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Energy and advanced exergy analysis of an existing hydrocarbon recovery process

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ABSTRACT

An advanced exergy analysis of the Ethane recovery plant in the South Pars gas field is presented. An industrial refrigeration cycle with propane refrigerant is investigated by the exergy analysis method. The equations of exergy destruction and exergetic efficiency for the main cycle units such as evaporators, condensers, compressors, and expansion valves are developed. Exergetic efficiency of the refrigeration cycle is determined to be 33.9% indicating a high potential for improvements. The simulation results reveal that the exergy loss and exergetic efficiencies of the air cooler and expansion sections respectively are the lowest among the compartments of the cycle. The coefficient of performance (COP) is obtained as 2.05. Four parts of irreversibility (avoidable/unavoidable) and (endogenous/exogenous) are calculated for the units with highest inefficiencies. The advanced exergy analysis reveals that the exergy destruction has two major contributors: (1) 59.61% of the exergy is lost in the unavoidable form in all units and (2) compressors contribute to 25.47% of the exergy destruction. So there is a high potential for improvement for these units, since 63.38% of this portion is avoidable.

1. Introduction

Natural gas contains valuable components that are recoverable in the form of hydrocarbon liquids at a low cost. Numerous processes are used for separation of these components. Usually, flexibility is a major characteristic of the proposed processes, which allows making changes in the process as necessary. The values of heavier hydrocarbon components than ethane will affect the performance of the process. This means the rich feed gases need more external refrigeration compared to the lean feeds. Also, when the feed is rich, more natural gas liquids is obtainable. In a variety of industrial gas processing units, expansion processes are used for the recovery of the hydrocarbon liquids. For instance, in ethane/propane recovery from high-pressure natural gas, the expansion processes play a significant role. The feed gas is expanded and cooled to a relatively low temperature to obtain the partial liquefaction [1]. The main parts of the process consist of demethanizer and deethanizer columns, heat exchanger, separator, and turbo expander. For energy integration and cost reduction of external refrigeration cycles, the overhead product of the columns is used in the multi-stream heat exchanger for cooling. For this purpose, the feed gas is cooled in the heat exchanger by side streams of the column to reduce the cost of the initial refrigeration. The hydrocarbon components of natural gas are separated at quite low temperatures and therefore, turboexpanders are used for further temperature reduction and simultaneous power generation. Kidnay and McCartney [2] reviewed the recovery of the natural gas condensates and optimization of the different aspects of the process. Chebbi et al. [3] studied the impact of the demethanizer column pressure. They concluded that the optimized value of ethane recovery in a conventional expansion process was obtained at an intermediate pressure of the demethanizer column. Mehrpooya and Vatani [4] used the genetic algorithm to optimize the NGL recovery process to achieve the maximum gain. A novel NGL recovery process to minimize energy consumption is proposed [1]. They evaluated the process characteristics by exergy analysis and proposed a new process for recovery of NGL and LNG. Vatani et al. [5] proposed a novel integrated process configuration for NGL/LNG production and analyzed it. The results of their studies show that the proposed process has a high efficiency and can recover ethane with higher purity than 93% from a typical rich gas feed. Tirandazi et al. [6] studied the refrigeration cycles of ethane and heavier hydrocarbon recovery plants and used the exergy analysis method in their investigations. Park et al. [7] proposed a novel process for NGL recovery and compared it with other

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Nomenclature

$\dot{E}$	rate of exergy (kW)
e	molar exergy (kJ/kmol)
Ex	exergy (kJ)
g	molar gibbs free energy (kJ/kmol)
h	molar enthalpy (kJ/kmol)
$\dot{H}$	rate of enthalpy (kW)
$\dot{I}$	irreversibility (kW)
m	number of cold streams
$\dot{m}$	molar flow rate (kmol/h)
n	number of hot streams
N	exergy loss number
P	pressure (bar)
$\dot{Q}$	heat duty (kW)
s	molar entropy (kJ/kmol °C)
$\dot{S}$	rate of entropy (kW/°C)
T	temperature (°C)
$\dot{W}$	work transfer rate (kW)
x	component mole fraction

