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Automated process design of acid gas removal units in natural gas processing

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ABSTRACT

This study looks at the design of the acid gas removal unit (AGRU) for natural gas processing. For the purpose of enhancing energy efficiency a number of different structural options are considered including multiple feeds, semi-lean and pump around modifications in addition to modification of operational parameters. Previous studies in this area have considered the comparison of different individual configurations but there has been a lack of research considering the simultaneous optimization of equipment configuration. Hence, in this study a superstructure-based optimization approach is used to simultaneously identify the most appropriate arrangement and operating conditions while the maximum energy recovery potential is also realized with the aid of energy composite curves (ECC). This methodology is applied to a case study where it is shown that the optimal configuration contains a combination of pump around and semi-lean process modifications allowing a 15.9% reduction of utility costs.

1. Introduction

Natural gas is extracted from gas wells as a mixture of hydrocarbons and other impurities including acid gases, water and mercury. The required composition constraints placed on sale gas are mainly controlled by market specifications, and typical natural gas pipeline limits for CO_2 and H_2S are 2% and 4 ppm (Baker, 2002). To meet these specifications a number of separation processes are typically required. One of the key separation processes implemented for the pretreatment of natural gas is the AGRU (acid gas removal unit) which is used to remove acid gases including H_2S and CO_2.

For this purpose chemical absorption with amine solvents is widely used for acid gas removal in gas processing industries. The conventional configuration of this process includes two columns: the absorber where amine solvents absorb acid gases and the regenerator where external heat is supplied to drive the desorption reaction and regenerate the amine solvent for reuse in the absorber (as shown in Fig. 1). It should also be noted that alternative technologies are available such as the use of physical absorption (Guo et al., 2012) but in this study we have focused on applications using chemical absorption.

Important design parameters for amine-based acid gas removal processes include the solvent circulation rate in addition to the type and concentration of solvent utilized. Also, to evaluate the performance of different designs the most important variables include the quantity of CO_2 removed and the regenerator reboiler duty (the dominant energy requirement).

AGRUs consume significant quantities of energy and numerous studies have looked at ways to improve the energy efficiency and reduce the operating costs of these units. For example Sakwattanapong et al. (2005) studied the effects of various blends of amine solvents on the regeneration energy required. More recently, Shi et al. (2014) have also looked at the effects of different blends of solvents together with the use of solid acid catalysts for the purpose of reducing regeneration energy and regenerator size. Also, a number of different authors have considered the combination of amine-based absorption and membrane separators in hybrid systems for CO_2 capture (Binns et al., 2015) and for natural gas sweetening (Niu and Rangaiah, 2014).

In addition to the basic configuration shown in Fig. 1 various modifications of the column configuration can also be considered in order to improve separation efficiency and reduce energy requirements. In the review of Le Moullec et al. (2014) a larger number of possible configuration options for enhancing performance and reducing energy consumption are discussed. Three of the basic design options include

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Nomenclature

A	parameter of penalty function for H_2S outlet, k\$ year^{-1} ppm^{-1}
B	parameter of penalty function for CO_2 outlet, k\$ year^{-1} ppm^{-1}
C_{CO_2}	carbon dioxide concentration of sweet gas, ppm
C_{H_2S}	hydrogen sulfide concentration of sweet gas, ppm
$COST_{CW}$	unit cost for cooling water, k\$ MWh^{-1}
$COST_{electricity}$	unit cost for electricity, k\$ MW$_e$ h^{-1}
$COST_{LP}$	unit cost for low pressure steam, k\$ MW h^{-1}
$COST_{utility}$	annualized utility cost, k\$ year^{-1}
M_j	multiple feed flowrate to absorber, ton h^{-1}
$P_{i,j}$	pump around flowrate at absorber, ton h^{-1}
Q_C	condenser duty, MW
$Q_{C_{min}}$	minimum hot utility demands, MW
$Q_{H_{min}}$	minimum cold utility demands, MW
Q_{pump}	electricity consumption for pumping, MW$_e$
Q_R	heat recovery, MW
$S_{i,j}$	semi-lean solvent flowrate from regenerator to absorber, ton h^{-1}
$t_{operatting}$	operating hours of the process, h year^{-1}
T_{lean}	lean amine inlet temperature to absorber, °C
T_{PA}	pump around stream return temperature to absorber, °C
T_{sem}	semi-lean amine inlet temperature to absorber, °C

Abbreviation

AGRU	acid gas removal unit
CW	cooling water
DEA	Diethanolamine
ECC	energy composite curve
GA	genetic algorithm
LNG	liquefied natural gas
LP	low pressure steam
MDEA	methyldiethanolamine
MEA	monoethanolamine

Subscripts

i	withdrawal stage location
j	feeding stage location

- semi-lean
- multiple feed
- pump around

which can be implemented to reduce energy consumption or to enhance acid gas removal efficiency (see Section 3 for details of these options).

