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WAY TO INCREASE THE ENERGY EFFICIENCY OF THE DISTILLATION UNIT AT ETHYLBENZENE MANUFACTURING TECHNOLOGY

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Abstract

The object of research is the installation of rectification columns for benzene, ethylbenzene, and polyalkylbenzenes. The purpose of this work is an optimization of rectification technological modes and energy efficiency increasing of distillation in the technology of ethylbenzene production by replacing of the used in reboilers vapor at 4 MPa by vapor at 2 MPa. The proposed optimization option of the rectification unit is efficient since the implementation of the proposed technical solution will be achieved using Vapor 2 with increased efficiency of the process, namely a reduction of vapor consumption. The total consumption of vapor after the upgrade will be 2.751 Gcal / hour, which is 2168 Gcal per year less than the current vapor load.

Keywords: *ethylbenzene; distillation; simulation; column; optimization.*

1. Introduction

The process of mixtures rectification is one of the most energy-intensive processes and is widely used in enterprises. Mass transfer columns have a complicated design, large metal content and high energy consumption as heating and cooling agents. Energy consumption is largely dependent on units design, that is, the efficiency of contact devices used in columns. From the theory and operation of rectification, it is known that the lower the efficiency of contact devices, the larger reflux flow rate (reflux ratio) and the vapor stream (vapor number) are required, therefore, increasing the costs of heating agent in a column reboiler and cooling agent in a dephlegmator.

Nowadays the main problem of rectification is the high power demand of installations [1]. Therefore, the process continues to occupy a leading position in energy consumption in the petrochemical and refining industries.

The purpose of this work is an optimization of rectification technological modes and energy efficiency increase of distillation in benzene with ethylene alkylation technology by replacing the used vapor at 4 MPa by vapor at 2 MPa.

Process modeling is a useful tool to optimize the operation of industrial plants [2–11]. Different models can solve and prevent various problems and emergencies as they are developed with due consideration of physicochemical reactor process. This makes them sensitive to changes in raw material composition and performance properties of the catalysts.

2. Object and methods of research

Ethylbenzene (EB) is used as an intermediate in the production of synthetic rubber and styrene [12-13]. Rectification unit of one of the ethylbenzene and dry benzene production enterprises (Fig. 1) includes three distillation columns K-52, K-62, and K-72. Column K-52 is designed for stripping of recycled benzene from alkylate, column K-62 is designed to separate ethylbenzene, and column K-72 is designed to separate polyalkylbenzenes (PABs) from resin.

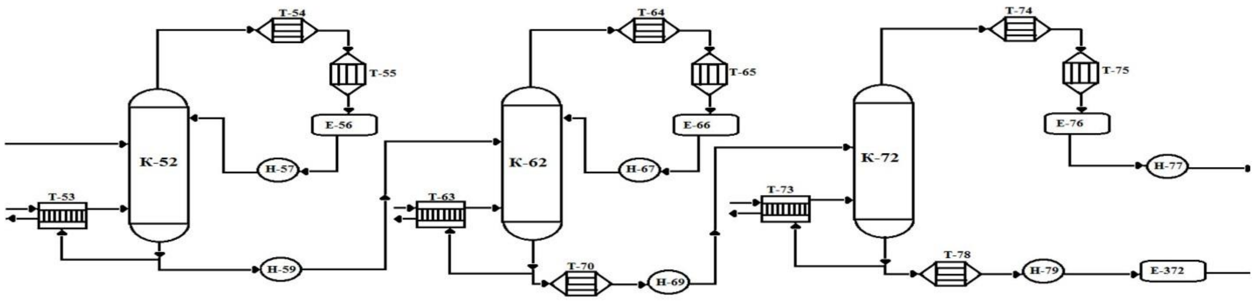

Figure 1. Rectification unit of one of the ethylbenzene and dry benzene production enterprises

For this study, the input data were parameters of technological regime obtained from the installation of ethylbenzene production for one of the petrochemical industries. Tab. 1 shows the structural characteristics of the existing columns.

Table 1. The design parameters of distillation columns

Column parameter	K-52	K-62	K-72
Inner diameter, mm	2000	2200	1400
Number of trays	60	80	37
Trays distance	450	450	400

Tab. 2 shows thermobaric performance characteristics of distillation columns, according to the current regulations of technology.

