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PARAMETRIC IDENTIFICATION OF THE PROCESS OF CONTACT MEMBRANE DISTILLATION

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ABSTRACT

The mathematical model of the contact membrane distillation process has such an unknown parameter as the membrane permeability coefficient. The coefficient of permeability of the membrane takes into account not only the transfer of heat with the vapor through the pores of the membrane, but also through the polymer structure. In order to determine the coefficient of permeability, which is represented by variables along the length of the channel and in time, methods of the theory of optimal control were applied. An algorithm for identifying variable length and time permeability coefficient is developed. The application of the initial approximation ensures the convergence of the algorithm in the fourth iteration of the gradient procedure. The refined mathematical model of the contact membrane distillation process can be used in control tasks.

Keywords: parametric identification, contact membrane distillation, membrane permeability coefficient, theory of optimal control, process.

INTRODUCTION

The task of water desalting is relevant for various industries and for agricultural production. For desalination of seawater, the membrane distillation (MD) method has a great interest, which has a number of advantages over traditional methods (distillation, electro-dialysis, reverse osmosis, etc.). MD is a new forward-looking method of separating non-volatile matter solutions. The decision of the problem of creating a mathematical model of the process of membrane distillation is very topical and has a significant theoretical and practical interest.

In order to develop a control system for the process of contact membrane distillation (CMD), a mathematical model of dynamic process was created that takes into account the temperature distribution in the longitudinal and transverse directions of the solution and discharging channels [1]. In this model, dependence is used to determine the flow of permeate on the basis of phenomenological coefficients that describe the heat transfer through the membrane and the mass transfer inside the pores. The model was calculated by the layered method. However, it is difficult to apply this model to manage the CMD process. Also, for the successful management of the process, it is necessary to perform membrane contamination forecasting. The permeable structure of real membranes for membrane distillation is a fairly complex non-uniform system, which made it necessary to consider the change in permeability of the membrane over time and along the longitudinal channel of the membrane.

MATERIALS AND METHODS

For the purposes of control, a simplified mathematical model of the KMD process [2] is proposed. As a mathematical model of the process, the simplified model of the process was used:

$$\frac{\partial \theta_P}{\partial t} = -W_{px}\frac{\partial \theta_P}{\partial x} - K_p(x,t)\frac{1}{\rho_p c_p l_y}\left(\xi_1\theta_p - \xi_2\theta_D\right)r\left(\overline{\theta}\right) \quad (1)$$

$$\frac{\partial \theta_D}{\partial t} = -W_{Dx}\frac{\partial \theta_D}{\partial x} + K_p(x,t)\frac{1}{\rho_D c_D l_y}\left(\xi_1\theta_p - \xi_2\theta_D\right)r\left(\overline{\theta}\right) \quad (2)$$

$$J_n = K_p(x,t)\left[P_p\left(b_p,\theta_p\right) - P_D\left(0,\theta_D\right)\right]. \quad (3)$$

where $K_P(x, t)$ - the permeability coefficient, which is represented by variables along the length of the channel and in time, can take into account changes in the membrane state, kg /(m ^{2}s Pa); P_P, R_D - partial pressure vapor of solvent vapor on both sides of the membrane, N/m^2; Θ_P, Θ_D - temperature of the solution and the distillate, K; b_P - concentration of dissolved salt, kg/kg; W_{Px} - speed of solution in the longitudinal direction of the channel, m/s; $S = l_y d$, d - area and channel width, m^2, m; c_P - density and heat capacity of the solution, kg/m^3, J/(kg ·K); r – latent heat of vaporization, J/kg; W_{Dx} - rate of the distillate in the longitudinal direction, m/s; ρ_D, C_D - the relative density and heat capacity of the distillate, kg/m3,J/(kg·K).

The simplified mathematical model of the CMD process has such an unknown parameter as the membrane permeability coefficient, which is difficult to determine along the longitudinal membrane channel based on a priori data. The coefficient of permeability of the membrane takes into account not only the transfer of heat with the vapor through the pores of the membrane, but also through the polymer structure. In order to determine the coefficient of permeability, which is represented by variables along the length of the channel and in time, methods of the theory of optimal control were applied. To determine the initial distribution of the coefficient, an optimality

criterion is chosen which provides the required driving force of the process [3-11]:

$$I(\cdot)=\int_0^{t_k}\int_0^{L_x} e^{(\theta_P-\theta_D)}dxdt\to\min, \quad (4)$$

on condition that $h=(\theta_P-\theta_D)-\Delta\theta\min\geq 0$.

