

Energy Analysis of Heat Schemes of Installations for Dividing of Separate Components from Waste Waters

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Abstract - An energy analysis of industrial installations for dividing of ethanol and methanol from waste waters is done. Suitable technical decisions for reduction in energy consumption of separating processes are offered. The quality of recovered components permits to use them repeatedly in the production process.

Keywords - recovery of organic solvents, dividing of waste waters, energy analysis, ethanol, methanol.

I. Introduction

The multicomponent mixtures ethanol - water - non volatile impurities and methanol - water - non volatile impurities are received as waste products in different productions. With a view to achieve a definite economic and ecological effect it is necessary to recover the valuable components of these waste mixtures and to use them repeatedly in the production process.

Heat-technological schemes of industrial installations for dividing of the mentioned mixtures in their composite components are work out for solving of this problem.

The aim of this paper is to be carried out an energy analysis of the offered installations and of different technical decisions for energy costs reduction for the used dividing processes and on that base to be offered the most appropriate decisions for the case.

II. Materials and Methods

The waste mixtures ethanol - water - non volatile impurities and methanol - water - non volatile impurities are brown, light viscous, oleaginous liquids. Their color, viscosity and oiliness are owing to the non volatile impurities dissolved in them, because the rest components - water, ethanol and methanol are colorless and unviscous liquids. The non volatile impurities have concentration about $2000 \div 5000 \mu\text{g/ml}$. If the amount of these impurities is ignored the ratio of the rest two components ethanol and water in the mixture ethanol - water - non volatile impurities vary about $20 \div 30$ volume %. The same refers to the ratio of methanol and water in the waste mixture methanol - water - non volatile impurities

The binary solution ethanol-water is a solution with completely solubility components and has an azeotropic point with a minimal boiling temperature of 78 degree centigrade and composition 96 weight % ethanol и 4 weight % water [12]. Data about the vapor - liquid equilibrium in that binary system is published in [5,11,12].

The ethanol is one of the few alcohols which in small quantities is not poison for the people. In greater quantities it is toxic and explosion hazardous. At concentration of 0,6 to 0,9 % in the air it is not recommended long staying in the area.

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Its maximum allowable concentration of inflammation in the air is up to 19 volume %.

The binary solution methanol-water is a solution with completely solubility components and has not an azeotropic point. Data about the vapor - liquid equilibrium in that binary system is published in [5].

The methanol is explosion hazardous and strongly poisonous at swallowing, inhaling and contact with the skin. Its maximum allowable concentration in the air is 0,02 %.

The heat - technological scheme of the installation for dividing of the waste mixture ethanol - water - non volatile impurities in its composite components is presented on figure 1. It is work out on base of the theory of the mass - exchange processes [3,6,10] and of data about the purity of the recovered components, obtained at the preliminary carried out experiments for dividing of the studied waste mixtures [2,9]. The installation works at atmospheric pressure and it is build up from consistently connected a batch distiller in which the non volatile impurities are divided from the waste mixture, and a continuous operating rectification column in which the ethanol is divided from the binary solution ethanol - water. The last solution has to be heated to its boiling temperature before entering into the column. The distillate obtained from the rectification column contains 95 volume % ethanol. The distillation residue leaded away from the column contains over 95 volume % water.

The analysis of different technical decisions leading to energy costs reduction of used dividing processes (heat integration, vapor re-compression, complex configurations of the column apparatuses, the thermodynamic state of feed solution of the rectification column, optimization and so on) is done.

III. Experimental Results and Data Analysis

Greatest attention is paid to the rectification column because it consumes the largest part from the total energy costs [8]. The results from the analysis of different technical decisions for reduction of the energy costs for realization of the used dividing processes show that:

a/There is a dependence between the thermodynamic effectiveness of the rectification column for dividing of binary systems and the composition, thermodynamic state and relative volatile of the feed solution [1]. The optimal thermodynamic parameters of the rectification column feed solution have to be determined according to that dependence. In the investigated case the feed solution with concentration about $20 \div 30$ volume % has to be entirely in liquid state and heated to its boiling temperature.

b/Thermal integration is possible only in the frames of the studied installation because of lack of data for the energy flows between the other equipment in the factory. In this aspect it is possible to utilize the heat of the residue from the

rectification column for heating of the initial waste mixture before entering in to the distiller and of the water - ethanol solution before its entering in to the rectification column.

