Performance Enhancement of APCI LNG Plant

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Abstract

Chemical and gas plants are energy-intensive facilities so that any enhancement of their efficiency will result in abundant reduction of energy consumption and green house gas emissions. Liquefied natural gas (LNG) plants consume a great amount of energy. In order to enhance LNG plant energy efficiency, the potential of various options for improving liquefaction cycle efficiency is investigated in this study. After developing models for the LNG process using ASPEN software, four expansion loss recovery options are simulated. The simulation results show that the compressor power reduction, expansion work recovery, and LNG production increase can be achieved as much as 2.187 MW, 3.9 MW, and 1.24%, respectively, by replacing conventional expansion processes with expanders. Therefore, the expansion work recovery is an important option to be implemented in LNG plants.

1. Introduction

The petroleum and gas industries are significant energy consumers. About 15% of fossil fuels are consumed in the production, process, and transport of fuels. Since natural gas is one of the cleanest fossil fuels, the natural gas demand has increased recently. However, LNG plants are large energy consumers. There are various ways to enhance LNG plant energy efficiency, such as improving liquefaction cycle efficiency, improving compressor driver efficiency and utilizing waste heat. In order to investigate the potential of various solutions for improving liquefaction cycle efficiency, several options to recover expansion losses were modeled using ASPEN software, which is one of the preferred software in the oil and gas industry.

2. Natural Gas Liquefaction Process

About 77% of LNG plants, including one at Abu Dhabi in the U.A.E., are using the propane pre-cooled multi component refrigerant (MCR) cycle licensed by Air Products and Chemicals, Inc. (APCI) for natural gas liquefaction, as illustrated in Figure 1 [1].

As shown in Figure 1, the feed gas is passed through the gas sweetening plant for the removal of H_2S, CO_2, H_2O and Hg. As it passes through the pre-cooler and cold box, its temperature decreases to about -30°C and some components condense at the same time. In the separator, the remaining gas and condensate

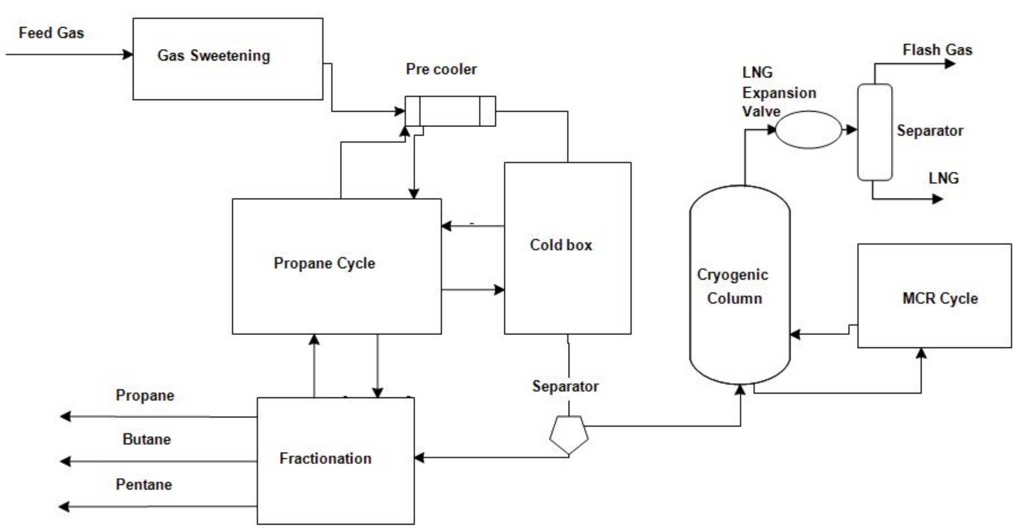

Figure 1. Schematic illustration of an LNG production process.

are separated. The condensate is being sent to the fractionation unit, where it is separated to propane, butane, pentane, and heavier hydrocarbons. The gas is further cooled in the cryogenic column to below -160°C and liquefied. Its pressure is then reduced to atmospheric pressure by passing through the LNG expansion valve. There are two refrigeration cycles utilized in this whole process: the propane cycle and the MCR cycle. The first cycle provides the required cooling to the pre-cooler, cold box and fractionation plant. The second cycle supplies the cooling demand of the cryogenic column.