Comparison of the transient characteristics of a simplified mathematical model and experiment showed that the maximum relative error of the model is 16.6 %. To improve the quality of the developed model of the CMD process, parametric identification of the process is required.

Adequacy of the mathematical model of the process under consideration is largely determined by the correspondence of the coefficient of permeability to its real value. In this article the results of the refinement of the membrane permeability coefficient in the mathematical model of the membrane distillation process are presented [2].

Criterion to identify the system (1) - (3) consists of minimizing the integral function presented in the form of a positive definite quadratic function of the discrepancy:

$$I(\cdot)=\frac{1}{2}\int_0^{t_k}\int_0^{L_x}\left\{q_{11}\left[\theta_P(x,t)-\theta_P(x,t)^{meas}\right]^2\right\}dxdt\to\min_{K_P}, \quad (5)$$

where θ_P^{meas} – measured values of the solution temperature, K; q_{11} – weight coefficient; (0 - t_k) - the period during which the temperature is measured by the thermocouple on the i - m layer along the channel.

The formulated problem was solved using the variational method. Hamiltonian takes the form:

$$\begin{aligned}H(\theta_P,\theta_D,\lambda_P,\lambda_D)&=\frac{1}{2}q_{11}\left[\theta_P(x,t)-\theta_P^{meas}\right]^2+\\&+\lambda_P(x,t)\left[-W_{Px}\frac{\partial\theta_P(x,t)}{\partial x}-\right.\\&\left.-K_P(x,t)\frac{1}{\rho_P c_p l_y}\left[\xi_1\theta_P(x,t)-\xi_2\theta_D(x,t)\right]r(\bar{\theta})\right]+\\&+\lambda_D(x,t)\left[-W_{Dx}\frac{\partial\theta_D(x,t)}{\partial x}+\right.\\&\left.+K_P(x,t)\frac{1}{\rho_D c_D l_y}\left[\xi_1\theta_P(x,t)-\xi_2\theta_D(x,t)\right]r(\bar{\theta})\right],\end{aligned} \quad (6)$$

where H (.) - Hamiltonian of unconditional optimization, $\lambda_P(x,t)$, $\lambda_D(x,t)$ - conjugate functions. In this case, the necessary conditions for the task of determination $K_P(x,t)$ have the form:

$$\begin{aligned}\frac{\partial\lambda_P(x,t)}{\partial t}&=-q_{11}\left[\theta_P(x,t)-\theta_P^{meas}\right]+\\&+K_p(x,t)\xi_1 r(\bar{\theta})\left(\frac{1}{\rho_P c_{pP} l_y}\lambda_P(x,t)-\right.\\&\left.-\frac{1}{\rho_D c_{p_D} l_y}\lambda_D(x,t)\right)-W_{P_X}\frac{\partial\lambda_P(x,t)}{\partial x},\end{aligned} \quad (7)$$

$$\begin{aligned}\frac{\partial\lambda_D(x,t)}{\partial t}&=K_p(x,t)\xi_2 r(\bar{\theta})\left(\frac{1}{\rho_P c_{pP} l_y}\lambda_P(x,t)-\right.\\&\left.-\frac{1}{\rho_D c_{p_D} l_y}\lambda_D(x,t)\right)-W_{D_X}\frac{\partial\lambda_D(x,t)}{\partial x};\end{aligned} \quad (8)$$

with limit and final conditions:

$$\lambda_P(L_x,t)=0,\ \lambda_P(x,t_f)=0, \quad (9)$$

$$\lambda_D(L_x,t)=0,\ \lambda_D(x,t_f)=0. \quad (10)$$

The solution of the parametric identification problem in a deterministic state is realized. In this case, the expression for the implementation of the identification procedure has the form:

$$\frac{\partial H(\cdot)}{\partial K_p}=r(\bar{\theta})\left(\frac{1}{\rho_P c_{pP} l_y}\lambda_P(x,t)-\frac{1}{\rho_D c_{p_D} l_y}\lambda_D(x,t)\right)\cdot\left(\xi_1\theta_P(x,t)-\xi_2\theta_D(x,t)\right); \quad (11)$$

