Journal of Cleaner Production 201 (2018) 974–987

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Carbon footprint reduction of acid gas enrichment units in hot climates: A techno-economic simulation study

Satyadileep Dara [a], Aisha A. AlHammadi [a], Abdallah S. Berrouk [a, b, e], Fadi Al Khasawneh [c], Abdulla Al Shaiba [d], Yasser F. AlWahedi [a, e, *]

[a] Chemical Engineering Department, Khalifa University of Science and Technology, PO Box 2533, Abu Dhabi, United Arab Emirates
[b] Mechanical Engineering Department, Khalifa University of Science and Technology, PO Box 2533, Abu Dhabi, United Arab Emirates
[c] Research & Development Department, Abu Dhabi National Oil Company, PO Box 898, Abu Dhabi, United Arab Emirates
[d] Projects and Engineering Division, Al Yasat Petroleum Operations Company Ltd., PO Box 44476, Abu Dhabi, United Arab Emirates
[e] Center for Catalysis and Separation, Khalifa University of Science and Technology, PO Box 127788, Abu Dhabi, United Arab Emirates

A R T I C L E I N F O

Article history:
Received 16 April 2018
Received in revised form
10 July 2018
Accepted 7 August 2018
Available online 8 August 2018

Keywords:
Acid gas enrichment
Ranque–Hilsch vortex tube
CO_2 footprint
Process simulation

A B S T R A C T

In natural gas processing plants, acid gas enrichment (AGE) units play a vital role in increasing H_2S purity in the acid gas feed of sulfur recovery units (SRUs). Moreover, AGE units also produce a CO_2-rich gas stream that is often vented to atmosphere. If CO_2 purity is sufficiently high, this stream can be used as an injection gas for enhanced oil recovery (EOR) or for sequestration. In hot climates, AGE units operate at significantly low efficiencies owing to the exothermic nature of their operation. Any enhancement in the efficiency can reap significant benefits. In this work, we study the economic and environmental impact of a process scheme wherein a Ranque–Hilsch vortex tube (RHVT) is used as a cooling system for a lean solvent in an AGE unit located in a hot region of the United Arab Emirates. A simulation model is built using the process simulator ProMax® and is validated using plant design data. It is found that reducing the lean solvent temperature increased the purity of H_2S and CO_2 product streams. At temperatures lower than 25 °C, the inverse occurs as CO_2 absorption becomes favorable thermodynamically. Consequently, a lean solvent temperature of 25 °C is identified to be optimal, thus achieving the lowest energy consumption and carbon footprint, while maintaining high purities of the product gases. At the optimal temperature, the proposed scheme results in steam savings of 13 kg/s (equivalent to 40% reduction in total steam rate). This reduced energy consumption leads to an annual CO_2 footprint reduction of 83.7 million kg (equivalent to 40% reduction in total CO_2 footprint). The optimal lean solvent temperature increases the purity of the H_2S-rich gas stream (acid gas) to 67.3 mol% compared to its base case value of 45.7 mol%. Further, the purity of CO_2-rich gas stream increases to 97 mol% compared to its base case value of 89 mol%, thus making it suitable for EOR or sequestration. Economically, the evaluated annual energy savings translate to 11.2 million USD, at a crude oil price of 50 USD. The computed payback period is 1.3 years, thus showing the potential of the proposed process. The process scheme proved to be superior to other commercial alternatives from economic and environmental perspectives.

1. Introduction

Acid gas enrichment (AGE) units play a vital role in any natural gas complex as they separate undesired acid gases (CO_2 and H_2S) to ensure compliance with safety and operational requirements. These units produce two major product streams: (i) a H_2S-rich gas stream, which is used as a feed gas for sulfur recovery units (SRUs) and (ii) a CO_2-rich gas stream, which is often vented to the atmosphere.

1.1. Motivation

CO_2-rich gas stream, which is the major product stream of the AGE, has significant potential applications. If the purity of the former is sufficiently high, this stream can be used as an injection gas for enhanced oil recovery (EOR) or can be sequestrated. This has triggered the investigation of various schemes and configurations to increase the purity of the CO_2-rich gas stream to allow its use in

* Corresponding author. Chemical Engineering Department, Khalifa University of Science and Technology, PO Box 2533, Abu Dhabi, United Arab Emirates.
E-mail address: yaalwahedi@pi.ac.ae (Y.F. AlWahedi).

https://doi.org/10.1016/j.jclepro.2018.08.067
0959-6526/

the aforementioned applications. Moreover, any enhancements in the operational efficiency and reduction in carbon footprint are desired. To this end, this paper focuses the attention on a commercial AGE plant, which operates on HIGHSULF process (a patented process that involves recycling a portion of acid gas to the gas absorber), based in United Arab Emirates and attempts to improve the performance in the aspects of operating costs and carbon footprint.