Table 2. Operating modes of columns

Column operating mode	K-52	K-62	K-72
Overhead vapor pressure, kPa	100	100	130-220
Bottom liquid pressure, kPa	120-160	120-170	5.3-21.3
Overhead vapor temperature, °C	75-100	125-139	not standardized
Bottom liquid temperature, °C	145-165	175-200	160-195

Distillation columns K-62 and K-72 consume heat which is supplied by vapor P = 2.8 MPa throttled from vapor P = 4 MPa through reboilers T-63 and T-73, the heat to the distillation column K-52 is fed by vapor P = 2 MPa through T-53 reboiler. For the operating mode of rectification columns, it requires vapor at about 200°C. According to the thermal power plant (TPP) that produces vapor with P = 2 MPa, T = 300°C and P = 4 MPa, T = 340°C, but due to the long-haul pipeline (about 10 km), the vapor parameters are significantly reduced. As a result, the necessary temperature for columns K-62 and K-72 with required operating modes can be ensured only by vapor P = 4 MPa.

The feasible option of optimization mode is the bottom temperature reducing, which will allow using Vapor 2 for the temperature difference between coolants (this option does not require significant overhaul). The lower temperature of Vapor 2 is determined as 194°C. The temperature reduction of the column bottom is possible by reducing the pressure in the column, which in turn will lead to boiling temperatures reduction of the component and a separated mixture of evaporated liquid in reboiler.

Calculations for determination of the columns optimal mode were carried out using a universal Aspen HYSYS simulation system. Simulation process was performed on purpose the flows compositions, top and bottom temperatures of the columns were as close as possible to those columns regime parameters presented in Tab. 2.

The basis of the program is the general principles of material and heat balances calculations. The connection of elements provides a flowsheet simulation with relevant transformations in the system. Calculation of hydrocarbon systems was carried out using the Peng-Robinson equation of state.

3. Results and discussions

As a result, calculations were made to determine the optimal operation of the processing circuit in order to increase the efficiency of the distillation process, ethylbenzene and the establishment of the possibility of reducing the temperature of the bottoms of the columns.

Aspen HYSYS simulation environment [14-15] allows to define the optimal parameters of the distillation columns, and reboilers with requirements to the production technology and assess the energy efficiency. The following basic formulas are required for the material heat balance of distillation column:

$F = P + W$ (1)

where F – the mass flow of feed mixture, *kg/s*; D – the mass flow of overhead products, *kg s*; W – the mass flow of bottom products, *kg/s*.

For continuous operation of the column taking into account heat losses:

$Q_{reboiler}+Q_f+Q_r=Q_w+Q_d+Q_{losses}$ (2)

As a result of technological calculations using the parameters of the technological regime material balances of columns, compositions of product and feed streams were obtained (Tab. 3). Further confirmatory analysis for reboilers was performed; the results are shown in Tab. 4.

Table 3. Material balance of columns

Flow	Units	Feed	K-52 Overhead vapor	K-52 Bottom liquid	K-62 Overhead vapor	K-62 Bottom liquid	K-72 Overhead vapor	K-72 Bottom liquid
Flow rate	kg/h	20070.00	10366.43	9699.57	5953.61	3745.96	3545.51	200.44
Temperature		95	72.3	151	74	174	81.5	132.7
Pressure	kPa	140	80	130	60	100	4	12
Reflux rate	kg/h	6740			8930		1060	
Composition								
Paraffins	mass fractions	0.0055	0.0106	0.0000	0.0000	0.0000	0.0000	0.0000
Benzene	mass fractions	0.5093	0.9857	0.0000	0.0000	0.0000	0.0000	0.0000
Toluene	mass fractions	0.0027	0.0036	0.0017	0.0028	0.0000	0.0000	0.0000
Ethylbenzene	mass fractions	0.3013	0.0000	0.6234	0.9961	0.0310	0.0327	0.0000
p-Xylene	mass fractions	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
m-Xylene	mass fractions	0.0001	0.0000	0.0002	0.0003	0.0001	0.0001	0.0000
o-Xylene	mass fractions	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000
Cumene	mass fractions	0.0017	0.0000	0.0034	0.0006	0.0079	0.0084	0.0000
i-Bbenzene	mass fractions	0.0050	0.0000	0.0103	0.0000	0.0268	0.0283	0.0000
sec-Bbenzene	mass fractions	0.0025	0.0000	0.0052	0.0000	0.0134	0.0142	0.0000
tret-Bbenzene	mass fractions	0.0025	0.0000	0.0052	0.0000	0.0134	0.0142	0.0000
1,3,5-Ethylbenzene	mass fractions	0.0026	0.0000	0.0053	0.0000	0.0137	0.0032	0.2001
1,3-Ethylbenzene	mass fractions	0.0947	0.0000	0.1959	0.0000	0.5072	0.5350	0.0150
1,2-Ethylbenzene	mass fractions	0.0324	0.0000	0.0671	0.0000	0.1736	0.1830	0.0081
1,4-Ethylbenzene	mass fractions	0.0324	0.0000	0.0671	0.0000	0.1736	0.1809	0.0460
Resin	mass fractions	0.0073	0.0000	0.0151	0.0000	0.0391	0.0000	0.7308