Greek letters

η	exergy efficiency
γ	activity coefficient
Δ	gradient
ε	slope of line

Subscripts

a	air
c	cold
D	destruction
F	feed
h	hot
i	inlet
j	component
K	Kth unit
L	losses
o	outlet
Others	other units
P	product
REV	reversible
sh	shaft
tot	overall system

Superscripts

ΔP	pressure component
ΔT	thermal component
°	standard condition
AV	avoidable
ch	chemical
E	excess property
EN	endogenous
EX	exogenous
ID	ideal system
mix	mixture
ph	physical
R	real system
UN	unavoidable

Abbreviations

AC	air cooler
C	compressor
COP	coefficient of performance
D	flash drum
J-T	Joule-Thomson valve
HX	heat exchanger
MIX	mixer
MSHX	multi-stream heat exchanger
NGL	natural gas liquids
P	pump
V	expansion valve

conventional NGL recovery processes. Their results show that the proposed scheme has a lower capital expenditure than other recovery processes. Mehrpooya et al. [8] proposed a novel process for hydrocarbons recovery from natural gas, which employs demethanizer and deethanizer columns to produce methane and ethane as pure products. They proposed a self-refrigeration cycle that has 38.57% lower power consumption than the external propane refrigeration cycle. Lee et al. [9] proposed methods for optimizing the NGL recovery processes from the different feed sources. They used an internal refrigeration cycle that has two parts. An open cycle with the output of the distillation column as the refrigerant and a closed-cycle refrigeration system. De Guido et al. [10] studied the refrigeration cycles for low-temperature purification of natural gas and showed that the configuration of the refrigeration cycles and the type of refrigerants can affect the efficiency of the process. Because of the high energy consumption of refrigeration systems and the vital role of the economic issues in the industry, it is reasonable to find the aspects of systems that can be improved. So, the efficiency of the process and operating conditions can be addressed by exergy analyses. A method that is used to evaluate the mass and energy conservation principles together with regard to the second law of thermodynamics is known as exergy analysis. Exergy analysis is used to identify types and magnitudes of the wastes and the losses of the energy systems with the goal of more efficient energy consumption. With increasing process costs and also a global effort to achieve environmental-friendly processes, today exergy aspects of the systems and the processes are increasingly more important. Exergy analysis is employed in LNG and NGL processes to show the different sides of these processes, which can be improved. Remeljej and Hoadley [11] carried out an exergy analysis for four small-scale liquefaction processes of the natural gas and showed that the type of refrigerant for the process has a big impact on the efficiency of the process and processes with a conventional refrigerant such as propane have low efficiency. Mehrpooya et al. [12] carried out an exergy analysis for their proposed hydrocarbon recovery processes. They showed that the simple design, using a reliable configuration in the refrigeration system and having better NGL recovery outputs compared to the similar cases were the advantages of their process. Tirandazi et al. [6] used exergy analysis to compare the efficiencies of ethane and heavier hydrocarbon recovery processes. Mehrpooya and Pishvaie [13] showed that the exergetic efficiency of their refrigeration cycle is about 26%, which indicates a great potential for improvements. They also found that the condenser and evaporator sections of the refrigeration cycle have the highest exergy losses. Further, by using exergy analysis Mehrpooya et al. [8] showed that the exergy losses in the columns and expansion valves have the highest values, and the self-refrigeration compression power consumption is 38.57% less than the external propane refrigeration cycle. Ghorbani et al. [14] carried out an exergy analysis for products of the hydrocarbon recovery process and also the refrigeration system of this process. They showed that the deethanizer column has a high exergy loss unlike a small exergy loss of demethanizer. Tahmasebi et al. [15] investigated the effect of various feed