The purpose of the identification task is to determine for the system (1) - (3) the value of the parameter K_P* for which the conditions $I(K_P^*)\leq I(K_P)$ for any admissible K_P would have been. The algorithm for solving the problem of determining the distributed field of the membrane permeability coefficient is as follows:

a) The parameter is assigned an initial value that is found as a result of the solution of the problem of minimizing the functional (5), $K_p^s=K_p^0$, $S=0$ where S is the index of the algorithmic cycle.

b) Using the given value K_P, the value of the derivative $\partial H(\cdot)/\partial K_p$ on the basis of the relation (11) is determined, solving the conjugate system of equations (7) - (8) with boundary conditions (9), (10).

c) A new estimation of the parameter is defined as follows:

$$K_p^{s+1} = K_p^s - K\frac{\partial H(\cdot)}{\partial K_p}, \quad (12)$$

where K - the step of the gradient procedure.

d) A condition $\left|I\left(K_p^{s+1}\right) - I\left(K_p^s\right)\right| / I\left(K_p^s\right) \le \varepsilon$ is checked, where ε - the given error of calculation of parameter K_p. If this condition is fulfilled, then the calculated parameter of the field of the permeability coefficient takes value K_p^{s+1} and the procedure ends, otherwise we return to item 2.

The conductivity coefficient K_p of the CD is calculated according to the following formula:

$$K_{p_{s,v}}^{m+1} = K_{p_{s,v}}^{m} - K\left(r\left(\overline{\theta}_{s,v}\right)\left(\frac{1}{\rho_P c_{pP} l_y}\lambda_{1s,v} - \right.\right.$$
$$\left.\left. - \frac{1}{\rho_D c_{p_D} l_y}\lambda_{2_{s,v}} \right)\left(\xi_1\theta_{P_{s,v}} - \xi_2\theta_{D_{s,v}}\right) \right). \quad (13)$$

RESULTS AND DISCUSSIONS

As a result of the solution of the identification problem (4), we find the distribution of the coefficient of permeability of the membrane K_p, which is shown in Figure-1. Initial data, in which calculations were made, are summarized in Table-1.

Calculations have shown that in the first iterations the functional decreases rapidly, but then, when approaching optimum, the process is slowed down. The gradient method of minimizing the used functional is sufficiently universal, which guarantees convergence to a minimum, for each iteration, a separate solution of the Cauchy problem for the main and conjugate systems is required.

The disadvantages include a significant number (8-10) of iterations and a slow convergence in the vicinity of a minimum. To increase convergence, you can choose the optimal step size or use second order or conjugate search procedures. Due to the preliminary finding of the initial distribution of the coefficient of permeability, the number of iterations decreased to four (Figure-2).

Charts for changing the permeability coefficient are presented in Figure-1. The maximum relative error of temperature distribution in the longitudinal direction of the channel in relation to the experimental data is 1%. At the same time, the maximum relative error of the transient characteristic of the simplified mathematical model of the CMD process relative to the experimental data is 14.1% (Figure-3).

Table-1. Data for the implementation of the algorithm for identifying the coefficient permeability of the membrane.

Parameter	Designation Parameter	Unit	Value
The length of the module	L_X	m	0.5
Channel width	d	m	0.01
Channel height	l_P	m	0.006
The sampling rate for the length of the module	Δx	m	0.001
Time of observation	t_k	s	15
Sampling time in time coordinate	Δt	s	0.01
Density of the solution	ρ	kg/m^3	1010.34
Heat capacity of the distillate	c_P	J/(kg·K)	4077
Specific heat of steam generation solvent	r	J/kg	2380000
The value of the intrinsic perturbation of the flow of the solution	$\Delta\theta_{P\,IN}$	°C	20
Step of gradient procedure	K	—	$1\cdot10^{-5}$
Convergence error	ε	—	0.1

