current process could not take this high increase of production. Therefore farter studies about this cycle should be done to get the optimum solution which is has low cost high production and small size of equipment.

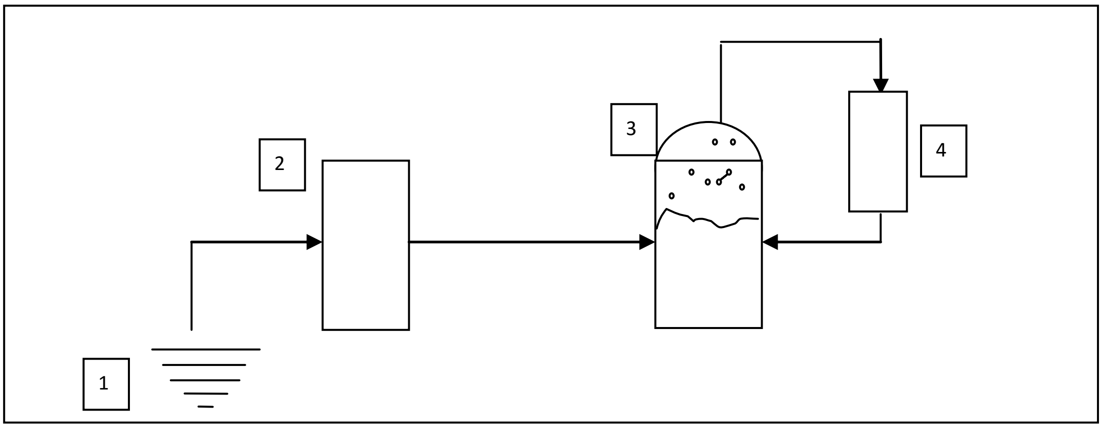


FIGURE 1.1 General Natural gas process

1.3 Objectives and Scope of study

1.3.1 Objectives

As solution for the problem statement the objective from this research is to build and simulate refrigeration system for LNG. This simulation should fulfil the optimum condition and discuses the problem that can face the real model. This objective is will be obtained through the flowing sub objectives:

- Do full study about the available technologies
- Do simulation for some of it with optimum condition for each
- Do some adjust in cycles if needed Optimize the process
- Do full comparison between them.
- Chose the best cycle

1.3.2 Scope of study

This project will cover only the LNG refrigeration process according to different studies. This project will be in simulation biases only. The environment that surrounds the project is Malaysia environment.

CHAPTER 2
LITERATURE REVIEW

To liquefy the natural gas the temperature of the gas should be reduced to -160 ^{o}C. liquefying process is not considered as big issue but to store the gas in liquid form is considered as problem because the temperature difference between LNG and the surrounding is about 197 ^{o}C. the design of the well thickness and the material has limitation because it can affect the amount of the profit that can come from the business. However, there is no 100% adiabatic system or close system to keep the temperatures constant there for large amount of the gas is vaporized by the factor of time which will lead to high pressures in thank and that's make people to release some of it to reduce the pressure and make more space so the boil of gas consider as lose of profit. Moreover, the natural gas in the vapour form is highly flammable that is why its need to be kept in liquid form. Therefore, engineers install refrigeration system attach to the LNG tanks keep the gas in the LNG form as much as it can. There is a lot of studies have been done about the refrigeration of the LNG. This gives us variety of processes and cycles for refrigeration of the LNG. All these models have one target which is best thermo economic model.

Form early of starting the liquefying the natural gas the methods is of cooling the gas and the refrigeration of the LNG are enhancing day after day. Most of the models that are have been build are targeted to get the highest production capacity with the best process efficiency. Most of the cooling and refrigeration models are closed loop thermodynamics cycles to prevent from high power consumption and to lower the entropy wastes due to temperature difference between the refrigerant and the LNG. Around the word there are different techniques are used in different liquefying platforms. Each platform is using the best technique for it according to amount of production, condition of the plant and the available technique during building up the plant. Some of these techniques are surmised bellow:

2.1 Liquefaction system based on reversed-Brayton cycle

The study reversed-Brayton cycle is focused in Methane gas as it considered as the primary component in natural gas by 45% to55%. Therefore, focused to liquefy the Landfill Gas (LFG) (Methane) to be stocked and transported easily in form of liquefied natural gas (LNG) with high energy density at a mild pressure. The transforming process of the LFG to LNG is implicated of sundry different a technical matter one of these issues is efficient cryogenic refrigeration to constantly liquefy the methane in a distributed scale. Barclay et al. stated about the term of ‘‘distributed scale” refers to liquefiers with LNG rate of production of 160–2350 L/hour. (Ho-Myung et al., 2009)

Reversed-Brayton cycle is methane liquefaction system which has thermodynamic efficiency, compactness and small size. Moreover, the advantage feature of reversed-Brayton cycle is that the concentration and flow rate of the feed gas have less effect on the thermodynamic performance of the cycle and more adaptable to contain various purification modules. (Ho-Myung et al., 2009)

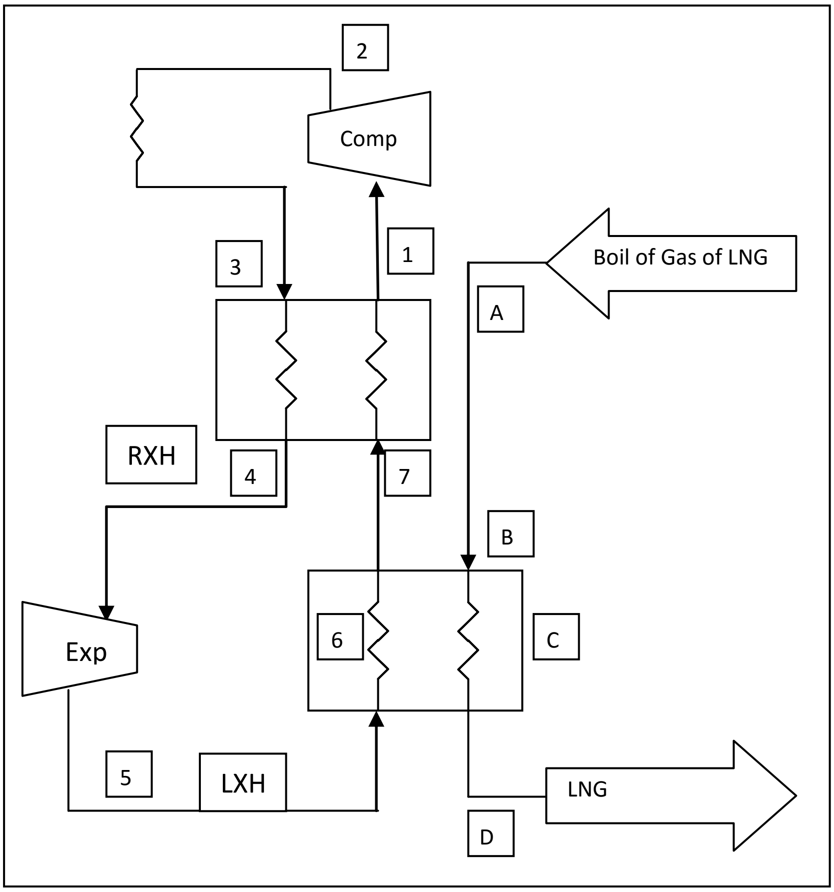


FIGURE 2.1 Reversed-Brayton Cycle

Figure 2.1 above shows the reversed-Brayton cycle of liquefying the LNG. In stage 5 for the cool gas from expander enter the heat exchanger to gain heat at stage 6 from the LNG gas vapour to produce LNG gas (D). This counter current heat exchanger known as Liquefying Heat Exchanger LHX. There is another heat exchanger in the system called Recuperative Heat Exchanger (RHX). The function of this heat exchanger is to reduce the temperature of the outlet of the coolant from the LHX to be ready for compression process. (Ho-Myung, C et al., 2009)

2.2 Liquefaction system based on modified reversed-Brayton cycle

Modified reversed reversed-Brayton cycle is similar to reversed-Brayton cycle in its main specification but with higher efficiency. The reason behind that is the gas vapour of LNG will enter The RHX before Entering the LHX to make the gas ready for the next stage. ΔT between the coolant and the LNG in the LHX will be lower than it is in the standard cycle. Figure 2.2 shows the Modified reversed reversed-Brayton cycle. (Ho-Myung, C et al., 2009)

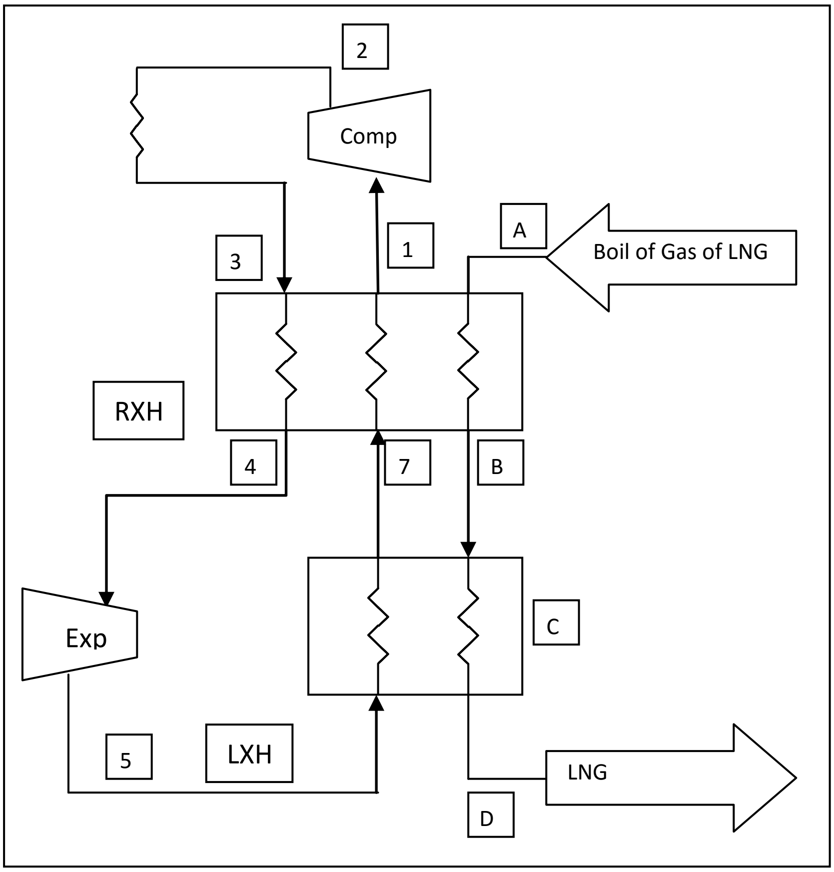


FIGURE 2.2 Modified reversed reversed-Brayton cycle

2.3 Liquefaction system based on modified Joule (Linde) cycle

One of the wide using in the now day's methods for the LNG refrigeration plan is Joule cycle (Linde cycle). There were many researches have been published about Joule cycles in the last few years. Starting from 1985 Vos did some studies about the capability of some heat engines at the higher power status. After that in 1989 Bejan constructed the notion of heat transfer-irreversible refrigeration plants. In 1998 Sahin did full study about the maximum power density of an irreversible Joule-Brayton engine. The study shows also a comparative performance of irreversible regenerative reheating Joule-Brayton engines.. (Hoseyn Sayyaadi et al,2010)

The above mentioned researches were mostly dedicated the energetic and thermodynamic sides of the Joule (Linde) cycle. However, the researches did not focus a lot in the advantage features of the economic part of Joule cycle. However, some economic feature analysis has been done for other cycles like Brayton refrigeration cycle which have been done by Tyagi et al. (2004, 2005, 2006a, b). Form this point the term of Thermo economics started. A Thermo economics study gives a strong way to merge between the economic aspects and optimization of energy systems. Thermo economics is a part of thermodynamic in which merges the exergy analysis with economic. The main aim of this theory is to optimize the process from all aspects to get the best result. (Hoseyn Sayyaadi et al,2010)

Figure 2.3 shows Schematic diagram of Liquefaction system for Boil of gas based on modified Joule (Linde) cycle. The beginning, the N_2 gas is pumped to three compressors and after that the N_2 goes through a heat exchanger (H-E1). A parcel of the N_2 gas is split from the main stream, and it will go through expender to expend the gas and cool it down, and after that he the expend gas will join the retuned stream before the second heat exchanger (H-E2). While the main stream pumped to (H-E2) and (H-E3) 3^{rd} heat exchangers. After the (H-E3) the stream will enter the condenser of the boil of Gas after the N_2 stream had been expanded in the expansion valve. In the condenser, the boil of LNG will condense again after it exchanges the heat with the nitrogen stream. After that the LNG returned to its tank. From the other hand the N_2 vapour will flow out from the condenser to go through the heat exchanger number 3 for to make the gas ready for the cooling process. According to some researches the temperature of the N2 that entered the heat exchanger number 3 is -35 °C and the lower pressure of the N_2 cycle is defend as 14 bar. The efficiency of the expender and compressors are evenly defined as 70%. In the LNG boil of gas cycle, the temperature for entering LNG to the compressor #4 is set to -120 °C, and the temperature of the exiting LNG in the condenser is set to -161 °C and the adiabatic efficiency of the compressor number four is set to be 70%as well. (Hoseyn Sayyaadi et al,2010)