However, while there has been considerable recent interest in modifications of this equipment for CO_2 capture from flue gases (Le Moullec et al., 2014); for the purpose of natural gas sweetening there have been very few studies which have considered such structural modifications. The most recent of these is the work of Bae et al. (2011) in which it is shown that a semi-lean configuration can lead to reduced regenerator energy, in particular for cases where the feed contains a higher concentration of CO_2. Additionally, Patil et al. (2006) have discussed various options including: semi-lean, multiple feeds and pump around. However, for their case study they have considered only the multiple feed option.

Considering the related application where CO_2 is captured from flue gases the most recent studies published have focused on the comparison of different configurations (Liang et al., 2015), but without optimization of the structural configuration this approach can miss important opportunities. While sensitivity analysis is commonly applied to investigate operating conditions and in some cases it is also applied to structural options such as feed locations, split fractions and column heights (Gao et al., 2014), optimization of structural options is usually not considered. One of the few studies where structural modifications are included in the optimization is the work of Patil et al. (2006) where multiple feeds are considered in parallel with modification of operational parameters as part of a superstructure optimization. Although more sophisticated superstructure approaches have been implemented for the related recovery of natural gas liquid products (Diaz et al., 1997) there is currently a lack of such research in the natural gas sweetening area. Hence, opportunities for identification of novel processes containing multiple different process modifications have not been fully explored.

In this study a new superstructure optimization framework is proposed which considers multiple different structural options (pump around, multiple feeding, semi-lean solvent) simultaneously in order to identify the most beneficial configuration and operating conditions. This new framework implements a more complex superstructure including more design options (also using more rigorous models) than the superstructure implemented by Patil et al. (2006). In this way the most cost-effective amine-based acid gas removal process can be identified considering one or more of these process modification simultaneously though optimization to identify the most suitable configuration.

Process modeling and simulation is carried out using Aspen HYSYS® which is interactively linked with an external stochastic optimization algorithm available in MATLAB®. This integrated procedure allows the exploitation of possible heat recovery within the optimization framework based on stream data extracted from process simulations.

For a given case study sensitivity analysis is used to determine the impact of different individual design configurations and operational parameters. Subsequently the new optimization framework is applied to this case to demonstrating the benefits of this approach.

2. Modeling and simulation of amine-based acid gas removal

Amine-based acid gas removal is modeled within the Aspen HYSYS® environment using the amine property package. Utilizing this thermodynamic property package the mass transfer within the two columns is calculated using the Kent-Eisenberg model (Kent and Eisenberg, 1976). This model has commonly been utilized for simulation of amine-based absorption and the study of

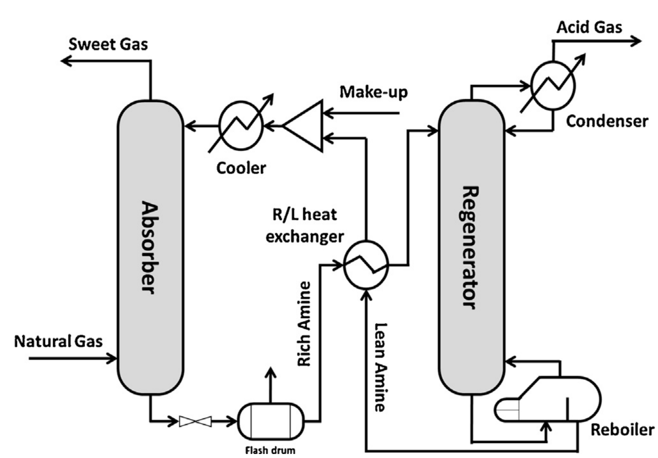

Fig. 1. A typical amine-based acid gas removal unit.