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Cold Energy Recovery in an LNG Plant

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This paper proposes an initiative to maximize the production of LNG and other by-products in an LNG complex. Using the concepts of cold recovery, the cold stream from the scrub column bottoms in the gas liquefaction process was used as a heat sink. Heat from the treated dry natural gas stream into the propane circuit at a high pressure stage is then removed by the cold scrub column bottoms. This heat exchange is to take place before heat removal from treated dry natural gas stream into the propane circuit at a high pressure stage. The modification would require an installation and operation of a new process-to-process heat exchanger. The expected benefits of having the modification are savings in compression power of the propane and mixed refrigerant compressors. In addition, the reboiler loading on the downstream fractionation unit was also reduced. The estimated value in extra annual production was about RM 43 million (USD 1.00 = RM 3.50). This is equivalent to approximately 0.5 bce or "big cargo equivalent" per year. The expected payback period was calculated within a week after the first year of operations with the newly installed heat exchanger.

1. Introduction

World market for liquefied natural gas (LNG) has been growing strongly over the recent years. The natural gas from the gas fields is first treated in the gas treating section to remove impurities. The treated gas is then sent to the liquefaction section where heavy hydrocarbons are removed and the remaining light hydrocarbon gas is liquefied. The gas undergoes cooling against high and medium pressure propane refrigerant. Then the cooled gas is fed into a scrub column in which the remaining heavy hydrocarbons is removed to prevent freezing in the main cryogenic heat exchanger (MCHE).

In the MCHE, the natural gas is liquefied and sub-cooled to a temperature of -152°C. LNG is then reduced in pressure in the LNG expander and further flashed into the endflash vessel. The flashed off LNG vapour is called endflash gas. This gas is warmed up and further boosted in pressure via a compressor to be sent into the high pressure fuel gas system. The LNG knocked out in this vessel is rundown to LNG tanks.

The heat removal from natural gas before the MCHE is done via propane cooling in four stages; the high-high pressure (HHP) stage, high pressure (HP) stage, medium pressure (MP) stage and low pressure (LP) stage. Liquid propane, supplied to different stages in the system at bubble point, vaporizes upon heat exchange with natural gas. The

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resulting vapour generated is re-routed to the propane compressor to be further boosted in pressure before being condensed and sent back into the system to complete a closed circuit for the propane loop. Natural gas is cooled against mixed refrigerants (MR) in the MCHE. The MR comprises a mixture of low boiling fluid. The vaporized MR from the MCHE shell side is further boosted in pressure via 3-stage MR compression using two compressors. The MR is then cooled in a set of four propane kettles at HHP, HP, MP and LP stages. The cooled MR is returned to the MCHE. This also completes a closed loop system for the MR circuit.

Gas turbines are used as drivers for the propane and MR compressors. Extra power requirement is supplied from the electrical grid to the compressor to sustain maximum allowable productions during hot ambient conditions. The exhaust of the gas turbines is used as heat source in other parts of the plant.

1.1 Problem Statement, Objectives and Scope of Study

The LNG plant under study has been designed with an approximate 10% extra margin for de-bottlenecking opportunities. De-bottlenecking initiatives are focused mainly on hardware modifications and upgrades such as the endflash compressor and the air-fin fan coolers to enhance cold recovery in LNG process. Although the LNG plant has been designed highly integrated, further studies on energy integration could still be performed to squeeze out every bit of opportunity available for efficient usage of energy and production maximization. The objective of this study is to identify further opportunities of recovering cold energy from the scrub column bottoms. The selected initiative involves a modification to be made in the scrub column section. The benefits of this modification in terms of potential extra productions of LNG and other saleable byproducts will be analyzed.

2. Literature Review

Site integration involves the study of the heat exchanger networks along with its utility system in a plant and how energy utilization can be minimized (Smith, 2005). The importance of effectively utilizing cold energy in a cryogenic process has been acknowledged by Lu and Wang (2009). In their work, a cascade power cycle was proposed by recovering cold energy from a vaporizing LNG stream to condense the working fluid in a Rankine power cycle. In the case of the liquefaction section in an LNG plant, there is no requirement for heating. Minimum cooling requirements were analyzed based on cascade diagrams and grand composite curves, upon which a basic heat exchanger network can be derived to spot the opportunities for energy integration.

In an LNG process involving single component refrigerants such as propane, the amount of propane required for cooling purposes is estimated in accordance to the amount of heat removal from the NG and MR systems. The heat duty of the propane kettles is hence determined by the amount and rate of heat removal from the hot streams, which are NG and MR streams.

