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Optimization and Thermodynamic Analysis of the Dual Mixed Refrigerant Process of the Natural Gas Liquefaction

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ABSTRACT: Natural gas liquefaction processes require a lot of investment and operation costs and are part of the energy-consuming industries. In this research, parameters such as refrigerant component, inlet and outlet pressure to compressors were optimized in the dual mixed refrigerant system to reduce operating costs. The optimized system was then evaluated by exergy to obtain the amount of exergy loss in various components of the system, finding illustrate the highest exergy losses were in compressors, heat exchangers, aftercoolers and throttle valves, respectively. The reason for the high loss of exergy in the compressors is their low polytropic efficiency. Exergy analysis showed that exergy loss in the main cycle heat exchanger, is 4% higher than that of the pre-cooling cycle heat exchanger, which is due to the higher temperature difference between input and output flows in the main cycle heat exchanger. Analysis of the effect of the size of the heat exchanger, which highly affects investment costs, on the specific power consumption is carried out and the results showed that this effect is minimum at the optimum point and increases proportionally to the distance from the optimum point.

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1. Introduction

Liquefied Natural Gas (LNG) has a significant energy content about 45–50 MJ/kg and density around 20–23 MJ/L [1]. LNG is 620 times denser than the gas state [2], and that's why it's suitable for storage.

Natural gas liquefaction processes have a lot of initial investment costs and energy consumption. Therefore, several studies have been conducted on these processes. Husnil and Lee [3] proposed an optimal control structure for Dual Mixed Refrigerant (DMR) process to maintain the compressor duty in the optimal state. Wang et al. [4] studied optimization of mixed refrigerant process with propane-pre-cooled and DMR from a thermodynamics and economics point of view with four different target functions and concluded that the greatest reduction in investment cost in compressors and heat exchangers would be achieved when the objective function was to simultaneously reduce the overall heat transfer coefficient (UA) and power consumption.

2. Methodology and Purpose

In this study, the Single Mixed-Refrigerant (SMR) proposed by Khan et al. [5] was selected as the base cycle and simulation verification, new assumptions along with a mixed refrigerant pre-cooling cycle were added to the base cycle to reduce Specific Power Consumption (SPC). Fig 1 shows the process of DMR liquefaction of the natural gas.

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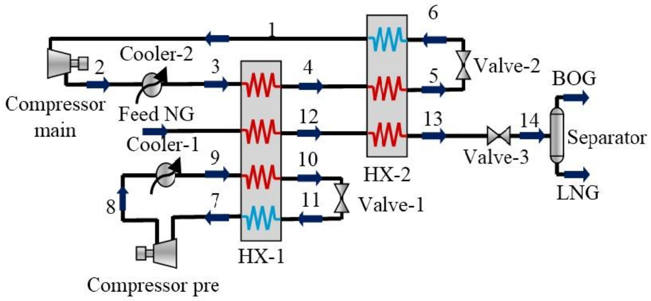

Fig. 1. The process of the liquefaction dual mixed refrigerant

DMR process is modeled in the Aspen HYSYS V10 software. The Peng-Robinson equation used by many researchers, such as Aslambakhsh et al. [6], Song et al. [7] has been used to predict the thermodynamic properties. The combination of refrigerant and pressure input and output to the compressor was optimized in a DMR system to reduce the Specific Power Consumption (SPC) using the particle swarm algorithm. The optimized system is evaluated by exergy to obtain the amount of loss of exergy in the various components and the efficiency of the system. Finally, the effect of the size of the heat exchanger on the total SPC and SPC of each cycle has been investigated.

3. Results and Discussion

The results of optimized parameters aimed at reducing the

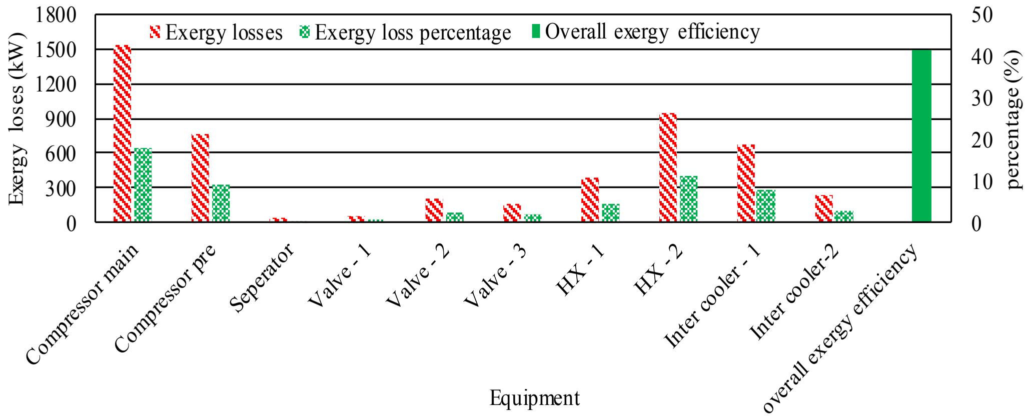

Fig. 2. Exergy losses overall process of DMR liquefaction process

SPC for mixed refrigerant processes are presented in Tables 1 and 2.

