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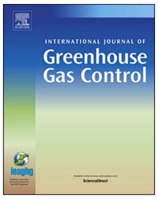

Novel acid gas removal process based on self-heat recuperation technology

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ABSTRACT

Chemical absorption is the most common technology used in the acid gas removal unit (AGRU) for treating natural gas. On the other hand, the regenerator requiring large amounts of energy needed for the latent heat of a phase change makes this an energy intensive process. In this study, several distillation columns with a modified heat circulation module based on self-heat recuperation technology were proposed to enhance the energy efficiency of the AGRU. This innovative self-heat recuperation technology circulates the latent and sensible heat in the thermal process. All simulations were conducted using ASPEN HYSYS V8.6, while KG-TOWER® software was employed to size all the columns. The results showed that the proposed modified configuration can save up 62.5% and 45.9% in terms of the reboiler duty and operating cost, respectively, compared to a conventional AGRU. This brought a saving of 38.0% in terms of the total annual cost. The results also indicated that the carbon emissions could be saved up to 45.4%. The proposed process can be employed to both close-boiling mixtures and wide-boiling mixtures. In addition, a sensitive analysis of the utility costs on the performance of the suggested AGRU configuration were investigated. The retrofit an existing acid gas removal process was performed to enhance both the energy efficiency and capacity.

1. Introduction

Natural gas is extracted from gas wells as a mixture of hydrocarbons and other impurities including acid gases, water, and mercury (Kidnay et al., 2011). Mercaptans (RSH) can be present when the H_2S concentrations are well above the ppmv level. The required composition constraints placed on sale gas are controlled mainly by market specifications, and typical natural gas pipeline limits for CO_2 and H_2S are 2% and 4 ppm, respectively (Mokhatab et al., 2012). In addition, mercaptans and other organic sulfur species that contribute to sulfur emissions must be removed (Mokhatab et al., 2014). A number of separation processes such as absorption, distillation, membrane, and adsorption are typically needed to meet these specifications. The acid gas removal unit (AGRU), which is used to remove acid gases, is one of the key separation processes implemented for the pretreatment of natural gas (Cho et al., 2015).

Chemical absorption, which is based on the reversible exothermic reaction of a suitable solvent with the gas stream, is the most common technology used in AGRU (Niu and Rangaiah, 2014). On the other hand, a large amount of energy used for releasing the acid gas in the stripper or regenerator makes AGRU an energy intensive process. To improve the AGRU, the development of different solvents (Shi et al., 2014) can be considered. Mixed amine solvents containing methyldiethanolamine (MDEA) and MEA or DEA, in most cases for the removal of acid gases have received increasing attention (Sohbi et al., 2007). Furthermore, process modification (Moullec et al., 2014; Cho et al., 2015) and process intensification (Jassim et al., 2007) can be attractive options to enhance the performance of AGRU.

The heating and cooling functions are generally integrated based on the heat exchange between the feed and product streams to reduce the energy consumption in distillation (Kansha et al., 2010). Many types of heat pump (HP) systems allowing the heat of condensation released at the condenser to be used for evaporation in the reboiler were proposed to maximize the heat recovery (Bruinsma and Spoelstra, 2010; Kiss et al., 2012). This heat pump approach is an economical way to improve the energy efficiency of distillation column when temperature difference between top and bottom of the column is small and large heat is released from the condenser.

To enhance the energy recovery efficiently and thoroughly, self-heat recuperation technology (SHRT) facilitating the recirculation of both latent heat and sensible heat, were proposed (Kansha et al., 2009; Long and Lee, 2013). In this technology, the heat of the process stream was recycled perfectly by recovering the cooling load using a compressor and exchanging the heat with the bottom liquid and feed streams, resulting no need for heat addition or only a small energy requirement. Several authors studied some innovative processes to investigate the

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industrial applications of this technology. Kansha et al. (2011) demonstrated that the energy requirement of the proposed cryogenic air separation process with SHRT decreased by more than 36% compared with the conventional cryogenic air separation process. Furthermore, crude oil distillation was also investigated to evaluate the possibility of improved energy reduction (Kansha et al., 2012). In addition, Long and Lee (2013) reported that the total annual cost (TAC) can be reduced by up to 44% when employing this SHRT in a deisobutanizer column. Recently, the use of this technology in the methanol synthesis process resulted in a substantial increase in energy efficiency (Kansha et al., 2014).

Several distillation columns with the modified heat circulation module based on SHRT were proposed to enhance the energy efficiency in this work. The proposed configurations can be applied to both close-boiling and wide-boiling mixtures. This innovative SHRT that circulates latent and sensible heat was then used to enhance the energy efficiency of the AGRU. ASPEN HYSYS V8.6 was used for conducting all simulations, while KG-TOWER® software was employed for sizing all columns. The effects of the utility on the operating cost saving of the proposed integrated AGRU were investigated. Furthermore, the carbon dioxide (CO_2) emissions was calculated to evaluate the proposed sequence and compared it with the conventional sequence. The use of this sequence to retrofit the acid gas removal process to save energy while increasing the capacity was also considered.

