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An Optimization of Static Operating Modes of the Installation of Contact Membrane Distillation

A. Zhulynskyi, L. Ladieva and A. Burban

Department of Automation of Chemical Production
National Technical University of Ukraine
"Kiev Polytechnic Institute named Igor Sikorsky"
Kiev, Ukraine

Abstract

The task of the optimization of static operating modes of the installation of the process of contact membrane distillation was considered. The target-factorial analysis of control of the process was made. An approach to the optimization of the installation was offered. There was set the specific cost of the process as the optimality criterion. The numerical analysis of the function of the purpose showed an existence of the isolated local minimum and allowed to determine an optimum of the solution supply speed and the thickness of the membrane.

Keywords: optimization, energy saving, membrane, control, contact membrane distillation, flow turbulence

Introduction

During exploitation the installation of the process of contact membrane distillation (CMD) considered the problem of optimizing static modes of flat-chamber membrane modules.

It is important that this process according to technical and economic assessment [1-6] can compete with conventional membrane technologies like reverse osmosis or ultrafiltration. And its efficiency can significantly increase during the optimization of the whole process, for which a target-factorial analysis of the process control was made.

Search of the optimum technological modes has caused a creation of mathematical models of the process. In these models is considered an influence on the process of diffusive transfer of the steam which is characterized by the current modes: molecular, Knudsen and transitional. There were developed mathematical models of the CMD process which consider the influence of the hydrodynamics of the solution current and distillate, sizes and characteristics of membranes, temperature polarization on a productivity of the process [7], change of permeability of the membrane [8].

Difficult character of mathematical models of the CMD process has caused to searching of the approach to optimization of the installation of the CMD process without use of mathematical models in an explicit form.

Approach to the optimization of the installation of the CMD process was offered.

An approach to the optimization of the installation of the CMD process consists of choosing specific cost price of the CMD process as the optimality criterion, that is advisable according to the position of energy saving. In terms of heat transfer through the membrane, increasing the thickness of the membrane reduces the thermal polarization, but this increases the diffusion path of solvent vapors. Therefore, it is necessary to consider the optimization process by choosing the thickness of the membrane.

1. The target-factorial analysis of management of the contact membrane distillation process

Analysis

In terms of energy saving of the CMD process possible objectives that might be structured (i.e. composed of subpurposes) were analyzed. On the figure 1 presented a target-factorial diagram for improving efficiency of the energy saving process.

The main factors that were taken into account at analyzing technical and economic efficiency of control of the process of contact membrane distillation are:

- energy consumption;
- estimated term of work of the membrane;
- running costs.

Running costs are often referred to a constant component of the cost price of the CMD process. During operating the process, capital costs for building the system and costs for replacement of membrane elements were not taken into account. Two purposes were marked, each of them consists of two subpurposes C_{11}, C_{12}, and C_{21}, C_{22}.

