Applications of vacuum rectification for energy optimization of the fractional facility of benzene and toluene

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Abstract. The article represents the possibility of the energy optimization of rectification facility of separation of benzene and toluene by using columns with circled energy flows. The modeling was conducted in Hysys environment using NRTL thermodynamic package. The modernization requires the vacuum in the benzene column to lower the temperature and increase the temperature difference between the top of the toluene and the bottom of the benzene column. The proposed technological configuration allows to significantly reduce the energy consumption in the form of heating steam and achieve a significant economic effect.

1. Introduction

Energy optimization is one of the main ways of the modernization of Russian oil refineries. In the last decade the trend of complication of hydrocarbon extraction processes, increase in hard to recover resources extraction and amplifying of the role of high north oil and gas fields is observed. As far as these trends results in high levels of hydrocarbon energy consumption, energy optimization of oil and gas refineries is one of the main goals of the industry [1].

Rectification as a method of separation is one of the most common and energy-intensive process of modern oil refinery. The process is conducted in fractionating column equipped with contact devices. The main ways of energy optimization of rectification columns are developing of high production complex facilities, automatization of rectification process, modernization and equipment of the refineries with modern contact devices (highly effective fillings), reuse of energy resources [2–4].

The catalytic reforming is the main process of aromatic hydrocarbons production complex [5]. Platforming is a process based on hydroforming process (dehydrogenation of naphtenes and dehydrocyclization of alcanes) of gasoline fraction on polymetallic Aluminum-Platinum catalyzer. The commercial product undergoes various separation processes, such as rectification, extraction, (including sulfanol extraction) and adsorption. The most common commercial products – benzene and toluene – aromatic hydrocarbons, which are the most common petroleum solvents used in the industry.
The section is intended for the fractionation of benzene, toluene, xylenes and heavy aromatic hydrocarbons C_9, C_{10}. The rectification takes place in two column equipped with perforated plates; 54 and 58 pieces in the benzene and toluene column, respectively. The temperature regime in the benzene column, which is the object of consideration for this work, is maintained by applying heat through a horizontal reboiler, heated by medium-pressure steam. The vapor condensation of both columns is carried out by an air cooling unit. The benzene and toluene columns operate under a slight overpressure of 0.65 atm. The purpose of the benzene fractionation column is to separate commercial benzene and low-boiling impurities in one column with the withdrawal of commercial benzene as a side flow from the fifth plate (counting from above), and low-boiling impurities from the top of the column in the form of distillate.

The main raw material of the facility is an aromatic extract containing benzene and toluene. The temperature of the raw material is not higher than 150°C. The composition of the raw-material (mass %): 18.07% benzene, 55.41% toluene, 0.89% ethylbenzene, 10.47% P-Xylene, 4.66% M-Xylene, 4.19% O-xylene, 0.7% water, 5.06% C_9, 0.55% C_{10}.

2. Materials and methods
The objective of this work is to analyze the possibilities of modernization of the facility of rectification of benzene and toluene in the productions of aromatic hydrocarbons in refineries and petrochemical plants.

The modeling of the facility was carried out in Hysys software using the NRTL thermodynamic package, and a model that adequately describes the actual object was obtained (figure 1). The correctness of the model was evaluated by the correlation of mass flow rates, compositions, temperatures of raw materials and products in the model with data from the operating sheet.

The main parameters of the modeling of the benzene column: top pressure - 1.32 atm, bottom pressure - 1.60 atm, number of theoretical plates - 34, feeding plate - 17 (counting from above), benzene comes from plate 4, raw material temperature - 128 °C, reflux ratio - 1721.

![Figure 1. Model of the facility of distillation of benzene and toluene.](image_url)
The main parameters of the modeling of the toluene column: top pressure - 1.15 atm, bottom pressure - 1.50 atm, number of theoretical plates - 38, feeding plate - 19 (counting from above), raw material temperature - 135 °C, reflux ratio - 1.543.

The operating parameters correspond to the stationary mode of operation according to the data of the operating sheet. The purity of obtained benzene and toluene corresponds to 99.99 and 99.92, respectively, which meets the current standards: GOST 9572-93 and GOST 14710-78 [9, 10].

3. Results and discussion

As part of the research the in-depth analysis of the various parameters of the facility and its configuration was carried out. The main goal of the modernization was to reduce the heat consumption and increase the energy efficiency of the facility. Two conceptual approaches for modernization were considered:

• Reducing the cost of rectification by combining the benzene and toluene columns into complex column with several side flows;

• Reducing the energy cost for heat supply of benzene column due to the use of heat of condensing toluene from the second column.

During modeling, it was found that the first option was unpromising, since the separation of the mixture in one column leads to a too significant increase in the number of theoretical plates, which makes the column unreasonably high.

The second approach to modernization includes the supply of heat to the benzene column due to condensation and cooling of toluene vapor from the top section of the toluene column. Unfortunately, this concept cannot be implemented without changing the configuration of the facility due to the negative temperature difference between the coolants. At the same time, vacuum rectification (top pressure - 0.4 atm, bottom pressure - 0.6 atm) allows to reduce the temperature of the bottom product of the benzene column (refrigerant) and thereby increase the temperature difference to an acceptable level of about 15-30°C: 100°C – the bottom of the benzene column and 124°C of the top of the toluene column [6, 7]. In addition, the temperature of the distillate of the benzene column is 46°C, which allows to use water for cooling, having a temperature in the summer period of about 25°C [8].

![Figure 2](image_url)

**Figure 2.** Technological configuration before (a) and after (b) modernization.

In accordance with the method of determining the optimum reflux ratio by the smallest volume of the distillation column, the optimum reflux ratio and the number of theoretical plates were determined [9, 10]. In accordance with the current standards for the calculation of distillation columns, the
operational point \( N = 33, R = 1420 \), which corresponds to the minimum rectification costs and a sufficient range of changes in the operational parameters of the distillation column was chosen as the most optimal operating point. Based on the similar recommendations a feeding plate was chosen.

The heat flows supplied to the bottom of the benzene column and necessary for condensation of vapors in the toluene column are 5.350 Gcal/h and 6.939 Gcal/h, respectively. The difference in heat flow is necessary to ensure the flexibility of the plant and can be compensated by the air-coolant.

Energy optimization makes it possible to achieve heat and cash savings of 5.4 Gcal/h and 53.78 million rubles/year, respectively. According to the results of the calculation, net present value amounted to 255.47 million rubles. The profitability index for the implementation period was 5.19. The payback period of the project is 1 year 4 months.

4. Conclusion
In this paper, the method of optimization of rectification facilities was proposed and analyzed with reference to the technological process of the fractionation of benzene and toluene. The method uses the heat of condensing toluene to heat up the bottom of the benzene column. This technological configuration allows to reduce the heat consumption required for the operation of the facility by 5.4 Gcal/h. The most optimal reflux ratio, feed plate and number of theoretical plates were determined. The approach of this technological solution has wide variety of applications in other petrochemical and refining industries.

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