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Presenting an Optimum Design for LNG BOG Re-liquefaction System with an Entropy Generation Minimization Approach

Mojtaba Babaelahi* and Mohammadhasan Khoshgoftar Manesh

Department of Mechanical Engineering, School of Engineering University of Qom, Iran

m.babaelahi@Qom.ac.ir

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Abstract

In this paper, the investigation of LNG-BOG re-liquefaction system has been performed, and the considerable system is analyzed based on energy conservation law and entropy generation principles. For these analyses, first the conservation of energy analysis is performed, and thermodynamic properties (pressure and temperature) of the cycle are defined. Then, entropy generation values in all components are calculated. The exergy destruction in each component and exergetic efficiency is calculated based on entropy generation values. Finally, NLP multi-objective function of the refrigeration cycle is performed for lowest entropy generation and highest exergetic efficiency. Results show good improvement in LNG-BOG re-liquefaction system characteristics.

Keywords: Exergetic, Re-liquefaction, LNG, Entropy, Optimization.

Introduction

One of the famous methods for natural gas transportation is the conversion of natural gas to liquid (LNG) and transporting it with LNG-ship. In the new Diesel-powered LNG-ship, the boil of LNG gas (produced in LNG tank) is liquefied in cooling cycle and return to tank. In recent years, important researches have been performed for analyzing various cooling cycles for re-liquefaction of LNG-boil of gas. One of the most important researches in this area was performed in 2007 by Moon and etc. [1]. The thermodynamic parameters of cooling cycle and their effects on the performance of cooling cycle were analyzed by Moon. In current paper, the multi-objective optimization of the LNG-BOG re-liquefaction system has been investigated. First, the energy balance and entropy generation calculation are performed for all components, and then the optimization for minimization of entropy generation and maximization exergetic efficiency are performed.

Modelling

The considered re-liquefaction system is shown in Figure 1. In order to determine the thermodynamic parameters, the energy balance equations are evaluated based on the selected decision variables.

For calculating entropy generation entropy generation in each component, the concept of thermal and pressure entropy generation is used as bellow:

$$S = S_{\Delta T} + S_{\Delta P} \tag{1}$$

The equation 1 can be rewritten with entropy generation number as bellow:

$$N_S = \frac{S_{\Delta T}}{C_{max}} + \frac{S_{\Delta P}}{C_{max}} \tag{2}$$

The exergetic efficiency at various components can be calculated with equation 3:

$$\varepsilon = 1 - \frac{\dot{E}_D}{\dot{E}_F} = 1 - \frac{T_0 \times \dot{S}_{gen}}{\dot{E}_F} \tag{3}$$

Two effective objective functions, (1) the exergetic efficiency that should be maximized and (2) entropy generation that should be minimized are selected for the optimization process. These two optimization functions are shown in equations equation 4 and 5.

$$f(1) = S = S_{\Delta T} + S_{\Delta P} \tag{4}$$

$$f(2) = \varepsilon = 1 - \frac{\dot{E}_D}{\dot{E}_F} \tag{5}$$

The minimization of entropy generation affects the considered system's cost, and the maximization of exergetic efficiency increases the cooling system performance.

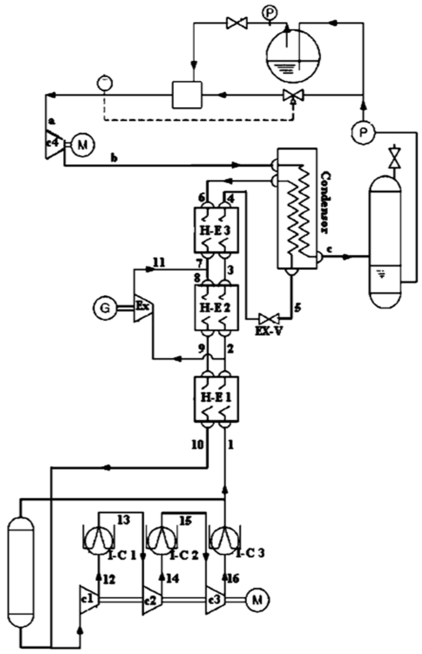

Fig. 1: The schematic view of LNG-BOG re-liquefaction system

Discussion and Results

Based on energy and entropy analysis, the effect BOG-compressor's pressure ratio on exergetic efficiency is shown in Figure 2. Results show that an increase in compressor's pressure ratio causes an increase in exergetic efficiency.

