Optimization Analysis of Peakshaving Cycle to Liquefy the Natural Gas

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In this paper, three kinds Peakshaving LNG cycles are optimized, namely nitrogen-methane expansion liquefaction cycle, propane pre-cooled mixed refrigerant liquefaction cycle, two stages mixed refrigerant liquefaction cycle. The three kind cycles are optimized with specific power consumption of unit LNG product as objective function. The optimum results are the optimum value of the objective function and the corresponding process parameters.

INTRODUCTION

Peakshaving liquefied natural gas (LNG) plays an important role in peak loads and increasing the reliability of gas supply.

In this paper, three kinds Peakshaving LNG cycles are optimized. The three LNG cycles are nitrogen-methane expansion cycle, propane pre-cooled mixed refrigerant cycle (MRC), two stages mixed refrigerant cycle. The specific power consumption of unit LNG production is used as the objective function [1].

LNG CYCLE

N_2-CH_4 Expansion Liquefaction Cycle

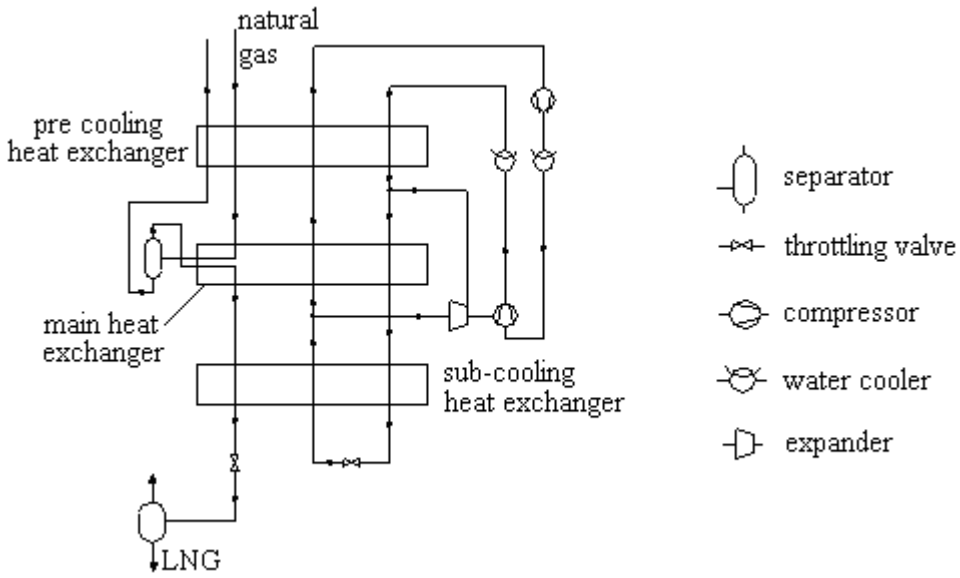

Figure 1 N_2-CH_4 expansion liquefaction cycle

Figure 1 is the N_2-CH_4 expansion liquefaction cycle. The purified natural gas is cooled in A1, then the liquid is separated in A2. The gas is cooled and liquefied in A3, sub-cooled in A4, then flows through the throttle valve. The produced Liquefied natural flows into storage tank.