Table 4. Results of confirmatory calculation for reboilers

	Temperature, °C	Pressure, kPa	Flow rate, kg/h	Technical features
Flow	Reboiler T-53			
Hot vapor P=2	194.0	1300.0	3800.0	A=182 m^2, D=1470 mm, H=4516 m, $P_{tube-side}$=1 MPa, $P_{shell-side}$=1.4 MPa
Cooled Vapor P=2	154.8	1250.0	3800.0	
EB	151.0	130.0	22420.1	
Hot EB	178.0	90.0	22420.1	
	Reboiler T-63			
Hot vapor P=2	196.0	1300.0	2500.0	A=182 m^2, D=1000 mm, P=4805 mm, $P_{tube-side}$=0.55 MPa, $P_{shell-side}$ =3.5 MPa
Cooled Vapor 2	180.4	1250.0	2500.0	
PABs	174.0	100.0	15539.6	
Hot PABs	191.2	90.0	15539.6	
	Reboiler T-73			
Hot Vapor 2	195.0	1300.0	435.0	A=61 m^2, D=630 mm, H=4830 mm, $P_{tube-side}$ =4 MPa, $P_{shell-side}$ =4 MPa
Cooled Vapor 2	134.5	1250.0	435.0	
Resin	132.7	12.0	2396.9	
Hot resin	189.2	2.0	2396.9	

According to calculations (Tab. 5), if under defined conditions the boiling point of the bottom liquid in column K-62 is about 174°C, it allows using Vapor 2 as a coolant in the reboiler of the column.

The column K -72 operates under vacuum. The boiling point of the bottom liquid under calculated conditions (Tab. 4) is 132.7°C. Thus, for the heating of the bottom liquid Vapor 2 can be used.

Based on the analysis of results it can be concluded that the proposed optimization option of rectification unit is efficient since the implementation of the proposed technical solution will be achieved using Vapor 2 with increased efficiency of the process, namely a reduction of vapor consumption. This option does not require substantial reconstruction (replacements of units or contact devices, etc.) and is quite cheaper.

In addition, condensers and reboilers loads with an average annual production ethylbenzene capacity of 35600 t/year were defined. Based on the obtained results, the thermal balance (Tab. 5) was defined.

Table 5. Heat balance

	Before modernization		After modernization	
№	Flow	Gcal/h	Flow	Gcal/h
The use of vapor heat				
1	Vapor 2 in T-53	1.321	Vapor 2 in T-53	1.321
2	Vapor 4 in T-63	1.546	Vapor 2 in T-63	1.200
3	Vapor 4 in T-73	0.155	Vapor 2 in T-73	0.230
Total		3.022		2.751

Thus, the total consumption of vapor after the upgrade will be 2.751 Gcal/hour, which is 2168 Gcal per year less than the current vapor load.

4. Conclusions

In this study optimization calculations for the rectification flowsheet of ethylbenzene and dry benzene from the reaction mass were conducted. Based on the results the optimized parameters of a technological mode that will improve the efficiency of the process are suggested.

In Aspen HYSYS environment calculations have shown the ability to operate temperatures decreasing in columns K-53, K-62 and K-72 from operating temperatures to the parameters supplied by Vapor 2 from the reboiler to the column bottom. This upgrade will allow using Vapor 2 instead of Vapor 4 and reducing the flow of consumed vapor.

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