Thermodynamic Analysis for Liquefaction of Natural Gas Using the C₃-MR Refrigeration Process

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Abstract—This paper presents a propane precooled mixed refrigerant (C₃-MR) liquefaction plant with 3 pressure levels of propane cooling that is planned to be built in Timor-Leste and the simulation of refrigeration system for C₃-MR process that is to predict liquefied natural gas (LNG) specific horse power of the system. By varying the natural gas temperature between 10 and 50°C and pressure between 20 and 60 bar respectively, the effect of natural gas temperature and pressure on specific horse power for the C₃-MR was determined. The result of simulation indicates that the specific horse power for the C₃-MR process depends on natural gas supply temperature and pressure. The increase of temperature from 30°C to 50°C results in 0.83% increase in specific horse power and the decrease of temperature from 30 to 10°C results in 0.82% decrease in specific horse power. The pressure increase from 40 to 60 bar results in 0.37% decrease in specific horse power and decrease from 40 to 20 bar results in 0.39% increase in specific horse power. In addition that, the production capacity per train increase by 4.78% when natural gas pressure supplied from 40 to 60 bar and 7.22% decrease when pressure decrease from 40 to 20 bar.

Index Terms—Liquefaction, refrigeration, LNG production, LNG specific power.

I. INTRODUCTION

Petroleum will be the most important factor in Timor-Leste's economy and government budget for the foreseeable future. Revenues from oil and gas already comprise 50% of the country's Gross National Income (GNI) and supply more than 90% of its government revenues. To date, this is entirely from offshore, upstream development, with downstream processing done in other countries. It is the hope of many Timorese, including the Timor-Leste government, that Timor-Leste will soon receive revenues from downstream (refining, processing and gas liquefaction). The most likely near-term possibility for this is an undersea pipeline from the Greater Sunrise gas field to the shore of Timor-Leste, with a Liquefied Natural Gas (LNG) liquefaction plant and tanker port to process the gas and ship it overseas [1]. An LNG plant – "Timor LNG" – is to be built in Beao, District of Viqueque, with an initial capacity of 5 MTPA (Million Tons Per Annum) and possible future expansion of up to 20 MTPA. The feed gas will be piped from Greater Sunrise and other adjacent fields through a world class subsea pipeline(s) [2].

Natural gas (NG) is the fastest growing fossil fuel. It is

predicted that by 2013, NG will grow to a 37% share of fossil fuels in power generation from 30% today. It is continued to grow due to the clean environmental advantages of natural gas over other fossil fuels and its superior thermal efficiency when used in power generation [3]. Natural gas is the mixture with methane, ethane, propane, butane, etc., and methane accounts for about 80% of these components, and normal boiling point is about -162°C [4]. LNG occupies approximately 1/600th of the volume of natural gas thereby creating more options for shipment and storage [5].

Liquefaction of natural gas is purely based on the principle of refrigeration that is applying thermodynamic refrigeration cycle where a refrigerant by means of successive expansion and compression functions, transport heat from the process side i.e. natural gas to the environment i.e. cooling media. The capacity of a liquefaction train is primarily determined by the liquefaction process, i.e. refrigerants use, the largest available size of the compressor/driver combination that drives the cycle and heat exchanger that cool and liquefies the natural gas [6]. Refrigeration is the transfer of heat from a lower temperature region to a higher temperature region. Devices that produce refrigeration are called refrigerators, the thermodynamic cycles on which they operate are called refrigeration cycle and the working fluid is called refrigerant. Therefore LNG plant are large refrigerators which use pure refrigerants (e.g. propane) and or mixed refrigerants (usually a mixture of methane, ethane, propane and nitrogen) to cool and liquefy the natural gas stream serving as feed to the process plant [7]. The natural gas liquefaction plant technology is currently dominated by the propane precooled mixed refrigerant cycle (C₃-MR) licensed by Air Products and Chemicals Inc (APCI) [8].