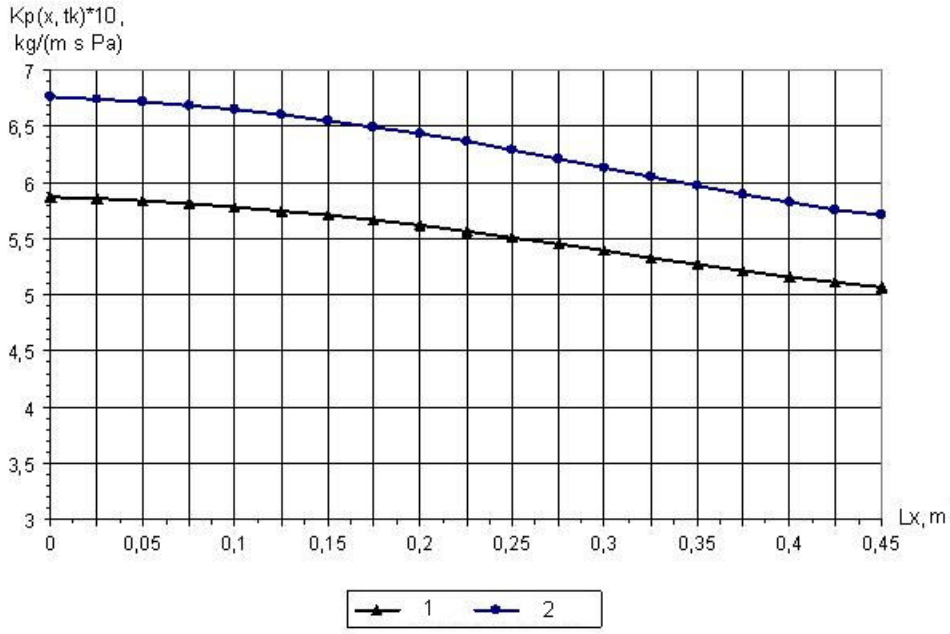

Figure-1. Distribution of the coefficient of permeability along the length of the module: 1- identification; 2- initial approximation.

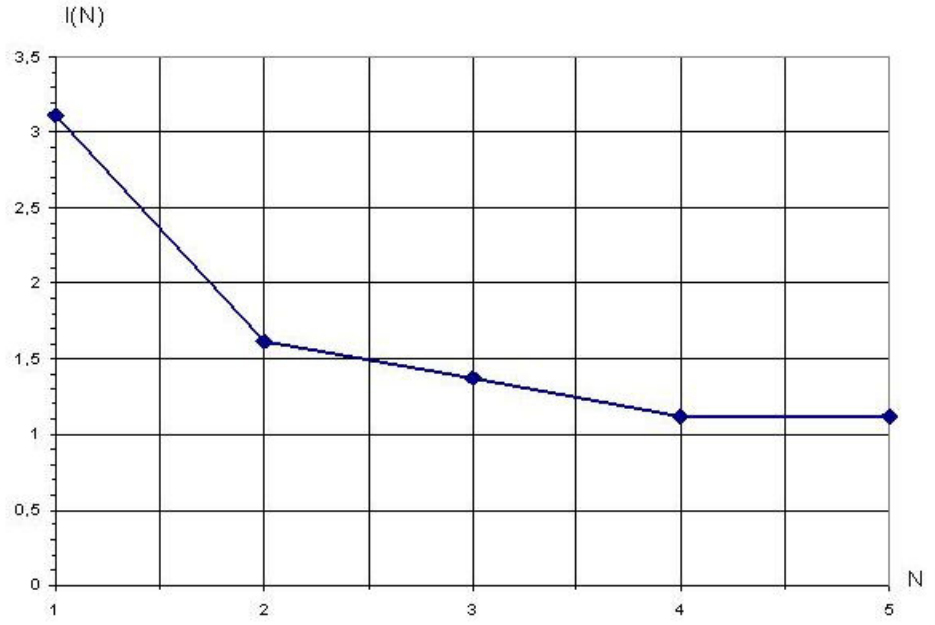

Figure-2. The result of the calculation of the criterion, depending on the iteration.

