Applying genetic algorithm for Minimization Energy consumption in a distillation unit

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Abstract
Distillation is the most widely used but the most energy consuming separation process in the chemical industries. Energy saving consumption in the distillation unit of LAB production plant was investigated. As an idea for reduction of energy consumption, in this work, a theoretical investigation by simulation means has been came out to split the feed into two streams and preheat only one of these feed of streams before enteriy the columns. In this evaluation, the unit was simulated by Hysys and Genetic algorithm was applied for minimizing energy consumption. According to the results of this study, 26% energy saving can be achieved by splitting and preheating feeds of the both columns.

Keywords: LAB, energy saving, feed splitting, Genetic algorithm.

1. Introduction

In order to produce LAB having, for example, from 11 to 13 carbon atoms per linear alkyle group, a stream linear paraffins comprising C_{11} to C_{13} hydrocarbons is desired. A suitable steram is a heartcut of the kerosene boiling range fraction suffices, provided that hydrocarbons with boiling points lower than C_{11} paraffins and hydrocarbons boiling points higher than C_{13} linear paraffins must be removed from the kerosene fraction. Generally, this heartcut is produced in a two-step, strip-and-rerun fractionation process (O’Brein, et al 2002)

Distillation, which is the workhorse of chemical process industries, is quite energy intensive and accounts for an estimated 3% of the world energy consumption (Humphrey and Siebert 1992). The higher the energy demands are, the larger the CO_{2} emissions to the atmosphere are. This is because the energy is mostly generated through the combustion of fossil fuel (Engelien and Skogestad 2004). To optimize the energy consumption of this process by analytical methods, the gradient of the fitness function in terms of decision variables must be defined. But definition the gradient of the fitness function is too difficult due to complication and existing variety of parameters. In this paper considering the feed splitting idea, genetic algorithm was used to optimize energy consumption of LAB distillation unit. Impressive parameters in this investigation are the flow ratio, the temperature of preheated stream and feed tray corresponded to two columns.

2. Theory

The basic form of the LAB plant which is necessary for the separation of the hydrocarbons is shown in Fig. 1. Feed is introduced into the first column by which light
cut containing lighter hydrocarbons than C_{10} are separated. The second column is used to separate hydrocarbons heavier than C_{13}. The heart cut, as the top product of second column, is the desired product of this plant.

**Fig. 1. Basis form of LAB distillation unit**

Energy consumption of the distillation process in the LAB plant like similar processes is a crucial issue. Considering distillation unit as an important part of LAB production, energy consumption of this unit could be reduced by some strategies like heat integration. UOP performed this idea by means of two heat exchangers that result in heat transferring between heart and heavy cuts and the feed stream (Fig. 2). This leads to use wasted heat of the hot streams for preheating the feed stream.

Another idea could be splitting of the feed streams of the two columns used (Soave and Feliu 2002, Deshmukha et al 2005, Soave et al 2006). Preheating one of the splitted streams could theoretically reduce the total energy consumption as describes below.

**Fig. 2. UOP design of LAB distillation unit**

Increasing the feed enthalpy and temperature could perform with internal or external heat sources. Preheating the feed with external heat requires an additional heat consumption which is equal to the variation of the heat content of the feed. If products’
conditions are held constant, preheating the feed results in reduction of the reboiler duty (Or) and consequently the heat removed from the condensed Qc (Engelien and Skogestad 2004). Feed preheating affects condenser and reboiler duties. Splitting the feed into two streams and preheating only one stream has two positive effects can (Ullmann 2003) (Fig. 3):

1. The warmer, preheated, stream would keep the minimum reboiler duty at a low level
2. The other stream would keep the minimum reflux ratio low (Kister 1992).

![McCabe-Thiele diagram](image)

*Fig. 3. McCabe-Thiele diagram (at the minimum reflux ratio) for a distillation tower with two feed streams at different temperatures (Engelien and Skogestad 2004)*

![Feed splitting diagram](image)

*Fig. 4. feed splitting of basic form.*

In this work two serial distillation column of the prefractionating unit of the LAB process was simulated in order to reduce energy consumption of the process. In order to simulate the LAB distillation unit, thermodynamic equation of Chao Seader was used because this equation could be efficiently used for heavy hydrocarbons.
Simulation was performed based on practical data from ICIIC LAB. Considering products and feed compositions and conditions, theoretical tray numbers have been computed using the shortcut methods. Consequently tray efficiency was calculated. In this work, focuses on the energy consumption of the unit. The composition of the products was kept constant with any changes so the composition of the products was used as specifications for solving the columns. Considering the basic form of the plant, feed splitting and preheating both resulted in considerable energy saving.

In this paper, the idea of the feed splitting was also applied in the process designed by UOP. There are three products in the basic configuration of the plant which have high temperatures and could be used for preheating the feed. In UOP design of LAB plant, the two products of second column are used for preheating the feed as shown in Fig 2.

