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Advanced exergy analysis of novel flash based Helium recovery from natural gas processes

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ABSTRACT

Two cryogenic Helium recovery processes which are based on the flash separation are investigated and analyzed. The presence of Helium in the natural gas affects shape of its phase envelope. Effect of various components concentration on the natural gas phase envelope shape is investigated. Two modified cryogenic flash based processes are introduced. Two new parameters are proposed in order to evaluate performance of the under consideration processes. Modified processes are investigated by the exergy analysis method. Exergy loss and exergy efficiency of the process components are calculated. Results show that the compressors have the lowest exergy loss in both processes. In the compressors high portion of exergy destruction is related to the avoidable part that means this exergy destruction can be decreased. But in the multi stream heat exchangers high portion of exergy destruction is related to the unavoidable exergy destruction. Endogenous/exogenous destructions shows that portion of endogenous exergy destruction in the components is higher than the exogenous part. In fact interactions among the components do not affect the inefficiencies significantly.

1. Introduction

Helium is one of the most common elements in the universe. It is called a noble gas because it doesn't chemically interact with other elements. Its atomic number is two and its weight is 4.002 [1]. Helium in natural state, doesn't have any smell, taste or color. It is widely used in medical applications, welding and magnet production, space technology, leak detection and cryogenic applications. Natural gas and atmosphere are main source of Helium in the earth. Amount of Helium in the atmosphere is quite small: only about 0.005% of the atmosphere is Helium and separation of it is not economical. Natural gas is the main source of Helium in the earth. Presence of Helium in natural gas reduces its heating value. Several methods are used for separation of Helium from natural gas [2]. Extraction of Helium from the gas sources that contains at least 0.1%–0.5% (volume) Helium is economical [3]. Separation of Helium from natural gas have two benefits; increasing heating value of the natural gas and marketing of the Helium. Separation methods are divided into three groups: Cryogenic processes, membrane separation and pressure swimming adsorption [4,5]. In the cryogenic processes separation is done at temperatures lower than −65 °C. Up to 90% of the helium can be recovered by the cryogenic separation method. Most new gas processing plants use cryogenic recovery technology. Cryogenic processes can be divided into two categories: multi-stage flash cycle process and high pressure distillation column process [6]. Gas mixtures can be effectively separated by the synthetic membranes made from polymers such as polyamide or cellulose acetate, or from ceramic materials. Membrane technology is not developed like other separation methods such as cooling or pressure swing adsorption. Membrane separation is based on gas diffusion Fick low theory [7]. Pressure swing adsorption (PSA) method is used to separate Helium from gas mixtures. This method is based on the absorption of gases on solid surfaces. Choosing the purification method depends on the type of the process and feed gas composition [4]. To achieve a high concentration of Helium usually several processes should be used. Refrigeration process is used to remove hydrocarbons. Then, the product which contains Helium, nitrogen and a small percentage of methane follows to the next section. To achieve a concentration of 99.99%, more advanced methods such as membrane or PSA is necessary [7–9]. Cryogenic process is a convectional way to

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Nomenclature

a, b	mixture parameters
A	Heat transfer area.
E	Exergy (kJ/kg mole)
H	Enthalpy (kJ/kg mole)
K	binary interaction
LMTD	log mean temperature difference (°C)
LNG	liquid natural gas
NGL	natural gas liquid
P	Pressure (kPa)
PR	Peng Robinson
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/m^2 °C)
V	molar volume (m^3/mol)
Z	vapor mole fraction
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))
η	Helium extraction rate

Subscripts

A	Air
C	Cold
H	Hot
I	Component i
I	inlet
J	Component j
υ	vapor phase
O	Outlet
ɪ	liquid phase
ʄ	fugacity (kPa)
tot	total
others	other components
D	destruction
P	production

Superscripts

AV	avoidable
UN	unavoidable
EN	endogenous
EX	exogenous
ph	Physical
Ch	Chemical
m	Mean

Abbreviations

F	flash dream
V	Valves
K	Compressor
AC	Air cooler

produce crude Helium stream from natural gas. Impurities such as water, mercaptan, carbon dioxide are removed from the natural gas by upstream units. Then the treated gas enters a low temperature heat exchanger and heavy hydrocarbon fractions separation process [10–12]. Vapor stream is cooled to about −157 °C and remaining heavy hydrocarbon are separated. Then the vapor stream which include Helium and nitrogen for production of high purity Helium is cooled to about −196 °C; in this temperature nitrogen is condensed and crude Helium is produced [2]. Cryogenic processes are used widely in industry for production of Helium from Helium-bearing natural gas streams. A cryogenic process which can produce LNG, Helium and synthesis gas is disclosed [3]. In this process natural gas stream is cooled to about −135 °C to produce sub-cooled gas. It reduces specific energy consumption for the liquefied natural gas production. Then it enters a flash drum as phase separator. Vapor and liquid phases comprising Helium and methane are separated respectively. At last a portion of the methane from this liquid is separated into a vapor phase comprising methane and this stream follows to a reactor and produce synthesis gas. This process is suitable to produce Helium from natural gas stream that concentration of Helium is less than 0.1% volume. A process to produce Helium and nitrogen from a stream comprising methane, Helium and nitrogen is introduced [13]. Inlet feed stream pressure is between 15 and 30 bar. It is cooled and enters a flash drum. Outlet vapor contains 50–95% Helium and liquid outlet contains methane and nitrogen. For production of nitrogen, liquid outlet is divided into several streams and enters the process. In this process a rectification column is used for controlling of the product specifications. Methane containing stream from the bottom and nitrogen is removed from the top of the tower. In this process high purity Helium (up to 99%) can be produced. A cryogenic process for production of a stream with at last 50% Helium and 50% nitrogen is disclosed [14]. In this configuration feed stream is cooled and follows to a phase separator. Vapor phase is cooled and enters a flash drum. The vapor phase contains Helium and for increasing its purity, it is sent to the downstream sections. A flash cycle process is introduced [15]. In this configuration feed gas is partially liquefied and separated from the vapor. In Ref. [6] a cryogenic process for production of a Helium vapor stream, methane enrich stream and liquid stream comprising heavier hydrocarbons than methane is disclosed. Temperature and pressure of the feed stream input to this process changes between −40−−10 °C and 30–50 bar respectively. In this configuration a distillation column is used for production of C_1 (Methane) and NGL. Concentration of Helium in rich Helium stream is about 50% mole.

In this paper, properties of the Helium is described and analyzed. Temperature-pressure phase diagram of the natural gas stream containing Helium are drawn and discussed. Ping-Robinson equation of state is used to plot the phase diagrams. Next the parameters which can affect the phase diagram of the natural gas mixtures containing Helium are investigated. Then cryogenic Helium recovery process configurations are discussed. Two new process configurations based on the flash based processes are introduced and analyzed. Exergy analysis method is used to evaluate the modified process configurations. Also advanced exergy analysis is done on the components with great exergy destruction to know about origin of the exergy destruction. In advanced analysis exergy destruction is divided into avoidable and unavoidable parts. The results of such classification reveals potential of the improvement in a component.