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Advanced exergoeconomic evaluation of single mixed refrigerant natural gas liquefaction processes

Mehdi Mehrpooya [a,*], Hojat Ansarinasab [b]

[a] Renewable Energies and Environmental Department, Faculty of New Science and Technologies, University of Tehran, Tehran, Iran
[b] Faculty of Energy Systems Engineering, Petroleum University of Technology (PUT), Iran

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ABSTRACT

Conventional exergoeconomic analysis cannot recognize part of exergy destruction cost and investment cost that can be avoided. Also this analysis does not have ability to determine interactions between the components. In this study advanced exergoeconomic analysis is studied on two single mixed refrigerant processes. Costs of investment and exergy destruction are divided into avoidable/unavoidable and endogenous/exogenous parts for the components with high inefficiency. According to the avoidable exergy destruction cost in Linde process, E-1 heat exchanger with 13,232.4 ($/h) and in APCI process, C-1 compressor with 476.9 ($/h) should be considered for modification. Because these devices have higher improving potential than the other devices. The results show that costs of investment and exergy destruction in most of the process components are endogenous. Interactions between the process components do not affect the inefficiencies significantly. Cost of exergy destruction in the compressors is avoidable while investment costs in these components are unavoidable. Cost of exergy destruction in heat exchangers and air coolers is unavoidable while investment costs in these components are avoidable.

1. Introduction

Liquefied natural gas (LNG) processes are costly and consume high amount of energy. Also these processes have high improvement potential. Therefore, recognizing the process components with high inefficiencies is necessary. Refrigeration systems have been analyzed by conventional exergy and exergoeconomic methods to identify the components with high irreversibility, cost of exergy destruction and investment cost. Energy and exergy analyses is used for five conventional liquefied natural gas processes (Vatani et al., 2014a). Exergetic analysis is done for a refrigeration system in ethylene and propylene production process (Fabrega et al., 2010). Ethane recovery plants refrigeration cycles are investigated by the exergy method (Tirandazi et al., 2011). A novel integrated LNG process is investigated by exergy analysis (Vatani et al., 2013). Exergy analysis method is used for a novel hydrocarbon recovery process with auto-refrigeration system (Mehrpooya et al., 2015). Exergy analysis indicates a great potential for improvement in this process. Exergy, exergoeconomic and exergoenvironmental analyses are applied to the PRICO liquefaction process and options for improvement are proposed (Morosuk et al., 2015). Thermoeconomic optimization of a cryogenic refrigeration cycle is investigated (Sayyaadi and Babaelahi, 2010). Thermoeconomic analysis of a large industrial propane refrigeration cycle is studied (Mehrpooya et al., 2009). Conventional exergy and exergoeconomic analysis does not have ability to determine interactions among the process components and these analyses cannot recognize sources of irreversibility. Advanced exergoeconomic analysis is used to determine the origin of irreversibilities and can compute improvement potential. This method is useful to split total exergy destruction, cost of exergy destruction and investment cost to four part, namely endogenous, exogenous, avoidable and unavoidable. Advanced exergetic analysis on five natural gas liquefaction processes is performed (Vatani et al., 2014b). The results show that structural optimization cannot be useful to reduce the overall process exergy destruction because components exergy destruction is endogenous. Advanced exergy analyses are applied to a vaporization liquefied natural gas and power plant system (Tsatsaronis and Morosuk, 2010a). According to the results, most of the exergy destruction for all components are endogenous. Conventional and advanced exergy analyses is studied

* Corresponding author.
E-mail address: mehrpoya@ut.ac.ir (M. Mehrpooya).

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Nomenclature

c	unit exergy cost ($/Gj)
$\dot{C}$	exergy cost rate ($/h)
$\dot{E}$	exergy rate (kW)
F	exergoeconomic factor (%)
$\dot{m}$	flow rate (kgmole/h)
P	pressure (bar)
r	relative cost difference (%)
T	temperature (C)
y	exergy destruction ratio
$\dot{Z}_k$	capital investment cost flow rate ($/h)