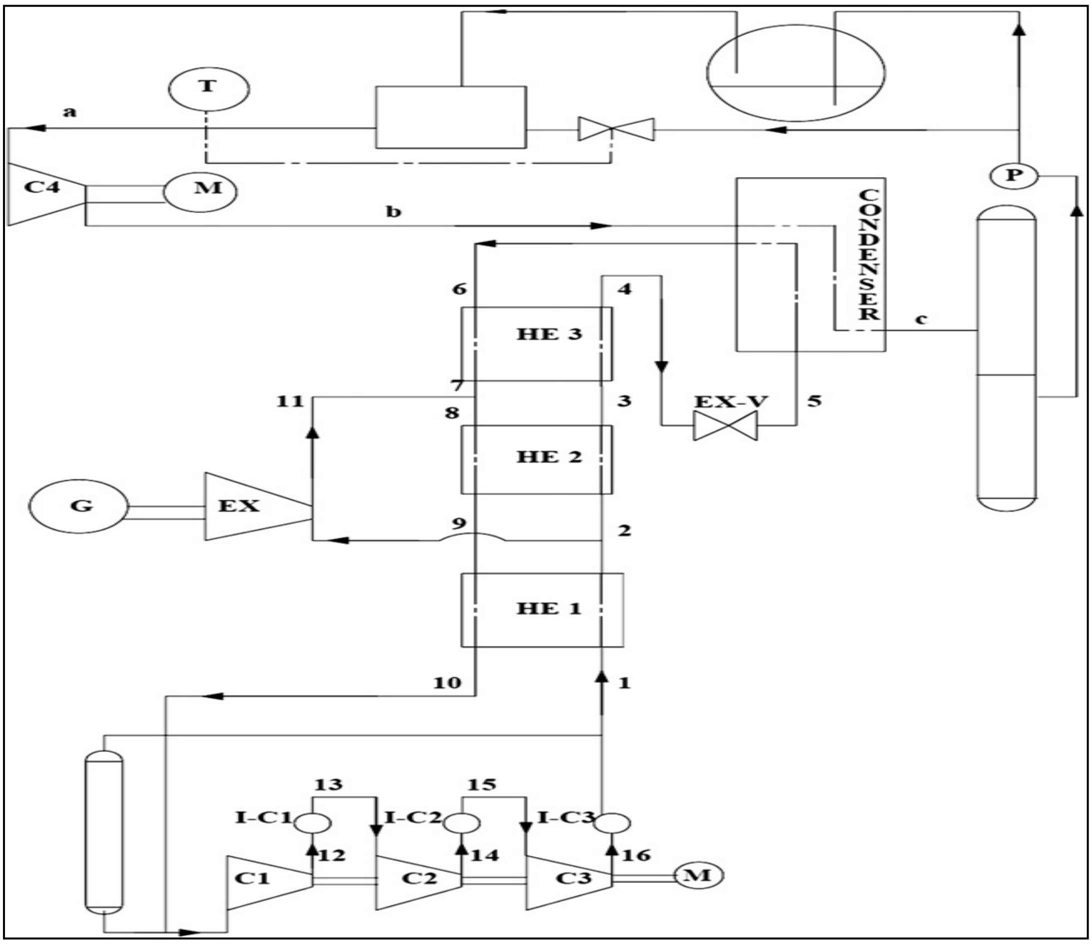


FIGURE 2.3 Liquefaction system based on modified Joule (Linde) cycle

There is a lot of study can be done about LNG boil of gas refrigeration cycle to get more efficient , more thermo economic and optimum system therefore this topic has been chosen.

CHAPTER 3
METHODOLOGY

3.1 Methodology

To achieve the objective of this research some method should be flowed. The method started with having a good study about the natural gas and it contains and how it behaves in gas and liquid form. After those studies about some refrigeration cycles and how to it works should be done. After have good studies about the refrigeration cycles. Then simulation for some of the cycles should be done to see how it will work and have better analysis. The cycle will be compared and evaluated with the other available cycles. Bellow is the summary of the methodology in point form:

- Analyze and study refrigeration system and the systems around it and study about the LNG (Continuous method should be happing during the all of the FYP process)
- Use the knowledge to chose modify one of the LNG cycle
- Do some mathematical calculation to check the possibility of the new process
- Start the simulation by using HYSYS for few cycles.
- Define the criteria of good cycle
- Do comparison between temperature profile of all cycles and optimize them
- Calculate the energy efficiency of each cycle
  Using the following equations

$$\text{Energy losses} = \Sigma\ \text{Source} - \Sigma\ \text{sink} \qquad (1)$$

$$\eta = \frac{\Sigma \text{sink}}{\Sigma\ \text{Source}}\ x\ 100 \qquad (2)$$

- Make weightage table to choose best cycle out of the number of cycles

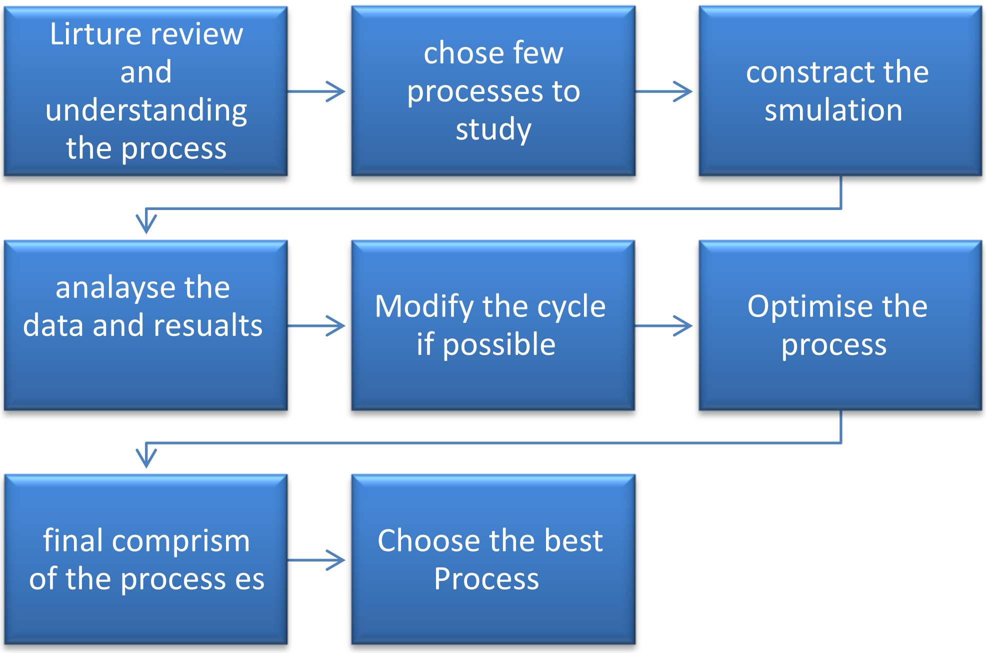
TABLE 3.1 Example of the weightage table

	Cycle 1	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle ….n**
Energy Efficacy (4-1)					
Insulation Price (4-1)					
Overall size (4-1)					
Easy to adjust (4-1)					
Total					

So the highest score in the weightage table have to be n

- Analyze the simulated process and compare it with previous studies with same criteria that have been used before for choosing the best cycle (efficiency, area temperature profile).

3.2 Process flow chart



3.3 Gantt Chart

TABLE 3.2 Final Year Project Gantt chart

No	Detail/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues															
2	Submission of Progress Report															
3	Project Work Continues															
4	Pre-SEDEX															
5	Submission of Draft Final Report															
6	Submission of Dissertation (soft bound)															
7	Submission of Technical PaperReport															
8	Viva															
9	Submission of Project Dissertation (Hard Bound)															

On going process

Done process

TABLE 3.3 The project Gantt chart

No	Detail/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	4 smulation with ther calculation	■	■	■	■	■	■	■								
2	Submission of Progress Report								●							
3	2 mores simulation with final comparison between the processes								■	■	■	■	■			
4	Pre-SEDEX										●					
5	Submission of Draft Final Report											●				
6	Submission of Dissertation (soft bound)												●			
7	Submission of Technical PaperReport												●			
8	Viva													●		
9	Submission of Project Dissertation (Hard Bound)															●

3.4 Tools

- ASPEN HYSYS
- Spreadsheet

CHAPTER 4

RESULT AND DISSUCSION

After good study about Liquefied Natural Gas (LNG) and its refrigeration process few cycles have been chosen to be simulated and analysed. This Reversed Brayton cycle, Modified Reversed Brayton cycle and Linde cycle have been chosen to simulate. The best result cycle from this cycle has been modified to get better cycle.

This analysis and result has been done two stages. The first stage is using other researches data to construct the system and the second stage is after analyse and find the optimum condition for the cycles.

4.1 Simulated cycles before Optimization

4.1.1 Reversed- Brayton cycle

The first simulation is about Brayton cycle. The reversed- Brayton cycle has be simulated by using N2 as refrigerant and the boil of LNG is defined as 87% methane , 6% ethane, 4% i-Butane and 3% and after that has been modified by hysys after set the stream temperature as -150˚C and the vapour rate. The fluid package that has been used is pang-Robinson. Figure 4.1 shows the process flow sheet from hysys.

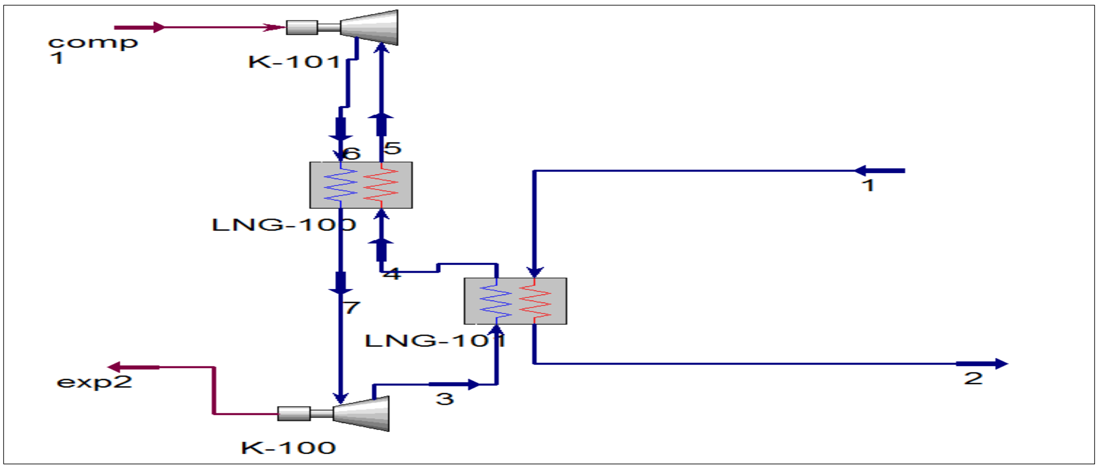


FIGURE 4.1 `Brayton Cycle simulation in hysys

As we can see from the simulation the re-liquefying area is in LNG-101 only and the rest is the refrigerant cycle. Figure 4.2 shows the refrigeration the temperature profile of the refrigerant and the LNG in the heat exchangers before and after it enters the heat exchanger to illustrate the change in the temperature. The temperature difference between 2 and 3 in bottom side of the heat exchanger LNG101 is 23˚ and the temperature difference between 1 and 4 in LNG 101 is 27.765˚C so the ΔT reduces by 4.765˚C along the heat exchanger. That shows good heat transfer between the 2 streams but it can be enhance more.

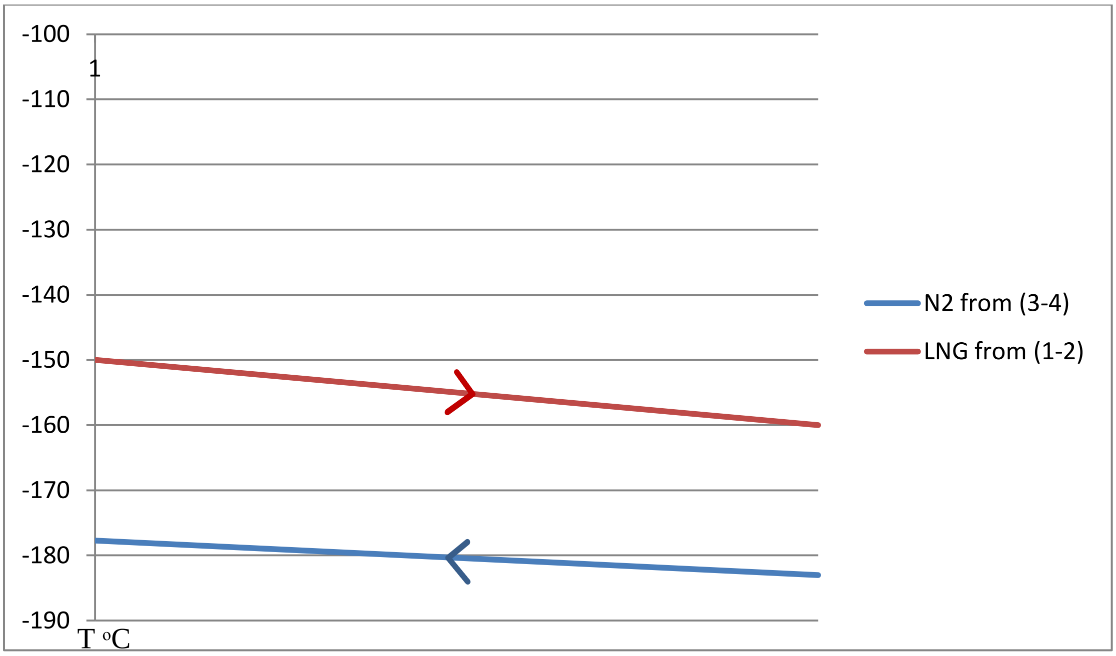


FIGURE 4.2 The temperature changes before and after heat exchanger LNG-101

The Figure 4.3 shows the N_2 temperature changing in the second heat exchanger for the refrigerant cycle. The temperature difference between 4 and 6 in LNG-100 is about 20.336˚C while the temperature difference between 5 and 7 is almost the same -20.176. The heat transfer in this heat exchanger is very low therefore it needs small modification to get better result on it.

