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Process development and sensitivity analysis of novel integrated helium recovery from natural gas processes

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ABSTRACT

Two novel integrated cryogenic helium extraction from natural gas processes are introduced and analyzed. Helium recovery efficiency, energy consumption per extracted helium, energy and exergy analyzes are studied for the proposed processes. Multi streams heat exchangers composite curves show that thermal design of the processes has been done with good efficiency. The results show that efficiency of the integrated processes is higher than the flash method. Efficiency of the modified Linde and Exxon mobile integrated processes are 96% and 95% respectively. Based on the results modified Linde process performance is better than the modified Exxon mobile process. Exergy analysis results show that valves have more exergy destruction comparing to the other equipment. Also air coolers have low exergy loss and high exergy efficiency.

1. Introduction

Helium is a noble gas and because of its particular properties is used widely in industry, such as aviation, electronics, space-rocket, nuclear industries, and medicine. Natural gas reservoirs can be classified into two parts based on the concentration of helium in natural gas. If the helium content would be more than 0.5% the field is rich and if helium content would be less than 0.1% is classified as poor reservoir. Atmosphere and natural gas are the main sources of helium. Concentration of helium in the atmosphere and natural gas is about 5.2 ppm and up to 7% by volume respectively. Extraction of helium from natural gas by low-temperature separation process that called fractional distillation is economic. Extraction of helium from natural gas by cryogenic process is common. The simplest process for producing helium is condensation of natural gas in the distillation columns. This process has been developed by Air Products (USA), Linde (Germany), and Air Liquid (France) companies. Linde Co. first proposed a method for producing helium. In this method, at the first stage, a volumetric flow of which contains at least 80% helium is produced [1–3]. Cryogenic processes can be divided into three categories: flash based, distillation based and combined flash and distillation process. Flash based helium recovery processes are studied and analyzed by advanced exergy analysis [4]. In this study two modified flash based helium recovery processes are proposed and discussed. Also in Refs. [5,6] flash based helium recovery processes are investigated by advanced exergoeconomic analysis methods. For production of high concentration helium, downstream processes such as membrane PSA, TSA must be used. Combined processes have high efficiency and high helium extraction rate, and the required energy towards the other processes is lower. In the conventional processes, the remained flash stage in LNG production units is used as the helium extraction unit feed. Helium extraction process includes different stages: pretreatment of natural gas containing helium, water and acid gases removal, and heavy hydrocarbons recovery. Operating temperature of the helium extraction unit (HeXU) is lower than the LNG plant. So concentration of the impurities in the feed of HeXU should be lower than the inlet feed to the LNG process [7]. At low temperatures, carbon dioxide particularly freezing starts and production of solid impurities cause operating problems [8]. Natural gas stream after primary treatment follows to the liquefaction process. Expansion process is used to decrease the natural gas stream

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Nomenclature

A	Heat transfer area
E	Exergy (kJ/kg mole)
h	Enthalpy (kJ/kg mole)
LMTD	log mean temperature difference (0C)
LNG	liquid natural gas
P	Pressure (kPa)
TSA	Temperature swing adsorption
PSA	Pressure swing adsorption
S	Entropy (kJ/kg mole °C)
R	Universal gas constant (J/kg.K)
T	Temperature (°C)
U	Overall heat transfer Coefficient (W/m2. °C)
M	flow rate (kg mole/s)
W	Work transfer rate (kW)

Greek letters

ε	exergy efficiency
Δ	gradient
ω	Power consumption ratio (kW/(kg/s))
H	Helium extraction rate

Subscripts

A	Air
C	Cold
H	Hot
i	Component i
I	inlet
J	Component j
O	Outlet
tot	total
others	other components
D	destruction
P	production

Superscripts

ph	Physical
Ch	Chemical
m	Mean

Abbreviations

D	Flash dream
VLV	Valves
K	Compressor
AC	Air Cooler
T	Distillation column
HX	Multi streams heat exchanger

temperature. Due to higher volatility of helium and nitrogen compared to other components, flash drum gas product contains these elements and liquid product doesn't contain helium with a small percentage of nitrogen. Helium production is generally considered as a part of nitrogen removal unit. Natural gases contains helium naturally have a high proportion of nitrogen as well. Nitrogen reduces the heating value of the natural gas that leads to problems in LNG transportation. For this reason percentage of nitrogen in the LNG must be lower than a specified value [9–11]. So integrated processes has been developed for removal of nitrogen and production of helium [7]. Gas stream with a high concentration of helium which has been produced from the nitrogen removal unit [12], enter the crude helium process. At this stage crude helium is produced by using cooling processes. This process typically includes several flash drums and the heat exchangers. Rich helium stream which includes helium, methane and nitrogen first is partially condensed. Helium have low boiling point towards the other components, so it goes to the gas phase and crude helium stream is produced [13]. Crude helium stream contains at least 50% mole helium [14]. Cooling duty of this process is provided by expansion of the methane and nitrogen stream. In the helium extraction processes, temperature deceases to lower than the minimum temperature occurs in the LNG processes. So auto refrigeration approach is used for supplying the required refrigeration. In this method the outlet temperature of LNG process decreases to about −185 °C. In the cryogenic processes performance of the multi stream heat exchangers is a determining factor and it can affect the required power in the process significantly. This point has been investigated in cryogenic natural gas process configurations [15–17].

Exergy analysis method can be used for evaluation of kind of energy systems [18–21]. LNG processes are investigated by exergy and exergy economic analysis methods [22–24]. The results show that multi stream heat exchangers performance has drastic effect on the energy and exergy efficiency of the process. This equipment based on its high-tech design has suitable performance. An industrial propane refrigeration cycle is investigated by exergy method [25]. The overall efficiency of the cycle is gained 26.5%. Exergy analysis is used for evaluation of the integrated NGL and LNG processes [26]. Hydrocarbon recovery process configurations are investigated based an index which is defined by exergy concept [27]. The results show that the introduced index can successfully classify the processes based on their integration level. Cryogenic air separation processes which uses cold energy of LNG are evaluated by exergy method [28,29].

In this study novel helium extraction integrated flash and distillation processes are designed and investigated. The process configurations and operating conditions are presented and discussed. Also the process equipment are designed and their data sheet are given. A sensitivity analysis is done to investigate the process performance against the effective parameters. Finally energy and exergy analysis methods are used for evaluation of the process performance.

2. Process description

Integrated processes have high efficiency towards the flash and distillation processes. Linde and Exxon companies tried to increase the efficiency of base flash and distillation processes. Figs. 1 and 2 illustrate schematic of Linde [30] and Exxonmobil [31] processes respectively. Helium extraction process consist of these parts: 1) heat exchanger 2) phase separator 3) distillation column.

Figs. 3 and 4 illustrate block flow diagrams of the Linde and ExxonMobil integrated processes respectively. Integrated processes include flash and distillation separation sections. This point increases the produced helium purity and decreases the required energy in the process. Multi stream heat exchangers are used to increase the cold recovery of the process by exchanging refrigeration of the cold outlet streams with the inlet streams. Inlet stream which contain 0.05% mole helium enters at 27 °C and 60 bar.