Table 1. Mole fraction of the optimized refrigeration composition

Component	Pre-Cooling	Main Cycle	Base Cycle
Nitrogen (%mole)	-	6.66	12.31
Methane (%mole)	-	24.55	33.66
Ethane (%mole)	31.84	44.69	28.58
Propane (%mole)	32.33	24.10	6.73
n-Butane (%mole)	35.83	-	18.72

The total exergy efficiency of the entire cycle after optimization was obtained 41.63% for the DMR process. Exergy losses of the other equipment used in the liquefaction cycle are shown in Fig. 2. The highest amount of exergy loss is related to compressors, heat exchangers, coolers and valves, respectively. The reason for an increase of 4% of the loss of exergy in the main cycle heat exchanger compared to the pre-cooler cycle heat exchanger is the high-temperature difference in the input and output flows to the main cycle heat exchanger. Fig. 3 shows the rate of SPC variations divided by changes in the UA. In the graph, the sum of the optimal point in terms of the lowest power consumption (1104.52) has a total heat transfer coefficient of 6254 kW/K. The change in the UA in the range of 1130-1104 for the main cycle is approximately 700 kW/K, while this amount is about 1500 kW/K for the pre-cooling cycle and shows that in this rang of changes the size of the main cycle heat exchanger will have a greater impact on the SPC. From the SPC of 1180 , the gradient of the two graphs (HX-1 and HX-2) is almost identical, which means the effect of the total heat transfer coefficient on both heat exchangers will be of the same magnitude.

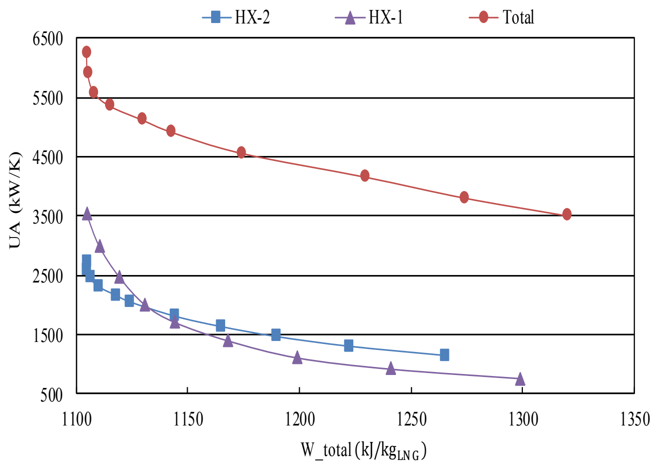

Fig. 3. Trade-off between specific power consumption and overall heat transfer coefficient for the DMR liquefaction process

4. Conclusions

After the addition of the mixed refrigerant pre-cooling cycle to the base cycle, the amount of SPC was reduced by 34%. The total coefficient of performance of the DMR cycle was 3.66 and for the base cycle was 2.94. From the analysis of exergy, it was found that compressors have the highest loss of exergy (28%) due to low polytropic efficiency, which can be compensated for by the choice of higher-efficiency compressors for exergy loss. The exergy efficiency of the entire cycle was obtained at 41.63%. The effect of the total heat

Table 2. Mole fraction of optimized refrigeration composition

Parameter	Pre-Cooling	Main Cycle	Base Cycle
Compressor suction pressure (bar)	3.37	1.78	5
Compressor discharge pressure (bar)	11	16.6	34.88
Power consumption (kJ/kg_{LNG})	395.27	709.25	1478.53
UA(kW / K)	3536	2718	4797
Cop	5.42	2.68	-
Total Cop	3.66		2.94

transfer coefficient on the SPC showed that the effect of the size of the heat exchanger on the power consumption is low at near optimal points and as the distance from the optimal point increases, the UA effect on the power consumption increases. The effect of the main cycle heat exchanger in the 1130-1104 range is greater than that of the pre-cooling heat exchanger and from the power consumption of 1180 onwards, the effect of the dimensions of both heat exchangers on specific power consumption will be the same.

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