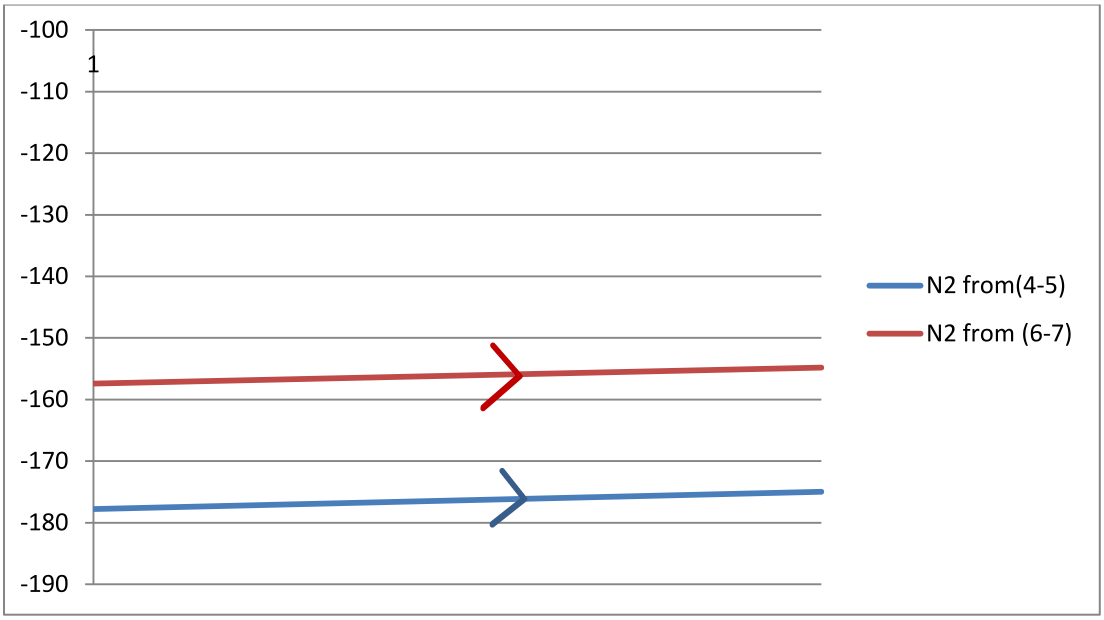


FIGURE 4.3 The temperature changes before and after heat exchanger LNG-101

Table 4.1 shows the main date for each stream in the system. The pressure of the LNG kept at 1atm as its stored at the atmospheric pressure while the pressure of the N_2 is 300kpa and I will be compressed to 900Kpa in the compressor and will expand again to 300Kpa to make the N_2 cold again (-183). The compressor changed the heat flow from 351824KJ/h-325054KJ/h (ΔH 26770KJ/h). While the expander change the heat flow from 330089- 366474KJ/h (ΔH -36385KJ/h).

TABLE 4.1 Material Streams Data from Hysys

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vapour Fraction		1	0	1	1	1	1	1
Temperature	*C*	-150	-160	-183	-177.7	-175	-157.4	-154.8
Pressure	*kPa*	101.33	101.33	300	300	300	900	900
Molar Flow	*Kg mole/h*	2.2457	2.2457	60	60	60	60	60
Mass Flow	*kg/h*	66.6	66.6	1680.8	1680.8	1680.8	1680.8	1680.8
Liquid Volume Flow	*m3/h*	0.158	0.158	2.0844	2.0844	2.0844	2.0844	2.0844
Heat Flow	*kJ/h*	251465	261080	366474	356859	351824	325054	330089

Table 4.2 illustrate the composition of the components in hysys in each stream.

TABLE 4.2 Compositions of the Material in the stream from hysys

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Comp Mole Frac (Methane)		0.639706	0.639706	0	0	0	0	0
Comp Mole Frac (i-Butane)		0.294118	0.294118	0	0	0	0	0
Comp Mole Frac (Nitrogen)		0	0	1	1	1	1	1
Comp Mole Frac (Propane)		0.022059	0.022059	0	0	0	0	0
Comp Mole Frac (Ethane)		0.044118	0.044118	0	0	0	0	0

To have another view for efficiency of the cycle the first low of the thermodynamics has been applied to the cycle to illustrate the process efficiency in term of energy in and out. The table 3 shows the date in form of energy

TABLE 4.3 Heat transfer direction

Source	**Sink**	**Sink**	**Sink**	**Source**	**Source**
1 to 2	**3 to 4**	**4 to 5**	**5 to 6**	**6 to 7**	**7 to 3**
9615.354006	9615.354	5034.881	26769.42	5034.881	36384.77

Σ Source = 51035.01 *kJ/h* $\eta = \frac{\Sigma sink}{\Sigma\, Source}\ x\ 100 =$

Σ Sink = 41419.65 *kJ/h* 81.1593%

By using equation 1 and 2 the energy loss can be calculated as shown below.

Energy losses = Σ Source – Σ sink = (1)

= 92454.66 *kJ/h*

$\eta = \frac{\Sigma sink}{\Sigma\, Source}\ x\ 100 =$ (2)

= 81.1593%

The total amount of energy in is 51035.01 KJ/h while the energy has been used its only 41419.65 KJ/h so about 92454.66 KJ/h is amount of the lose energy. However, the process efficiency is not too bad it is about 81.16%.

4.1.2 Modified reversed-Brayton cycle

The second hysys that has been simulated is modified reversed-Brayton cycle. Figure 4.4 shows the flow sheet of the reversed-Brayton cycle that has been simulated in hysys. The all parameters of the second simulation are the same as the first cycle. The only change is the stream number 1 is pre-cooled in the heat exchanger (LNG-100) before it enters the main heat exchanger (LNG-101).

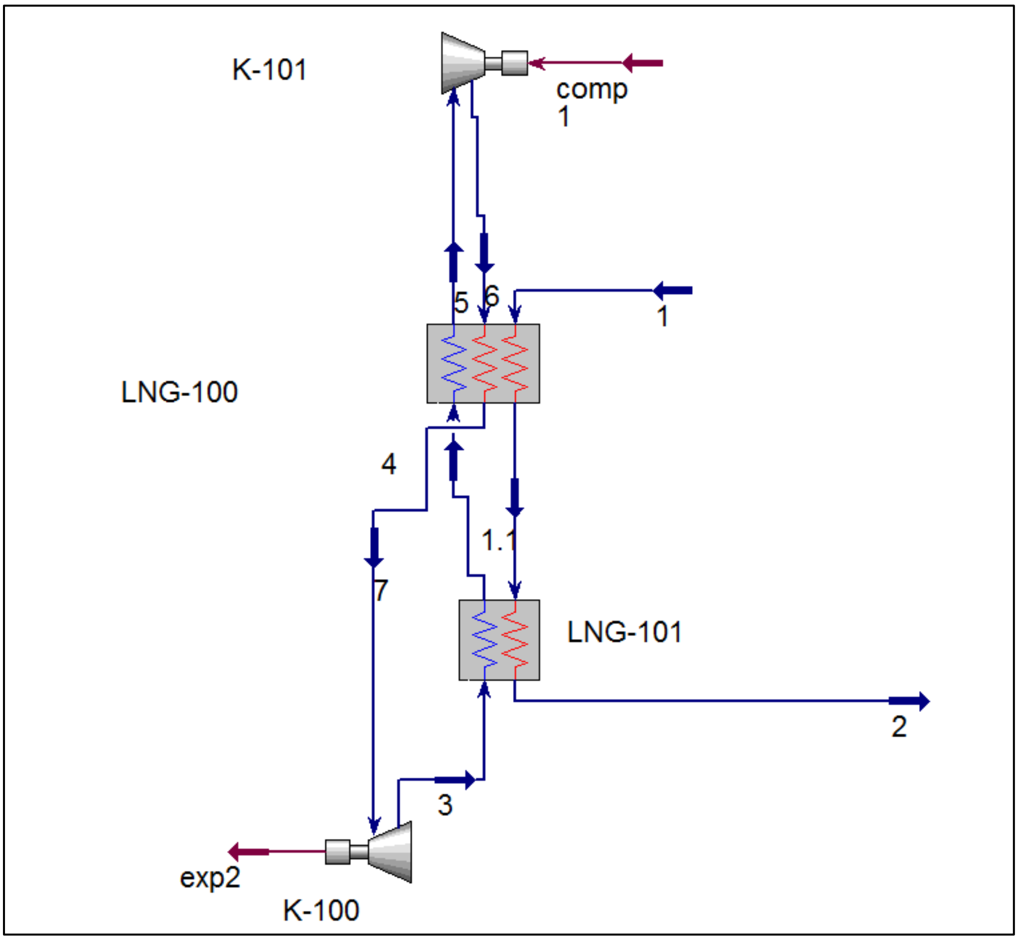


FIGURE 4.4 Modified reversed- Brayton cycle

Figure 4.5 shows the temperature changing before and after the heat exchanger LNG-101 of the LNG stream 1.1- 2 and the stream 3-4 of the N_2. The ΔT between the LNG and N_2 modified reversed Brayton cycle is smaller than ΔT in the normal reversed Bryaton cycle.

The temperature difference between 1.1 and 4 in LNG-101 is about 26.37˚C and the temperature difference between 2 and 3 is 23˚C. So the advantages of this cycle is the ΔT in between 1.1 and 4 is better than the cycle in Figure 4.4.

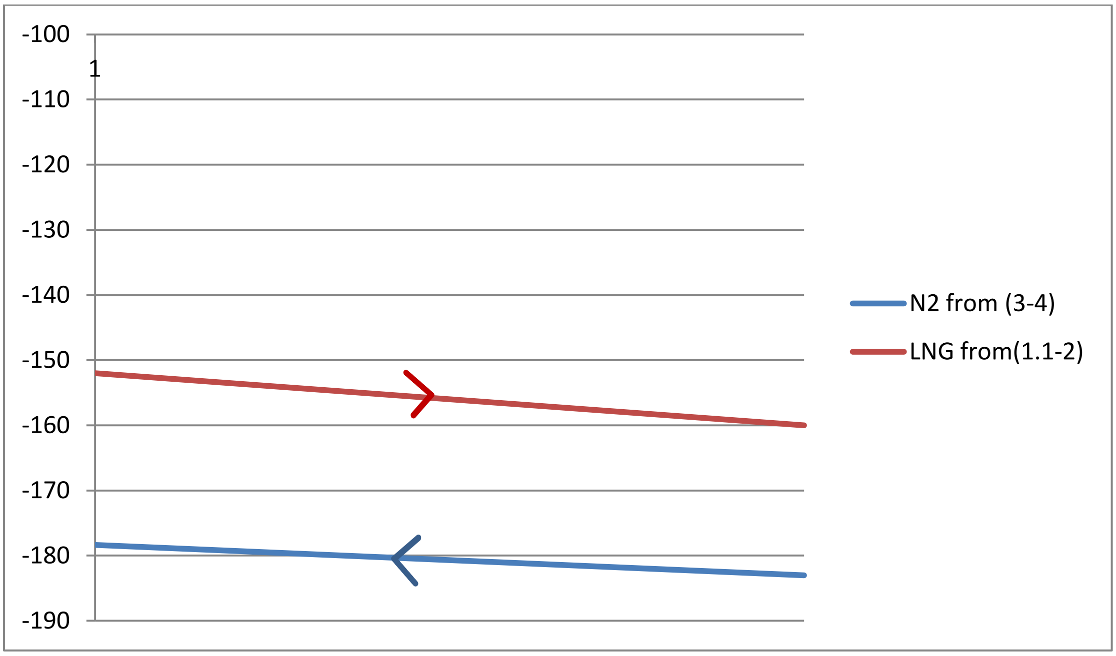


FIGURE 4.5 Temperature changes before and after heat exchanger LNG-101

The Figure 4.6 shows the temperature changes before and after heat exchanger LNG-100 for LNG stream 1-1.1 and N_2 stream 4-5 and 6-7. The 6-7 and 4-5 are acting as pre cooler for the LNG stream to make the ΔT smaller for the next heat exchanger.

The temperature difference between 5 and 1 in LNG-100 is 25 ˚C and the temperature between 5 and 6 is 17.571˚C while the temperature difference between 6 and 1 is 7.429˚C. In the other side of the heat exchanger the temperature difference between 4 and 7 is 23.546 ˚C and the temperature difference between 4 and 1.1 is 26.37 while the temperature difference between 1.1 and 7 is 2.824˚C.

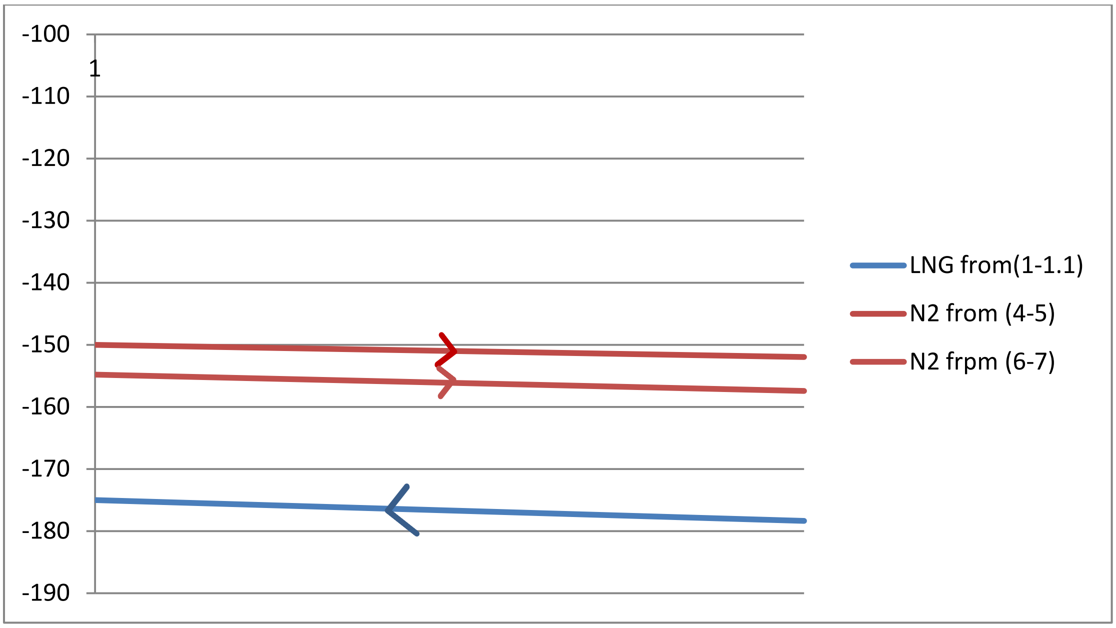


FIGURE 4.6 Temperature changes before and after heat exchanger LNG-100

Table 4.4 shows the main date for each stream in the system. The pressure of the LNG kept at 1atm as its stored at the atmospheric pressure while the pressure of the N_2 is 300kpa and I will be compressed to 900Kpa in the compressor and will expand again to 300Kpa to make the N_2 cold again (-183). The compressor changed the heat flow from 351824 KJ/h-325054 KJ/h (ΔH 26770KJ/h). While the expander change the heat flow from 330089- 366474KJ/h (ΔH -36385KJ/h).

