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Performance improvement and efficiency enhancement of a debutanizer column (a case study in South Pars gas field)

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ABSTRACT

Due to the growing demands for processes such as gas to liquid and steam-methane reforming, in which precious chemicals especially methanol and gasoline are produced, performance enhancement of the debutanizer columns has become the center of attention. Debutanizer column, that is one of the main units of refineries and petrochemical complexes, has the responsibility of separating C_4 cuts and lighter components from natural gas liquids, typically gasoline. In this paper, an industrial debutanizer column was simulated applying a steady state flow sheet simulator in order to investigate possible sources of low-efficiency separation problem. In this regards, the reflux ratio and the feed tray location were changed theoretically to achieve higher performance of the column. The results clearly revealed that the 19th tray can be selected as the tray with the best separation performance. Moreover, the optimum reflux ratio was determined and it was proved that better separation can be achieved by applying both modifications simultaneously. In addition, the feedstock liquefaction and the optimum number of liquid furnaces were studied. The results demonstrated that applying three furnaces is more beneficial than one, two or four furnaces and feedstock liquefaction has a slight positive effect on the quality of the separation. In order to investigate whether the application of the optimum reflux ratio and three furnaces can practically improve the separation performance, the aforementioned conditions were subjected to the industrial debutanizer column. The results confirm the improvement of the separation process leading to substantial savings in energy and cost.

1. Introduction

In modern life, refinery products such as 1,3 butadiene and gasoline have shown a growing market demand all over the world. Consequently, performance improvements of the unit operations have become a critical concern in refineries.

1.1. Natural gas liquids

Natural gas liquids (NGLs) are commonly defined as heavier hydrocarbon liquids of natural gas. They are mainly composed of propane, butanes and sometimes ethane. In a typical natural gas processing plant, various components of NGLs are separated one by one from the natural gas stream applying a series of fractionation columns namely demethanizer, deethanizer, depropanizer, debutanizer, etc.

1.2. Debutanizer column

Distillation column is considered to be one of the most commonly applied unit operations in chemical industries. However, its complex behavior and highly un-predictive nature has made it as a complicated and difficult-to-handle unit operation for engineers (Canete et al., 2008). Hence, it is of great importance to attain the desired purity of the products by manipulating the composition of the top and bottom product components accurately. In order to control the composition of each component at its optimum value, it is necessary to predict it with high precision simultaneously with fast response. A special distillation column is the debutanizer column in which 1, 3 butadiene, C_4 cut and gasoline are its main products. 1,3-butadiene, which is a colorless non-corrosive gas with mild aromatic or gasoline-like odor, has the boiling point of −4.4 °C at atmospheric pressure (Jalali and Saffari,

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2006). This important chemical compound is the raw material in the production of synthetic rubber. The other main product, gasoline, is a mixture of hydrocarbons, additives, and blending agents. The composition of gasoline varies widely depending on the petroleum and the refining process. The typical composition of gasoline hydrocarbons mainly includes paraffins, naphthenes, olefins and aromatics.

The presence of light hydrocarbons especially methane in the top product stream is more substantial which is the main feed source of vital processes such as methanol synthesis and steam-methane reforming (Rahimpour et al., 2012; Bayat et al., 2014; Arab Aboosadi et al., 2011).