The plant considered in this study is an LNG facility that to be built in Timor-Leste whose liquefaction process planned is based on the C₃-MR cycle. In this process, which is illustrated in Fig. 1, natural gas is cleaned and dried in a pretreatment section for the removal of CO₂, H₂O and Hg. The pretreated gas is then cooled in propane kettles to about -30°C and subcooled to about -161°C in the main cryogenic heat exchanger (MCHE) by exchanging heat with the evaporating mixed refrigerant. The LNG is then sent through an LNG expander to the LNG storage tank. The two refrigeration cycles present in the C₃-MR process is the propane cycle, illustrated in Fig. 2, and the mixed refrigerant cycle, illustrated in Fig. 3. The propane cycle precools the natural gas and partially condenses the mixed refrigerant in the propane kettles and the mixed refrigerant cycle provides the required cooling in the MCHE. Power is delivered to the cycles by the gas turbines and helper motors [8], [9].

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Fig. 1. Schematic representation of LNG plant C₃-MR liquefaction process

Fig. 2. Schematic representation of propane cycle

Fig. 3. Diagram of mixed refrigerant cycle

Tastaronis and Morosuk [10] analyzed a three cascade system for the liquefaction of natural gas using conventional and advanced exergy analysis which revealed the potential for improving the thermodynamic efficiency of components and the overall system as well as the interactions among components and their effect on the exergy destruction within each component. Their study demonstrated some capabilities associated with advanced exergy analysis. Mafi *et al.* [11] provided an exergy analysis for multicascade low temperature refrigeration systems with propylene and ethylene as refrigerant used in olefin plant. The exergetic efficiency of the multistage cascade process was calculated to be 30.88%. The paper also proposed the replacement of the ethylene circuit with a mixed refrigerant circuit which showed improved exergetic efficiency of 34.04% due to closer temperature of approach in the heat exchangers. Ravavarapu *et al.* [12] performed a comprehensive thermodynamic analysis of the propane precooled mixed refrigerant (C₃-MR) process with 3 pressure levels of propane cooling. The results showed that the propane and mixed refrigerant cycle operated at 34.3% and 58.3% thermodynamic efficiency respectively with an overall efficiency of 40.6%. Konoglu [13] also provided a comprehensive thermodynamic analysis of a multistage

cascade refrigeration cycle used in natural gas liquefaction. The exergetic efficiency was determined to be 38.5%. Remelie and Hoadley [14] concentrated on the duty curve to analyze the efficiency of heat exchange trains of LNG plant.

Previous works related to the present research have been based on thermodynamic model for liquefaction of natural gas using the C₃-MR refrigeration process LNG production rate of a functional industrial LNG plant [15]. It is constructed in ASPEN HYSYS VERSION 3.2 simulation software. These studies were limited to the calculation of the work required to produce a unit mass of LNG for different feed gas temperature and pressure. The main objective of this research paper is to demonstrate the thermodynamic analysis and process simulation using thermodynamic models constructed in process simulation software on the basis of Peng-Robinson equation of state was used to predict the specific horse power of a functional industrial LNG plant. This is achieved by obtaining plant process data from LNG facility that is to be built in Timor-Leste and make simulation in order to find out specific horse power for the LNG plant. This paper also investigates the sensitivity analysis of specific horse power of the plant.

II. THERMODYNAMIC ANALYSIS

The thermodynamic principles of liquefaction and refrigeration process are quite similar but the designing of the two systems are different. The refrigeration process/cycle for liquefaction of natural gas involves some equipment in which refrigerant is compressed, cooled to reject heat at ambient conditions and expanded to produce refrigerant capacity required. In refrigeration cycles which operate as close loop, refrigerants is constantly circulating as working fluid and there is no accumulation or withdraw of refrigerant from the cycle. The diagram showing a simple refrigeration circuit is given in Fig. 4. The system comprises of four components evaporator, compressor, condenser and throttling valve.

Fig. 4. Flow diagrams for single cycle refrigeration system

The refrigerant is in closed circuit and circulated by compressor. By keeping the pressure of refrigerant low in evaporator, the refrigerant boil by absorbing heat from the fluid to be cooled and at the same time it continues to remove the vaporized refrigerant and compress it to the condensing pressure. The condensing pressure must be higher enough to make refrigerant condense at ambient conditions using water or air. Ambient temperature must be less than the critical

temperature of the refrigerant to effect condensation using the environment as a coolant. The temperature of the evaporator is usually near the normal boiling point of the refrigerant, so the pressure of the evaporator may be approximately atmospheric. The throttling valve maintains a pressure difference between the higher and lower side of the refrigeration cycle [16]. The pressure of the refrigerant is then let down in an expander or flash valve to a low pressure. Its temperature also decreases as a result of reduction in pressure. The refrigerant is sent through the main heat exchangers where it cools and liquefies the natural gas to produce LNG. Note that the work supplied to the refrigeration cycle increases with the temperature lift (difference from evaporating to condensing temperature) [16].

