Energy xxx (2016) 1–15

Contents lists available at ScienceDirect

Energy

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

A new retrofit approach to the absorption-stabilization process for improving energy efficiency in refineries

X.G. Liu, C. He, C.C. He, J.J. Chen, B.J. Zhang**, Q.L. Chen*

School of Chemical Engineering and Technology, Guangdong Engineering Technology Research Center for Petrochemical Energy Conservation, Sun Yat-Sen University, No. 135, Xingang West Road, Guangzhou, 510275, China

ARTICLE INFO

Article history:
Received 27 July 2016
Received in revised form
27 October 2016
Accepted 29 October 2016
Available online xxx

Keywords:
Absorption-stabilization
Process retrofit
Energy-use efficiency
Two-stage condensation
Heat integration

ABSTRACT

In a refining complex, an absorption-stabilization process used in the production of end-use petroproducts (i.e. stable gasoline and liquefied petroleum gas) is energy-intensive and costly. A new absorption-stabilization process with a two-stage condensation section is introduced in this work to further improve energy-use performance. In the new process, a condenser, a condensed oil tank, and a side-reboiler are integrated into the original process and then a heat integration scheme is performed. Compared with the existing process, the proposed process can reduce the cold utility and hot utility by 17.98% and 25.65%, respectively, as well as decrease the total annual operating costs of the heat exchanger network by 17.48%. Additionally, the process retrofit reduces the annual operating costs of cooling water and steam by about $346,617 at the expense of capital costs around $487,006, and the corresponding payback period is approximately 17 months.

1. Introduction

An absorption-stabilization process (ASP) is typically used to co-process compressed rich gas (i.e. H_2, CO, CO_2, C_{1-6} components) and crude gasoline produced from the main fractionators of fluid catalytic cracking (FCC), delayed coking (DC), and hydrogen cracking (HC) units in a crude oil refining complex. Specifically, in this process the dry gas (C_{2-} components) and liquefied petroleum gas (LPG, C_{3-4} components) are separated from the compressed rich gas while the stable gasoline is up-graded from crude gasoline [1]. In the existing ASP, a four-tower process including an absorption tower, reabsorption tower, desorption tower, and stabilization tower is widely used to implement the above mentioned separation and up-grading objectives [2]. In this four-tower process, there is a very close relationship between the absorption and desorption towers since they provide feed for each other, that is, the rich absorption oil from the absorption tower is used as the liquid feed to the desorption tower. Similarly, the desorbed gas from the desorption tower is recycled to the absorption tower as the gas feed. The absorption tower, together with the desorption tower play an important role in improving the energy-use performance for the whole ASP and the recovery rate of C_{2-} components, as well as maintaining the normal operation of the stabilization tower. However, the operating conditions and requirements of the two towers are normally different due to their separation tasks. Thus, it is necessary to reveal the interacting and inter-related relationships between the absorption and desorption towers to improve the whole system's performance.

The feeding modes of the desorption tower, including hot feeding, cold feeding, and feed splitting, significantly influence the cold and hot utility requirements of the absorption and desorption towers [3]. In particular, the hot feeding mode can efficiently lower the reboiler duty of the desorption tower and adequately recover the heat surplus of the stable gasoline. However, this hot feeding mode may increase the feed flow rates of the condensed oil tank and the absorption tower, leading to greater energy consumption. Additionally, as we use the hot feeding mode, the concentrations of the total C_{3+} components in dry gas will increase and the concentrations of the total C_{3+} components in LPG will decrease, and vice versa when we employ the cold feeding mode. This cold feeding mode reduces the cold loads of the condensed oil tank and the absorption tower. However, the cold feeding mode normally increases the reboiler duty of the desorption tower and consumes more steam. Therefore, by combining with the advantages of the two feeding modes, feed splitting has been adopted to reduce the

---

* Corresponding author.
** Corresponding author.
E-mail addresses: zhbingj@mail.sysu.edu.cn (B.J. Zhang), chqlin@mail.sysu.edu.cn (Q.L. Chen).

http://dx.doi.org/10.1016/j.energy.2016.10.128
0360-5442/

Please cite this article in press as: Liu XG, et al., A new retrofit approach to the absorption-stabilization process for improving energy efficiency in refineries, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.10.128

C_{3+} concentrations of dry gas and energy consumption of the desorption tower over the last few decades [4,5].

In the feed splitting, the condensed oil is split into a minority cold feed to the top and a majority hot feed to the middle of the desorption tower. The hot feed is heated by stable gasoline from the stabilization tower. This arrangement aims to recover the heat of stable gasoline, reducing the heat load of the desorption reboiler and the stable gasoline cooler. The feed splitting has a significant advantage in improving product quality and lowering the fuel consumption of the system [6,7]. However, it was found that the desorption tower usually had a feed split of identical composition but different temperature, potentially disturbing the normal gas-liquid distribution thus weakening the mass transfer performance. Bandyopadhyay et al. [8] pointed out that multiple feeds having different temperatures and compositions were beneficial to improve the mass transfer performance and the separation efficiency of a distillation column. Binkley et al. [9] demonstrated that an ideal feed location should be feeding to a section of the distillation column where the column internal liquid traffic composition was similar to the feed stream composition. Given the above literature, we can suggest that changing the temperature and composition of the double feeds to the desorption tower would effectively intensify the mass transfer of the desorption tower, and further improve the energy-use performance of the existing ASP.