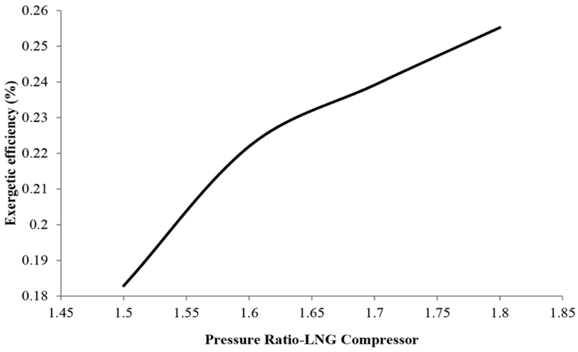

Fig. 2: Effect of BOG compressor´s pressure ratio on exergetic efficiency.

Because an increase in pressure ratio increases the exergy value in condenser inlet, and thus the exergy loss ratio is decreased.

Based on energy and entropy analysis, the optimization process for minimization of entropy generation and maximization of exergetic efficiency is performed.

The normalized Pareto front for this optimization process is shown in Figure 3. All of the point on Paret front can be evaluated as an optimum point. The selection of optimum point is depended to decision making policy. In this paper, the optimum point is selected based on ideal unreachable point (normalized entropy generation=0, normalized exergetic efficiency=1). Based on this method, the point on the Pareto front with the lowest distance from ideal unreachable point is selected as the optimum point. The values for decision parameters and objective function at the optimum point are shown in the Tables 1 and 2.

Conclusion

In this paper, the optimization of LNG-BOG re-liquefaction cycle used in LNG-ship is considered.

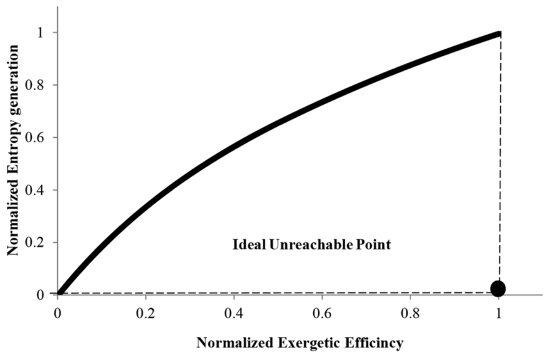

Fig. 3: Normalized Pareto front.

Table 1: The optimum decision variable.

variable	Optimum Value	Base Value [1]
Pinch temperature difference HE 3	5.08	15
Pinch temperature difference HE 2	7.59	15
Pinch temperature difference HE 1	11.92	15
Pinch temperature difference °C	11.61	15
Pinch temperature difference Cond	7.81	7
Pressure ratio-N_2 Compressor	1.48	1.8
Pressure ratio-BOG Compressor	2.60	3.0

Table 2: The optimum objective function at selected optimum point

variable	Optimum value	Base (Code calculation)	Base [2]	improvement
Exergetic efficiency (%)	29.54	25.52	25.8	4.02%
Entropy Generation (kJ/kg.K)	11.69	10.60	---	10%

The values for decision parameters and objective function at the optimum point are shown in the Tables 1 and 2.

Conclusion

In this paper, the optimization of LNG-BOG re-liquefaction cycle used in LNG-ship is considered. The entropy generation minimization and exergetic efficiency maximization are selected as optimization's objects. The results of optimization show that, in optimum point, the exergetic efficiency and entropy generation are improved 4 and 10 percent respectively.

Reference

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