Applied Thermal Engineering 115 (2017) 885–898

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Evaluation of novel process configurations for coproduction of LNG and NGL using advanced exergoeconomic analysis

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HIGHLIGHTS

- Advanced exergoeconomic analysis is applied on two processes for co-production of LNG/NGL.
- Cost of investment is divided into avoidable/unavoidable and endogenous/exogenous.
- Results show that interactions between the components is not considerable.

ARTICLE INFO

Article history:
Received 3 August 2016
Revised 3 January 2017
Accepted 6 January 2017
Available online 9 January 2017

Keywords:
Liquefaction process
Advanced exergy analysis
Advanced exergoeconomic analysis
Exergy destruction cost
Investment cost

ABSTRACT

Advanced exergoeconomic analysis is applied on two novel process configurations for co-production of LNG and NGL. Dual mixed refrigerant (DMR) and mixed fluid cascade (MFC) refrigeration systems are used for supplying the required refrigeration. Based on the avoidable cost of exergy destruction in DMR process configuration, C-300 compressor with 504.43 ($/h) and in MFC process configuration, C-200A compressor with 251.05 ($/h) should be modified first. Based on the avoidable endogenous/exogenous part, three strategies are proposed for reducing exergy destruction cost in the process components. Cost of exergy destruction and investment in most of the process components are endogenous. So interactions among the components in these processes is not strong. Investment cost of turbo expander and compressors are unavoidable due to technological and economic limits while air coolers and heat exchangers have potential for improvement. Cost of exergy destruction of the air coolers and heat exchangers are unavoidable while turbo expander and compressors are avoidable.

1. Introduction

Liquefied natural gas (LNG) operating condition is −161 °C at 101 kPa [1]. But there are impurities in natural gas that should be separated. Natural gas liquids (NGL) are extracted for added value and as a main feed in the petrochemical processes [2]. LNG production and NGL recovery are cryogenic processes so refrigeration system is the most important part in both of them. Increasing the level of integration is logical to increase the efficiency and to decrease the capital and operating costs [3]. The produced residue gas in NGL recovery plants leaves the demethanizer tower at about −100 °C so is can be used for supplying a part of the required refrigeration in the process before flowing to the pipeline. The main idea of integrated NGL and LNG process configurations is using outlet low temperature gas from the demethanizer tower straightly to the liquefaction unit as inlet feed. With integration of NGL recovery and LNG processes total cost decreases and efficiency increases [4]. Required refrigeration in nonintegrated processes is provided by separated heat exchangers and cycles, while in integrated processes, refrigeration is supplied from the shared refrigeration cycles and devices, In other words it is obvious that NGL and LNG processes are series plants. Integrated hydrocarbon recovery processes are investigated by stochastic optimization methods [5]. In this study operating condition and process configuration are considered as continuous and discrete decision variables respectively. Benefits of integration have been attracted companies to design integrated systems. In another paper a currently in operation ethane recovery plant is optimized by shuffled frog leaping optimization algorithm [6]. The results show that by adjusting the operating variables, ethane recovery can be increased up to 18%.

Fluor Technologies indicates that by integration of LNG and NGL processes 10% of the required energy is saved [7]. LNG production

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http://dx.doi.org/10.1016/j.applthermaleng.2017.01.019
1359-4311/

Nomenclature

c	unit exergy cost ($/Gj)
$\dot{C}$	exergy cost rate ($/h)
$\dot{E}$	exergy rate (kW)
f	exergoeconomic factor (%)
$\dot{m}$	flow rate (kg mole/h)
P	pressure (bar)
r	relative cost difference (%)
T	temperature (C)
y	exergy destruction ratio
$\dot{Z}$	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	*k*th component
P	production
tot	total
c	critical