1.2. Literature survey

Several studies were reported that assessed various techniques to improve the performance of AGE units in terms of product gas purity and energy consumption. Weiland and Khanmamedov (2010) carried out a process simulation study of three AGE processes: 1) the HIGHSULF process, 2) the AGE process with two absorbers, and 3) the conventional AGE process. They concluded that the HIGHSULF process results in a more concentrated (19% higher) acid gas stream compared with the conventional AGE process and the AGE process with two absorbers. Khanmamedov (2013) also recommended the HIGHSULF process over the other processes due to a potential reduction of 8% in capital cost of the downstream SRU besides the increased acid gas purity. To this end, the above two studies conclude that HIGHSULF process is the most efficient scheme of the available AGE processes. On the other hand, it is worth to note that the commercial AGE unit being studied in this paper operates on the HIGHSULF process thus leaves no scope for any potential performance improvement by means of retrofitting with a different AGE scheme. Parks et al. (2010) mentioned that the use of FLEXSORB SE and FLEXSORB SE PLUS can replace MDEA (Methyldiethanolamine)-based solvents owing to their higher selectivity for H_2S, thereby increasing the purity of the H_2S-rich gas stream from 30 mol% to 65 mol%. However, this also leads to a major increase in the operating expenses due to high cost of proprietary solvents. In general, such schemes require major modifications to the plant hardware rather than simple changes in operating conditions or minor modifications. The latter are often more attractive as they do not involve any significant downtime in unit operation. However, studies on the impact of major process variables are lacking in the field of AGE. In contrast, in the field of natural gas sweetening, several studies have been conducted on the impact of major operating variables. A lean solvent temperature has been reported to have the strongest influence on plant performance. For instance, Lunsford and McIntyre (1999) showed that decreasing the absorber temperature from 74 °C to 30 °C leads to a decrease in sweet gas H_2S concentration from 6000 ppm to 10 ppm. Addington and Ness (2009) performed a simulation study of a Russian gas plant and showed that a reduction in lean solvent temperature from 50 °C to 10 °C resulted in a decrease in the concentration of sweet gas H_2S from 28 ppm to 4 ppm. Pandey (2005) carried out an on-site parametric study of a commercial amine sweetening unit (Hazira Gas Processing Plant, Oil and Natural Gas Corporation Limited, India) and demonstrated that H_2S absorption selectivity over CO_2 can be increased by 25% by decreasing the lean solvent temperature from 50 °C to 39 °C. Dara and Berrouk (2017) performed a process optimization study on a middle-east-based commercial amine sweetening unit and identified the optimum conditions of major operating variables. They concluded that low solvent temperatures are suitable for better performance of the absorber owing to the increased solubility of acid gas governed by vapor liquid equilibrium. They showed that steam consumption rate can be reduced by 13.5% as a result of changing the lean solvent temperature from 65 °C to 50 °C. They reported that the concentration of sweet gas CO_2 decreases with lean amine temperature until 54 °C and then follows a reverse trend for further reduction until 50 °C. They concluded that the optimum choice of lean solvent temperature is not straightforward and should be investigated thoroughly in order to achieve optimum energy consumption and appropriate balance of absorption degrees of H_2S and CO_2. The aforementioned studies in natural gas sweetening units show that optimizing the lean solvent temperature can achieve two benefits: (i) energy savings that would thus lead to cost savings and (ii) increased purity levels of H_2S and CO_2 streams.

In hot climates where refrigeration costs are high, lowering the solvent temperature can be achieved by means of a Ranque–Hilsch vortex tube (RHVT) provided a high pressure inert gas is available. The RHVT is a static device that uses vortex motion to separate a compressed gas flow into a hot stream and a cold stream. Saberi et al. (2016) reported the improvement of surface grinding process performance through the minimum quality lubrication (MQL) technique coupled with a simple and inexpensive vortex tube by achieving a cold air jet temperature of →4 °C compared with the conventional coolant temperature of 15.5 °C. Jozic et al. (2015) investigated the application of the RHVT to produce cold air in the end milling process. They reported that the cutting speed increased by 50% upon using the RHVT for cooling, which enhanced process efficiency.

Also, many novel techno-economic studies were carried out for investigating various innovative methods involving utilization of ambient conditions for energy conservation purposes. Esen et al. (2006) performed performance experiments and economic analysis of a horizontal ground source heat pump (GSHP) system for space heating. They proved that this system offers several economic advantages over many other conventional techniques. Esen et al. (2007) reported a techno-economic comparison between a ground-coupled heat pump (GCHP) system and an air-coupled heat pump (ACHP) system for space cooling. They concluded that GCHP systems are economically preferable to ACHP systems for the purpose of space cooling. Esen and Yuksel (2013) carried out experimental investigation of greenhouse heating by biogas, solar and ground energy in Elazig, Turkey climate conditions. They reported the effects of climatic conditions and operating parameters on the system performance parameters.

1.3. Contribution

In this work, we propose the application of RHVT for cooling the lean solvent in an AGE unit based in the United Arab Emirates. Pressurized nitrogen gas, which is readily available in the plant as the by-product of the air separation unit in the same plant complex, is used as the RHVT feed. A simulation model is built for the combined system by using the process simulator ProMax® and is validated using the AGE plant design data. The model is used for studying the impact of lean solvent temperature on the product streams. Then, potential energy savings of the proposed scheme are evaluated. The economic feasibility and environmental impact of the RHVT-based AGE unit are assessed by considering achievable reductions in operating cost, energy consumption and carbon footprint. To the best knowledge of the authors, the integration of RHVT with AGE and the evaluation of the associated benefits have not been studied in the reported literature. Also, the proposed process scheme is compared to other commercial processes in order to benchmark its potential benefits against commercial options.

2. Process description

2.1. Acid gas enrichment unit

Fig. 1 depicts the process flow diagram of the commercial AGE unit considered in this study. In the commercial AGE unit, feed gas