2. Proposed sequences

2.1. Heat pump

In a distillation column, the latent heat of condensation of the overhead is available at the condensers, which can be recovered to provide a partial/total heating duty at the reboiler or to generate electric power (Chew et al., 2014; Long et al., 2015). A significant amount of energy can be saved by upgrading the low temperature waste heat to high temperature using a HP. Several HP concepts, such as vapor compression (VC) heat pump, mechanical vapor recompression (MVR) heat pump, and bottom flashing heat pump (Fig. 1), have been considered for retrofit to reduce the energy requirement of distillation columns. Among them, the MVR has been employed widely in the separation of mixtures with close boiling points. The use of mechanical compression as a HP is economical, mainly in separating low relative volatility mixtures (De Rijke, 2007). The advantage over a VC is that the condenser in a MVR is smaller and the temperature lift is approximately 10 °C lower because heat is exchanged only once. This results in a higher thermodynamic efficiency (Bruinsma and Spoelstra, 2010).

Fig. 2 shows the scheme of a MVR system, which lifts the temperature of the top vapor to use this as the heat source for the reboiler. The temperature lift can be calculated as follows:

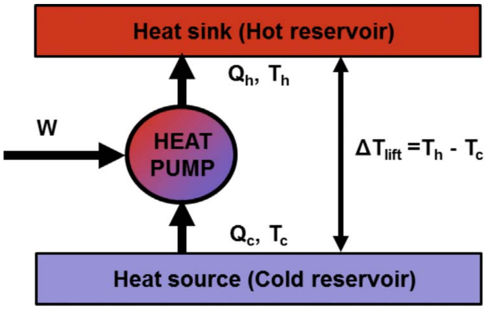

Fig. 2. Scheme of a heat pump.

$$\Delta T_{lift} = T_h - T_c = \Delta T_{column} + \Delta T_{HEX} \quad (1)$$

where ΔT_{column} is the temperature difference between the top and bottom of the column; and ΔT_{HEX} is the optimized temperature difference over the heat exchanger (typically 10 °C).

From the first law of thermodynamics, the amount of heat delivered to the hot reservoir (Q_h) at a higher temperature (T_h) is related to the amount of heat extracted (Q_c) from the cold reservoir at a low temperature (T_c) and the external work by the following equation (Bruinsma and Spoelstra, 2010):

$$Q_h = Q_c + W \quad (2)$$

The coefficient of performance (COP), which is the ratio of the heat rejected at high temperatures to the work input, is used to measure the HP performance (Bruinsma and Spoelstra, 2010),

$$COP = \frac{Q_h}{W} \quad (3)$$

The upper theoretical value of the COP obtainable in a HP is the COP_c related to the Carnot cycle:

$$COP_c = \frac{T_h}{T_h - T_c} \quad (4)$$

The HP is strongly recommended if the Q/W ratio is more than 10. More evaluations are needed if it is between 5 and 10. When the ratio is lower than 5, a HP should not be considered for improving the energy efficiency (Pleşu et al., 2014).

2.2. Self-heat recuperation technology

In HP system, only latent heat is utilized while the sensible heat is neglected. Thus, the SHRT facilitating the recirculation of both the latent and sensible heat in a process using compressors and self-heat exchangers was proposed (Kansha et al., 2009; Matsuda et al., 2011) (Fig. 3a). Recently, Long and Lee (2013) suggested a modified SHRT (Fig. 3b), which can maximize heat recovery by dividing feed stream

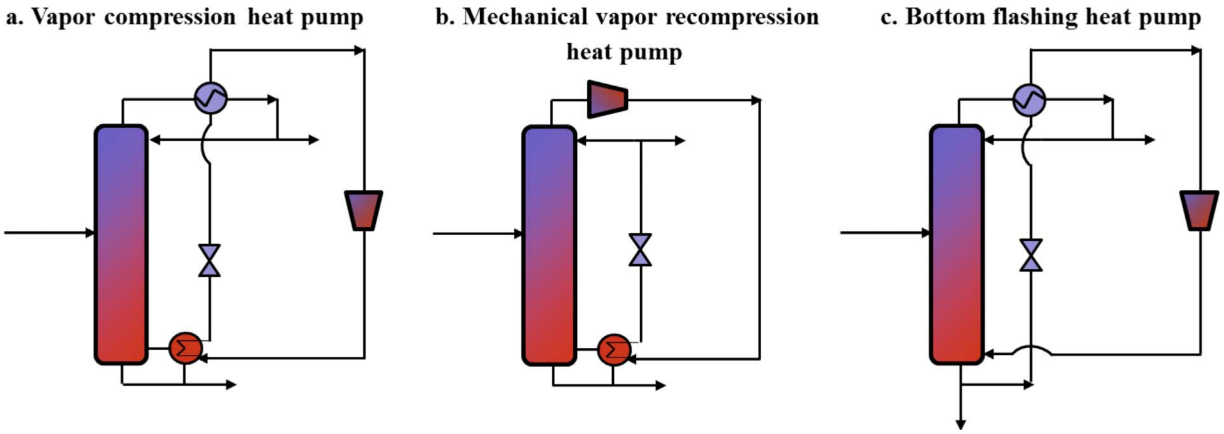

Fig. 1. Schematic diagram of the heat pump systems: (a) vapor compression; (b) mechanical vapor recompression; and (c) bottom flashing.