c/The number of the rectification column contact trays is determined by means of the technico-economical optimization. The computer software from [7] is used for that purpose. Mathematical simulation from the type 2⁴ is carried out. Therefore the variables are four and their areas of varying are: concentration of the feed solution x_f - (20 ÷ 30) volume %; ethanol content of the column residue x_w - (3 ÷ 5) volume %; reflux ratio R - from 1,59 to 2,8 (1,4.Rmin ÷ 1,8.Rmin); heating steam pressure - (0,2 ÷ 0,4) MPa. The coefficient of efficiency of the column trays is 0,54 for the stripping part of the column and 0,51 for the rectifying part and it is determined as function of the relative volatile and the dynamic viscosity of the operated medium [6]. The heating steam costs are calculated according to the present operating price of the heat power - 80 BGL per MWh. The ethanol price is 3,78 BGL per litre. The number of the real column trays - N , the number of the feed tray - N_F and the total reduced costs - K for producing of 1 dl absolute alcohol are determined in result of that optimization. The obtained results are shown in tables I and II.

TABLE I

Number of the real column trays - N and number of the feed column tray - N_F

№	x_f	R	x_w assigned	x_w obtained	N_F	N
-	mol %	-	mol %	mol %	№	Number
1	7,08	2,2	0,95	1,21	5	39
2	7,08	2,2	1,60	1,305	4	39
3	11,33	1,59	0,95	0,953	6	86
4	11,33	1,59	1,60	1,005	6	86
5	7,08	2,8	0,95	0,86	4	31
6	7,08	2,8	1,60	1,585	3	30
7	11,33	2,05	0,95	0,67	5	42
8	11,33	2,05	1,60	1,50	4	41

The equipment depreciation costs - K_{DEP} , the repairing costs - K_{REP} , the heating steam costs - $K_{H,S}$, the costs for the alcohol lead away with column residue - K_{RES} and the building depreciation costs - K_{BUIL} also are shown in table II.

TABLE II

Results from technico-economical optimization of the rectification column

№	K_{DEP}	K_{REP}	$K_{H,S}$	K_{RES}	K_{BUIL}	K
-	BGL per dl absolute alcohol					
1	0,1937	0,1937	0,6451	7,13	0,0232	8,19
2	0,1967	0,1967	0,6449	7,82	0,0236	8,88
3	0,2568	0,2568	0,5192	3,00	0,0308	4,06
4	0,2576	0,2576	0,5191	3,18	0,0309	4,24
5	0,1524	0,1524	0,7627	4,78	0,0183	5,87
6	0,1581	0,1581	0,7583	9,98	0,0190	11,08
7	0,1225	0,1225	0,6074	2,05	0,0147	2,92
8	0,1282	0,1282	0,6056	4,98	0,0154	5,86

The optimal variant is seventh and its parameters are: $x_f = 30$ volume %, $R = 2,05 = 1,8.R_{min}$ и $x_w = 3$ volume %. The heating steam pressure doesn't give substantial influence. The total reduced costs - K are 2,92 BGL per each obtained dl absolute alcohol and they are lowest in comparison with the other seven variants.

d/The vapor re-compression is one technical decision with wide application at separation of difficult dividing binary solutions but it isn't recommended for rectification columns for separation of water - ethanol solutions because of the relatively large temperature difference between the top and the bottom of the column. Using of vapor re-compression in such cases leads to quite great capital costs owing to the investments for the compressor (the compressor price is a function of the work which it has to do and of the volume of the re-compressed vapor) [8].

e/The complex configuration of column apparatuses (feed streams prefractioning; columns with side flows and other) are known but rarely used in practice. These configurations usually require greater capital costs and their introduction in production rear could excuse these investments[4].

The energy flows necessary for the waste mixture dividing are determined from the energy balances of the apparatuses from the installation and they are graphically shown on the energy flow diagram of Senkey (fig. 1). Dry saturated steam with pressure of 0,2 MPa is used as a heating carrier and industrial water with temperature of 16 degree centigrade is used as a cooling carrier. The heat loss are assumed to be 10 % from the heat necessary for the distiller and 4 % from the heat necessary for the rectification column.

1.The process of the waste mixture heating and evaporating in **the distiller 4** is a batch process and the duration of 1 cycle is 60 minutes. The amount of the mixture processed for 1 cycle is 1 m³. It is experimentally established that the ethanol content in the distillation residue is below 0,2 weight % [2].

At these conditions the necessary heat flow rate is

$$\dot{Q}_{UTILL} = \dot{Q}_{HEAT} + \dot{Q}_{EVAP} = 537,1 \text{ kW}, \quad (1)$$

and the mass flow rate of the heating steam is

$$\dot{m}_{H,S} = (\dot{Q}_{UTIL} + \dot{Q}_{LOSS}) / r = 0,268 \text{ kg/s}, \quad (2)$$

where \dot{Q}_{HEAT} and \dot{Q}_{EVAP} are heat flow rates for heating and evaporating of the waste mixture respectively, kW;

\dot{Q}_{UTILL} и \dot{Q}_{LOSS} are utilized heat flow rate and heat loss respectively, kW;

r is a specific boiling heat of water, kJ/kg.