MR cycles are designed in order to try to closely approach the cooling curve of the gas being liquefied. Special mix of multi-component refrigerants is used in attempting to match the cooling curves at different stages of the liquefaction process to achieve high refrigeration efficiency and reduce energy consumption (Bartholomew, 2008). However, when gas composition deviates from the design gas case, the enthalpy/temperature curve shifts, but the refrigeration does not because it is fixed by premixed refrigerants with a set composition. Consequently, temperature approaches are not achieved as designed and therefore the refrigeration efficiency deviates.

Currently, there are alternative technologies, such as Kryopak's EXP® (Kryopak, 2007), that employs refrigeration generated by a single semi-closed isentropic expansion of gases instead. Composition of the refrigeration gas used is the same as the LNG vapour produced from flashing. By recycling this gas, the slope of the enthalpy-temperature curves is changed accordingly as per cooling input at the different stages by the recycling refrigerant gas. The refrigeration is used to assist the liquefaction process and the work extracted is used to partially recompress the refrigerant gas.

A reboiler for distillation column functions as the heat source for vapour generation to provide vapour flow for vapour-liquid traffic required in the separation of mixtures with different boiling points (Perry, et. al, 1997). The Demethanizer is a reboiled column with no reflux flow. The overhead gas flow is maintained in the gas phase to be reinjected into the MCHE. Smith (2005) states that the amount of reboiling required in a column is based on the feed temperature, feed quality for a fixed number of trays, tray spacing, column diameter, and the boiling points of the key components for the separation. In theory, the reboiler duty will be reduced if the feed temperature of the flow entering the column were higher, as long as the temperature has not reached the boiling point of the component itself before entering the column.

3. Methodology

Evaluation of opportunities for further site integration in terms of cold recovery from the LNG plant is performed using basic heat integration analysis and process simulation works. Information is gathered and obtained from open literatures and process operations data, as well as technical discussions with process technologists and plant engineers. Data on operating parameters around the scrub column, the MR compression circuit, propane compression circuit, natural gas circuit and the fractionation unit are obtained as inputs for simulation of the liquefaction process section. The operating parameters above include basic parameters such as flow, pressure, temperature and composition. The simulations are developed using a SHELL proprietary property package known as SMIRK.

A basic heat integration analysis is carried out to study the heat/cold requirements for cooling of NG in the LNG process. Specifically the study focuses on the propane-to-natural gas (C3-NG) circuit and propane-to-mixed refrigerant (C3-MR) circuit in the LNG cooling process. The minimum cooling requirements for the C3-NG and C3-MR circuits are calculated based on the shifted interval temperatures at ΔT_{min} of 4°C. Another cooling loop is the MR-NG cooling circuit, which takes place completely in the MCHE. The MR-NG flows and temperatures determine propane vaporization rate solely. The study to be performed on cold recovery initiatives via process-to-process heat exchange, without involving any utility systems. The liquefaction section was studied upon in further detail on the possible recovery opportunity of the cold scrub column bottoms product to cool down the incoming NG. Cold recovery in this case involves addition of a new process-to-process heat exchanger. There are a few options on the placement of the new heat exchanger, either upstream of the HHP propane kettle, or HP propane kettle or even the MP propane kettle. Each option is simulated on PRO/II and the economic feasibilities are evaluated using the payback period method.

4. Results And Discussions

The location of the heat exchanger to recover the cold energy from scrub column bottom is illustrated in Figure 1. Simulation was done on the existing line-up and also on the proposed modifications in the scrub column unit. The resulting changes in compression power for the C3 and MR compressors were compared. Power savings on each stage of both machines were first computed and then totalized to obtain the net savings of compression power. Tables 1 to 3 show the simulation results and power savings from the modification project.

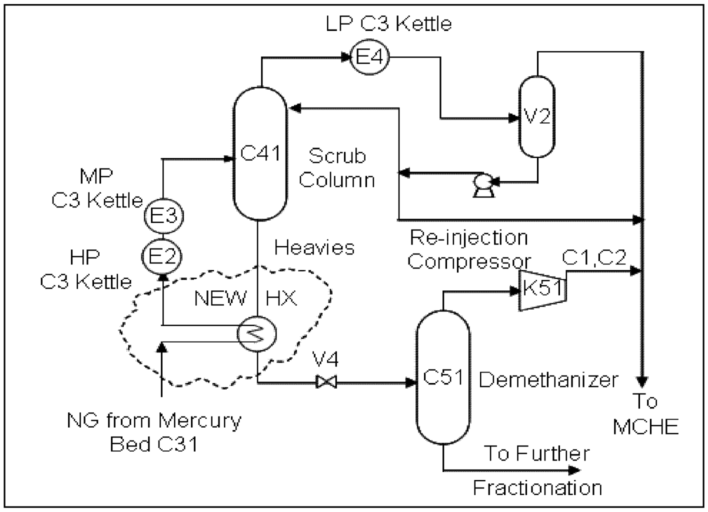

Figure 1: Schematic Diagram for the Scrub Column Unit Line-up (proposed modification in dotted lines)