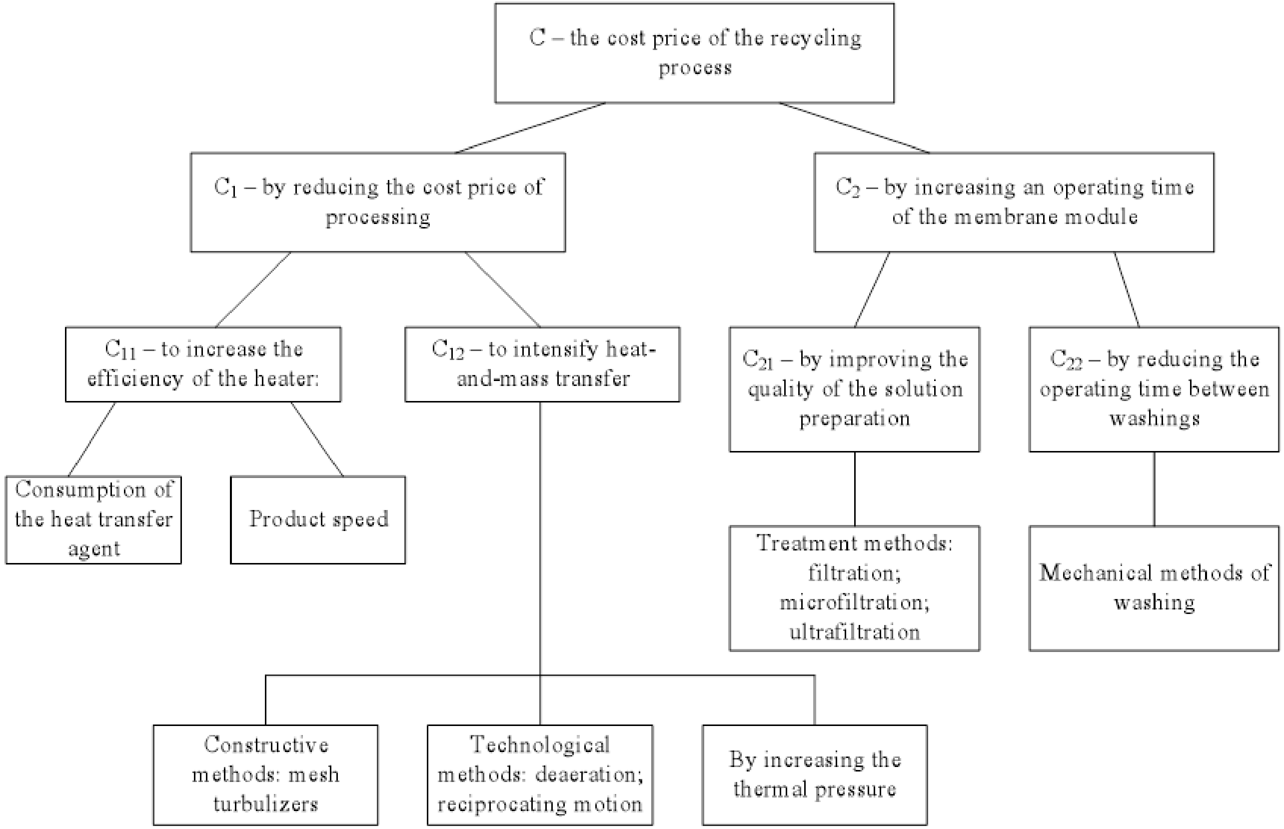

Figure 1. The target-factorial diagram of improving efficiency of the energy saving for CMD process

2. The optimization of the installation of contact membrane distillation

The installation of the CMD process includes a heat exchanger to heat the solution, pump and the membrane module. As the heat transfer agent low-energy (secondary) heat can be used. There is considering the problem of the unit optimization, to increase the energy saving efficiency of the CMD process.

Centrifugal pump with thyristor control circuit was used during the CMD process, thus reducing power consumption.

There was set the specific cost of the CMD process as the optimality criterion, including power expenses for heating the solution, pumping it and depreciation costs of membranes.

The cost of the recycling process in the membrane module can be represented by the equation:

$$C = a_1 Q_{vap} + a_2 N_2 + C_m + C_0', \tag{1}$$

where a_1 – the cost per Joule of the heat, supplied by steam, USD/J; Q_{vap} – the amount of heat that is perceived by the solution from the heating steam, J/h; a_2 – the cost of one kilowatt-hour of the electric power, spent for the pump drive, USD/(kW*h); N_2 – power of the electric motor, spent for the pump drive, kW; C_m – the cost of production expenses (includes depreciation charges, a repair price, etc.), USD/h; C_0' – a constant component of the cost price, USD/h.

It is known that in the industrial practice in case of exploitation of thermal units, production expenses $C_{вир}$, including depreciation charges, often conditionally accept as a constant. This value can be provided:

$$C_m = a_o Q_{M_o}. \tag{2}$$

where a_o – the coefficient, that is considering the specific cost of production expenses per one joule of heat, USD/J; Q_{M_0} – the fixed amount of heat which is perceived by the membrane, J/h.

Then taking into account (2) the equation (1) takes a form:

$$C = a_1 Q_{vap} + a_2 N_2 + a_o Q_{M_o} + C_0'. \tag{3}$$

In other equal conditions, the amount of heat which is perceived by the membrane from solution depends on intensity of a thermolysis. It can be expressed by a ratio:

$$\frac{Q_м}{Q_{м_0}} = \frac{\alpha}{\alpha_0}, \text{ чи } Q_{м_o} = Q_м \frac{\alpha_o}{\alpha}, \tag{4}$$

where α – the thermolysis coefficient from the solution to the membrane at the current value of heat that is brought, W/(m^2*K); α_{20} – the same at the fixed value, W/(m^2*K).