TABLE 4.4 Material Streams date from hysys

	Unit	1	2	3	4	5	6	7	1.1
Vapour Fraction		1	0	1	1	1	1	1	0.92
Temperature	*C*	-150	-160	-183	-178.37	-175	-157.43	-154.82	-152
Pressure	*kPa*	101.325	101.325	300	300	300	500	900	101.325
Molar Flow	*Kg mole/h*	2.24565	2.24565	60	60	60	60	60	2.24565
Mass Flow	*kg/h*	66.6	66.6	1680.78	1680.78	1680.78	1680.78	1680.78	66.6
Liquid Volume Flow	*m3/h*	0.15798	0.15798	2.08437	2.08437	2.08437	2.08437	2.08437	0.15798
Heat Flow	*kJ/h*	251465	261080	366474	357964	351824	325054	330089	252570

TABLE 4.5 Compositions of the streams from hysys

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1.1**
Comp Mole Frac (Methane)		0.639706	0.639706	0	0	0	0	0	0.639706
Comp Mole Frac (i-Butane)		0.294118	0.294118	0	0	0	0	0	0.294118
Comp Mole Frac (Nitrogen)		0	0	1	1	1	1	1	0
Comp Mole Frac (Propane)		0.022059	0.022059	0	0	0	0	0	0.022059
Comp Mole Frac (Ethane)		0.044118	0.044118	0	0	0	0	0	0.044118

To have another view for efficiency of the cycle the first low of the thermodynamics has been applied to the cycle to illustrate the process efficiency in term of energy in and out. The table 6 shows the date in form of energy

TABLE 4.6 Heat transfer direction

Source	**Source**	**Sink**	**Source**	**Sink**	**Sink**	**Source**
1 to 1.1	**1.1 to 2**	**3 to 4**	**4 to 5**	**5 to 6**	**6 to 7**	**7 to 3**
1105.426355	8509.928	8509.928	6140.307	26769.42	5034.881	36384.77

Σ Source = 52140.43 KJ/h

Σ Sink = 40314.23 KJ/h

To calculate the energy loss and the efficiency equation 1 and 2 has been used.

Energy losses = Σ Source – Σ sink = (1)

= 11826.21 KJ/h

$$\eta = \frac{\Sigma \text{sink}}{\Sigma \text{ Source}} \; x \; 100 = \qquad (2)$$

= 77.32%

As the data analysis show that energy needs to change between the stream by the compressor and the expander is the same between the two cycles. So the only advantages of the modified cycle is the ΔT in the second heat exchanger is lower means we can use smaller heat exchanger than the first one. Therefore, more cycles have to be study to find the best combination of equipment.

4.1.3 Liquefaction system based on modified Joule (Linde) cycle

The third simulation is about Joule (Linde) cycle. In this simulation the LNG vapour enters the cycle at -150 ˚C in the LNG-103 heat exchanger. The LNG cooled back to temperature of -165˚C and turns to liquid and returns back to the storage tank. The refrigeration cycle used nitrogen as refrigerant and the fluid package in this simulation is pang-Robinson.

Figure 4.7 shows the simulated cycle. The refrigeration cycle starts at stream number 1 with flow rate of 2000 kg/h, pressure of 1000 kPa and temperature of -53.13˚C. The stream enters the heat exchanger LNG-100 and out as 2 after it exchanges the heat with stream 8. Stream 2 temperature is -110˚C. Stream 2 split to two streams first one stream is 2.1 with mass flow of 1400kg/h and the stream is 10 with mass flow of 600kg/h. Stream 10 will move to expander K-101 and stream 2.1 will continuo forward to heat exchanger LNG-101. Stream 2.1 changed to be stream 3 after it exchange the heat with stream 7.1. Stream 3 temperature is -170.99˚C. Stream 3 exchange the heat with stream 6.1 in LNG-102 heat exchanger to give stream 4. Stream 4 temperature is -190. Stream 4 inter expanding valve and loss the pressure and energy in state of heat and due to that stream 5 temperature will reduces to -195.803 stream 5 enter the heat exchanger LNG-103 and take the heat from the LNG to reliquefy the LNG. The pressure drop between stream 5 and 4 is about 798.7 kPa. Stream 5 temperature drops and become stream 6 temperature is 195.7˚C the stream recycled in the simulation to give the right calculation by recycle tool. Stream 6.1 enters heat exchanger LNG-102 and out as stream 7 after it gains heat from steam 3. Stream 7 temperature is -170.998. Stream 7 is mixed with stream 11 which is result of expansion of stream 10. Steam 10 temperature is -110˚C and its pressure is 900 kPa. After it expands to pressure of the atmosphere the temperature will drop to 171.763 ˚C in stream 11. Stream 7 and 11 will form stream 7.1 and enters LNG-101 heat exchanger. After the heat exchanger the stream 7.1 will be stream 8. Stream 8 temperature is -195.804˚C. Stream 8 will enter heat exchanger LNG-100 and out as 9 after it gain energy from stream 1. Stream 9 temperature is -180. Stream enters high compression system of the three stages (three compressors k-100, k-102, k103). In the first compressor the stream pressure will increase to 362.1 kPa and the temperature will increase to -123.363˚C. In the second compressor the pressure will increases to be 503.435 kPa and the temperature will increase to -103.167˚C. In the last compressor the stream will compressed to give us the data of the stream 1 as mentioned above.

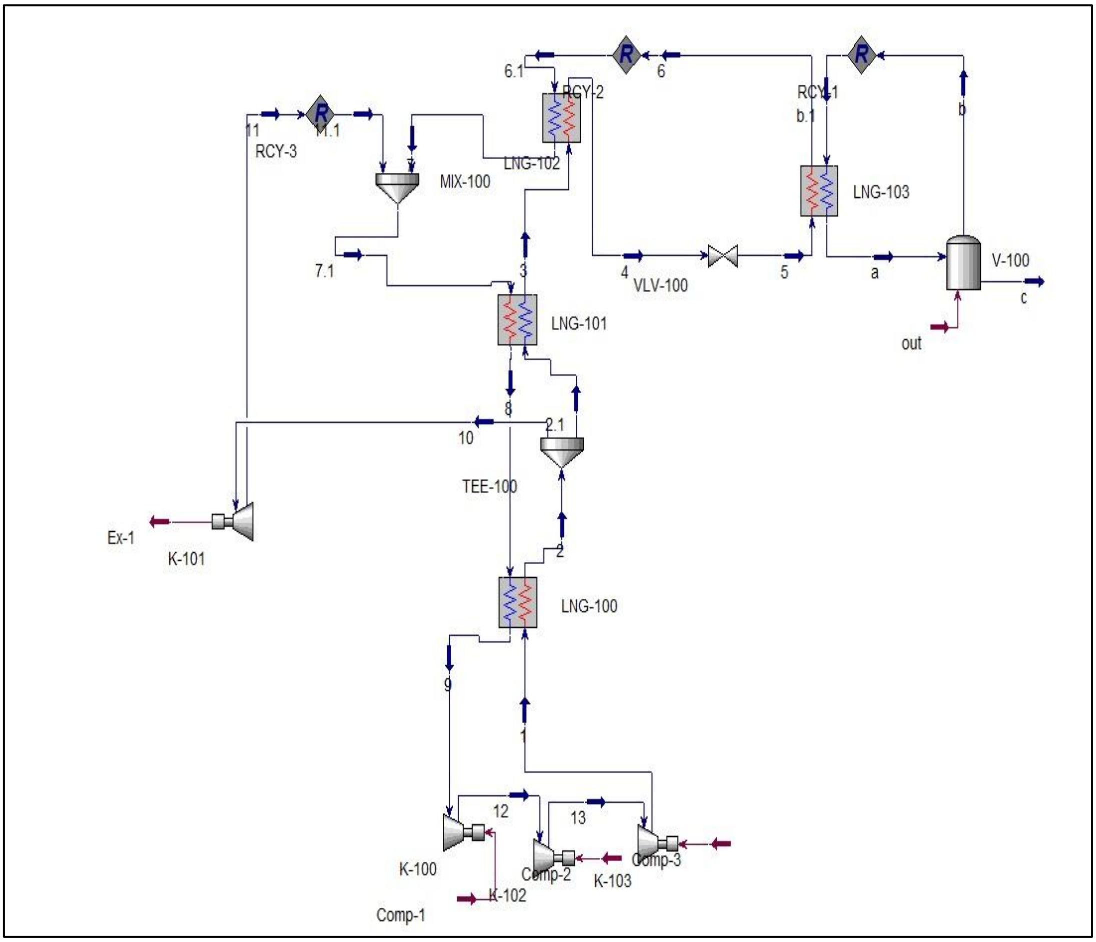


FIGURE 4.7 Liquefaction system based on modified Joule (Linde) cycle

Figure 4.8 shows the temperatures profile of stream 1-2 and stream 8-9 in the heat exchanger LNG-100. The temperature difference between stream 1and 9 is 126.8˚C which big difference. And the difference between 2 and 8 is 85.804˚C. The ΔT reduces about 41˚C if we considered stream 1-2 is our targeted stream.

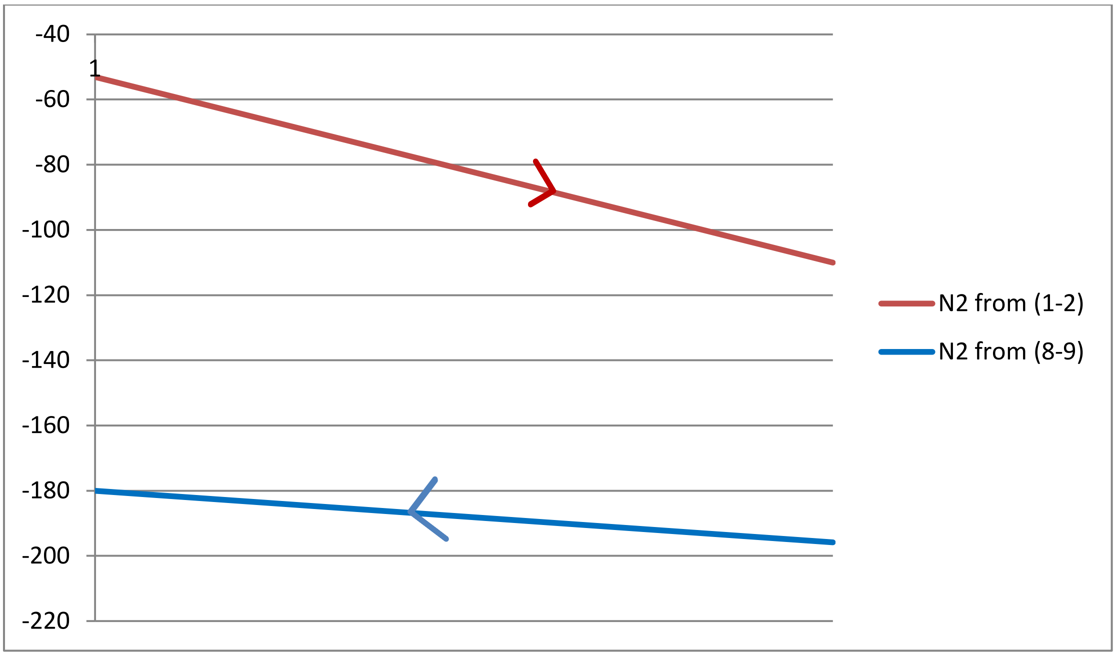


FIGURE 4.8 Temperature changes before and after heat exchanger LNG-100

Figure 4.9 illustrates the temperature changing in streams 21-3 and 7.1-8 in the LNG-101. The temperature difference between 2.1 and 8 is it the same like ΔT 8 and 2(85.804˚C). The different is the mass flow of stream 2 after it change 2.1. The temperature difference between 3 and 7.1 is 13.242˚C. ΔT is getting narrower between the streams.