The energy coefficient of efficiency of the distiller is

$$\eta = \dot{Q}_{UTIL} / (\dot{Q}_{UTIL} + \dot{Q}_{LOSS}) = 537,1 / 590,78 \approx 0,91, \quad (3)$$

2.The condensation of the distillation vapors and the cooling of the obtained condensate to temperature of 86 degree centigrade are performed in **the condenser 5**. The heat flow lead away is

$$\dot{Q} = \dot{Q}_{KON} + \dot{Q}_{COOL} = 520 \text{ kW}, \quad (4)$$

and the cooling water flow rate –

$$\dot{m}_w = \dot{Q} / (C_p \cdot \Delta t) = 2,07 \text{ kg/s}, \quad (5)$$

where \dot{Q}_{KON} and \dot{Q}_{COOL} are the heat flow rates necessary

for the vapor condensation and cooling of the obtained distillate respectively, kW;

C_p is water specific heat capacity, kJ/(kg.K);

Δt - the water temperature difference, K.

3. The rectification column 9 is with the continuous operation and capacity 962,22 kg/h initial feed solution ethanol - water (with concentration of 30 volume). The initial solution according to point a/ has to be heated to its boiling temperature - 85,85 °C, and the obtained residue has temperature of 102 °C. The distillate contains 95 volume % ethanol, and the distillation residue contains 3 volume % ethanol.

The heat flow necessary for column bottom heating is

$$\dot{Q}_{\text{UTIL}} = 208,34 \text{ kW},$$

and the heating steam flow rate is

$$\dot{m}_{\text{H.S}} = (\dot{Q}_{\text{UTIL}} + \dot{Q}_{\text{LOSS}}) / r = 217,02 / 2202,2 = 0,099 \text{ kg/s}.$$

The energy coefficient of efficiency of the rectification column is

$$\eta = \dot{Q}_{\text{UTIL}} / (\dot{Q}_{\text{UTIL}} + \dot{Q}_{\text{LOSS}}) = 208,34 / 217,02 \approx 0,96.$$

4. The heat exchanger 8 is continuously operating and has purpose to heat the rectification column initial feed to its boiling temperature of 85,85 °C if there is a necessity. The rectification column residue heat is utilized for the aim.

5. The reflux condenser 10 is continuously operating. Partial condensation of the distillation vapors is performed in it. The heat flow lead away is 134 kW, and the cooling water flow rate is 0,64 kg/s.

6. The condenser - cooler 11 is continuously operating. Condensation of distillation vapors and cooling of the obtained distillate to 25 °C is performed in it. The heat flow lead away is 75,8 kW, and the cooling water flow rate is 0,36 kg/s.

7. The heat exchanger 2 is continuously operating. The initial waste mixture is heated in it to temperature of 70 °C, as the rectification column residue heat is utilized for that purpose. The necessary heat flow rate for heating of that mixture is $\dot{Q}_{\text{UTIL}} = 52,1$ kW, and the heat loss - 5,2 kW. Therefore the total heat flow rate which have to bring in the heat exchanger 2 is 57,3 kW.

The heat flow of 52,1 kW is saved in result of this heat integration at ethanol recovery installation. This is about 24 % from the heat flow necessary for the rectification column and 6,5 % from the total heat flow necessary for the whole installation

About 0,394 kg/s heating steam flow rates with pressure 0,2 MPa are necessary for heating of the distiller and the rectification column, and 3,07 kg/s cooling water flow rates are necessary for condensation of vapors and cooling of the distillates from the distiller and the rectification column.

The energy analysis of the installation for dividing of the second waste mixture methanol - water - non volatile impurities shows that the processes for dividing of that mixture could be realized in the installation for dividing of the first waste mixture ethanol - water - non volatile impurities. The heat flow rates saved as a result of the heat integration in heat exchanger 2 at methanol recovery is 5,4 % from the total heat flow necessary for the whole installation.

Conclusions

1. Different technical decisions leading to reduction of energy costs for the dividing processes for recovery of the organic solvents from industrial waste waters are analyzed and the most appropriate of them (carrying out of technico-economical optimization of the rectification column for determining of the optimal column trays; selecting of the optimal thermodynamic state of the initial feed for the rectification column; heat integration in the frame of the installation) are selected for the investigated case.

2. The heating steam and the cooling water flow rates for the different apparatuses are calculated from the energy analysis of the offered installation.