3. Model Development

ASPEN Plus, which is steady-state process modeling software, was employed for modeling the APCI LNG production process [2]. ASPEN has a range of database containing thermodynamic and chemical properties for a wide variety of chemical compounds and thermodynamic models for simulation of thermal systems. An ASPEN model is based on blocks corresponding to unit operations such as compressors, heat exchangers and expansion valves. By interconnecting the blocks using material (fluid), work and heat streams a complete process flow sheet can be constructed. Simulation is performed by specifying the following parameters:

- Flow rates, compositions and operating conditions of the inlet streams.
- Operating conditions of the blocks used in the process, e.g. temperature and pressure.
- Operating heat and/or work inputs into the process.

Based on these input data, the model computes flow rates, compositions and state conditions of all outlet material streams as well as the heat and work output. For modeling the property of substances, the Peng-Robinson-Boston-Mathias equation of state was used [3]. Convergence tolerance for all ASPEN models was set to $1x10^{-4}$. For the sake of simplicity the gas sweetening process was not modeled. The gas composition provided for the liquefaction cycle is listed in Table 1. Hexane plus was approximated by n-hexane and iso-hexane with 0.16 and 0.24 for their mole fractions, respectively. Some of the other modeling assumptions used are summarized in Table 2. Propane and MCR compressors were assumed to be centrifugal and axial types, respectively. It was assumed that condensers and inter-coolers were cooled by sea water. The propane cycle was assumed to have five stages of cooling. The MCR consisted of nitrogen, methane, ethane, and propane with mole fractions of 0.09, 0.36, 0.47 and 0.08, respectively. The MCR compressor had an intercooler, which was cooled by sea water. The fractionation unit was modeled by using "*radfrac*" component of ASPEN [3]. All the expansion processes of the APCI cycle were done by expansion valves, which is true for some of APCI's LNG plants. This cycle option is referred as "*APCI base cycle*" in this paper. Flash gas recovery process is not considered. The schematic of the *APCI base cycle* modeled in ASPEN is shown in Figure 2.

Table 1. Gas composition after sweetening.

Component	Mole Fraction [%]
Nitrogen	0.1
Carbon Dioxide	0.005
Methane	85.995
Ethane	7.5
Propane	3.5
i-Butane	1
n- Butane	1
i-Pentane	0.3
n-Pentane	0.2
Hexane Plus	0.4
Total	100

Table 2. Model assumptions.

Axial compressor isentropic efficiency	0.86
Centrifugal compressor isentropic efficiency	0.83
Pinch temperature	3 K
Sea water temperature	35°C
Refrigerant temperature at condenser or super heater exit	40°C
LNG temperature at the exit of cryogenic column	-160°C
Degree of superheating in propane cycle	10 K
LNG expander exit pressure	101.3 kPa

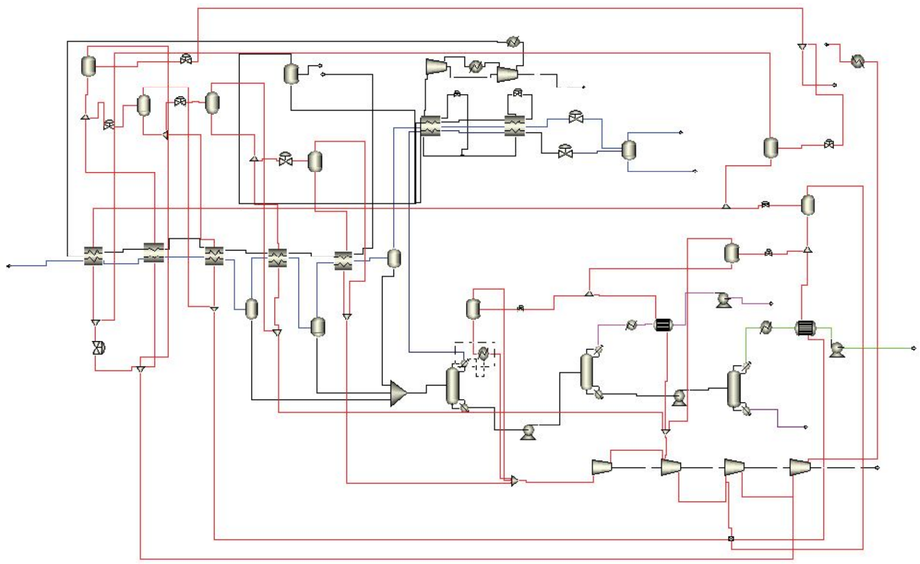

Figure 2. APCI base cycle modeled with ASPEN.