Exergy analysis combines the first and second law of thermodynamics and is a powerful tool for analyzing both the quality and quantity of energy utilization. Exergy analysis of the liquefaction process is based on the following assumptions: The Composition of feed gas stream is the same as the composition of the LNG stream; no NGL scrubbing occurs as the natural gas is liquefied; LNG production rate is the same as the feed gas supply to the main heat exchanger; and the main heat exchanger is adiabatic.

Disregarding, kinetic and potential energy changes, the specific flow exergy (X) of natural gas at any state is given by:

$$X = (H - H_0) - T_0(S - S_0) \quad (1)$$

The reversible work (W_{revin}) required to liquefy natural gas is given by the exergy change between the two states.

$$W_{revin} = X_2 - X_1 = h_2 - h_1 - T_0(S - S_0) \quad (2)$$

where, subscript 1 and 2 represents the inlet state of natural gas to the main heat exchanger and the outlet state of LNG from the main heat exchangers. The reversible co-efficient of performance (COP_{rev}) for liquefaction of natural gas is given by:

$$COP_{rev} = \frac{Q}{W_{netin}} \quad (3)$$

where, W_{netin} is net work input to the liquefaction cycle (KW)

Taking an energy balance about the natural gas stream as it flows through the main heat exchangers. The refrigeration duty (Q) is given by:

$$Q = h_1 + h_2 \quad (4)$$

The specific power (W_s) is the work required to produce a unit mass of LNG. It is the ratio of the power consumed by the refrigerant compressors to the amount of LNG produced

$$W_s = \frac{W_{Com}}{m_{LNG}} \quad (5)$$

W_{com} is the total gas hp for refrigeration compressors, KW
 m_{LNG} is the LNG production rate, ton/hr

The compressor work input W_{Com} is given by;

$$W_{Com} = W_{PR} + W_{MR} + HM_{PR} + HM_{MR} \quad (6)$$

where W_{PR} , W_{MR} , HM_{PR} and HM_{MR} are the work input from

the propane compressor turbine mixed refrigerant compressor turbine, power delivered by the propane compressor helper motor and mixed refrigerant compressor helper motor.

LNG production rate m_{LNG} is given by;

$$m_{LNG} = \text{molar flow rate of LNG (MMSCFD)} * \quad (7)$$

$$\text{Gross Heating Value(GHV)} \left(\frac{\text{BTU}}{\text{SCF}} \right)$$

$$\frac{\text{BTU}}{\text{SCF}} = y_i \times GHV_i \quad (8)$$

y_i is the mole fraction of natural gas composition.

III. OPERATING DATA/SOLUTION TECHNIQUES

The composition of natural gas piped from the offshore Greater Sunrise entering the onshore plant as shown in Table I. These data were obtained from the study report of Conceptualization and Cost Estimation for a LNG plant in Timor-Leste [2].

TABLE I: FEED CONDITIONS

Component	NG Composition (%)
C1	84.1560
C2	4.8823
C3	2.1352
iC4	0.5328
nC4	0.7583
iC5	0.0400
CO2	4.4531
H2O	0.0000
N2	3.0423

The design landing temperature and pressure at Beaco, Timor-LNG is expected to be between 1-3°C and 66-76 bar respectively. The expected arrival temperature is between 1-3°C because the minimum seawater temperature in the deepest part of the trough is expected to be about 3°C. The gas flow corresponding to a liquefaction rate of 5.0 MTPA is approximately 900 MMSCFD.

The detailed study for the gas processing in Timor-Leste is yet to be undertaken and hence definitive pressure and temperature for dry gas entering the LNG plant may vary significantly. However, in this paper, LNG feed gas temperature and pressure entering to liquefaction unit is assumed to be 30°C and 40 bar and during the simulation varying the temperature and pressure between 10 & 50°C and 20 & 60 bar respectively. Moreover, in this study natural gas flow rate entering to liquefaction unit is assumed to be 450 mmscfd.