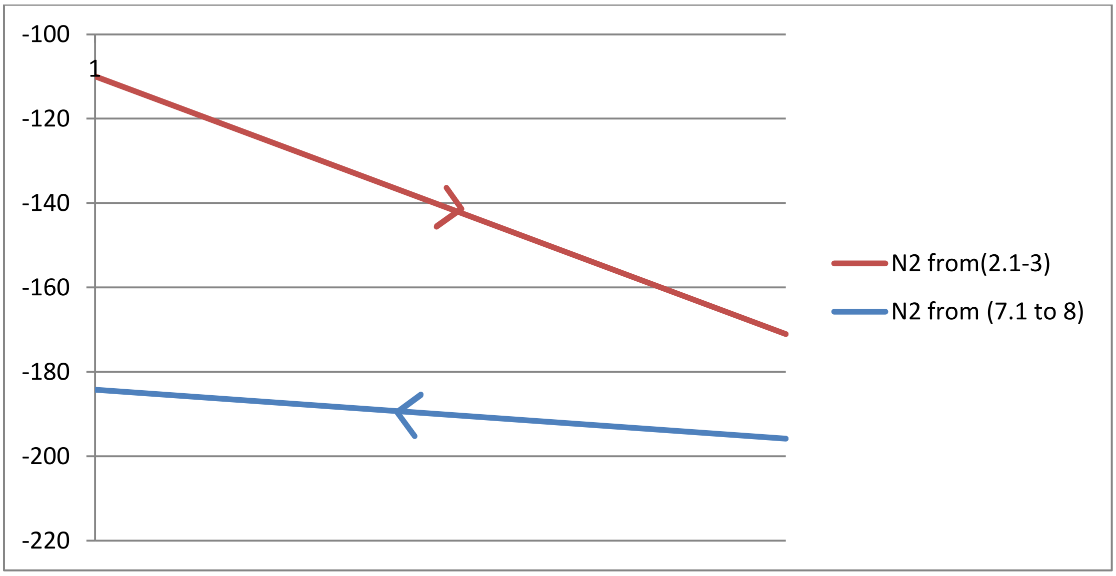


FIGURE 4.9 Temperature changes before and after heat exchanger LNG-101

Figure 4.10 shows the temperature profile of the streams 3-4 and 6.1-7 in LNG-102. The temperature difference between streams 3 and 7 is -20˚C. The temperature difference between streams 4 and 6 is 5.8˚C which too close. So starting from the first heat exchanger to the last on before the exchanging the energy between LNG and the cycle the temperature difference getting narrower and narrower. This is a good indication for the system.

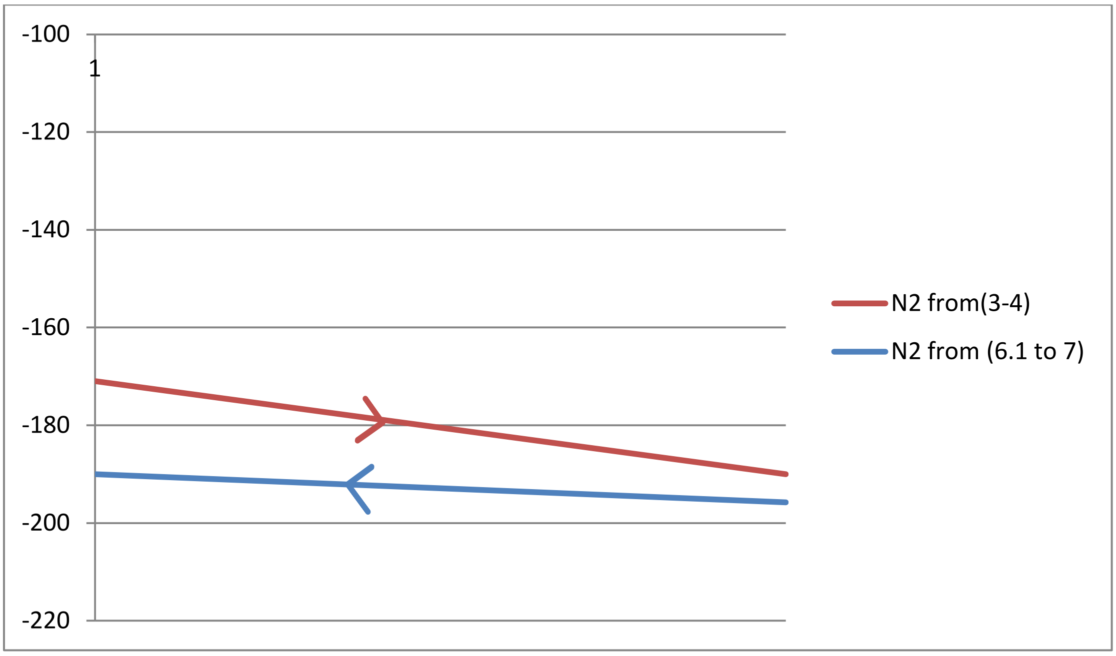


FIGURE 4.10 Temperature changes before and after heat exchanger LNG-102

Figure 4.11 shows the temperature changing in LNG-103 heat exchanger. LNG-103 is the heat exchanger that connected to LNG re-liquefaction cycle. The temperature difference between stream b and 6.1 is 45.8˚C. In the other side in the heat exchanger is the temperature difference between stream a and 5 is 30.8˚C. The temperature difference between the streams is a bit high therefore optimising for this part is needed to the system.

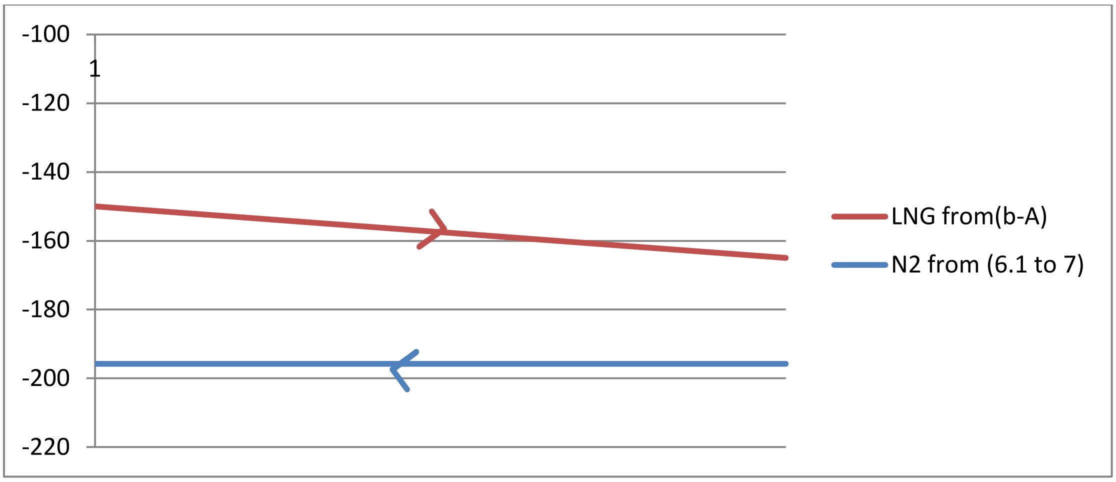


FIGURE 4.11 Temperature changes before and after heat exchanger LNG-103

Table 4.7, 4.8 and 4.9 shows the data that has been used in the simulation

TABLE 4.7 Material Streams date from hysys

	Unit	1	2	3	4	5	6	7
Vapour Fraction		1	1	0.719637	0	0.058639	0.25617	1
Temperature	***C***	-53.126	-110	-171	-190	-195.8	-195.7	-190
Pressure	***kPa***	1000	900	900	900	101.325	101.325	101.33
Molar Flow	***Kg mole/h***	71.395422	71.39542	49.9768	49.9768	49.976796	49.976796	49.9768
Mass Flow	***kg/h***	2000	2000	1400	1400	1400	1400	1400
Liquid Volume Flow	***m3/h***	2.48024	2.48024	1.73617	1.73617	1.73617	1.73617	1.73617
Heat Flow	***kJ/h***	171041	291836	364689	579677	579677	524812	309824

TABLE 4.8 Material Streams date from hysys

	Unit	8	9	2.1	10	11	7.1	12
Vapour Fraction		0.7777	1	1	1	1	1	1
Temperature	***C***	-195.8	-180	-110	-110	-170.8	-184.3	-123.4
Pressure	***kPa***	101.33	101.33	900	900	101.33	101.33	362.1
Molar Flow	***Kg mole/h***	71.395	71.395	49.977	21.419	21.419	71.396	71.396
Mass Flow	***kg/h***	2000	2000	1400	600	600	2000	2000
Liquid Volume Flow	***m3/h***	2.480239	2.480239	1.736167	0.744072	0.744072	2.480239	2.480239
Heat Flow	***kJ/h***	542801	422006	204285	87551	120919	430742	311006

TABLE 4.9 Material Streams date from hysys

	Unit	13	a	b	c	b.1	6.1	11.1
Vapour Fraction		1	0	1	0	1	0.2562	1
Temperature	***C***	-103.2	-165	-150	-150	-150	-195.8	-170.8
Pressure	***kPa***	503.44	101.33	101.33	101.33	101.33	101.33	101.33
Molar Flow	***Kg mole/h***	71.395	6.2302	6.2302	0	6.2302	49.977	21.418
Mass Flow	***kg/h***	2000	99.999	100	0	99.999	1400	600

	Unit	13	a	b	c	b.1	6.1	11.1
Liquid Volume Flow	*m3/h*	2.4802 39	0.3339 47	0.3339 47	0	0.3339 47	1.7361 67	0.7440 72
Heat Flow	*kJ/h*	271006	558875	504010	0	504010	524812	120919

Table8 shows the energy transferred in the system and ladled them under energy source and energy sink.

TABLE 4.10 Heat transfer directions

Source	**Source**	**Source**	**Sink**	**Sink**	**Source**	**Source**	**Sink**	**Sink**	**Sink**
1 to 2	**2.1 to 3**	**3 to 4**	**5 to 6**	**6.1 to 7**	**7.1 to 8**	**10 to 11**	**9 to 12**	**12 to 13**	**13 to 1**
120794. 96	160403. 8	214988. 2	54865.4 6	214988. 2	112058. 1	33367.9	111000	40000	99964.2 9

Σ Source = 641612.9 kJ/h

Σ Sink = 520817.9 kJ/h $\frac{\Sigma sink}{\Sigma\, Source}\; x\; 100 =$

81.173234%

The energy losses and the efficiency have been calculated by using equation 1 and 2.

Energy losses =Σ Source – Σ sink = (1)

=120795 kJ/h

$\eta = \frac{\Sigma sink}{\Sigma\, Source}\; x\; 100 =$ (2)

= 81.173234%

The calculation above shows how the system have 641612.9 kJ/h energy go in to it while the amount that used from it is 520817.9 kJ/h. There is about 120795 kJ/h is lost energy. This result will make the efficacy of the system about 81.173%. This efficiency considered high and good but the system can be optimized more to get the best ΔT in all heat exchangers.

4.1.4 Second Modified reversed-Brayton cycle

This cycle is never used before in real life its modification of modified reversed-Brayton cycle. The modified reversed- Brayton cycle has be simulated by using N2 as refrigerant and the boil of LNG is defined as 87% methane , 6% ethane, 4% i-Butane and 3% and after that has been modified by hysys after set the stream temperature as -150 and the vapour rate. The fluid package that has been used is pang- Robinson. Figure 4.12 shows the process flow shit by hysys.

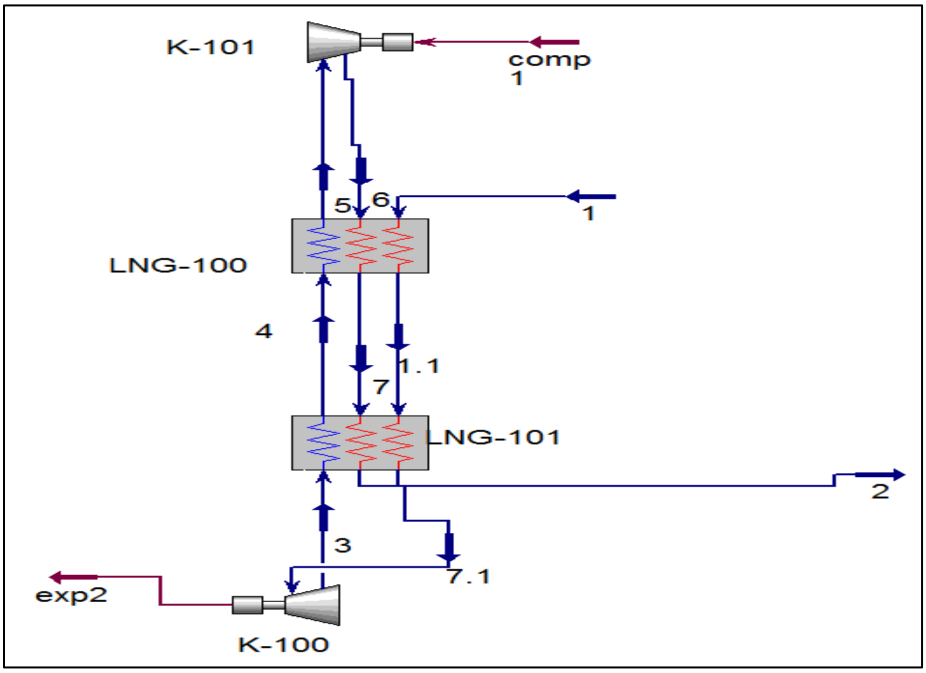


FIGURE 4.12 Liquefaction system based on modified reversed- Brayton cycle

The modification in the this cycle is in stream in LNG-101 heat exchanger the stream 7-7.1 have been added to the heat exchanger to make assistance to the stream 4-5 in cooling the LNG stream.

Figure 4.13 shows the changing in temperature in the LNG-100 heat exchanger. Form the first side the temperature difference between 5and 1 is 25˚C and between stream 5 and1 is 17.571˚C and between stream 1 and 6 is 7.429˚C. In the other side of the heat exchanger the temperature difference between stream 4 and 1.1 is 25.176˚C and the difference between streams 4 and 7 is 23.693˚C and ΔT between 1.1 and 7 is 4.307˚C.