3. Heat flow rates of 52,1 kW are saved only in result of heat integration in the frames of the installation for dividing of the first waste mixture ethanol - water - non volatile impurities. This is about 24 % from the heat flow necessary for the rectification column and 6,5 % from the heat flow necessary for the whole installation.

4. The heat flow rates saved as a result of the heat integration in heat exchanger 2 at methanol recovery is 5,4 % from the total heat flow necessary for the whole installation.

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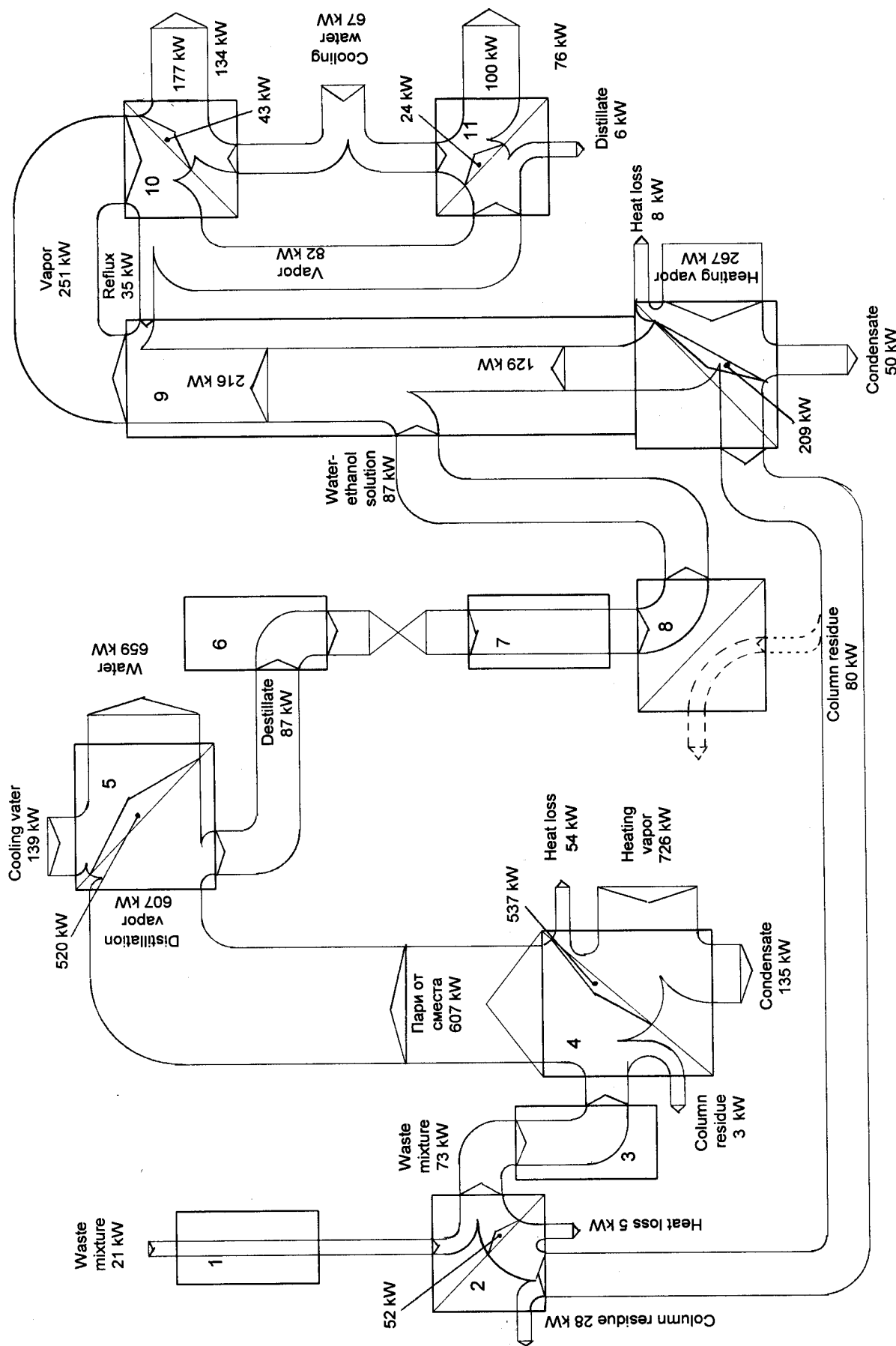


Fig. 1. Energy Diagram of the Installation for Dividing of the Waste Mixture Ethanol - Water - Non Volatile Impurities

- 1 - Reservoir, 2 - Heat exchanger, 3 - Reservoir, 4 - Distiller, 5 - Condenser, 6 and 7 - Reservoirs, 8 - Heat exchanger,
- 9 - Rectification column, 10 - Reflux condenser, 11 - Condenser - Cooler