Feed to LNG Plants is composed primarily of methane, together with ethane, propane, butane and heavier hydrocarbon components. Non-hydrocarbon components such as nitrogen, carbon dioxide, hydrogen sulphide and mercury are also usually present [17]. Typical LNG feed gas composition entering to liquefaction unit is assumed as shown in Table II.

The simulation software on the basis of Peng-Robinson equation of state was used to obtain the specific horse power (equation 5) and LNG production (equation 7) by inputting

the composition, temperature and pressure required. Thereafter, the solution of equation 5 and 7 were obtained using Microsoft excel spreadsheet.

TABLE II: TYPICAL LNG FEED GAS COMPOSITION AND OTHER ASSUMPTION

Property	Condition	Comments
NG temperature	30(°C)	Close to ambient temperature
NG pressure	40 (bar)	Pressure of NG pipe line
NG flow rate	450 (mmscfd)	Large-scale simulation
NG composition (%mole fraction)		
	C1	90
	C2	7.32
	C3	0.35
	iC4	0.00075
	nC4	0.0001
	iC5	0.04
	N2	2.3
	CO2	0.0005
Compressors adiabatic efficiency	0.75	Compressor adiabatic Efficiency range typically between 70 and 80%

IV. RESULTS AND DISCUSSION

Fig. 5. shows the graph of the effect of natural gas temperature on specific horse power. The specific horse power increases linearly as the feed of natural gas temperature increases. By considering 30°C and 40 bar as reference point, the graph shows that when natural gas temperature decreases from 30 to 10°C, specific horse power decreases from 5.84 to 5.79 kWh/MMBTU-LNG results in 0.82% decrease and when the natural gas supply temperature increases from 30 to 50°C, its specific power increases from 5.84 to 5.88 kWh/MMBTU-LNG results in 0.83% increase. In general it can be described that at given natural gas pressure and temperature, an increase in natural gas supply temperature increase specific power and a decrease in natural gas supply temperature decreases specific power.

The effect of natural gas temperature on specific power at different natural gas pressure (20, 30, 40, 50 and 60 bar) supplied to APCI C₃-MR process is also presented in Fig. 5. With reference to the simulated conditions of LNG heat exchanger (30°C and 40 bar), Fig. 5, shows clearly that as temperature decreases from 30°C to 10°C at any natural gas supply pressure, specific power decreases and when supply temperature increases from 30°C to 50°C, specific power increases. Furthermore, the graphs described that natural gas supplied at higher pressure has low specific power (e.g. graph with pressure 60 bar) and natural gas supplied at low pressure has higher specific power (e.g. graph with 20 bar pressure) irrespective of natural gas supply temperatures. For example with reference to simulated conditions of this process, natural gas supplied at (30°C, 60 bar) and (30°C, 40 bar) have specific power of 5.81 and 5.84 kWh/MMBTU-LNG which amounts to a difference of 0.4% with respect to 40 bar.

Fig. 5. The effect of natural gas inlet temperature on specific power at different pressure

Fig. 6 shows the effect of natural gas pressure on specific horse power when natural gas is supplied at 30°C. The specific horse power decreases linearly as the natural gas inlet pressure increases. The figure indicates that when natural gas pressure decreases from 40 to 20 bar, specific power increases from 5.83 to 5.86 kWh/MMBTU-LNG results in 0.39% increase and natural gas pressure increases from 40 to 60 bar specific horse power decreases from 5.83 to 5.81 kWh/MMBTU-LNG results in 0.37 % decrease. In general when natural gas is supplied at a given pressure and temperature, specific power will increase when supply pressure decreases and specific power will decrease when supply pressure increases.