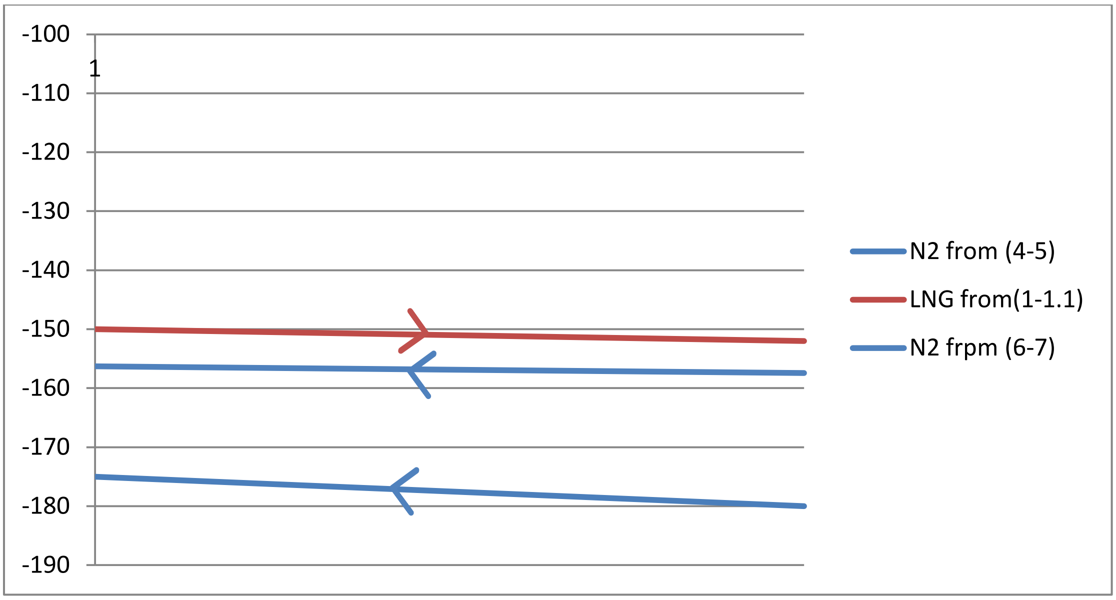


FIGURE 4.13 Temperature changes before and after heat exchanger LNG-100

Figure 4.14 shows the temperature difference in the LNG-101 heat exchanger. From the first side the temperature difference between stream 4 and 1.1 is 25.176˚C and the difference between streams 4 and 7 is 23.693˚C and ΔT between streams 1.1 and 7 is 4.307˚C. From the other side of the heat exchanger the temperature difference between stream 3 and 7.1 is 28.18˚C and between stream 3 and 2 is 23˚C and between streams 7.1 and 2 is 5.176˚C. As it shows in the graph there is temperature cross between stream 1.1-1 and stream 7-7.1. This situation is not possible in the two streams system but it happened because there is third stream that causes this temperature cross. This process can be optimize by adjusting stream 3-4 till the temperature cross between the other two streams in the heat exchanger disappear.

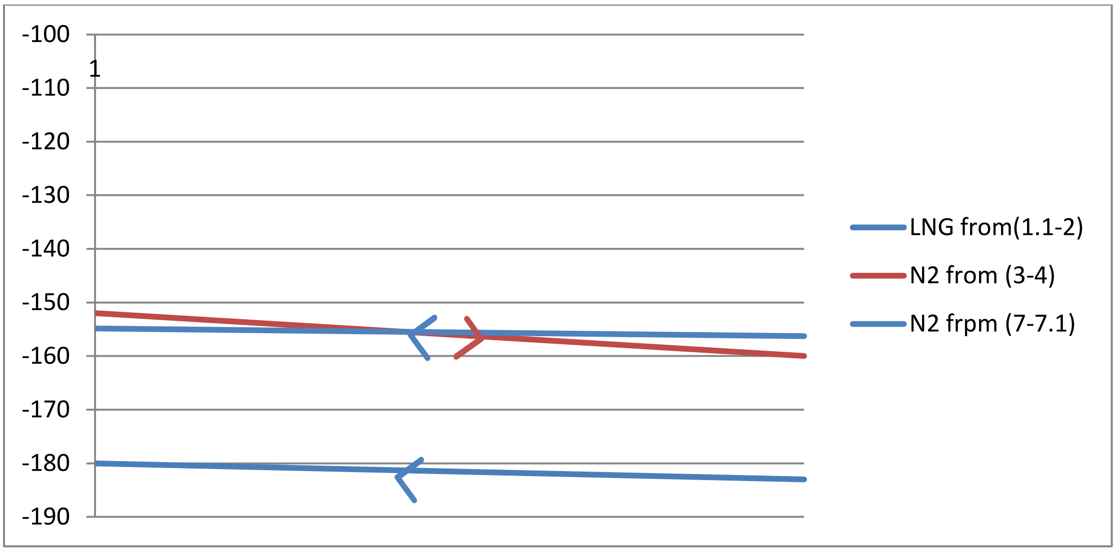


FIGURE 4.14 Temperature changes before and after heat exchanger LNG-101

Table 4.11 shows the data that has been used in the simulation in hysys. The data main parameters did not change from the normal cycle that has been simulated before to make the comparison easier.

TABLE 4.11 Material Streams date from hysys

	Unit	1	2	3	4	5	6	7	1.1	7.1
Vapour Fraction		0.459495	0	1	1	1	1	1	0.411366	1
Temperature	*C*	-150	-160	-183	-180	-175	-157.4	-156.3	-152	-154.8
Pressure	*kPa*	101.3	101.3	300	300	300	900	900	101.3	900
Molar Flow	*Kg mole/h*	2.246	2.246	60	60	60	60	60	2.246	60
Mass Flow	*kg/h*	66.6	66.6	1680.78	1680.78	1680.78	1680.78	1680.78	66.6	1680.78
Liquid Volume Flow	*m3/h*	0.15797	0.157978	2.084368	2.084368	2.084368	2.084368	2.084368	0.157978	2.084368
Heat Flow	*kJ/h*	251464.86	261080	366474	360949	351824	325054	333074	252570	330089

Table 4.12 shows the energy in form of sink and source according to first law of thermodynamics. From this table we can find out the energy that has been used and the energy that has been lost.

TABLE 4.12 Heat transfer directions

Sink	**Sink**	**Sink**	**Source**	**Sink**	**Source**	**Source**
3 to 4	**4 to 5**	**5 to 6**	**6 to 7**	**7 to 7.1**	**7.1 to 3**	**1 to 2**
5524.914541	9125.32	26769.42	8019.894	2985.013	36384.77	9615.354

Σ Source = 54020.02 kJ/h

Σ Sink = 44404.66 kJ/h

Energy losses = Σ Source – Σ sink= (1)

= 9615.354 kJ/h

$$\eta = \frac{\Sigma \text{sink}}{\Sigma \text{ Source}} \square\ 100 = \qquad (2)$$

= 82.2%

The calculation above shows that the total energy enters the system is 54020.02 KJ/h and the energy that has been used is 44404.66 KJ/h, so about 9615.354kJ/h is the amount of the lost energy. This data will give us 82.2% energy efficiency which is high.

From the previous data the as conclusion of the result the best temperature profile is the third process and its efficacy considered high but the insulation price is high as it got 3 compressors and one expander and 3 heat exchangers. The forth process has the highest efficacy and low installation cost but the temperature profiles not perfect enough. In general all the cycle need that has been simulated needs to optimized more to get the best result of each of it. After that a weightage table has to be formed to choose the best cycle to be applied in the real life.

4.2 Simulated Cycles After optimization

4.2.1 Reversed Brayton Cycle

The reversed Brayton cycle has been optimise by reducing the ΔT between the hot and the cold stream resulting. This change will make the energy transfer more efficient as it is just the amount needed to transfer. Moreover, the energy used to compress is will be lower as because the fluid hotter.

TABLE 4.13 Material Streams date from hysys

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vapour Fraction		0.4595	0	1	1	1	1	1
Temperature	*C*	-150	-160	-163	-157.6	-151	-128.31	-130.96
Pressure	*kPa*	101.33	101.33	300	300	300	500	900
Molar Flow	*Kg mole/h*	2.2457	2.2457	60	60	60	60	60
Mass Flow	*kg/h*	66.6	66.6	1680.8	1680.8	1680.8	1680.8	1680.8
Liquid Volume Flow	*m3/h*	0.158	0.158	2.0844	2.0844	2.0844	2.0844	2.0844
Heat Flow	*kJ/h*	251465	261080	330231	320615	308923	272320	284013

Figure 4.15 shows the temperature profile of heat exchanger LNG-101 in Figure 4 after adjusting the refrigerant temperature. The temperature in the first side is 7.6 ˚C. From the other side the temperature difference is 3 ˚C. The temperature difference between the streams reduces by 20.082˚C along the heat exchanger. This is good improving to the temperature difference.

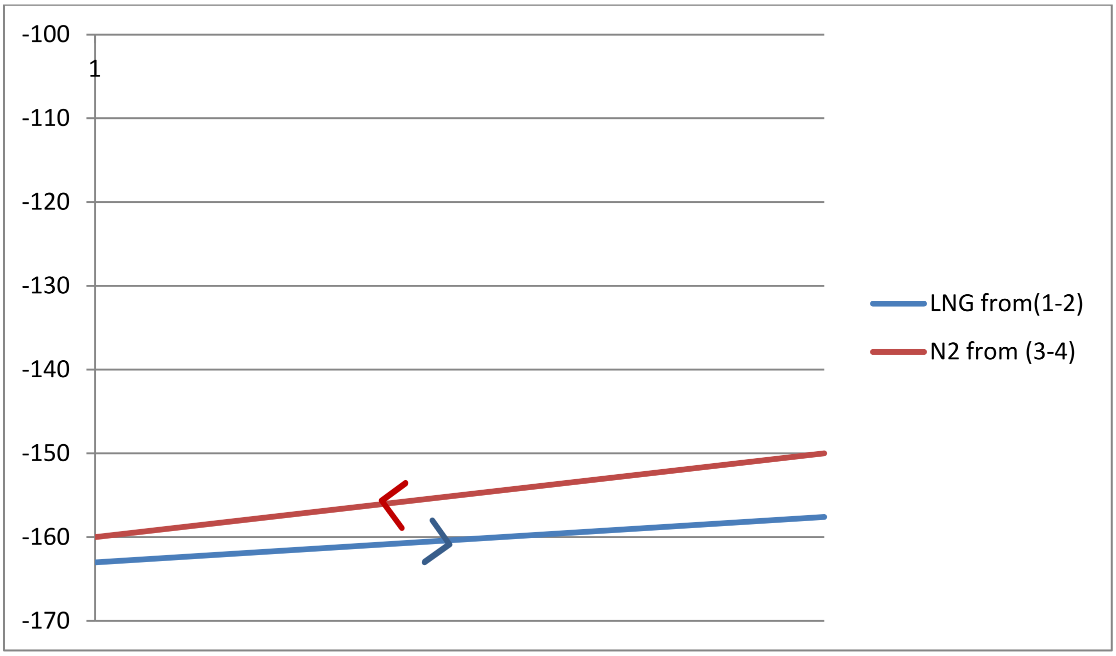


FIGURE 4.15 Temperature changes before and after heat exchanger LNG-101

Figure 4.16 show the temperature changing along heat exchanger LNG-100. The temperature difference between stream 4 and 7 is 26.65˚C and the temperature difference between 5and 6 is 22.6˚C. The overall temperature difference increases by 4.625˚C from the process before optimization. However, this increase is very small compare to the reduction in the ΔT after the other heat exchanger. That makes the optimization in right direction.

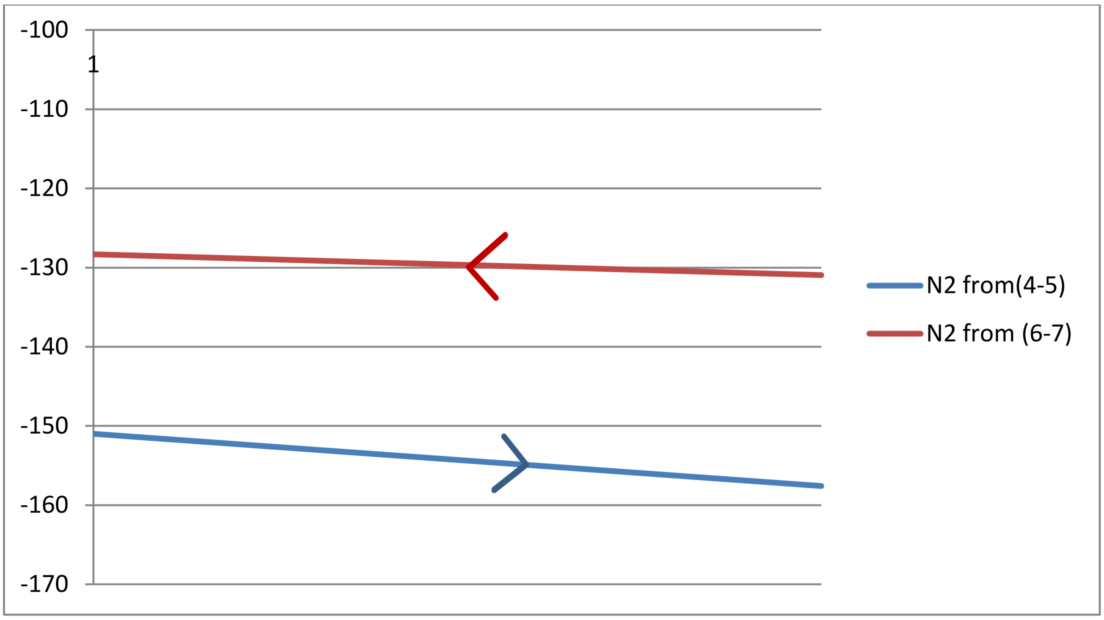


FIGURE 4.16 Temperature changes before and after heat exchanger LNG-100

Table 4.14 shows the energy direction in term of sink and source. The energy difference has been calculated from the hysys date.