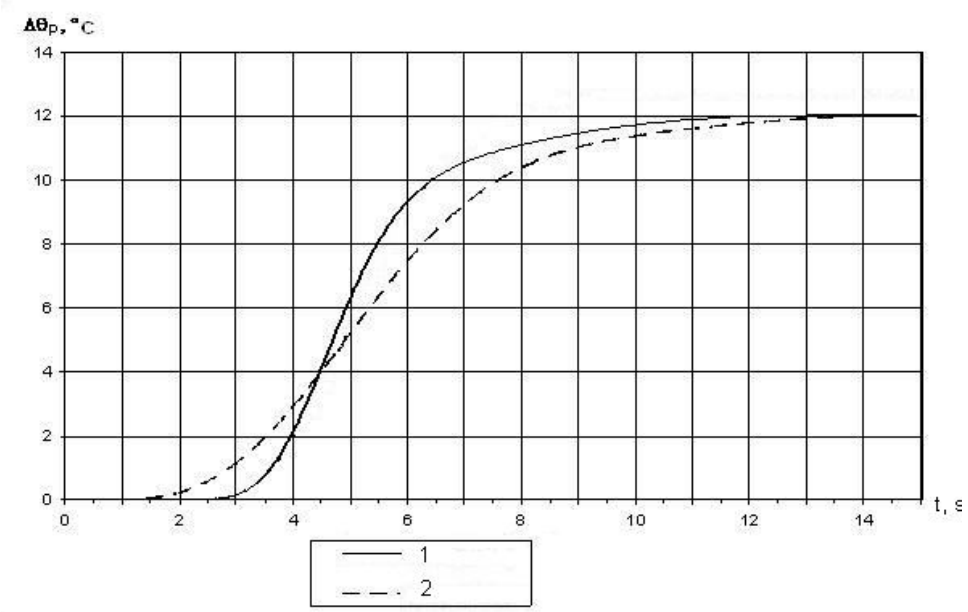

Figure-3. Transition processes along the channel "solution temperature at the input – the temperature of the solution at the module output": 1- by model; 2 - experiment.

CONCLUSIONS

Therefore an algorithm for identifying variable length and time permeability coefficient is developed. The application of the initial approximation ensures the convergence of the algorithm in the fourth iteration of the gradient procedure. The refined mathematical model of the CMD process can be used in control tasks.

REFERENCES

[1] Zhulynskyi A., Ladieva L. 2014. The mathematical description of process of the concentration of the solution by method of contact-membrane distillation based on temperature-polarization. The Advanced science Open access journal. 2014(7): 49-52.

[2] Ladieva L., Zhulinskyi A. 2005. Collection Automation of production processes. (1): 34-37.

[3] Zhulinskyi A., Ladieva L., Burban A. 2017. An Optimization of static operating modes of the installation of contact membrane distillation. Contemporary Engineering Sciences. 10(9): 439-446.

[4] Ladieva L., Dovbnia S., Dubyk R. 2017. Mathematical model of membrane distillation. Naukojemni tehnologii. 2(34): 178-183.

[5] Zhulinskyi A., Ladieva L. 2016. Simplified mathematical model of the cntact membrane distillation process. East European Scientific Journal. 7(№4)(8): 83-86.

[6] Ladieva L., Onishchenko V., Dubik R. 2016. Mathematical Modeling of heat and mass transfer in membrane distillation process. International Scientific Journal. (2): 90-93.

[7] Ladieva L., Momotenko D. 2016. Fuzzy-cognitive approach to the problem of controlling the process of contact membrane distillation. Naukojemni tehnologii. (№2)(30): 147-151.

[8] Burban A. F. 2014. Membrane distillation in the processes of water treatment, desalting and sewage treatment. Nuakovi zapysky NaUKMA, T. 157: Chimitchni nauky i tehnologiji, 15-24.

[9] Korniyenko B., Osipa L. 2018. Identification of the granulation process in the fluidized bed. ARPN Journal of Engineering and Applied Sciences. 13(14): 365-4370.

[10] Babak V., Shchepetov V., Nedaiborshch S. 2016. Wear resistance of nanocomposite coatings with dry lubricant under vacuum. Scientific Bulletin of National Mining University. (1): 47-52.

[11] Samotyy V., Telenyk S., Kravets, P., Shymkovych V., Posvistak. T. 2018. A real time control system for balancing a ball on a platform with FPGA parallel implementation. Technical Transactions. 5: 109-118.