About 0.104 MW of power was saved from the HP stage as a result of having the new HX in place. The HHP stage instead showed a saving of 3.5 times higher in terms of compression power compared to that of the HP stage. However, the opposite was noticed on the lower pressure stages. Both MP and LP stages showed an increase in compression power demand totaling approximately 0.06 MW. Although higher compression load on the lower pressure stages is undesirable, the amount is only 12.6% of the total power saved from the higher pressure stages. A possible reason for the slight increase in MP stage loading is that there is a need to balance the total cooling load on both the HP and MP as a whole in order to maintain the inlet temperature of the scrub column. The inlet temperature is critical for separation of the heavies from the bulk of treated dry NG feed into the scrub column. The LP stage kettle also experienced a slight increase of 45.14 kW in loading, which is due to the fact that the temperature of the reflux flow into the scrub column and the NG flow into the MCHE has to be maintained within the region of -36°C to -39°C. Total compression power reduction on the C3

Table 1 Power Savings on C3 Compressor for Different Pressure Stage

	WORK (POWER in MW)			
	HHP stage	HP stage	MP stage	LP stage
Before modifications:				
Theoretical	33.228	9.508	6.249	2.956
Polytropic	34.115	9.622	6.332	2.999
Actual	44.235	12.981	8.318	3.992
After modifications:				
Theoretical	33.503	9.432	6.249	2.956
Polytropic	34.399	9.545	6.332	2.999
Actual	44.604	12.877	8.318	3.992
Savings:				
Theoretical	0.275	0.076	-0.0108	-0.0334
Polytropic	0.284	0.077	-0.0109	-0.0339
Actual	0.369	0.104	-0.0144	-0.0451

compressor from all 4 stages is 0.413 MW. In terms of specific power reductions, HHP stage specific power reduces from 308.9 kJ/kg to 308.1 kJ/kg giving an improvement of about 0.27%. In addition, the HP stage specific powers reduce by 0.03% from 89.9 kJ/kg before modification.

Table 2 Compression Power Savings on LP and MP stages of MR Compressor

	WORK (POWER in MW)		
	1st HP stage	2nd HP stage	LP stage
Before modifications:			
Theoretical	13.686	11.806	42.049
Polytropic	13.895	11.939	43.047
Actual	18.510	15.003	49.337
After modifications:			
Theoretical	13.569	11.698	41.715
Polytropic	13.777	11.831	42.706
Actual	18.353	14.867	48.945
Savings:			
Theoretical	0.117	0.107	0.334
Polytropic	0.119	0.108	0.342
Actual	0.158	0.136	0.392

Reduction of compression power in the propane cycle would also affect the compression power demand for the MR compressors. The amount of actual compression power that was saved on the LP stage of the MR axial compressor is about 0.392 MW as shown in Table 2. Lower reductions in loading would be expected on the two HP stages of the MR centrifugal compressor. This is due to the fact that the range of compression power demand for the later 2 stages are lower, i.e. 34% less compared to that of the upstream axial compressor. The load reductions in the downstream HP stages are approximately 0.158 MW and 0.136 MW. Consequently, a total of 0.686 MW compression power reduction in the MR compressors is possible after the modifications. Furthermore, the compression power savings in the MR compressors is higher than that of the C3 compressor by at least a factor of 1.66.

The economic feasibility of this modification project was based on annual price obtained by multiplying the price of 1 big cargo equivalent (bce) of product by the volumetric flow rate per annum of product generated. An estimated amount of 96 tonnes per day in LNG and LPG productions was expected to be generated with this modification. This amount contributes to 0.82 percent increase in total daily production or to almost 0.5 bce. The expected total revenue generated is RM 43 million per year. Cost estimations showed that a total investment of RM 0.72 million is required to accommodate the addition of a new heat exchanger HX. This means that the investment capital can be recovered within 7 days after the first year of operation with the modifications in place.

5. Conclusion

Initiatives to enhance cold energy recovery from the LNG process has been explored and the proposed modification project on installing a new process-to-process heat exchanger upstream of the HP stage propane kettle has shown potential benefits. The total amounts of energy saved are 0.413 MW on C3 compressors and 0.686 MW on MR compressors. Extra energy required in terms of extra cooling duty in the Fractionation Unit is 0.055 MW giving net total energy savings of 1.045 MW in the LNG plant. Simple payback analysis showed that the investment could be recovered within 7 days of operations with the new exchanger in place. This indicates the project for cold recovery from Scrub Column bottoms in an LNG process is highly favorable.

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