In addition, by combining the three-link exergo-economic structural model [10] with the onion model [11], improvement of chemical reactions and separation processes leads to better energy performance of process systems than optimization of heat recovery processes [12]. Therefore, process change, integration of processes, and heat exchanger networks (HENs) have been attracting more attention in recent years. Lu et al. [13] presented a novel design process for vapour recovery units which can eliminate the two recycle streams in the existing ASP and obtain better economic benefits. Li et al. [14] analysed and compared the three energy conservation processes for an absorber-stripper-stabilizer system in which the three processes showed distinct benefits for both economic and energy conservation. Li et al. [15] introduced a brand-new process and operating case based on process integration, resulting in significant energy savings and C_3/C_{3+} recovery. In his study, the desorption tower adopted a cold feeding mode and arranged a side-reboiler, as well as a side light gasoline to be drawn from the stabilization tower to be used as a supplemental absorbent. Lei et al. [16] developed a new energy-saving process for ASP in which a side draw was added to the absorption tower. Although previous studies have demonstrated the methods of designing and retrofitting and the advantages of their application, no studies have systematically attempted to elucidate the heat integration for the new retrofit processes. It is worthy of mention that some energy-saving opportunities usually arise after the process retrofit of an ASP.

In addition to process retrofit, Heat Integration (HI) also provides a powerful tool to improve the energy-use efficiency and reduce utility requirements. It is well known that the three HI methods of pinch technology, mathematical programming, and exergo-economic analysis have been widely used in previous studies [17]. Based on pinch technology, Walczyk et al. [18] and Feng et al. [19] developed a method for retrofitting of HEN, and presented the principles of how to define a boundary for HI in refineries. Dhole et al. [20] extended the pinch analysis used in distillation columns, and then, Nguyen et al. [21] and Cabrera-Ruiz et al. [22] employed the column grand composite curve (CGCC) to assess the performance of the conventional distillation and internal heat integrated distillation columns (HIDiC) to achieve HI between distillation column trains with HEN. These graphical techniques give a visual sense of the heat flow in processes. Mathematical programming is also widely used to obtain the minimum TAC, energy requirement or emission of processes. Based on LP, MILP models, Diakaki et al. [23] and Chen et al. [24] succeeded in synthesizing HEN that provided a minimum investment cost. Recently, Navarro-Amorosa et al. [25] and Zhang et al. [26] developed new mathematical models to simultaneously target the utilities for columns and HEN in refineries. To develop HI between units and reduce the calculation scale of the superstructure model, the interval-based MINLP and MILP models, and a genetic algorithm (GA) were proposed for the synthesis of HEN [27,28]. However, the above mentioned methods still make it difficult to solve industrial scale problems due to their high non-linearity. Moreover, based on the exergo-economic analysis [29,30], Chen et al. [31,32] adopted an exergo-economic structural model to improve the energy-use efficiency of the aromatic separation and DC systems. Morosuk et al. [33,34] and Kelly et al. [35] split the exergy destruction into endogenous/exogenous and unavoidable/avoidable parts to represent a new development in the exergy analysis of energy conversion systems. However, these methods often exhibit computational complexities in calculating exergy destruction and their investment costs.

The objective of this paper is to conduct a systematic study on the process retrofit coupled with heat integration for an existing ASP with feed splitting by means of process simulation and pinch technology. In this way, a new ASP with a two-stage condensation section is introduced in this work. Specifically, a condenser, a condensed oil tank, and a side-reboiler are added into the original ASP, and a heat integration is then performed. To evaluate the advantage of the new ASP reasonably, both the existing and new retrofit ASPs are optimized and compared based on energy targets and tech-economic evaluation. The accurate and efficient HEN syntheses for the existing and new ASPs are also performed using an Aspen Energy Analyzer [36]. Compared with the existing ASP, the new ASP has two significant advantages. One is the efficient avoidance of the potential interference from the feed splitting of the desorption tower in the existing ASP. The other is the efficient reduction of the amount of utilities consumed, and the operating costs through a two-stage condensation section and heat integration. Simultaneously considering the process retrofit and heat integration to improve energy-use efficiency of an existing ASP with double feeding is the key novelty of this work.

2. Process description and simulation of existing ASP

2.1. Existing ASP

Fig. 1 shows a typical ASP including absorption, reabsorption, desorption, and stabilization towers, plus other auxiliary equipment. As can be seen, compressed rich gas from the top of the main fractionators of FCC, DC or HC units is first mixed with the desorbed gas from the desorption tower and the rich absorption oil from the absorption tower. After being cooled to 40 °C, the mixture is separated into gas and liquid phases by passing through a condensed oil tank, A. The resulting gas and liquid streams are fed into the bottom of the absorption tower and the top of the desorption tower, respectively. Then, crude gasoline and a portion of stable gasoline enter the top of the absorption tower as the main absorbent and supplemental absorbent, respectively. The heat released from the absorption tower is removed by two side coolers. Next, lean gas exiting from the top of the absorption tower is fed directly into the bottom of the reabsorption tower. To recover dry gas (C_{2-} components) and residual gasoline from the lean gas, light diesel oil is simultaneously introduced into the top of the reabsorption tower as the absorbent. Meanwhile, the liquid stream from tank A is split into two streams as double feeds of the desorption tower. One stream (accounting for around one third of the liquid stream from tank A) is directly fed into the top of the desorption

Please cite this article in press as: Liu XG, et al., A new retrofit approach to the absorption-stabilization process for improving energy efficiency in refineries, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.10.128