Abbreviations

AC	air cooler
C	compressor
C3MR	C3 precooled mixed refrigerant
D	flash drum
DMR	dual mixed refrigerant
E	multi stream heat exchanger
LNG	liquefied natural gas
MFC	mixed fluid cascade
MIX	mixer
NG	natural gas
NGL	natural gas liquid
P	pump
SMR	single mixed refrigerant
T	demethanizer tower
TE	turbo expander
V	expansion valve

capacity of ConocoPhillips integrated process is almost 7% more, while it requires same power [2]. Four integrated LNG and NGL process configuration is proposed which are different in the NGL recovery section [8]. A novel integrated process configuration for NGL/LNG production is introduced. This process uses two mixed refrigerant cycles to provide the required refrigeration [9]. LNG and NGL processes are costly and consume high amount of energy. This will show the necessity of a techno-economic evaluation for such processes. Many researchers has utilized conventional exergy and exergoeconmic analysis methods on the refrigeration cycles to determine the improvement potential. Energy and exergy optimization is performed for cogeneration plant consisting of an Otto cycle [10], Brayton cycle [11] and irreversible Carnot heat engine [12]. Energy and exergy analysis of internal combustion engine fueled with diesel and natural gas are presented [13]. Thermodynamic and exergy analysis are carried out for heat engine and combined cogeneration systems with steam and gas turbines [14,15]. A hybrid power cycle using solar energy and cold energy of LNG is evaluated by exergy analysis [16]. The results show that the most exergy lost is related to the air preheater, combustion chamber and boiler. An integrated combined cooling heating and power process is investigated by exergy analysis method [17]. A currently in operation is investigated by advanced exergy analysis method [18]. The results show that the exergy destruction is related to the air coolers. Cryogenic helium extraction from natural gas processes are evaluated by advanced exergy analysis method [19]. The results show that the compressors have the lowest exergy destruction. Cryogenic air separation processes are investigated by exergy analysis method. In [20] one column configuration and in [21] two column configuration are considered. In both of them cold energy of LNG is used as the cold sources in the process. A novel hydrocarbon recovery process with auto-refrigeration system is analyzed by exergy method [22]. Exergy analysis is applied to refrigeration cycles in ethylene and propylene production processes. Rate of exergy destruction in the process can be decreased by adjusting the operating conditions of the cycles [23]. A new parameter is introduced for evaluation of the integration level in the hydrocarbon recovery processes. This parameter is defined based on the exergy concept [24]. Exergy analysis of the cascade refrigeration cycles used for natural gas liquefaction is investigated [25]. Exergy analysis is applied to multistage cascade low temperature refrigeration systems utilized in olefin plants [26]. Exergy analysis of absorption refrigeration machines is presented by a new method [27]. The exergy analysis of a hydrogen liquefaction system is considered [28].

An integrated natural gas liquids (NGL) and liquefied natural gas (LNG) processes is investigated by exergy and exergoeconomic analysis methods [29]. Exergoeconomic analysis is performed on the process for the coproduction of liquefied natural gas (LNG) and natural gas liquids (NGL) based on the mixed fluid cascade (MFC) refrigeration systems, as one of the most important and popular natural gas liquefaction processes [30]. Exergoeconomic analysis is carried out for single mixed refrigerant natural gas liquefaction processes [31]. PRICO liquefaction process is analyzed by exergy-based methods [32]. Exergy and exergoeconomic analyses on product recovery and separation systems of natural gas plant is performed [33]. A large industrial propane refrigeration cycle is analyses by thermoeconomic analysis method [34]. Conventional exergy and exergoeconomic analysis does not useful to determine the origin of irreversibilities and compute improvement potential. Advanced exergy and advanced exergoeconomic analysis are important tools to recognize sources of irreversibility and determine interactions among the process components. Advanced exergy analysis is applied on a hybrid fuel cell power plant [35]. The results show that the most portion of the exergy destruction is avoidable (more than 65%). An industrial propane refrigeration cycle is investigated by the advanced exergy analysis method [18]. The results shows that 59.61% of the exergy is lost in the unavoidable form in all components. Advanced exergy analysis on five conventional LNG processes is done [36]. Power plant