At substitution (4) in the equation (3), the last takes a form:

$$\mathrm{C} = \mathrm{a}_1 Q_{vap} + \mathrm{a}_2 N_2 + a_o Q_M \frac{\alpha_o}{\alpha} + C_0', \tag{5}$$

Assume that the heat, that the solution receives, is given to the membrane: $Q_{vap} \approx \mathrm{Q_M}$. Dividing right and left parts of the equation on Q_{vap} and referring a_1 to C_o, we will receive the function of the purpose, formulated as specific cost price of the process of recycling in the membrane installation:

$$R = a_2 \frac{N_2}{Q_M} + \mathrm{a}_0 \frac{\alpha_o}{\alpha} + C_o, \tag{6}$$

It is considered that for membranes with good permeability, heat transfer through the membrane is made, primarily, by using solvent vapor flow:

$$Q_M \approx J_{vap} S_{\text{м}} \mathrm{r}, \tag{7}$$

where J_{vap} – specific vapor flow through the membrane, kg/(m^2*s); $S_{\text{м}}$ – the membrane surface, m^2; r – latent heat of vaporization, J/kg.

Then taking into account (7) the equation (6) takes a form:

$$R = a_2 \frac{N_2}{J_{vap} S_{\text{м}} r} + a_0 \frac{\alpha_0}{\alpha} + C_0. \tag{8}$$

The presented equation (8) of the expression of the function of the purpose, contains relative change of the thermolysis $\frac{\alpha_0}{\alpha}$, engine capacity which is spent for the drive of the pump $\mathrm{N_2}$ and the vapor flow through the membrane $\mathrm{J_{vap}}$.

Values of the fixed α_o and the current α coefficients of the thermolysis can be counted on the formula [9]. The index "0" designates fixed values of technological and structural parameters, and without index – its current values. Then:

$$\frac{\alpha_0}{\alpha} = \left(\frac{W_0}{W}\right)^{0,8} \cdot \left(\frac{\bar{d}}{\bar{d}_0}\right)^{0,2}. \tag{9}$$

where W – feed rate of solution, m/s.

Vapor flow in the hydrophobic microporous membrane in the CMD process is described by the equation [10]. This equation, except coefficients of porosity and tortuosity, includes structural parameter – the membrane thickness.

Power consumption of the pump engine N_2, is defined as follows:

$$N_2 = \rho g W S H \,, \tag{10}$$

where H – pressure, m; S – cross sectional area of the flow line of the pump, m^2; ρ – the density of the pumped-over liquid, kg/m^3.

3. Results of the numerical analysis of the function of the purpose

During the optimization of the CMD process on the control action, solution supply speed, the equation (8) taking into account (10), takes a form:

$$R = 1{,}668 \cdot 10^{-7} \delta W + a_0 \left(\frac{W_0}{W} \right)^{0{,}8} \left(\frac{\bar{d}}{\bar{d}_0} \right)^{0{,}2} + C_0 \,. \tag{11}$$

Results of the numerical analysis of the installation of the CMD process are shown on Fig. 2. As can be seen from graphs, curves $R = f(W)$ have expressed extreme character. Increasing the thickness of the membrane leads to significantly shifting of extreme points to the left in the direction of lower solution supply speed.

The first partial derivative of the function of the purpose presented by the equation (11) and on condition of d = const, being equal to zero, takes a form:

$$\frac{\partial R}{\partial W} = -0{,}106 \cdot 10^{-11} \frac{W_0^{\;0{,}8}}{W^{1{,}8}} + 6{,}672 \cdot 10^{-11} = 0 \,. \tag{12}$$

Solving this equation concerning solution supply speed, will be received:

$$W_{op} = \frac{0.000302 W_0^{\;0.44}}{\delta^{0.55}} \;. \tag{13}$$

The dependence (13) allows to calculate W_{op} for different technological and structural parameters. To ensure the existence of the optimum, write down the Hesse matrix:

$$\nabla^2 R(W, \delta) = \begin{bmatrix} 0{,}106 \cdot 10^{-11} \cdot 1{,}8 \dfrac{W_0^{0{,}8}}{W^{2{,}8}} & 0 \\ 0 & 1{,}668 \cdot 10^{-7} \end{bmatrix}, \tag{14}$$

which is positively defined. This confirms the existence of the isolated local minimum (Fig. 2).