1.3. Literature review

Application of process simulators is an effective method for analyzing, designing and economically evaluating unit operations as well as optimizing the conditions in a short time with high accuracy (Galbe and Zacchi, 1992). In 1992, Galbe and Zacchi were successful in simulating and optimizing of ethanol production from lignocellulosics by Aspen Plus simulator. Based on the investigation of water recycling effects as an important parameter of the process, a reduction about 89.9% and a raise from 2.5% to 10% were observed in the amount of waste water and ethanol concentration at the entrance of the distillation column, respectively which lead to energy benefits (Galbe and Zacchi, 1992). Muñoz et al. studied two alternatives to simulate distillation columns for separating isobutyl alcohol and isobutyl acetate using Aspen Plus simulator. They also optimized the condition by HYSYS in order to find the optimum number of trays and the feed tray location of the alternative columns (Muñoz et al., 2006). Tijani and his team focused on finding the optimum design of a distillation column (stripping column of hydrocarbon recovery plant) in such a way that minimum energy and costs obtained. They modeled the process in Aspen Plus simulation environment and more importantly optimized the model economically by variation of feed stage and side stream withdrawal considering some constraints. From their results it appears that introducing a side stream is more preferable because of more acceptable column performance and expenses (Tijani et al., 2007). More studies that include column simulation and/or optimization are Batista Fabio and Meirelles (2011), Bolun et al. (2006) and Zapata et al. (2012). Chemical industries encounter lots of problems in monitoring the debutanizer column (DBC). Up to now, the majority of investigations on DBC have dealt with different controlling strategies. For instance, in 1994, Maricia and co-workers suggested a practical dual composition control for DBC (Maricia et al., 1994). The problem they encountered was related to the disability of the system in maintaining both top and bottom specifications in the automatic mode, and the column was being operated manually most of the time. By developing a dynamic simulation program, they attained significant economic benefits (Maricia et al., 1994). Afterwards, a comparison between nonlinear control and PID control strategies was made by Ansari and Tade (1998). They applied both strategies individually for a debutanizer column in order to control both the composition of iC_5 at the top of the column and Reid vapor pressure of feedstock. The results ultimately showed the superiority of nonlinear model-base control over the PID one. However, to the best of our knowledge, the application of nonlinear control laws for DBCs has been rarely investigated (Huang and Riggs, 2002).

Despite all of the conducted researches on DBC controlling, it seems that individual simulation or modeling of the column has not been widely studied.

1.4. Objectives

The main objective of this study is to simulate and optimize an industrial debutanizer unit using a simulation software. In this case, some of the design mode characteristics of the industrial plant are collected in Table 1. In order to optimize the conditions and improving the column performance, some possible and beneficial methods are applied. Simulation results are compared with the industrial plant data. Furthermore, optimization results offer the better separation operation and saving in energy and costs.

2. Process description

In this work, the industrial debutanizer column, which is located in an olefin plant, operates under particular conditions, applying a certain number of liquid furnaces. The process of naphtha thermal cracking occurs in these furnaces and the raw gas consisting of ethane, propane and other organic compounds is produced. The continuous feed stream of the column with the flow rate of 63,361 kg/hr is prepared from the bottom product of a depropanizer tower which is the upstream unit. As mentioned earlier, the DBC feed stream is a multi-component mixture mainly composed of gasoline, 1,3 butadiene and C_4 cut. The main objective of the tower is the separation of C_4 cut from gasoline. The specifications of the feedstock introduced to the column are tabulated in Table 2.

After the separation operation in the column, the distillate is fed to the butadiene unit in which 1, 3 butadiene is converted to normal butane and become saturated. However, if the unit does not work efficiently, butadiene must be fed to a hydrogenation reactor to prevent coke formation produced by unsaturated hydrocarbons in the olefin furnaces. In the hydrogenation reactor, butadiene is completely hydrogenated in order to become ready to be sent to olefin furnaces.

The bottom product, which is mostly gasoline, is sent to an atmospheric storage tank. A simplified schematic of the debutanizer is shown in Fig. 1.

3. Plant operational problem

The industrial debutanizer column investigated in the current study (Industrial debutanizer unit in south pars gas processing field, 2014) operates under low-efficiency separation operation and encounters instability problems. Any instability in the distillation column would lead to undesirable consequences such as operational problems, reduction in the production rate, the loss of purity of the products and efficiency decrease. This unfavorable phenomenon not only may affect downstream and even up stream units, but also can cause serious damage to the column equipment and stop the production (Wauquier, 2000; Himmelblau et al., 2001).

In fact, the amount of light and heavy components in bottom and top streams, respectively, is very vital. In other words, an

Table 1
Components mass fraction percent of the feed, distillate and bottom of the column in design mode.

Component	Feed	Distillate	Bottom
MAPD	0.07	0.14	0.0
Propylene	0.01	0.02	0.0
Propane	0.01	0.03	0.0
1,3-Butadiene	23.46	41.4	0.58
Other c4's	33.26	58.21	1.42
Gasoline	42.99	0.2	97.57
Fuel oil	0.19	0.0	0.43