Applied Energy 204 (2017) 353–361

Contents lists available at ScienceDirect

Applied Energy

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

Natural gas purification by heat pump assisted MEA absorption process

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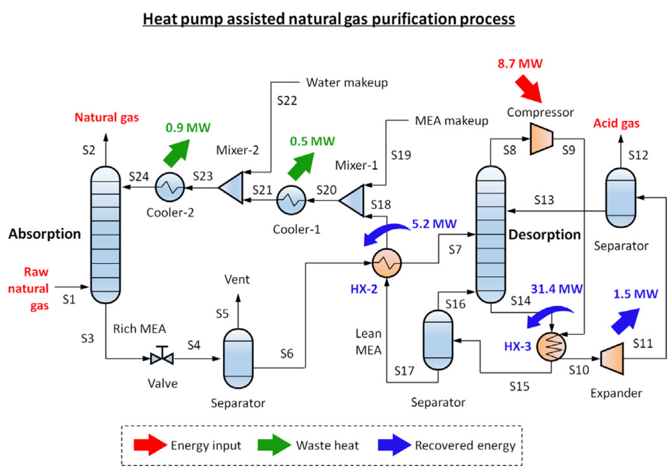
HIGHLIGHTS

- A novel energy-saving natural gas purification process is designed.
- Heat pump technology is used to recover the wasted condensation heat.
- Heat integration of heat exchangers is optimized by efficient heat coupling.
- Energy consumption is reduced to 17.5% that of the conventional process.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 January 2017
Received in revised form 20 June 2017
Accepted 15 July 2017

Keywords:
Natural gas purification
CO_2 absorption
MEA
Heat pump
Heat integration

ABSTRACT

Natural gas purification is a critical pretreatment process before it can be injected into the pipeline delivery grid. Generally, Acid impurities (i.e. CO_2 and H_2S) in natural gas can be removed by MEA (monoethanolamine) absorption process. However, excessive energy consumption is still the challenge for the current absorption processes. In this work, a novel heat-pump assisted absorption process is proposed. To recover the waste condensation heat in desorption stage, the vapor distillate stream is compressed to elevate the exergy rate, and then coupled with the bottom stream. Meanwhile, the waste pressure of distillate is recovered by an expander. The simulation results indicated that the net energy input of the proposed absorption process could be saved to 7.2 MW, which equaled to 17.5% of the conventional process. The energy consumption of impurity removal (set CO_2 as reference) for the heat-pump assisted absorption process can be reduced to 1.78 MJ/kg CO_2.

1. Introduction

Fossil fuel is the primary energy source worldwide. Natural gas, as one of the most important and popular alternatives, will play a key role in the next decades [1,2]. However, due to existed in deep

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http://dx.doi.org/10.1016/j.apenergy.2017.07.052
0306-2619/

underground reservoirs, natural gas may contain several nonhydrocarbon components, such as carbon dioxide (CO_2) and hydrogen sulfide (H_2S) [3,4]. These impurities are undesirable compounds and may cause several technical problems, i.e., corrosion and environment pollution [5,6]. Moreover, removal of CO_2 from natural gas can effectively increase the heating value of sale gas and other products [7].

Natural gas purification by using alkanolamine solutions has been considered as one of the most mature technologies in comparison with the other available technologies [8–10]. The advantages of amine based absorption processes are cost effectiveness, high capability of handling large amounts of the feed stream, and easily to be retrofitted in an existing industrial plant without significant changes of installation [11–14]. However, except installation corrosion and degradation, its main challenge is high energy consumption (typically 3–4 MJ/kg CO_2) for rich solvent regeneration [15,16].

To reduce the energy consumption, extensive studies have been carried out on amine absorption-based acid gas (i.e. CO_2, SO_2 and H_2S) removal technology, including development of novel solvents and optimization of process configuration [9,17,18]. Hereinto, heat pump assisted solvent regeneration is an effective alternative for waste heat integration and energy saving. In 2009, Yu et al. proposed an innovative process for simultaneous removal of CO_2 and SO_2 from flue gas. The proposed process recovered the waste heat of flue gas and inter-stage compression, and the energy consumption could be decreased to 2.75 GJ/ton CO_2, which equaled to about 91% that of the reference process [19]. In 2011, Kishimoto et al. put forward a novel CO_2 absorption concept based on exergy recuperation. In detail, the exothermic heat of the absorber and the condensation heat of the stripper were recuperated and reused for solvent regeneration and H_2O vaporization using heat pump and vapor recompression. The simulation results showed the energy consumption of the proposed exergy recuperative process could be decreased to 30% that of the conventional CO_2 absorption process [20]. In 2014, Zhang et al. used flash evaporation and thermal vapor compression to reduce heat consumption of CO_2 capture processes. Their analysis results indicated that the proposed CO_2 capture system reduced the specific heat consumption from 4.421 GJ/ton CO_2 to 4.161 GJ/ton CO_2, and the specific exergy consumption from 1.368 GJ/ton CO_2 to 1.275 GJ/ton CO_2 [21]. In 2014, Waheed et al. modified heat pump configuration in fractionating close-boiling mixtures to reduce the heat loss and heat pump size [22]. It should be noting that although various chemical CO_2 absorption processes have been designed and optimized, most of them are still energy intensive (higher than 2.5 MJ/kg CO_2) due to solvent regeneration, which contributes around 80% of the total energy consumption [23,24]. A target of 2 MJ/kg CO_2 (including both the capture and compression steps) is often mentioned and corresponds to the European Union recommendations [25,26]. Therefore, more effort should be paid on process optimization.