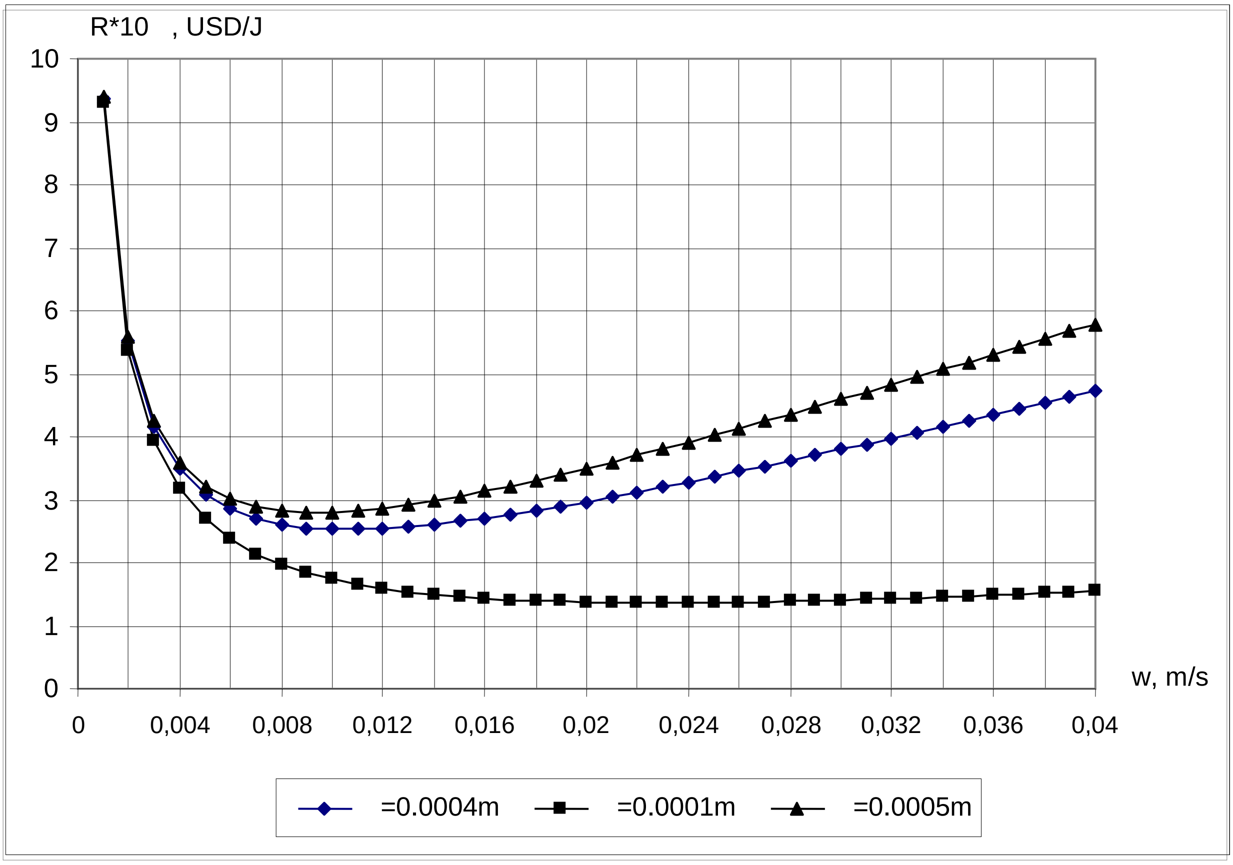

Figure 2. Dependence of the function of the purpose from solution supply speed

4. Conclusions

There was developed the method of calculating optimum technological parameters of the installation of the CMD process. The numerical analysis showed the existence of the explicit extremum of the function of the purpose from solution supply speed.

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