Propane Pre-cooling Mixed Refrigerant Liquefaction Cycle

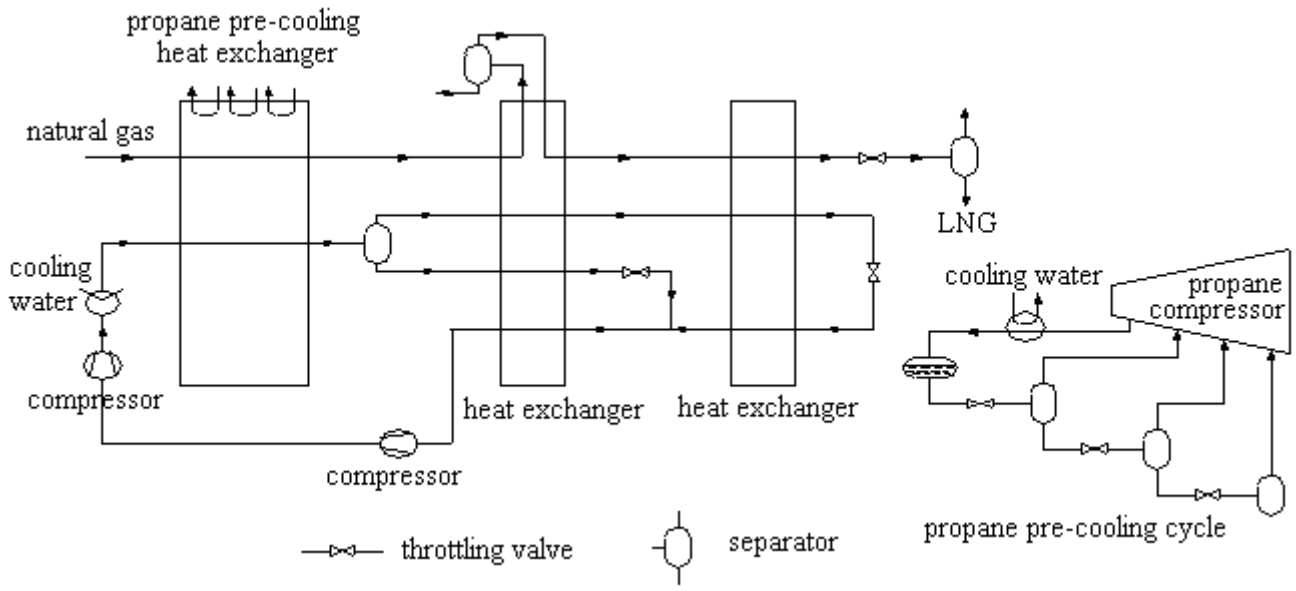

Figure 2 C_3H_8 pre-cooling mixed refrigerant liquefaction cycle

As shown in Figure 2, C_3H_8 pre-cooling mixed refrigerant liquefaction cycle mainly consists of 3 loops: two closed refrigerating cycles, that is, C_3H_8 pre-cooling cycle which is used to pre-cool natural gas and refrigerant mixture and mixed refrigerant refrigerating cycle which is used to condense and sub-cool natural gas; one open cycle-natural gas liquefaction cycle.

Two Stages Mixed Refrigerant Liquefaction Cycle

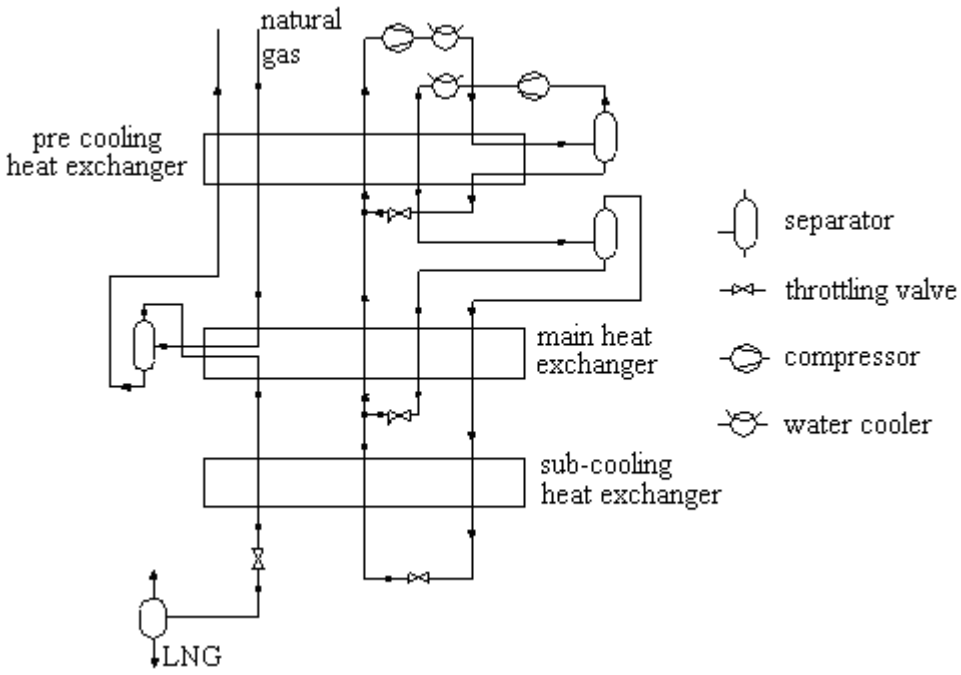

Figure 3 Two-stages mixed refrigerant liquefaction cycle

Figure 3 is the two-stages mixed refrigerant liquefaction cycle. This cycle includes refrigerating cycle and natural gas cycle.

OPTIMIZATION ANALYSIS OF CYCLES

The sequential modular is used to calculated the thermodynamic parameter of the three LNG liquefaction cycle showed as figure 1~3. The optimization analysis is based on the thermodynamic simulation.