The objective of this study is to design a novel natural gas purification process with heat integration to reduce the overall energy consumption. To recover the waste condensation heat of acid gases, heat pump assisted distillation is utilized in desorption stage. Meanwhile, waste pressure along with products is recovered by an expander. Energy and material balance of the conventional and proposed CO_2 absorption processes is analyzed in detail. Furthermore, the heat integration performance of each heat exchanger in different processes is also investigated.

2. Natural gas purification process

2.1. Conventional MEA absorption

The conventional natural gas purification process by MEA (monoethanolamine) solvent absorption is shown in Fig. 1. The raw natural gas is compressed to enhance the partial pressure of acid gas impurities (i.e. CO_2 and H_2S), and then introduced into the absorption column. After sufficient reaction with MEA solution, the upgraded natural gas is gathered on the top of the absorber. On the other hand, the rich MEA solution is obtained from the bottom of the column. It is decompressed by a valve, and the solved methane (namely flash gas) is separated by a flash tank. Before pumped to the desorption column (also named stripper), the rich MEA is preheated by lean MEA (bottom stream of stripper) in the heat exchanger (HX-1) to recover the sensible heat. At the top of stripper, the hot stream is cooled by a condenser, and the condensed water is as the reflux. Meanwhile, the acid stream (mainly CO_2 and H_2S) is obtained for further treatment. At the bottom of the stripper, the MEA solution is usually heated by a reboiler.

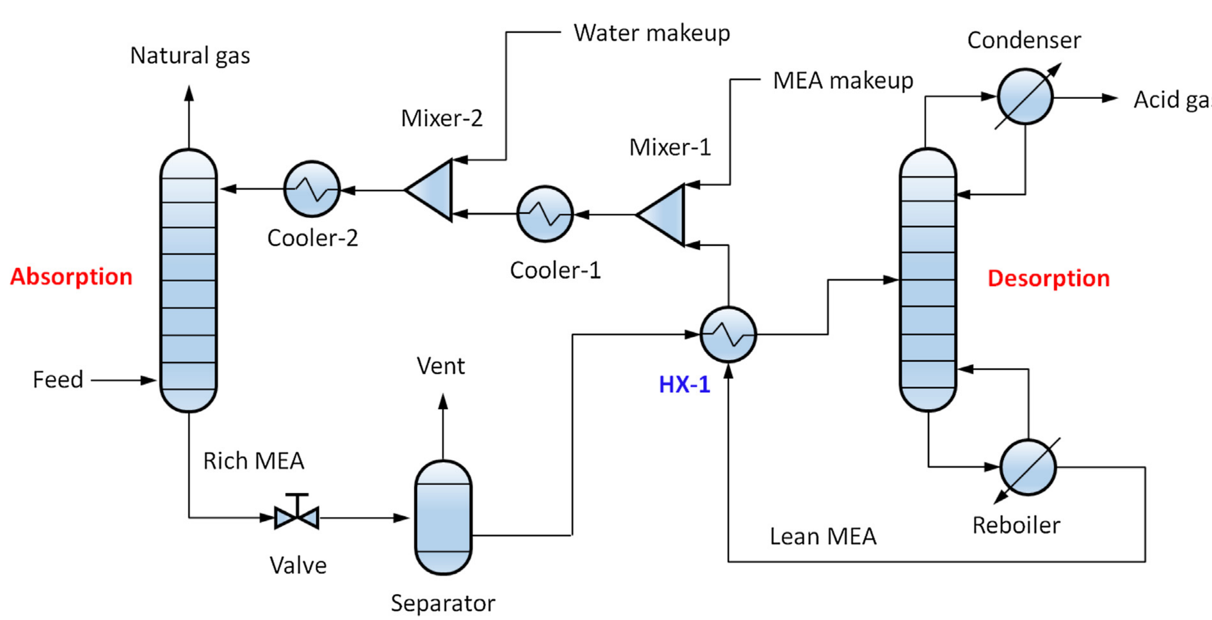

Fig. 1. The typical flow diagram of conventional MEA based natural gas purification process.