TABLE 4.14 Heat transfer directions

Source	Sink	Sink	Sink	Source	Source
1 to 2	3 to 4	4 to 5	5 to 6	6 to 7	7 to 3
9615.354	9237.114	11313.94	36224.56	11692.18	46218.16

After that the total in and total energy used has been calculated. The total energy in is 67525.69 kJ/h. In the other hand the total energy used is 57910.34 kJ/h. This shows that the amount of the energy lost is 125436 kJ/h. By this data the overall energy efficiency of the system is 84.08%. The efficiency of the system increases by almost 3% after optimising the system which consider good amount of energy has been saved.

Σ Source = 67525.69 kJ/h

Σ Sink = 56775.614 kJ/h

By using equations 1 and 2:

Energy losses = Σ Source – Σ Sink = (1)

= 125436 kJ/h

$$\eta = \frac{\Sigma \text{ Sink}}{\Sigma \text{ Source}} \square\ 100 = \quad (2)$$

$$= 84.08\%$$

4.2.2 Modified Reversed - Brayton Cycle

The modified Brayton cycle can be optimized in the temperature difference between hot and cold stream. The reduction in the temperature difference between hot and cold streams in heat exchanger LNG-101 gives the data shown in table 4.15.

TABLE 4.15 Material Streams date from hysys

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1.1**
Vapour Fraction		0.459	0	1	1	1	1	1	0.282
Temperature	*C*	-150	-160	-161	-157.7	-155	-131.7	-128.5	-155
Pressure	*kPa*	101.33	101.33	300	300	300	500	900	101.33
Molar Flow	*Kg mole/h*	2.246	2.246	60	60	60	60	60	2.246
Mass Flow	*kg/h*	66.6	66.6	1680.8	1680.8	1680.8	1680.8	1680.8	66.6
Liquid Volume Flow	*m3/h*	0.158	0.158	2.0844	2.0844	2.0844	2.0844	2.0844	0.158
Heat Flow	*kJ/h*	251465	261080	326664	320869	316002	278429	279475	255286

Figure 4.17 shows the temperature profile along the heat exchanger LNG-101. The temperature difference between stream 3 and 2 is 1˚C and the temperature difference between streams 4 and 1.1 is 2.743˚C. The temperature difference between the system between the system before and after reducing the temperature differences reduces by 22.7 ˚C along the heat exchanger.

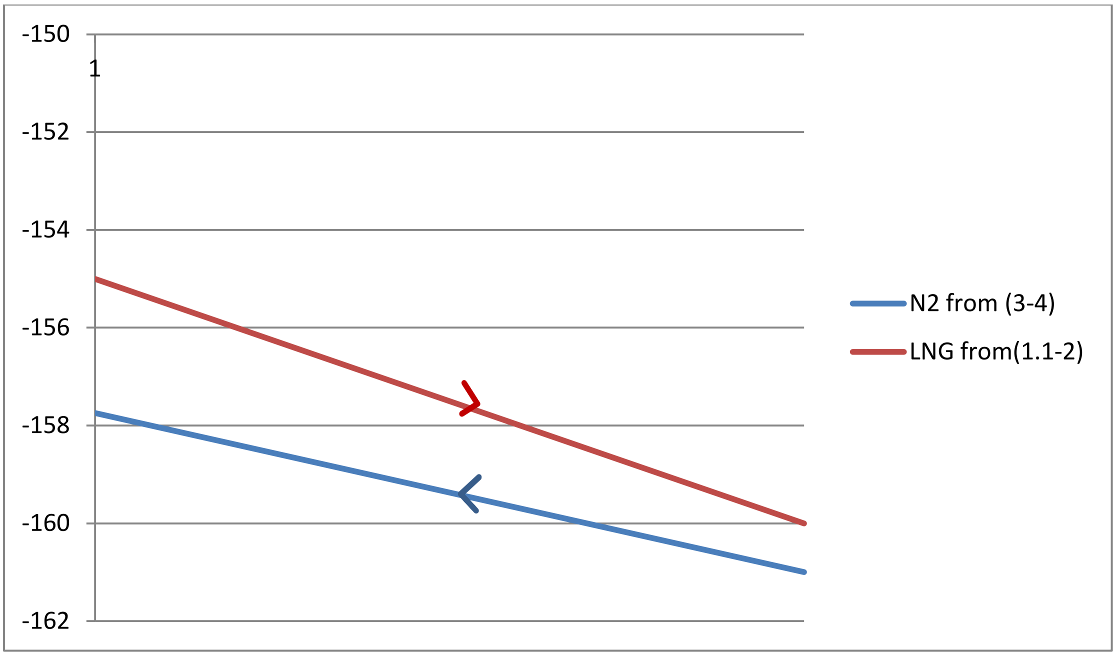


FIGURE 4.17 Temperature changes before and after heat exchanger LNG-101

Figure 4.18 illustrates the temperature the temperature behaviour along the heat exchanger LNG-100 in the Figure 5. The LNG-100 has 3 streams. The temperature difference between a 1 and 6 is 18.278 ˚C. The temperature difference between streams 5 and 6 is 23.3˚C and the temperature difference between streams 4 and 7 is 29.2˚C. This result shows that the temperature difference increases by 5.6863 ˚C after optimizing the other heat exchanger. The other comparison in the same heat exchanger is between the streams 6-7 and 1-1.1. The temperature difference between 6 and 1 is 18.278 ˚C and the temperature difference between 1.1 and 7 is 26.468˚C. The temperature difference between this two streams increases by 12.12˚C after optimizing the other heat exchanger in the system. The last two streams to compare in the LNG-100 heat exchanger are 5-4 and 1-1.1. The temperature difference between streams 5-1 is 5˚C and on the other side the temperature difference between 4 and 1.1 is 2.743 ˚C. The temperature difference between these two streams is reducing by 21.814 ˚C after optimizing the LNG101 heat exchanger. So overall the optimizing LNG-101 affects the heat exchanger LNG-100 positively and negatively in the same time as it increases the temperature difference between two streams and reduces the ΔT between the other two streams.

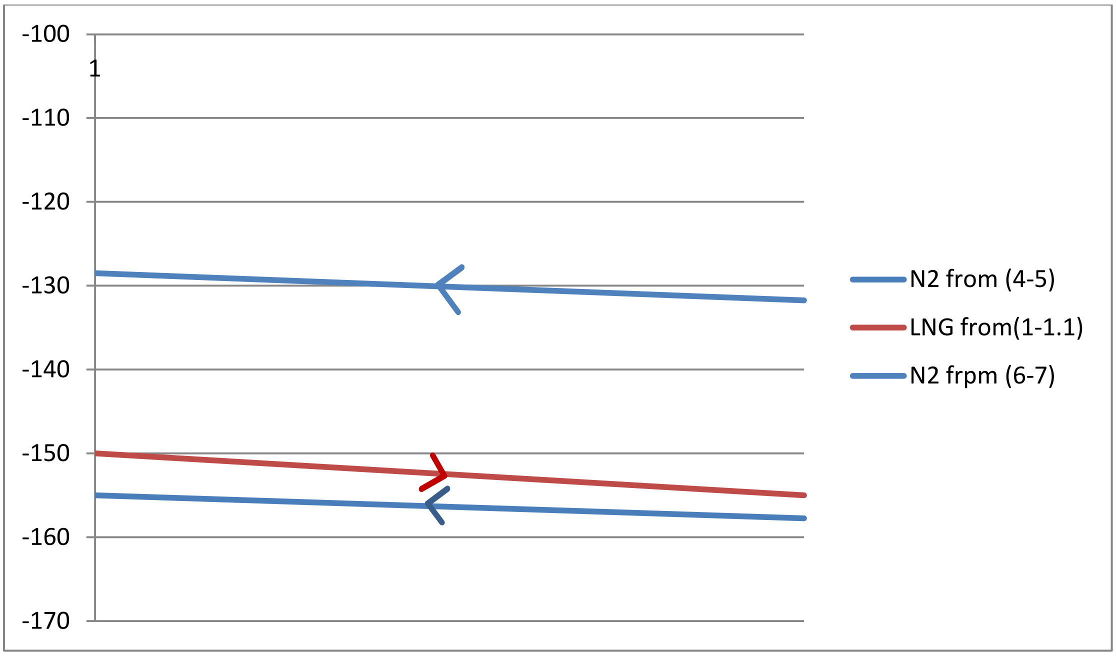


FIGURE 4.18 Temperature changes before and after heat exchanger LNG-100

Table 4.16 shows the data of the energy direction in the system to give understanding about the energy transfer within the system.

TABLE 4.16 Heat transfer directions

Source	Source	Sink	Source	Sink	Sink	Source
1 to 1.1	1.1 to 2	3 to 4	4 to 5	5 to 6	6 to 7	7 to 3
3821.078	5794.276	5794.276	4867.095	37572.98	1046.016	47188.33

From the data in table 4.16 the total source energy is 61670.78kJ/h. The total energy that has been used is 44413.27kJ/h. The shows that about 17257.51kJ/h is lost. The overall system efficancy is 72.02%. This system shows that the efficiency drops after optimising the LNG-101 by 5.303% which is big drop. Therefore, the optimising of this system should be done through many iteration of changing temperature till it reach the optimum point.

Σ Source = 61670.78 kJ/h

Σ Sink = 44413.27 kJ/h

By using equations 1 and 2:

Energy losses = Σ Source – Σ Sink = (1)

=17257.51 kJ/h

$$\eta = \frac{\Sigma \text{sink}}{\Sigma \text{ Source}} \square \; 100 = \qquad (2)$$

=72.01672 %

4.2.3 The Second Modified Reversed Brayton Cycle

The last cycle has been optimised is the second modified Brayton cycle. The temperature has been adjusted to make the smallest ΔT possible between the streams in the heat exchanger. The table shows the data from hysys after the system optimized.

TABLE 4.17 Material Streams date from hysys

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1.1**	**7.1**
Vapour Fraction		0.459495	0	1	1	1	1	1	0.281542	1
Temperature	*C*	-150	-160	-164	-160	-155	-132.5	-131.5	-155	-132.2
Pressure	*kPa*	101.33	101.33	300	300	300	500	900	101.33	900
Molar Flow	*Kg mole/h*	2.247	2.247	60	60	60	60	60	2.247	60
Mass Flow	*kg/h*	66.6	66.6	1680.78	1680.78	1680.78	1680.78	1680.78	66.6	1680.78
Liquid Volume Flow	*m3/h*	0.157978	0.157978	2.084368	2.084368	2.084368	2.084368	2.084368	0.157978	2.084368
Heat Flow	*kJ/h*	251465	261080	332017	324883	316002	279894	284953	255286	286294

Figure 4.19 shows the temperature behaviour for each stream in the LNG-100 in figure 7. The heat exchanger LNG-100 has 3 streams going through it. From the one of the sides the temperature difference between streams 5 and 6 is 22.46˚C and the temperature difference between streams 1 and 6 is 17.46˚C. The temperature difference between streams 5 and 1 is 5˚C. From the other side of the heat exchanger the difference between streams 4 and 7 is 28.545˚C and the temperature difference between stream 1.1 and 7 is 23.545˚C while the temperature difference between stream 4 and stream 1.1 is 5˚C.

The ΔT between stream (6-7) and stream (1-1.1) in LNG-100 increase by 8.7715˚C after optimising LNG-101. The temperature difference between stream (5-4) and stream (6-7) increases by 4.8705˚C after optimising the other heat exchanger. The temperature difference between streams 5-4 and 1-1.1 reduces by 20.088˚C from the data of the process before optimising the system.

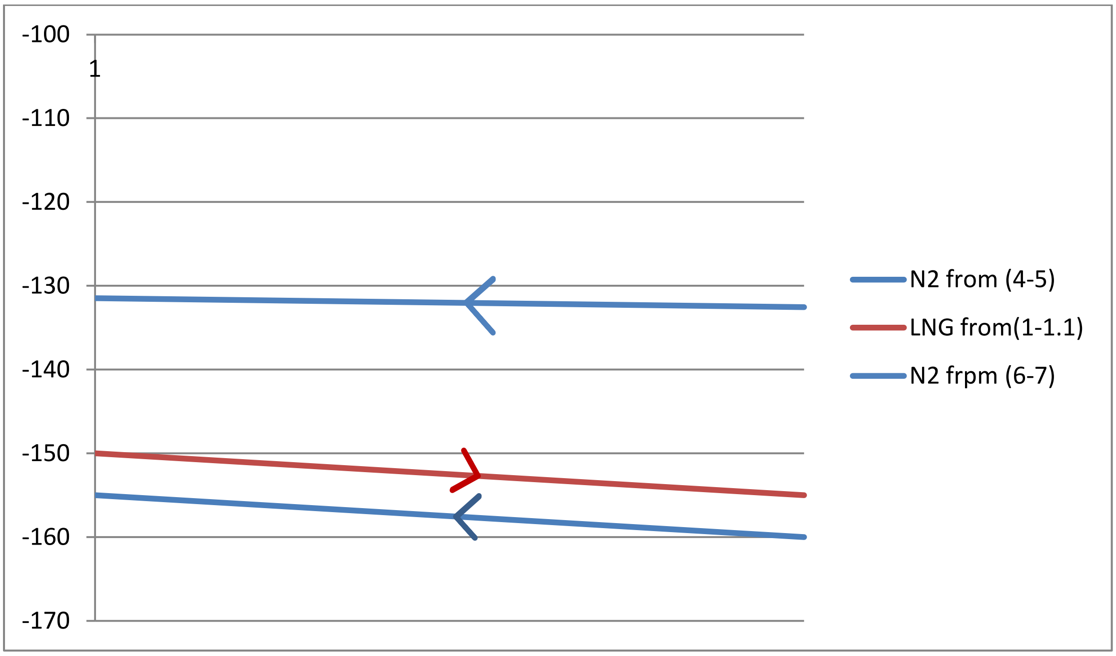


FIGURE 4.19 Temperature changes before and after heat exchanger LNG-100

Figure 4.20 shows temperature profile graph heat exchanger LNG-101 in figure 4.12. For heat exchanger LNG-101 the optimising changing gives the flowing temperature difference. The temperature difference between stream 4 and 7 is 28.545˚C. The temperature difference between stream 1.1 and stream 7 is 23.545 and the temperature difference between stream 4 and 1.1 is 5. Form the other side of the heat exchanger the temperature difference between stream 3 and 7.1 is 31.931˚C and between stream 7.1 and 2 is 27.831˚C and the temperature difference between stream 3 and 2 is 4˚C.