Objective Function

During optimization analysis of three kinds of cycles shown in Figure 1-3, the power consumption per unit LNG product is chosen as the objective function of optimization.

Known Parameters

Inflow rate of natural gas: 1kmol/s

Pressure of natural gas: 4.8MPa

Components and mole percentage of natural gas: N_2 (0.7%), CH_4 (82%), C_2H_6 (11.2%), C_3H_8 (4%), i-C_4H_{10} (11.2%), n-C_4H_{10} (0.9%);

LNG storage pressure: 0.12MPa

Iterative Step

In the optimization calculation, the pressure iterative step is 100kPa, the iterative step of mol percentage is 0.02, and the temperature iterative step is 2K.

Restricted Conditions

In the optimization calculation, the restricted conditions are as follows:

(1) The sum of mol percentage is equal to 1.
(2) The mixed refrigerant flowing into the compressor is vapor phase only.
(3) The temperature of refrigerant gas after expansion is higher than the dew point of vapor in low pressure circuit.
(4) The liquid and vapor must be produced when mixed refrigerant flows through every separator.
(5) The temperature difference between hot and cold fluid in every heat exchanger should not be minus.
(6) The energy of every heat exchanger must be balance.

Optimization Results

In N_2-CH_4 expansion liquefaction cycle, the designed variables and gained optimization values are as follows: the high pressure of refrigerant is 4400kPa; the low pressure is 600kPa, the mol percentage of N_2 and CH_4 is 0.56 and 0.44 respectively, the temperature before expansion is 244.2K, the temperature of natural gas at cold side of main heat exchanger is 157.15K.

In C_3H_8 pre-cooling mixed refrigerant liquefaction cycle, the designed variables and gained optimization values are as follows: the high pressure of mixed refrigerant is 2550kPa, the low pressure is 310kPa, the mole percentage of N_2, CH_4, C_2H_6, C_3H_8 is 0.02, 0.42, 0.41, and 0.15 respectively.

In the two stags mixed refrigerant liquefaction cycle, the designed variables and gained optimization values are as follows: the high pressure of mixed refrigerant is 4260kPa, the low pressure is 360kPa, the mole percentage of N_2, CH_4, C_2H_6, C_3H_8, n-C_4H_{10}, i-C_4H_{10}, n-C_5H_{12}, i-C_5H_{12} is 0.052, 0.246, 0.295, 0.204, 0.048, 0.0554, 0.0486 and 0.051 respectively, the temperature of separator S1 is 269.75K, the temperature of S2 is 243.35K.

Comparison of Peakshaving Liquefaction Cycles

Based on the optimization results of liquefaction Cycles, the parameters standing for the performance of the three kinds of peakshaving liquefaction natural gas cycles could be calculated, shown as Table 1.

Table 1 Comparison of three liquefaction cycles

Liquefaction Cycles	Natural gas flow rate (kmol/s)	Refrigerant flow rate (kmol/s)	Cooling load of natural gas (kW)	Compressor power consumption (kW)	Liquefaction rate	Unit power consumption (J/mol)
C_3H_8 pre-cooling MRC	1.0	1.463	13945.3	14260.5	0.904	20069.9
N_2-CH_4 expansion LC	1.0	4.749	14080.0	28635.5	0.923	39434.4
Two stages MRC	1.0	3.138	14201.6	21934.4	0.941	29642.0

CONCLUSION

Three kinds of peakshaving natural gas liquefaction cycles are optimized in this paper, the specific power consumption of unit LNG product is used as the objective function.

The results of optimization analysis indicate the power consumption of C_3H_8 pre-cooling mixed refrigerant liquefaction cycle is the least and power consumption of N_2-CH_4 expander liquefaction cycle is the largest.

Based on the optimization results, we can get conclusions as follows:

(1) N_2-CH_4 expansion liquefaction cycle is compact, flexible and with good applicability but its power consumption is large, so it's suitable for small and medium-sized LNG system, which is used to recycle natural gas resources of marginal gas field.

(2) C_3H_8 pre-cooling mixed refrigerant liquefaction cycle has complicated equipments, its power consumption is low so it is suitable for large-sized, base load LNG system.

Two stages mixed refrigerant liquefaction cycle is simple and flexible, its power consumption is low and the liquefaction rate is high, so it's suitable for small and medium-sized peakshaving LNG system.

REFERENCE

1. Zhu G., The Optimization Research of Peakshaving liquefaction cycle and the transfer properties of natural gas, Shanghai Jiaotong University, Shanghai, (2000)