3. Optimization using GA

To optimize the energy consumption of this process by analytical methods, the gradient of the fitness function in terms of decision variables must be defined. But definition the gradient of the fitness function is too difficult due to complication and existing variety of parameters. Thus, in this study non-gradient based optimization methods have been used for optimization. These methods do not require knowledge of the gradient of the objective functions which makes them particularly suitable for solving optimization problems for which an analytical expression for the fitness function is not known. In this regards, over the recent years, a class of random search algorithms simulating natural evolutionary processes has attracted broad attention. This class of algorithms showed good characteristics when solving difficult optimization problems. The class of algorithms includes Simulated annealing, Genetic Algorithms, Particle Swarm Optimization and Ant Colony, between others. In this paper, genetic algorithm has been used to generate an efficient optimization method. This method was successfully applied for nonlinear optimization problems in many dimensions, where more traditional methods are often found to fail.
Each individual in the population is called a chromosome, representing a potential solution of the problem (Holland 1992). A chromosome can be presented by a binary string; each part of this binary string represents one of the decision variables. A population of chromosomes is formed initially from a random set of solutions. Consequently new generations are produced, and some measures of fitness for the chromosomes are used to guide the selection. Offsprings are formed by either (a) merging two chromosomes from the current generation using a crossover operator, or (b) modifying a chromosome using a mutation operator. Offsprings is formed by selecting some of the parents and children, based on the fitness values, and rejecting others to keep the population size constant (Goldberg 1998). Fitter chromosomes have higher probabilities of being selected. After several generations, the algorithm converges to the best chromosome, which represents the optimal solution to the problem provided by the GA (Ponce-Ortega et al 2009).

In this paper, GA was used to optimize the LAB distillation process. In order to obtain the optimum values of the parameters by Genetic Algorithm, energy consumption is used as the fitness function of the Genetic Algorithm. The decision variables are as follows: Splitting ratio, rate of preheated stream and feed stages of each column.

4. Results and Discussion

Splitting two columns’ feed in LAB distillation unit showed significant effects on the energy consumption. There are eight factors that should be considered which are flow ratio, temperature and intance tray number of preheated feed for two columns along with intrace tray number for other feed streams. Firstly effects of these parameters were considered one at the time and mutual effects of parameters were neglected. Consequently in order to find the best combination of parameters in which the process has minmun energy consumption, Genetic algorithem was used.

For the first column, preheating the feed showed remarkable effect on total energy consumption. Increasing temperature of the second feed of the column up to about 240ºC, the energy consumption approximately remains constant. Where as the temperature has more effect on energy consumption at temperatures higher than 240 ºC. Reduction of total energy consumption not only depends on temperatures but also depends on the flow of the preheated feed stream. It should be noted that energy which is needed for preheating the feeds should obviously concept of the considered in evaluation of total energy consumption. The second column feed splitting showed less effect on energy consumption than what had been calculated for the first column. The total energy consumption was reduced with increasing temperature of the preheated feed stream. The opposite trend was observer with have been the found. The temperature in which minmun energy consumption was found depends on flow ratio of feed splitting. The higher the flow of preheated feed, the higher the temperature will be. Another factor that should be considered is the intrance tray number of the preheated feed that could affect the process. Effect of this factor also depends on the temperature of the stream. It should be noted that the intrance tray number of the other feed stream was kept the same in this part where as it was considered as one of parameters using Genetic algorithm. The effect of the intrance tray number of the preheated feed for the first column was shown in Fig.6. Temperature of the preheated feed was fixed at 240ºC
which was equal to 42nd tray temperature. The total energy consumption for the trays above 42 was the same while for the lower trays it was reduced. It seems that in order to reduce the total energy consumption, the preheated feed should introduce into the column at lower trays.

The preheated stream of second column could introduce at various trays which effects on the energy consumption differently. It is found that where the temperature of the preheated feed was 240ºC and flow ratio was 0.5, 41st tray was the best choice. As mentioned above, we are dealing with the numerous to find the parameters that affect energy consumption of this system. Using the conventional method, finding optimum values of these parameters is rather difficult. Thus, in table 1 applying GA method the optimum values of these parameters which is minimized the total energy consumption was obtained as shown.

The energy consumption corresponding to these optimum parameters is estimated to around 63900 kW, which is about 23000 kW lower than what was found for the basic configuration (non integrated non prefractiooned).
5. Conclusions
In order to minimizing energy consumption of the LAB distillation unit genetic algorithm (GA) was used. In this regard, the feed stream of each column was divided into two streams in which one of them was considered to be preheated before enteriy the column. This resulted in 26% energy saving compared with the basic configuration. Energy consumption of this configuration was compared with the base case and UOP case in Table 2.

Table 2: energy consumption Comparison of the LAB distillation unit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Energy Consumption</th>
<th>Energy saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case (non integrated non prefractioned)</td>
<td>86770 kW</td>
<td>0</td>
</tr>
<tr>
<td>Prefractioned</td>
<td>63900 kW</td>
<td>26%</td>
</tr>
<tr>
<td>Integrated</td>
<td>49520 kW</td>
<td>43%</td>
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References