The temperature cross that has been in the process before changing the temperature has been eliminated by the new changes in the temperature of the refrigerant in the heat exchanger LNG-101. The temperature difference between stream (3-4) and stream (7-7.1) has been increased by 4.182˚C. The ΔT between stream (1.1-2) and stream (7-7.1) increased by 20.9465 ˚C and the temperature difference between stream (1.1-2) and stream (3-4) reduced by 19.588˚C.

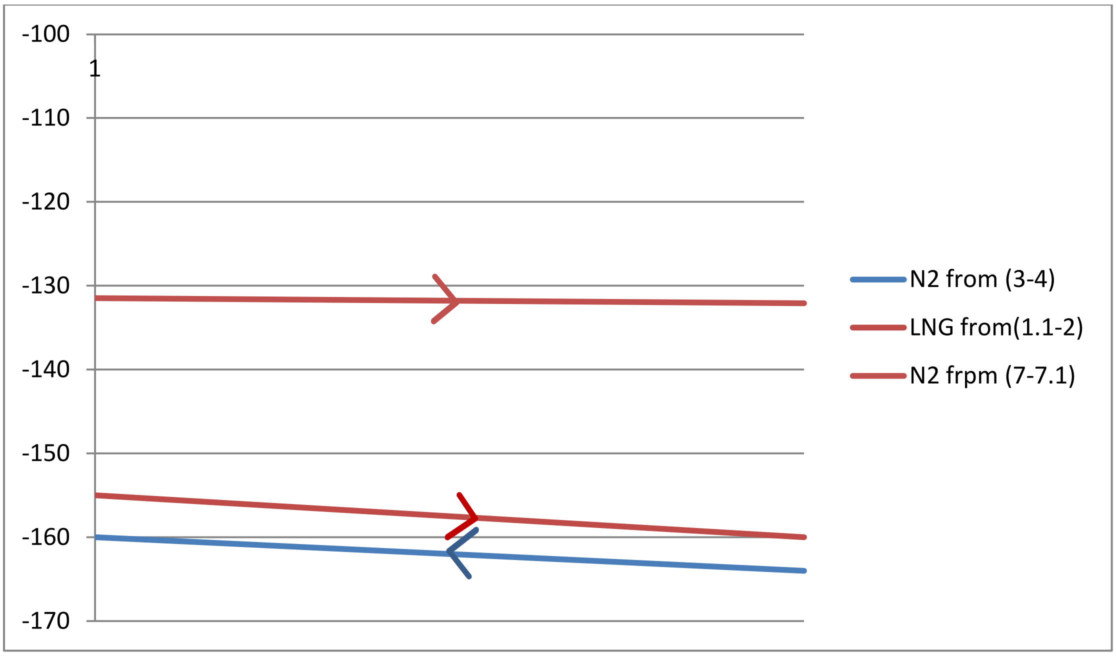


FIGURE 4.20 Temperature changes before and after heat exchanger LNG-101

Table 4.18 show the energy direction in the overall system for figure 4.4 after optimisation. The energy illustrated in term of sink source.

TABLE 4.18 Heat transfer directions

Sink	Sink	Sink	Source	Source	Source	Source
3 to 4	4 to 5	5 to 6	6 to 7	7 to 7.1	7.1 to 3	1 to 2
7472.9	9218.64	36192.9211	5059.358	1340.42	45723.72	9615.354

From the table we can calculate the total energy that has been used and the lost energy. The total used energy source is 60398.43kJ/h and the total energy sink is 50783.08kJ/h. That shows that about 9615.35kJ/h is lost. The efficiency after optimizing is 85.659% the energy efficiency increase by 3.4% which is good result.

Σ Source = 61738.43 kJ/h

Σ Sink 52884.461kJ/h

By using equations 1 and 2:

Energy losses = Σ Source – Σ Sink = (1)

= 8853.97 kJ/h

$\eta = \frac{\Sigma \text{sink}}{\Sigma \text{ Source}}$ □ *100* = (2)

=85.659%

4.3 Overall Discussion

The optimization in the temperature profile in heat exchanger has big effect in the performance of the system. For normal Reversed Brayton cycle the reducing the ΔT was easy and have direct effect on the efficiency of the system. The modified Brayton cycle didn't show a good respond as the efficiency drops after the reducing the temperature difference in the main refrigeration heat exchanger that because the stream that have been added to the other heat exchanger has direct effect from the temperature difference that has been reduced. That not means the modified can't be modified that shows that the cycle need a lot of iteration to fined the optimum temperature difference. For Linde cycle the optimization trails has been failed as the system is complicated and each part can affect many parts in the cycle therefore, the cycle considered in the optimum condition. The last cycle that has been optimised is the cycle that has been developed in this research which is the second modified Brayton cycle. This cycle shows the good respond because the two heat exchangers are connected to gather in all the streams that have passed through them so, any positive change any of heat exchanger will show the same positivity in the other heat exchanger.

According to the previous studies Reversed Brayton cycle heat exchanger size without the compressor and expander is 0.9 m^3 while the modified Reversed Brayton cycle size is 1m^3 using compact heat exchanger. That will give hint that the size of the second modified Brayton cycle that has been developed will be in the range of 0.9-1.1 m^3. The lined cycle size is big comparing to Brayton cycles family as it has 4 heat exchangers and 3 compressors and one expander. The total size of heat exchangers in the system according to the previous researches is 8 m^3.

Installation cost of the cycle is directly proportional to the number of the equipment and the size of it. So according to the cycle in this research the reversed Brayton cycle and both modified cycle has almost the same cost while Linde cycle will be expansive because the number of the equipment and the size of the system.

Table 4.19 shows the final weightage table to choose the best cycle. The weightage score out of four as there are 4 cycles the highest score is better. The one or more process can have the same score if have the similar attributes.

TABLE 4.19 Weightage Table of the best cycle

	Reversed Brayton Cycle	**Modified Reversed Brayton Cycle**	**Modified Linde Cycle**	**Second Modified Reversed Brayton Cycle**
Energy Efficacy (4-1)	3	1	3	4
Insulation Price (4-1)	4	4	2	4
Overall size (4-1)	4	4	2	4
Easy to adjust (4-1)	3	2	1	4
Total	14	11	8	16

From table 4.19 above can conclude that the best cycle is second modified Reversed Brayton cycle.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this project, study of the LNG and its refrigeration cycle has been done. Some process and modified process from many cycles are suggested to study deeper and simulated. Few comparisons have been done between the cycles by choosing few criteria. This criteria is had been made to achieve optimized thermo economic process for the boil of gas of the LNG with the target to reduce the unit cost of the system of refrigeration of the LNG. Criteria like energy efficiency the temperature difference, size of heat exchangers, installation price and the flexibility to adjust the system during the process have been chosen. But before that full analysis and thermo dynamics study through hysys simulation has been done. Four cycles have been simulated and 2 more left. According to the selected cycles the best cycle result is the seconded modified Brayton cycle because it has the highest efficiency, the smaller number of equipment , good installation price and easy to adjust and control the cycle during the process

5.2 Recommendation

- Heat exchanger and equipment size has to be calculated to confirm the available data
- For farther checking for the efficiency of the cycle the a prototype have to be done to check the system in the real disturbance (surrounding environment)

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APPENDIX

All hysy data

Material Streams

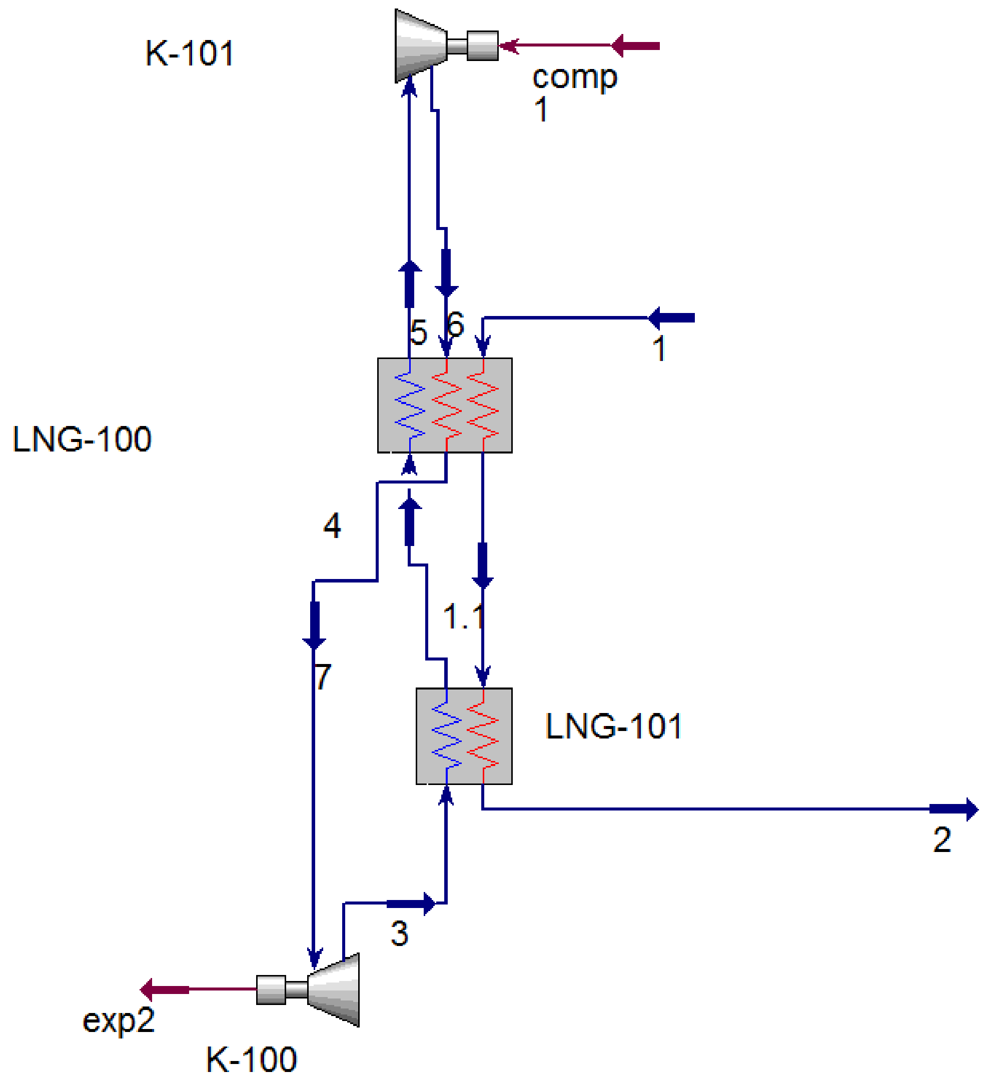
	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1.1**
Vapour Fraction		0.459495	0	1	1	1	1	1	0.411366
Temperature	*C*	-150	-160	-183	-178.37	-175	-157.429	-154.824	-152
Pressure	*kPa*	101.325	101.325	300	300	300	500	900	101.325
Molar Flow	*kgmole/h*	2.245647	2.245647	60	60	60	60	60	2.245647
Mass Flow	*kg/h*	66.6	66.6	1680.78	1680.78	1680.78	1680.78	1680.78	66.6
Liquid Volume Flow	*m3/h*	0.157978	0.157978	2.084368	2.084368	2.084368	2.084368	2.084368	0.157978
Heat Flow	*kJ/h*	-251465	-261080	-366474	-357964	-351824	-325054	-330089	-252570

Compositions

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1.1**
Comp Mole Frac (Methane)		0.639706	0.639706	0	0	0	0	0	0.639706
Comp Mole Frac (i-Butane)		0.294118	0.294118	0	0	0	0	0	0.294118
Comp Mole Frac (Nitrogen)		0	0	1	1	1	1	1	0
Comp Mole Frac (Propane)		0.022059	0.022059	0	0	0	0	0	0.022059
Comp Mole Frac (Ethane)		0.044118	0.044118	0	0	0	0	0	0.044118

Energy Streams

	Unit	**comp 1**	**exp2**
Heat Flow	*kJ/h*	26769.42	36384.77



Material Streams

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vapour Fraction		0.459495	0	1	1	1	1	1
Temperature	*C*	-150	-160	-183	-177.765	-175	-157.429	-154.824
Pressure	*kPa*	101.325	101.325	300	300	300	500	900
Molar Flow	*kgmole/h*	2.245647	2.245647	60	60	60	60	60
Mass Flow	*kg/h*	66.6	66.6	1680.78	1680.78	1680.78	1680.78	1680.78
Liquid Volume Flow	*m3/h*	0.157978	0.157978	2.084368	2.084368	2.084368	2.084368	2.084368
Heat Flow	*kJ/h*	-251465	-261080	-366474	-356859	-351824	-325054	-330089

Compositions

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Comp Mole Frac (Methane)		0.639706	0.639706	0	0	0	0	0
Comp Mole Frac (i-Butane)		0.294118	0.294118	0	0	0	0	0
Comp Mole Frac (Nitrogen)		0	0	1	1	1	1	1
Comp Mole Frac (Propane)		0.022059	0.022059	0	0	0	0	0
Comp Mole Frac (Ethane)		0.044118	0.044118	0	0	0	0	0

Energy Stream

	Unit	comp 1	exp2
Heat Flow	*kJ/h*	26769.42	36384.77