Fig. 6. The effect of natural gas inlet pressure on specific power at given temperature 30°C

Fig. 7. The effect of natural gas pressure on specific power when natural gas supplied at different temperature

The graphs showing the effect of natural gas pressure on specific power when natural gas is supplied at different temperatures is presented in Fig. 7. The figure shows that at any supply temperature of natural gas, when natural gas

pressure decreases from 40 to 20 bar, specific power increases and when supply pressure increases from 40 to 60 bar specific power decreases. The graphs described that when natural gas is supplied at higher temperature, specific power is higher (e.g. graph with 50°C) and when supplied at low temperature, specific power is low (e.g. graph with 10°C) at any supply pressure. For example natural gas supplied at (30°C, 40 bar) and (50°C, 40 bar) have specific power of 5.83 and 5.88 kWh/MMBTU-LNG which amounts to a difference of 0.82% with reference to 30°C.

Fig. 8 shows the graph of LNG production against feed gas supply pressure. The LNG production rate increases with feed gas pressure but at a reducing rate. The figure indicates that when natural gas pressure decrease from 40 to 20 bar, LNG production decrease from 2.86 to 2.66 MTPA/train (decrease 7.22%) and when natural gas pressure increases from 40 to 60 bar LNG production increase from 2.86 to 3 MTPA/train (increase 4.78%).

Fig. 8. The effect of natural gas inlet pressure on lng production at given temperature 30°C

In-depth thermodynamic analysis is conducted in order to provide better understanding of the process. It will use data from the process simulation to explain why and how the trends of Fig. 5- Fig. 8 arose. The temperature and entropy (T-S) diagram of natural gas mixture with phase envelop and lines of constant pressure for C3-MR process is plotted in Fig. 9.

By considering pressure 40 bar as reference point, the graph shows that when natural gas pressure decreases from 40 to 20 bar, specific power increases from 5.83 to 5.86 kWh/MMBTU-LNG (Fig. 6 and Fig. 7). The specific horse power increases because compressor work (area W) in Fig. 9 is increase and there is some increase on amount of heat required to be removed from natural gas (area Q). In addition, an increase in feed gas pressure results in an increase in LNG production (Fig. 8) because at higher pressures the feed gas liquefies at higher temperatures (with smaller enthalpies of condensation) and lower refrigeration duty which is more efficient.

On the other hand, An increase in feed gas temperature results in an increase in specific horse power (Fig. 5) because at higher temperatures the work supplied to the refrigeration cycle increases and compressor work (area W) will be increase which leads to higher specific horse power. Thermodynamically it is useful to liquefy natural gas at

highest possible pressure and lowest temperature so that work can be saved and reduce the heat load [16].

Fig. 9. Temperature entropy of natural gas with area showing heat removed (Q) and ideal work for reversible C3-MR liquefaction process (W)

V. CONCLUSION

A thermodynamic analysis that predicts the specific horse power of an LNG plant was studied. The analysis prediction was simulated with data from LNG plant that to be build in Timor-Leste. Simulation indicates that specific horse power for the C₃-MR plant that will be operated in Timor Leste depends on supply temperature and pressure. The temperature increase from 30°C to 50°C results in 0.83% increase in specific horse power and decrease from 30 to 10°C results in 0.82% decrease in specific horse power. The pressure increase from 40 to 60 bar results in 0.37% decrease in specific horse power and decrease from 40 to 20 bar results in 0.39% increase in specific horse power. In addition, the production capacity per train increase by 4.78% when natural gas pressure supplied from 40 to 60 bar and 7.22% decrease when pressure decrease from 40 to 20 bar.

It has been clearly shown by the available results that by varying the natural gas feed pressure and temperature could influence the specific horse power of the system. However, In future work, different feed composition of natural gas in Timor-Leste entering the LNG plant will be considered during the simulation of C₃-MR liquefaction process in order to find out power consumption for the LNG plant.

NOMENCLATURES

- m_{LNG} : LNG production rate (Kg/s)
- HM : Helper motor power (KW)
- Q : Refrigeration duty (KW)
- S : Specific entropy (KJ/Kg K)
- W : Work input (KW)
- Ws : Specific power for liquefier, KWh/tonne
- W_{comp} : Compressor work (KW)
- X : Specific exergy (KJ/Kg)

ABBREVIATIONS

- C₃-MR: Propane precooled mixed refrigerant
- Cw: Cooling water
- COP_{rev}: Reversible Coefficient of performance