Greek letters

ε	exergy efficiency
Δ	gradient

Superscripts

AV	avoidable
EN	endogenous
EX	exogenous
tot	total
UN	unavoidable

Subscripts

D	destruction
F	fuel
k	kth component
L	loss
P	production
tot	total

Abbreviations

AC	air cooler
APCI	Air Products Chemicals, Inc
C	compressor
D	flash drum
E	multi stream heat exchanger
GDHS	geothermal district heating systems
LNG	liquefied natural gas
SMR	single mixed refrigerant
NG	natural gas
P	pump
V	expansion valve

on a combined cycle power plant (Petrakopoulou et al., 2011). Results show that most of the exergy destruction of the process components is unavoidable. Conventional and advanced exergy analyses are carried out on a cascade refrigeration system for liquefaction of natural gas (Tsatsaronis and Morosuk, 2010b). Results shows the interactions between the components and improvement potentials. Advanced exergy and advanced exergoenvironmental methods are applied on a natural-gas degasification plant (Morosuk et al., 2012). Advanced exergy analysis is performed for a combined power plant (Petrajopoulou et al., 2012). Advanced exergoeconomic analysis is studied on an electricity-generation facility that operates with natural gas in Turkey (Açıkkalp et al., 2014a). The results show that high-pressure steam turbine, combustion chamber and condenser have great economic improvement potential due to their high exergy destruction cost. Also according to the endogenous exergy destruction, the interaction among the process components are strong. Advanced exergy and exergoeconomic is carried out on thermal processes in an industrial plant (Vuckovic et al., 2014). Advanced exergoeconomic analysis is used for comparison and evaluation of two geothermal district heating systems (Keçebas et al., 2014). Geothermal district heating systems are investigated by conventional and advanced exergoeconomic analyses (Keçebas and Hepbasli, 2014). The results show that cost rate of avoidable part within the components is higher than that of the unavoidable one and exergoeconomic factor is 5.53% while the modified exergoeconomic factor is 9.49%. Advanced exergoeconomic analysis is performed on a trigeneration system using a diesel-gas engine (Açıkkalp et al., 2014b). The results show that the condenser, high pressure steam turbine and combustion chamber have great economic improvement potential due to their high cost of exergy destruction. A heat pump food dryer is investigated by advanced exergoeconomic evaluation methods (Erbay and Hepbasli, 2014). According to this analyses, decreasing the temperature causes an increase in the performance cost of drying. A power plant with chemical looping combustion is analyzed by advanced exergoeconomic method (Petrakopoulou et al., 2013). In components of the main gas turbine system the avoidable costs is higher than the unavoidable costs and represent the potential for improvement. Cost of exergy destruction for compressor, expander and reactor is avoidable. A cogeneration system is investigated by advanced exergoeconomic and exergoenvironmental method (Khoshgoftar Manesh et al., 2013). Exergoeconomic evaluation of single mixed refrigerant natural gas liquefaction processes is done (Mehrpooya and Ansarinasab, 2015). Cost of exergy destruction, exergoeconomic factor, exergy destruction and exergy efficiency are calculated in this paper.

In advanced exergoeconomic analysis, economic performance of the process components are analyzed in more general and comprehensive perspective and their interaction with other devices are also taken into consideration. This analysis gives more information for costs of exergy destruction and investment with more sense about the processes. In this paper, advanced exergoeconomic analysis is used on two single mixed refrigerant (SMR) LNG processes. Scope of this paper is calculation of improvement potential which can be avoided. Important advanced exergoeconomic parameters like: advanced exergy destruction rate, advanced exergy destruction cost rate, advanced investment costs, advanced exergy destruction cost rate and advanced investment costs are calculated and discussed.

2. Process description

2.1. SMR-Linde process

Fig. 1 shows the process flow diagram of SMR-Linde (Foerg et al.). SMR-Linde process uses E-1 and E-2 heat exchangers for precooling the natural gas and E-3 and E-4 heat exchangers for subcooling and liquefaction, respectively. Inlet natural gas enters E-1 heat exchanger at 13 °C and 60 bar. Natural gas temperature is reduced to −67 °C, −93 °C and −161 °C in precooling, liquefaction, and subcooling sections, respectively. Finally in D-4 separator, liquid product is extracted. Operating conditions of SMR-Linde process streams are presented in Table 1.

2.2. SMR-APCI process

Air Products and Chemicals, Inc (APCI), has a simplified single mixed refrigerant process (Roberts et al.). Fig. 2 shows the process flow diagram. Complexity and fixed costs of this process is low because it has only two heat exchangers. Inlet gas at 30 °C and