4. Results of APCI Base Cycle Model

The entire APCI base cycle except the gas sweetening process was modeled with ASPEN. The results of the APCI base cycle model are shown in Table 2. These results could be enhanced by recovering expansion losses in refrigerant cycles and LNG expansion process, which is discussed in the next section.

Table 2. Model results for APCI base cycle.

Propane compressor power	35.317 MW
Mixed refrigerant compressor power	66.534 MW
Propane cycle cooling capacity	115.469 MW
Mixed refrigerant cycle cooling capacity	67.635 MW
Propane cycle COP	3.267
LNG vapor fraction after the expander	0.014 %
LNG production	98.83 kg/s
LPG (propane, butane, pentane and heavier hydrocarbons)	11 kg/s
Flash gas flow rate after LNG expander valve	1.28 kg/s

5. Base Cycle Enhancements

The APCI base cycle efficiency could be improved by replacing expansion valves with expanders. Liquid turbines or hydraulic turbines are a well established technology. They are available with efficiencies over 90% [4]. They can easily replace expansion valves used in the MCR cycle and the LNG expansion process. In order to apply them to the propane cycle, propane should be sub-cooled before entering the turbine, however. Two-phase expanders are under development with current efficiencies in the vicinity of 80% [5,6]. They can easily replace expansion valves used in vapor compression cycles. For expanding gases, gas expanders could be used instead of expansion valves. Gas expanders or gas turbines are a readily available technology and typically exist with efficiencies greater than 80% [7].

The effect of replacing expansion valves used in the MCR and propane cycles and the LNG expansion process with expanders was investigated. Depending on their locations, liquid turbines and two-phase expanders could replace expansion valves. For the expansion valves used in the MCR cycle and the LNG expansion process, only two-phase expanders were considered. For the expansion valves used in the propane cycle, both two-phase expanders and liquid turbines were considered. Except for the case of using two-phase expander for the LNG expansion process, a gas expander was considered to replace the expansion valve of the first stage of the propane cycle, which had the highest evaporating pressure. The isotropic efficiency of the gas expander, liquid turbines and two-phase expanders were assumed to be 0.86, 0.85 and 0.85, respectively. The results of these enhancements are shown in Table 3.

As can be seen from Table 3, the APCI cycle enhanced with two-phase expanders and liquid turbines for LNG and propane expansion process, shown in Figure 3, is the most efficient cycle among the cycles investigated.

Its total power consumption, flash gases after the LNG expander and energy consumed per unit mass of LNG are lower than those of the APCI base cycle approximately by 2.15, 96.09 and 3.39 percent, respectively. It is also able to recover about 3.83 percent of total consumed power. The LNG production is also higher than that of the APCI base cycle by 1.24% from the same amount of feed gas. The coefficient of performance (COP) of mixed refrigerant cycle is not considered due to the fact that it receives cooling from the propane cycle. Therefore, the conventional definition of COP, which is the ratio of the cooling capacity provided and the amount of power provided to the system is not suitable.

Table 3. Model results for APCI enhanced cycles.