MR: Mixed refrigerant
 LNG: Liquefied natural gas
 PR: Propane
 MCHE: Main cryogenic heat exchanger
 APCI: Air Products and Chemicals Inc
 MTPA: Million Tons per Annum
 NGL: Natural Gas Liquid
 MMSCFD: million metric cubic feet per day
 BTU: British thermal unit
 SCF: Standard cubic feet
 GHV: Gross Heating Value
 LMTD: Log Mean Temperature Difference

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REFERENCES

- [1] La'o Hamutuk. (February 2008). Sunrise LNG in Timor-Leste. Dreams, Realities and Challenges. [Online]. pp. 3-23. Available: <http://www.laohamutuk.org/Oil/LNG/LNGReportLoRes.pdf>
- [2] *Conceptualization and Cost Estimation for LNG Plant in Timor-Leste*, GS Engineering & Construction, KBC Advance Technology Pte Ltd, February 2010.
- [3] CEE, C. F. E. E. Introduction to LNG, P. D. Michelle Michot Foss, Chief Energy Economist and CEE Head, Austin, *Energy Economics Research*, 2012.
- [4] S. G. Lee and Y. M. Yang, "The state of art of LNG Liquefaction Plant Technologies," *The 3rd Korean Congress of Refrigeration*, vol. 3, pp. 65-68, 2009.
- [5] S. L. Sakmar, "The Globalization and Environmental Sustainability of LNG: Is LNG a Fuel for the 21st Century?" *World Energy Congress*, Montreal, Canada1, September 12-16, 2010
- [6] A. A. Wordu, "Functional Thermodynamics Model Equations for Simulation of Compression-Liquefaction Process of Natural Gas Plant," *Transnational Journal of Science and Technology*, vol. 3, no. 3, 2013.
- [7] T. G. Morosuk, "Advanced Exergetic Analysis of a Refrigeration System for Liquefaction of Natural Gas," *International Journal of Energy and Environmental Engineering*, pp. 1-17, 2010.

- [8] P. Bosma and R. K. Nagelwort, "Liquefaction Technology: Developments through History," *Proceedings of the first Annual Gas Processing Symposium*, Doha, Qatar, pp. 1-13, 2009.
- [9] D. E. Brandt and R. R. Wesorick, "GE Gas Turbine Design Philosophy," *GE Industrial and Power Systems Schenectady*, NY, GER-3434D, 1994.
- [10] G. Tsatsaronis, "Advance Exergetic Analysis of a Refrigeration System for Liquefaction of natural gas," *International Journal of Energy and Environmental Engineering*, vol. 1, pp. 1-17, 2010.
- [11] M. Mafi, S. M. Mousavi, and M. Amidpour, "Exergy Analysis of Multistage Cascade Low Temperature Refrigeration Systems used in Olefin Plants," *International Journal of Refrigeration*, vol. 32, pp. 279-294, 2009.
- [12] V. Ravavarapu, J. H. Oakley, and C. C. White, "Thermodynamic Analysis of a Baseload LNG Plant, Proceeding of the Chemeca 96, Excellence in Chemical Engineering," in *Proc. 24th Australian and New Zealand Chemical Engineering Conference and Exhibition*, pp. 143-148, 1996.
- [13] M. Konoglu, "Exergy Analysis of Multistage Cascade Refrigeration Cycle used for Natural Gas Liquefaction," *International Journal of Energy Research*, vol. 26, pp. 763-774, 2000
- [14] C. W. Remeliey and A. F. A. Hoadley, "An Exergy analysis of small-scale Liquefaction Natural Gas (LNG) Liquefaction Processes," *Energy*, vol. 31, pp. 2005-2019, 2006.
- [15] Dagde, K. Kenneth, and O. C. Okonkwo, "Development of Predictive Thermodynamic Model for Liquefaction of Natural Gas Using the C3-MR Refrigeration Process," *International Journal of Engineering and Technology*, vol. 2, no. 11, November, 2012.
- [16] M. J. A. R. Agrawal, *Dual Mixed Refrigerant Cycle for Gas Liquefaction*, Patent, filed December 9, 1998 with application No.09/208, vol. 562, 1998.
- [17] Z. Jenny, S. Tariq, T. Tony, and W. Foster, *Handling LNG feed Gas Variation*, 2012.

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