Cycle Option	Base APCI cycle	Enhanced with two-phase expanders for LNG expansion process	Enhanced with two-phase expanders for LNG and MCR expansion process	Enhanced with two-phase expanders for LNG, MCR, and propane expansion process	Enhanced with two-phase expanders and liquid turbines for LNG and propane expansion process
Propane cycle compressor power [MW]	35.317	35.317	34.766	34.637	34.296
MCR cycle compressor power [MW]	66.534	66.534	65.375	65.375	65.368
Propane cycle cooling capacity [MW]	115.469	115.469	113.939	113.937	113.962
MCR cycle cooling capacity [MW]	67.635	67.635	67.634	67.635	67.631
Propane cycle COP	3.267	3.267	3.277	3.289	3.323
LNG vapor fraction after the expander	0.0142	0.0006	0.0006	0.0006	0.0006
LNG production [kg/s]	98.83	100.06	100.06	100.06	100.06
LPG (propane, butane, pentane and heavier hydrocarbons) production [kg/s]	11	11	11	11	11
Flash gases after LNG expander [kg/s]	1.28	0.05	0.05	0.05	0.05
Recovered power from expanders [MW]	---	0.648	2.528	3.296	3.821
Total power consumption [MW]	101.851	101.851	100.141	100.012	99.664
Energy consumption per unit mass of LNG [MJ/kg]	1.031	1.018	1.001	1.000	0.996

Note: LPG = liquefied petroleum gas. MCR = multi-component refrigerant.

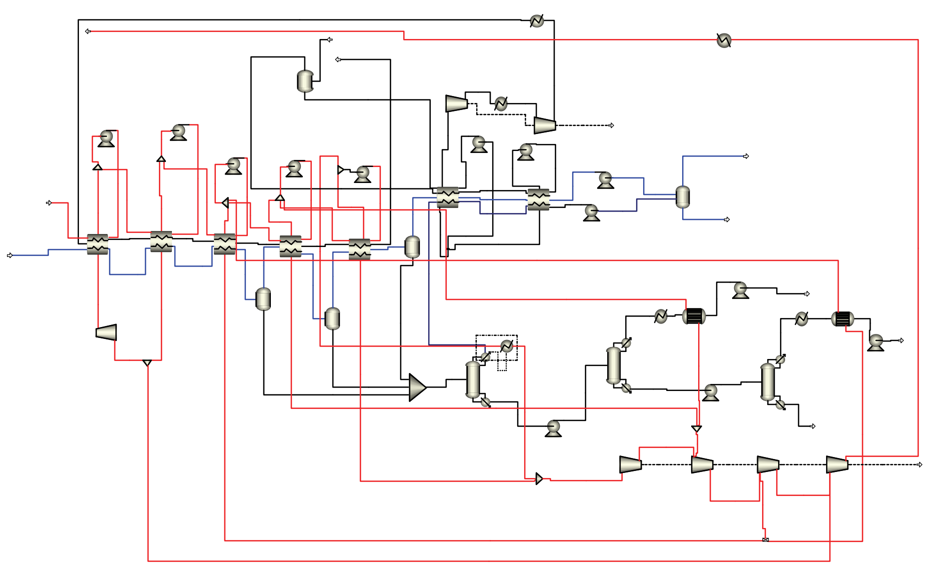

Figure 3. APCI Cycle Enhanced with two-phase expanders and liquid turbines for LNG and propane expansion processes.

6. Conclusions

Liquefied natural gas (LNG) plants consume great amount of energy. In order to enhance LNG plants energy efficiency, potentials of various options for improving liquefaction cycle efficiency were investigated in this study. After developing models for the LNG process using ASPEN software, four expansion loss recovering options were simulated. The simulation results show that the compressor power reduction, expansion work recovery, and LNG production increase can be achieved as much as 2.187 MW, 3.9 MW, and 1.24%, respectively, by replacing conventional expansion processes with expanders. Therefore, the expansion work recovery is an important option to be implemented in the LNG plants.

7. References

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Author Biographies

Mr. Amir Mortavazi is currently pursuing his Ph.D. in Mechanical Engineering at the University of Maryland. His current research is in modeling APCI LNG plants for waste heat utilization. He graduated from The Sharif University of Technology with a B.S. in Mechanical Engineering.

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Dr. Peter Rodgers, Ph.D., is Associate Professor of Mechanical Engineering at The Petroleum Institute, U.A.E. He has extensive experience in thermofluid modeling and experimental characterization. His current research activities are focused on waste heat utilization in the oil and gas industry; the development of polymeric heat exchangers for sea water cooling applications; computational fluid dynamics; electronics reliability; and engineering education. He is presently a member of several international conference program committees, and serves as program co-chair for both EuroSimE 2009 and Energy 2030. He has authored or co-authored over 60 journal and conference publications.